INDC-362

NCSAC - 31
EANDC(US)-143 "U"
INDC(USA)-22 "U"
WASH-1155

Reports to . . .

THE AEC NUCLEAR CROSS SECTIONS ADVISORY COMMITTEE

Meeting at

ARGONNE NATIONAL LABORATORY
CHICAGO, ILLINOIS

May 20-22, 1970

Compiled by . . . .

R.E. Chrien, Secretary, NCSAC

PREFACE

The reports in this document were submitted to the AEC Nuclear Cross Sections Advisory Committee (NCSAC) at the meeting at Argonne, Illinois, on May 20-22, 1970. The reporting laboratories are those having a substantial effort in measuring neutron and nuclear cross sections of relevance to the U. S. applied nuclear energy program. The material contained in these reports is to be regarded as comprised of informal statements of recent developments and prelininary data. Appropriate subjects are listed as follows:

1. Microscopic neutron cross sections relevant to reactor development, including shielding. Inverse reactions where pertinent are included.

2. Charge particle cross sections, especially as appropriate in developing and testing nuclear models.

3. Gamma-ray production, radioactive decay, and theoretical developments in nuclear structure.

4. Proton and alpha-particle cross sections, at energies of up to 1 GeV, which are of interest to the space program.

These reports cannot be regarded as a complete summary of the nuclear research effort of the AEC. A number of laboratories, whose research is less programmatically oriented do not submit reports; neither do the submitted reports reflect all the work related to nuclear cross sections in progress at the submitting laboratory.

Persons wishing to make use of these data should contact the individual experimenter for further details. The data which appear in this document should be quoted only by permission of the contributor and should be referenced as private communication, and not by this document number.

This compilation has been produced almost completely from master copies prepared by the individual contributors listed in the Table of Contents. It is a pleasure to acknowledge their help in the preparation of these reports.

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Previously submitted Reports to the AEC Nuclear Cross Sections Advisory Committee include the following:

September 1969 Meeting at Rice University	WASH-1136 EANCC(US)-122U INDC(US)- 14U
April 1969 Meeting at Oak Ridge, Tennessee	WASH-1127 EANDC(US)-120U INDC(US)- 10U
October 1968 Meeting at Columbia University	WASH-1124 EANDC(US)-111U INDC(US)- 9U
April 1968 Meeting at Brookhaven, New York	WASH-1093 EANDC(US)-105U INDC(US)- 2U
October 1967 Meeting at Idaho Falls, Idaho	WASH-1079 EANDC(US)-104U INDC(US)- 12U
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November 1966 Meeting at Argonne, Illinois	WASH-1071 EANDC(US)- 91U INDC(US)- 5U
March 1966 Meeting at Washington, D. C.	WASH-1068 EANDC(US)- 85U INDC(US)- 3U
October 1965 Meeting at Duke University	WASH-1064 EANDC(US)- 79U
March 1965 Meeting at National Bureau of Standards	WASH-1056 EANDC(US)- 72U
October 1964 Meeting at Oak Ridge National Laboratory	WASH-1053 EANDC(US)- 70U
June 1964 Meeting at Columbia University	WASH-1048 EANDC(US)- 57U

The following is an index to measurements in WASH-1155 pertinent to requests listed in either one of the two compilations currently in circulation. These are WASH-1078 "Compilation of Requests for Nuclear Cross Section Measurements" (June 1967) and WASH-1144, draft version, (November 1969). A CINDA-type index has been prepared by L. T. Whitehead of the Division of Technical Information Extension, and follows on page viii.

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127		ZR-90	DEL	2
128		ZR-91	DEL	2
129		ZR-92	DEL	2
130		ZR-94	DEL	2
131		ZR-96	DEL	2
264		U-233	FR	3
286		U-235	NF	4
287		U-235	NF	4
288		U-235	NF	4
307		U-238	SIN	2
309		U-238	NG	4
312		U-238	FR	3,4
341		PU-239	NF	4
342		PU-239	NF	4
343		PU-239	FR	4
355		PU-240	SIN	3
357		PU-240	NG	192,194
358		PU-240	NG	192,194
386		CM-243	TOT	4
	31	C	ELASTIC	167
	32	C	ELASTIC	31
	33	C	ELASTIC	167
	38	N	TOTAL	164
	39	N	ELASTIC	167,212
	40	N	ELASTIC	167,212
	41	N	EMISSION	212
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	100	FE	ELASTIC	214
	101	FE	INELASTIC	214
	102	FE	EMISSION	214
	119	NI	ELASTIC	31
	120	NI	INELASTIC	31
	218	NB-94	$\sigma(n,\gamma)$	71
	223	MO	$\sigma(n,\gamma)$	63
	228	RH	$\sigma(n,\gamma)$	20,66,63
	239	CS	$\sigma(n,\gamma)$	17
	240	CS	$\sigma(n,\gamma)$	17
	241	NO-143	$\sigma(n,\gamma)$	42
	242	NO-145	$\sigma(n,\gamma)$	42
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	254	SM-152	$\sigma(n,\gamma)$	45
	265	EU-151	$\sigma(n,\gamma)$	45,103
	266	EU-151	$\sigma(n,\gamma)$	45
	274	GD	$\sigma(n,\gamma)$	63,64
	276	GD	RES INT	64
	278	GD-155	$\sigma(n,\gamma)$	64
	279	GD-155	RES INT	64
	280	GD-155	Γn, $\Gamma\gamma$	64
	284	GD-157	$\sigma(n,\gamma)$	64
	285	GD-157	RES INT	64
	286	GD-157	Γn, $\Gamma\gamma$	64
	292	DY	$\sigma(n,\gamma)$	17,23
	293	DY	TOTAL γ PROD	17
	294	ER-166	$\sigma(n,\gamma)$	45
	295	ER-167	$\sigma(n,\gamma)$	42,45
	313	HF-177	$\sigma(n,\gamma)$	42
	318	TA	$\sigma(n,\gamma)$	63
	321	W	TOTAL γ PROD	214
	322	W	TOTAL γ PROD	214
	325	W-182	$\sigma(n,\gamma)$	42,45
	327	W-184	$\sigma(n,\gamma)$	42,45
	330	W-186	$\sigma(n,\gamma)$	42,45
	331	AU	$\sigma(n,\gamma)$	63,118
	343	TH	$\sigma(n,\gamma)$	132
	344	TH	ABS	132
	353	U-233	$\sigma(n,F)$	130
	354	U-233	$\sigma(n,F)$	130
	361	U-233	DELAYED NEUT.YIELD	156
	370	U-234	TOTAL	180
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	383	U-235	$\sigma(n,F)$	114

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	390	U-235	DELAYED NEUT. YIELD	156
	392	U-235	DELAYED γ YIELD	20
	393	U-235	RES PAR	42,112
	403	U-237	$\sigma(n,\gamma)$	132
	404	U-237	DESTRUCT. OF TARGET	132
	413	U-238	$\sigma(n,\gamma)$	214,63
	414	U-238	$\sigma(n,\gamma)$	214,63
	415	U-238	TOTAL γ PROD	214
	417	U-238	DEL. γ YIELD	123
	428	PU-238	$\sigma(n,F)$	70
	432	PU-238	$\sigma(n,\gamma)$	129
	433	PU-238	$\sigma(n,\gamma)$	130
	436	PU-238	DESTRUCT. OF TARGET	132
	445	PU-239	DEL. NEUT. YIELD	156
	448	PU-239	DEL. γ YIELD	20,123
	449	PU-239	RES PAR	20
	478	PU-242	DEL. NEUT. YIELD	156
	479	PU-242	$\sigma(n,\gamma)$	71
	492	AM-243	TOTAL	69,70
	493	AM-243	$\sigma(n,\gamma)$	69,70
	499	CM-244	TOTAL	138
	503-518	CM-22 to CM-248	VARIOUS	138
	526	CF-252	$\sigma(n,F)$	138

ELEMENT S A	QUANTITY	TYPE	ENERGY MIN	ENERGY MAX	DOCUMENTATION REF	VOL	PAGE	DATE	LAB	COMMENTS	SERIAL NO.
H 001	TOTAL XSECT	EXPT-PROG	3. -3	2. -2	WASH1155	25		5/70	BNL	HOUK+,PARAHYDROGEN,TBC,NO DATA GVN	51907
H 001	N,GAMMA	EXPT-PROG	2.5-2		WASH1155	57		5/70	COL	COKINOS+,NO DATA GIVEN,TBP IN PR	51889
H 001	N,GAMMA	EVAL-PROG	NDG		WASH1155	160		5/70	LAS	YOUNG+,2.22MEV GAM PROD SIG,NO DATA	51933
HE 004	DIFF ELASTIC	EXPT-PROG	8. 6		WASH1155	221		5/70	DKE	STAMMBACH+,POL NEUTS,NO DATA,TBP PR	51882
HE 004	POLARIZATION	EXPT-PROG	8. 6		WASH1155	221		5/70	DKE	STAMMBACH+,POL NEUTS,NO DATA,TBP PR	51883
BE 009	N,GAMMA	EXPT-PROG	NDG		WASH1155	154		5/70	LAS	JURNEY,TO BE DONE	51939
C	TOTAL XSECT	EXPT-PROG	5. 5	1.5 7	WASH1155	164		5/70	NBS	SCHWARTZ+,0.1 NS/M RESOL,CURV SHOWN	51902
C	SCATTERING	EXPT-PROG	2. 3		WASH1155	75		5/70	MTR	SMITH+,ANAL TO BE COMPLETED,NO DATA	52000
N	EVALUATION	EVAL-PROG			WASH1155	160		5/70	LAS	YOUNG+,IN ENDF/B FORMAT,NO DATA GIVN	51924
N	TOTAL XSECT	EVAL-PROG	NDG		WASH1155	160		5/70	LAS	YOUNG+,IN ENDF/B FORMAT,NO DATA GIVN	51900
N	TOTAL XSECT	EXPT-PROG	5. 5	2.[illegible] 7	WASH1155	164		5/70	NBS	SCHWARTZ+,0.1 NS/M RESOL,CURV SHOWN	51901
O	EVALUATION	EVAL-PROG			WASH1155	160		5/70	LAS	YOUNG+,IN ENDF/B FORMAT,NO DATA GIVN	51925
O	TOTAL XSECT	EVAL-PROG	NDG		WASH1155	160		5/70	LAS	YOUNG+,IN ENDF/B FORMAT,NO DATA GIVN	51926
O	INELST GAMMA	EVAL-PROG	NDG		WASH1155	160		5/70	LAS	YOUNG+,IN ENDF/B FORMAT,NO DATA GIVN	51927
O 016	TOTAL XSECT	EXPT-PROG	2.4 6		WASH1155	39		5/70	GA	KALYNA+,TRANS,VDG,TO BE COMPL,NDG	52034
O 016	SPECT NGAMMA	EXPT-PROG	NDG		WASH1155	154		5/70	LAS	JURNEY,4 GAMMA ES 870-3270KEV	51940
NA 023	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51961
AL 027	SCATTERING	EXPT-PROG	2. 3		WASH1155	75		5/70	MTR	SMITH+,ANAL TO BE COMPLETED,NO DATA	51999
AL 027	NONEL GAMMAS	EXPT-PROG	8.5 5	1.6 7	WASH1155	66		5/70	GA	ORPHAN+,GE(LI) DET,ANAL TBC,NO DATA	52035
AL 027	N,GAMMA	EXPT-PROG	7.0-2	8.4-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51919
K	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51962
CA	N,GAMMA	EXPT-PROG	THR		WASH1155	106		5/70	LRL	CRANSTON+,MOXON-RAE DET,VALUE GIVEN	51951
CA 040	N,GAMMA	EXPT-PROG	THR		WASH1155	106		5/70	LRL	CRANSTON+,FROM CAPT SPEC,VALUE GIVEN	51948
CA 042	N,GAMMA	EXPT-PROG	THR		WASH1155	106		5/70	LRL	CRANSTON+,MOXON-RAE DET,VALUE GIVEN	51950
CA 043	N,GAMMA	EXPT-PROG	THR		WASH1155	106		5/70	LRL	CRANSTON+,MOXON-RAE+CAPT SPEC,VALUES	51945
CA 044	N,GAMMA	EXPT-PROG	THR		WASH1155	106		5/70	LRL	CRANSTON+,MOXON-RAE DET,VALUE GIVEN	51949
CA 046	N,GAMMA	EXPT-PROG	THR		WASH1155	106		5/70	LRL	CRANSTON+,FROM CAPT SPEC,VALUE GIVEN	51947
CA 048	N,GAMMA	EXPT-PROG	THR		WASH1155	106		5/70	LRL	CRANSTON+,FROM CAPT SPEC,VALUE GIVEN	51946
TI	DIFF ELASTIC	EXPT-PROG	1. 5	1.5 6	WASH1155	1		5/70	ANL	SMITH+,NO DATA,TO BE PUBLISHED	51877
TI	DIFF INELAST	EXPT-PROG	1. 5	1.5 6	WASH1155	1		5/70	ANL	SMITH+,NO DATA,TO BE PUBLISHED	51876
V	N,GAMMA	EXPT-PROG	1.1-1		WASH1155	24		5/70	BNL	SAILOR+,POL METHOD,J DEPEND OF SIG	51906
CR	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51963
MN 055	N,GAMMA	EXPT-PROG	NDG		WASH1155	50		5/70	COL	ARBO+,NEVIS,MOXON-RAE DET,TO BE DONE	52090
FE	NONEL GAMMAS	EXPT-PROG	8.5 5	1.6 7	WASH1155	66		5/70	GA	ORPHAN+,GE(LI) DET,ANAL TBC,NO DATA	52039
FE	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51964
FE 054	INELST GAMMA	EXPT-PROG	4.4 6		WASH1155	32		5/70	CSE	VELKLEY+,GE(LI) DET,NO GAMS TO GND	52077
FE 056	DIFF ELASTIC	EXPT-PROG	5.1 6	5.6 6	WASH1155	31		5/70	CSE	LINDOH+,ANAL TO BE COMPL,NO DATA GVN	51957
CO 059	TOTAL XSECT	EXPT-PROG	3. 5	8. 6	WASH1155	123		5/70	LOK	FISHER+,SPIN-SPIN EFFECT MEASD,CURVE	51959
CO 059	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51965
NI	N,GAMMA	EXPT-PROG	3.3-2	2.7-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51913
NI	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51966
CU	NONEL GAMMAS	EXPT-PROG	1.4 7		WASH1155	61		5/70	COL	STAMATELATOS+,GAM SPEC MEASD,NO DATA	52001
CU	N,GAMMA	EXPT-PROG	3.3-2	2.7-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51914
CU	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51967
SR 086	RESON PARAMS	EXPT-PROG	5.9 2	2.3 4	WASH1155	40		5/70	COL	CAMARDA+,24RESON,CRV LVL NO. VS. EN	51890
SR 087	RESON PARAMS	EXPT-PROG	3.5 0	1.0 3	WASH1155	40		5/70	COL	CAMARDA+,37RESON,CRV SIG.G+WN VS. EN	51895
SR 087	STRNTH FNCTN	EXPT-PROG	3.5 0	1.0 3	WASH1155	40		5/70	COL	CAMARDA+,7 RESON,CRV LVL NO. VS. EN	51891
SR 087	STRNTH FNCTN	EXPT-PROG	3.5 0	1.0 3	WASH1155	40		5/70	COL	CAMARDA+,VALUE GIVEN	51892

ELEMENT S A	QUANTITY	TYPE	ENERGY MIN	ENERGY MAX	DOCUMENTATION REF	VOL	PAGE	DATE	LAB	COMMENTS	SERIAL NO.
SR 088	RESON PARAMS	EXPT-PROG	1.2 4	8.8 4	WASH1155	40		5/70	COL	CAMARDA+,7 RESON,CRV LVL NO. VS. EN	51894
Y 089	INELST GAMMA	EXPT-PROG	3.5 6	5.0 6	WASH1155	215		5/70	TNC	BUCHANAN,GE(LI),LVL SCHEME GIVN,TBP	51881
ZR	NONEL GAMMAS	EXPT-PROG	1.4 7		WASH1155	61		5/70	COL	STAMATELATOS+,GAM SPEC MEASD,NO DATA	52003
ZR	N,GAMMA	EXPT-PROG	3.3-2	2.7-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51915
ZR	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51968
NB 093	N,GAMMA	EXPT-PROG	THR		WASH1155	71		5/70	MTR	YOUNG+,VALUE GIVEN	52010
NB 093	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51969
NB 094	TOTAL XSECT	EXPT-PROG	1		WASH1155	71		5/70	MTR	YOUNG+,TRANSMISSION CURVES SHOWN	52015
NB 094	RESON PARAMS	EXPT-PROG	1.2 1	2.3 1	WASH1155	71		5/70	MTR	YOUNG+,TRANS,REDUCD WN FROM SIG TOT	52016
NB 094	N,GAMMA	EXPT-PROG	THR		WASH1155	71		5/70	MTR	YOUNG+,VALUE GIVEN	52009
NB 095	N,GAMMA	EXPT-PROG	THR		WASH1155	71		5/70	MTR	YOUNG+,UPPER LIMIT GIVEN	52011
MO	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51986
MO	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51970
RH 103	RESON PARAMS	EXPT-PROG	1.3 0	3.2 2	WASH1155	64		5/70	GA	CARLSON+,WG 2G*WN J FOR 10 RESON	51896
RH 103	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51987
RH 103	N,GAMMA	EXPT-PROG	NDG		WASH1155	50		5/70	COL	ARBO+,NEVIS,MOXON-RAE DET,TO BE DONE	52088
RH 103	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51976
AG	N,GAMMA	EXPT-PROG	7.0-2	8.4-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51920
AG 110	SPECT NGAMMA	EXPT-PROG	THR	0	WASH1155	25		5/70	BNL	KANE+,CURVE+AG110 LEVEL SCHEME	51912
CD 110	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52058
CD 112	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52059
CD 114	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52060
CD 116	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52061
IN	RESON PARAMS	EXPT-PROG	2. 1	2. 3	WASH1155	40		5/70	COL	CAMARDA+,193RESON ANALYZED,NO DATA	52054
IN 113	RESON PARAMS	EXPT-PROG		8.9 4	WASH1155	40		5/70	COL	CAMARDA+,NO DATA GIVEN	52052
IN 115	RESON PARAMS	EXPT-PROG		8.9 4	WASH1155	40		5/70	COL	CAMARDA+,NO DATA GIVEN	52053
IN 115	N,GAMMA	EXPT-PROG	1. 4	1. 6	WASH1155	108		5/70	LRL	GARDNER+,OPTMDL CALCULATION,CURVE	51943
SB	NONEL GAMMAS	EXPT-PROG	1.4 7		WASH1155	61		5/70	COL	STAMATELATOS+,GAM SPEC MEASD,NO DATA	52002
XE 124	SPECT NGAMMA	EXPT-PROG	0	1	WASH1155	28		5/70	BNL	KANE+,TO BE COMPL,NO DATA GIVEN	51909
XE 129	SPECT NGAMMA	EXPT-PROG	0	1	WASH1155	28		5/70	BNL	KANE+,TO BE COMPL,NO DATA GIVEN	51910
XE 131	SPECT NGAMMA	EXPT-PROG	0	1	WASH1155	28		5/70	BNL	KANE+,TO BE COMPL,NO DATA GIVEN	51911
XE 132	RESON PARAMS	EXPT-PROG	1.4 1	1	WASH1155	28		5/70	BNL	KANE+,PROBABLE J GIVEN	51908
LA 139	RESON PARAMS	EXPT-PROG	7.0 2	1.0 4	WASH1155	40		5/70	COL	CAMARDA+,56RESON,ONLY AVG D SHOWN	52050
LA 139	STRNTH FNCTN	EXPT-PROG	7.0 2	1.0 4	WASH1155	40		5/70	COL	CAMARDA+,VALUE GIVEN	52051
LA 139	SPECT NGAMMA	EXPT-PROG	NDG		WASH1155	154		5/70	LAS	JURNEY,NO DATA GIVEN	51938
CE 140	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52062
ND	N,GAMMA	EXPT-PROG	3.3-2	2.7-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51916
SM 152	RESON PARAMS	EXPT-PROG		1.5 3	WASH1155	40		5/70	COL	CAMARDA+,29RESON,AVG WG G*WN D GIVEN	51859
SM 152	STRNTH FNCTN	EXPT-PROG		1.5 3	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51873
SM 154	RESON PARAMS	EXPT-PROG		2.5 3	WASH1155	40		5/70	COL	CAMARDA+,20RESON,AVG WG G*WN D GIVEN	51858
SM 154	STRNTH FNCTN	EXPT-PROG		2.5 3	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51872
EU	RES INT ABS	EXPT-PROG	2. 2	1. 4	WASH1155	103		5/70	LRL	CZIRR,LINAC,VALUE GIVN,SEE UCRL50804	51953
EU	N,GAMMA	EXPT-PROG	2. 2	1.2 4	WASH1155	103		5/70	LRL	CZIRR,LINAC,CURV,SEE UCRL-50804	51888
EU 151	RESON PARAMS	EXPT-PROG		1. 2	WASH1155	40		5/70	COL	CAMARDA+,90RESON,AVG WG G*WN D GIVEN	51861
EU 151	STRNTH FNCTN	EXPT-PROG		1. 2	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51863
EU 151	RES INT ABS	EXPT-PROG	2. 2	1. 4	WASH1155	103		5/70	LRL	CZIRR,LINAC,VALUE GIVN,SEE UCRL50804	51954
EU 151	N,GAMMA	EXPT-PROG	2. 2	1.2 4	WASH1155	103		5/70	LRL	CZIRR,LINAC,NO DATA,SEE UCRL-50804	51956
EU 153	RESON PARAMS	EXPT-PROG		1. 2	WASH1155	40		5/70	COL	CAMARDA+,68RESON,AVG WG G*WN D GIVEN	51860

ELEMENT S A	QUANTITY	TYPE	ENERGY MIN	ENERGY MAX	DOCUMENTATION REF	VOL	PAGE	DATE	LAB	COMMENTS	SERIAL NO.
EU 153	STRNTH FNCTN	EXPT-PROG		1. 2	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51862
GD	RES INT ABS	EXPT-PROG	5. -1	1. 5	WASH1155	63		5/70	GA	FRIESENHAHN+,VALUE GIVEN,TBP IN NP	51887
GD	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51988
GD 154	RESON PARAMS	EXPT-PROG		3.2 3	WASH1155	40		5/70	COL	CAMARDA+,107RESON,NO DATA GIVEN	52049
GD 155	RESON PARAMS	EXPT-PROG	3. 0	2. 2	WASH1155	63		5/70	GA	FRIESENHAHN+,AVG PARAMS,NDG,TBP NP	51994
GD 155	STRNTH FNCTN	EXPT-PROG	-1	5	WASH1155	63		5/70	GA	FRIESENHAHN+,NO DATA,TBP IN NP	52040
GD 155	RES INT ABS	EXPT-PROG	5. -1	1. 5	WASH1155	63		5/70	GA	FRIESENHAHN+,VALUE GIVEN,TBP IN NP	52042
GD 155	N,GAMMA	EXPT-PROG	3. 0	2. 4	WASH1155	63		5/70	GA	FRIESENHAHN+,NO DATA,TBP IN NP	52037
GD 157	RESON PARAMS	EXPT-PROG	3. 0	2. 2	WASH1155	63		5/70	GA	FRIESENHAHN+,AVG PARAMS,NDG,TBP NP	51995
GD 157	STRNTH FNCTN	EXPT-PROG	-1	5	WASH1155	63		5/70	GA	FRIESENHAHN+,NO DATA,TBP IN NP	52041
GD 157	RES INT ABS	EXPT-PROG	5. -1	1. 5	WASH1155	63		5/70	GA	FRIESENHAHN+,VALUE GIVEN,TBP IN NP	51886
GD 157	N,GAMMA	EXPT-PROG	3. 0	2. 4	WASH1155	63		5/70	GA	FRIESENHAHN+,NO DATA,TBP IN NP	52038
GD 158	RESON PARAMS	EXPT-PROG		5. 3	WASH1155	40		5/70	COL	CAMARDA+,40RESON,NO DATA GIVEN	52048
GD 158	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52068
GD 160	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52069
TB 159	N,GAMMA	EXPT-PROG	3.3-2	2.7-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51917
TB 159	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51971
DY	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51972
DY 160	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52063
DY 161	RESON PARAMS	EXPT-PROG	2.7 0	1.8 1	WASH1155	23		5/70	BNL	POSTMA+,J FOR 8RESON BY POL METHOD	51904
DY 161	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52064
DY 162	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52065
DY 163	RESON PARAMS	EXPT-PROG	1.7 0	1.6 1	WASH1155	23		5/70	BNL	POSTMA+,J FOR 2RESON BY POL METHOD	51903
DY 163	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52066
DY 164	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52067
HO 165	RESON PARAMS	EXPT-PROG	1.8 1	8.6 1	WASH1155	5		5/70	ANL	POENITZ+,J FOR 14RESON,NDG,TBP IN NP	51884
HO 165	RES INT ABS	EXPT-PROG	2. 2	1. 4	WASH1155	103		5/70	LRL	CZIRR,LINAC,VALUE GIVN,SEE UCRL50904	51955
HO 165	N,GAMMA	EXPT-PROG	2. 2	1.2 4	WASH1155	103		5/70	LRL	CZIRR,LINAC,CURV,SEE UCRL-50804	51958
HO 165	SPECT NGAMMA	EXPT-PROG	1.8 1	8.6 1	WASH1155	5		5/70	ANL	POENITZ+,GE(LI),NO DATA,TBP IN NP	51885
ER	N,GAMMA	EXPT-PROG	3.3-2	2.7-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51918
ER 166	RESON PARAMS	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52027
ER 166	STRNTH FNCTN	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51867
ER 167	RESON PARAMS	EXPT-PROG	4.6-1	9.6 0	WASH1155	24		5/70	BNL	SAILOR+,POL METHOD,J FOR 4LOWEST RES	51905
ER 167	RESON PARAMS	EXPT-PROG	1. 0	1.7 3	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52028
ER 167	STRNTH FNCTN	EXPT-PROG	1. 0	1.7 3	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51866
ER 168	RESON PARAMS	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52029
ER 168	STRNTH FNCTN	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51865
ER 169	SPECT NGAMMA	EXPT-PROG	THR		WASH1155	155		5/70	LAS	BUNKER+,ABSTRACT ONLY,TBP IN PR	51897
ER 170	RESON PARAMS	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52020
ER 170	STRNTH FNCTN	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51864
TM 169	N,GAMMA	EXPT-PROG	1. 2	1. 5	WASH1155	108		5/70	LRL	GARDNER+,OPTMDL CALCULATION,CURVE	51944
TM 169	N,GAMMA	EXPT-PROG	NDG		WASH1155	50		5/70	COL	ARBO+,NEVIS,MOXON-RAE DET,TO BE DONE	52089
YB 171	RESON PARAMS	EXPT-PROG	1. 0	1.7 3	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52031
YB 171	STRNTH FNCTN	EXPT-PROG	1. 0	1.7 3	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51871
YB 172	RESON PARAMS	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52032
YB 172	STRNTH FNCTN	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51870
YB 174	RESON PARAMS	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52033
YB 174	STRNTH FNCTN	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51869

ELEMENT S A	QUANTITY	TYPE	ENERGY MIN	ENERGY MAX	DOCUMENTATION REF	VOL	PAGE	DATE	LAB	COMMENTS	SERIAL NO.
YB 176	RESON PARAMS	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52030
YB 176	STRNTH FNCTN	EXPT-PROG		2. 4	WASH1155	40		5/70	COL	CAMARDA+,SO VALUE GIVEN	51868
LU	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51973
LU 175	RESON PARAMS	EXPT-PROG	2.6 0	4.1 1	WASH1155	20		5/70	BNL	CHRIEN+,J FOR II RESON GIVEN	52006
LU 175	RESON PARAMS	EXPT-PROG		5. 3	WASH1155	40		5/70	COL	CAMARDA+,PARAMS FOR 312RESON,NO DATA	52047
LU 175	N,GAMMA	EXPT-PROG	3. 3	3. 5	WASH1155	108		5/70	LRL	GARDNER+,OPTMOL CALCULATION,CURVE	51941
HF	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51974
TA 181	N,GAMMA	EXPT-PROG	7.0-2	8.4-1	WASH1155	23		5/70	BNL	MALIK+,MOXON-RAE DET,4ES,NO DATA	51921
TA 181	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51989
W	TOTAL XSECT	EXPT-PROG	2.1 1	8.2 4	WASH1155	40		5/70	COL	CAMARDA+,HIGLIRESOL,NO DATA GIVEN	51893
W	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51990
W	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51975
W 182	RESON PARAMS	EXPT-PROG	0.	1.5 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52078
W 182	STRNTH FNCTN	EXPT-PROG	0.	1.5 4	WASH1155	40		5/70	COL	CAMARDA+,VALUE GIVEN	52055
W 184	RESON PARAMS	EXPT-PROG	0.	1.5 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52079
W 184	STRNTH FNCTN	EXPT-PROG	0.	1.5 4	WASH1155	40		5/70	COL	CAMARDA+,VALUE GIVEN	52056
W 186	RESON PARAMS	EXPT-PROG	0.	1.5 4	WASH1155	40		5/70	COL	CAMARDA+,ONLY AVG D SHOWN	52080
W 186	STRNTH FNCTN	EXPT-PROG	0.	1.5 4	WASH1155	40		5/70	COL	CAMARDA+,VALUE GIVEN	52057
RE	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51991
IR	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51977
PT	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51978
AU 197	N,GAMMA	EVAL-PROG	1.3 1	6.9 2	WASH1155	118		5/70	LOK	GRENCH+,RE-EVAL OF EARLIER DATA	51928
AU 197	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51992
AU 197	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51979
HG	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51980
TL	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51981
TL 203	RESON PARAMS	EXPT-PROG	2.9 2		WASH1155	70		5/70	MTR	WATANABE TRANS,REDUCED WN GIVEN	52017
TL 203	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52070
TL 205	RESON PARAMS	EXPT-PROG	NDG		WASH1155	50		5/70	COL	CAMARDA+,TO BE DONE	52071
PB	SCATTERING	EXPT-PROG	2. 3		WASH1155	75		5/70	MTR	SMITH+,ANAL TO BE COMPLETED,NO DATA	51998
PB	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51982
BI 209	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51983
TH 232	DELAYD NEUTS	EXPT-PROG	3.1 6	1.5 7	WASH1155	156		5/70	LAS	KRICK+ PRELIMINARY NEUT YLDS GIVEN	51898
TH 232	N,GAMMA	EXPT-PROG	NDG		WASH1155	50		5/70	COL	ARBO+,NEVIS,MOXON-RAE DET,TO BE DONE	52081
TH 232	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51984
U	SPECT NGAMMA	EXPT-PROG	2. 3		WASH1155	76		5/70	MTR	GREENWOOD+,ANAL TO BE COMPL,NO DATA	51985
U 233	RESON PARAMS	EXPT-PROG	NDG		WASH1155	56		5/70	COL	FELVINCI+,J FROM CAPT SP,TO BE DONE	52085
U 233	ETA	EXPT-PROG	9.5-2	2.6-1	WASH1155	72		5/70	MTR	SMITH+,MN BATH,ANAL TBC,REL MEAST	52013
U 233	DELAYD NEUTS	EXPT-PROG	THR	1.5 7	WASH1155	156		5/70	LAS	KRICK+,PRELIMINARY NEUTRON YLDS GIVN	51937
U 233	FISS YIELD	EXPT-PROG	0	2	WASH1155	55		5/70	COL	FELVINCI+,ANAL TO BE COMPLETED,NDG	52044
U 233	FRAG SPECTRA	EXPT-PROG	0	2	WASH1155	55		5/70	COL	FELVINCI+,ANAL TO BE COMPLETED,NDG	52043
U 233	SPECT NGAMMA	EXPT-PROG	NDG		WASH1155	56		5/70	COL	FELVINCI+,TO BE DONE	52082
U 235	RESON PARAMS	EXPT-PROG	NDG		WASH1155	56		5/70	COL	FELVINCI+,J FROM CAPT SP,TO BE DONE	52086
U 235	SCATTERING	EXPT-PROG	2. 3		WASH1155	75		5/70	MTR	SMITH+,ANAL TO BE COMPLETED,NO DATA	51997
U 235	FISSION	EXPT-PROG	1.5 3	5. 5	WASH1155	114		5/70	LRL	BOWMAN+,LINAC,CURVE,MUCH STRUCTURE	52021
U 235	ETA	EXPT-PROG	1.6-1	2.6-1	WASH1155	72		5/70	MTR	SMITH+,MN BATH,ANAL TBC,REL MEAST	52007
U 235	ALPHA	EXPT-PROG	5. 1	2.8 4	WASH1155	106		5/70	LRL	CZIRR,TABLE	51952
U 235	DELAYD NEUTS	EXPT-PROG	THR	1.5 7	WASH1155	156		5/70	LAS	KRICK+,PRELIMINARY NEUTRON YLDS GIVN	51936

ELEMENT S	A	QUANTITY	TYPE	ENERGY MIN	ENERGY MAX	DOCUMENTATION REF	VOL	PAGE	DATE	LAB	COMMENTS	SERIAL NO.
U	235	SPECT FISS G	EXPT-PROG	5. 6	1.5 7	WASH1155	123		5/70	LOK	IMHOF+,ANAL TO BE COMPLETED,NO DATA	51929
U	235	SPECT FISS G	EXPT-PROG	5. 5		WASH1155	123		5/70	LOK	IMHOF+, TO BEDONE	51960
U	235	FISS YIELD	EXPT-PROG	THR		WASH1155	52		5/70	COL	DERENGOWSKI+,NO DATA GIVE,TBP IN PR	52073
U	235	FRAG SPECTRA	EXPT-PROG	THR		WASH1155	52		5/70	COL	DERENGOWSKI+,NO DATA GIVE,TBP IN PP	52074
U	235	SPECT NGAMMA	EXPT-PROG	0	1	WASH1155	20		5/70	BNL	CHRIEN+,SOME DATA GIVEN	52004
U	235	SPECT NGAMMA	EXPT-PROG	NDG		WASH1155	51		5/70	COL	DERENGOWSKI+,TO BE COMPLETED,NO DATA	52072
U	235	SPECT NGAMMA	EXPT-PROG	NDG		WASH1155	56		5/70	COL	FELVINCI+,TO BE DONE	52083
U	237	FISSION	EXPT-PROG	1. 5	2. 6	WASH1155	132		5/70	LAS	MCNALLY+,NUCL SHOT,CURV,TBP LA 4420	51879
U	237	FISSION	EXPT-PROG	4. 1	1. 3	WASH1155	132		5/70	LAS	MCNALLY+,NUCL SHOT,CURV,TBP LA 4420	51880
U	238	DELAYD NEUTS	EXPT-PROG	3.1 6	1.5 7	WASH1155	156		5/70	LAS	KRICK+ PRELIMINARY NEUT YLDS GIVEN	51899
U	238	SPECT FISS G	EXPT-PROG	5. 6	1.5 7	WASH1155	123		5/70	LOK	IMHOF+,ANAL TO BE COMPLETED,CURVES	51930
U	238	N,GAMMA	EXPT-PROG	1.3 5	1.4 6	WASH1155	3		5/70	ANL	POENITZ,NO DATA,SEE NSE 40 383 6/70	51875
U	238	N,GAMMA	EXPT-PROG	1. 4	1. 6	WASH1155	108		5/70	LRL	GARDNER+,OPTMDL CALCULATION,CURVE	51942
U	238	N,GAMMA	EXPT-PROG	1. 3	1. 6	WASH1155	63		5/70	GA	FRICKE+,ABSOL AVG SIGS,NO DATA GIVEN	51993
U	238	SPECT NGAMMA	EXPT-PROG	2. -2	1. 5	WASH1155	67		5/70	GA	JOHN+,TO BE COMPLETED,NO DATA GIVEN	52036
NP	237	RESON PARAMS	EXPT-PROG	NDG		WASH1155	56		5/70	COL	FELVINCI+,J FROM CAPT SP,TO BE DONE	52087
NP	237	SPECT NGAMMA	EXPT-PROG	NDG		WASH1155	56		5/70	COL	FELVINCI+,TO BE DONE	52084
PU	238	RESON PARAMS	EXPT-PROG	1.9 1	5.0 2	WASH1155	70		5/70	MTR	YOUNG+,NUCL SHOT,PARAMS FOR 48RESON	52014
PU	238	FISSION	EXPT-PROG	1.7 1	5.0 2	WASH1155	70		5/70	MTR	YOUNG+,NUCL SHOT,CURVE	52018
PU	239	SCATTERING	EXPT-PROG	2. 3		WASH1155	75		5/70	MTR	SMITH+,ANAL TO BE COMPLETED,NO DATA	51996
PU	239	FISSION	EXPT-PROG	1.3 5	1.4 6	WASH1155	3		5/70	ANL	POENITZ,NO DATA,SEE NSE 40 383 6/70	51874
PU	239	DELAYD NEUTS	EXPT-PROG	THR	1.5 7	WASH1155	156		5/70	LAS	KRICK+,PRELIMINARY NEUTRON YLDS GIVN	51935
PU	239	SPECT FISS G	EXPT-PROG	5. 5	1.5 7	WASH1155	123		5/70	LOK	IMHOF+,TO BE DONE	51931
PU	239	FISS YIELD	EXPT-PROG	THR		WASH1155	54		5/70	COL	CAMARDA+,BE+SM FILTERS,ABST ONLY,TBP	51922
PU	239	FISS YIELD	EXPT-PROG	THR		WASH1155	54		5/70	COL	TORASKAR+,ABST ONLY,TO BE PUBLISHED	52076
PU	239	FRAG SPECTRA	EXPT-PROG	THR		WASH1155	54		5/70	COL	CAMARDA+,BE+SM FILTERS,ABST ONLY,TBP	51923
PU	239	FRAG SPECTRA	EXPT-PROG	THR		WASH1155	54		5/70	COL	TORASKAR+,KE DIST,ABST ONLY,TBP	52075
PU	239	SPECT NGAMMA	EXPT-PROG	0	1	WASH1155	20		5/70	BNL	CHRIEN+,SOME DATA GIVEN	52005
PU	240	FISS YIELD	EXPT-PROG	SPON		WASH1155	54		5/70	COL	CAMARDA+,CFD PU239 NF,ABST ONLY,TBP	52046
PU	240	FRAG SPECTRA	EXPT-PROG	SPON		WASH1155	54		5/70	COL	CAMARDA+,CFD PU239 NF,ABST ONLY,TBP	52045
PU	241	ETA	EXPT-PROG	1.6-1	2.6-1	WASH1155	72		5/70	MTR	SMITH+,MN BATH,ANAL TBC,REL MEAST	52008
PU	242	TOTAL XSECT	EXPT-PROG	1.2-3	1.0 0	WASH1155	71		5/70	MTR	YOUNG+,TRANS,FAST CHOPPER,CURVE	52012
PU	242	DELAYD NEUTS	EXPT-PROG	THR	1.8 6	WASH1155	156		5/70	LAS	KRICK+,AVG NEUT YLD GIVN 0.1-1.8MEV	51934
AM	243	TOTAL XSECT	EXPT-PROG	1. -2	1. 0	WASH1155	70		5/70	MTR	BERRETH,FAST CHOPPER,CURVE,ANAL TBC	52019
AM	243	TOTAL XSECT	EXPT-PROG	5. -1	1. 3	WASH1155	69		5/70	MTR	SIMPSON+,TRANS,CURVES	52022
AM	243	TOTAL XSECT	THEO-PROG	0.	6.0 1	WASH1155	69		5/70	MTR	SIMPSON+,B-W FIT TO RESON,T#320DEGK	52024
AM	243	RESON PARAMS	EXPT-PROG	-2. 0	6.0 1	WASH1155	69		5/70	MTR	SIMPSON+,TRANS,WN FOR 81RESON,CURVE	52023
AM	243	SCATTERING	THEO-PROG	0.	6.0 1	WASH1155	69		5/70	MTR	SIMPSON+,B-W FIT TO RESON,T#320DEGK	52025
AM	243	FISSION	EXPT-PROG	1. 5	3. 6	WASH1155	132		5/70	LAS	SEEGER, NUCL SHOT,NDG,TBP LA-4420	51878
AM	243	N,GAMMA	THEO-PROG	0.	6.0 1	WASH1155	69		5/70	MTR	SIMPSON+,B-W FIT TO RESON,T#320DEGK	52026

ARGONNE NATIONAL LABORATORY

ACCELERATOR PROGRAMS

A. Fast Neutron Physics

1. Fast Neutron Total and Scattering Cross Sections

a. ^{10}B, ^{11}B, ^{12}C

(J. L. Adams,* A. J. Elwyn, R. D. Koshel,* R. O. Lane,* A. Langsdorf, Jr., J. E. Monahan, F. P. Mooring, and C. E. Nelson*)

The polarization and differential cross sections for neutrons scattered from ^{10}B, ^{11}B, and ^{12}C for energies in the interval 0.075—2.2 MeV were measured at Argonne several years ago. Recently we have analyzed these data to obtain spectroscopic information about the resonances excited in these reactions. In particular, an attempt has been made to interpret these spectra in terms of single-particle and particle-hole shell-model configurations. One report on this work has been published and another is in preparation. (Pertinent to request #31, WASH-1078)

b. Titanium

(A. Smith, J. Whalen, E. Barnard,[a] J. de Villiers,[a] D. Reitmann[a])

This work has been completed to 1.5 MeV and a final paper is in preparation. Numerical total, elastic and inelastic scattering cross sections have been transmitted to the NNCSC. In addition, the ENDF file is being updated in light of these recent results. (Pertinent to requests #76—77, WASH-1078)

c. Mo-92, 94, 96, 98, 100

(A. Smith, J. Whalen, and J. Meadows)

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[a]South African Atomic Energy Board, Pelindaba, Transvaal, Republic of South Africa.

Studies from incident energies of 0.1 to 1.5 MeV are complete. Numerical data is available from the authors on request. The results are being analyzed in terms of an intermediate coupling model. (Pertinent to requests #127—131, WASH-1078)

d. ^{165}Ho
(J. Meadows, A. Smith, and J. Whalen)

Total neutron cross sections of ^{165}Ho were measured from 0.1 to 1.5 MeV with resolutions of $\leq$2.5 keV. They varied slowly with energy and displayed no significant structure. Differential neutron elastic and inelastic scattering cross sections were determined at intervals of $\leq$50 keV from 0.3 to 1.5 MeV. The inelastic excitation of states in ^{165}Ho at; 98, 214, 371, 460, 517, 586, 712, 824, 995, 1104 and 1143 keV was positively observed with probably identification of several additional states. The measured cross sections were compared with calculated values based upon; spherical and deformed optical-potentials, and compound-nuclear reactions. Total cross sections were best described by a spherical potential while the differential elastic angular distributions were better represented by deformed calculations. Resonance interference effects were small and, at the energies of the present experiments, the contribution of direct processes was not large.

Numerical results have been forwarded to the NNCSC and a final report is available in draft form.

e. ^{238}U
(P. Lambropoulos and A. Smith)

The recent experimental study of inelastic scattering from ^{238}U to incident energies of 1.7 MeV and the associated analysis have been completed. The results support and extend similar values obtained at this Laboratory some years ago and indicate that the inelastic scattering cross section of ^{238}U is smaller than given in some of the more widely used evaluations. (Pertinent to request #307, WASH-1078)

f. ^{240}Pu
(A. Smith and J. Whalen)

Measurements of total and elastic and inelastic scattering cross sections to 1.5 MeV have been completed. The data is being processed and will soon be available as final cross sections. (Pertinent

to request #355, WASH-1078)

2. Fission Properties

a. Fission ratios U-233/U-235 and U-238/U-235
(J. Meadows)

A remeasurement of the fission cross sections of a number of isotopes relative to U-235 is being carried out. The experimental method uses back-to-back fission sources in a double ionization chamber of very light construction. Nanosecond pulsing techniques are used to reduce the background and eliminate fissions by thermal neutrons. Some preliminary results are listed below.

E_n	U-233/U-235	U-238/U-235
1500 keV	1.560	0.234
1400	1.591	0.098
1300	1.556	
1200	1.565	
1100	1.540	
1000	1.573	
900	1.651	
800	1.686	
700	1.685	
600	1.725	
500	1.725	

The typical error from all known sources for the 238/235 ratio is $\sim 1.5\%$. For the 233/235 ratio the typical error is $\sim 1\%$ not inclusive of the assay of the U-233 deposits. The values reported here are based on low geometry alpha counting assuming 1.591×10^5 yrs. for the U-233 half life. The final assay will be based on chemical analysis. (Pertinent to requests #264 and 312, WASH-1078)

b. Measurements of the cross section ratios of $^{235}U(n,f)$, $^{238}U(n,\gamma)$ and $^{239}Pu(n,f)$ in the energy range 130—1400 keV.
(W. P. Poenitz)

A paper with the title given above has been submitted to Nuclear Science and Engineering and will be published in June, 1970.

Changes in the order of 1% on the values reported previously[b] were due to a more accurate mass assignment for the U-235 sample. (Pertinent to requests #343, 342, 341, 312, 309, 386, 287, WASH-1078)

c. U-235 fission cross section
(W. P. Poenitz)

Measurements of the absolute fission cross section of U-235 in the 500—700 keV energy region have been carried out using the associated activity method. A spherical ionization chamber has been used to detect the fission events. The Cr^{51} activity associated to the neutrons from the $V^{51}(p,n)$ source reaction has been used to determine the absolute neutron flux. Data evaluation is presently in progress. (Pertinent to requests #286, 287, 288, WASH-1078)

d. Prompt fission neutron spectra
(A. Smith)

The prompt fission neutron spectra of ^{235}U and of ^{239}Pu have been measured using time-of-flight techniques. The data is being reduced to yield the energy dependent spectrum of fission neutrons to 1.5 MeV. At higher energies the ratio of the $^{235}U/^{239}Pu$ spectra will be deduced from the measured values. The experimental results should resolve much of the current uncertainty between average fission neutron energies determined microscopically and those derived from macroscopic measurements and should provide an improved knowledge of the difference between ^{235}U and ^{239}Pu spectra over a wide energy interval.

3. Standard Cross Sections

a. Total neutron cross section of Li^6
(J. Meadows)

The total cross section of Li-6 has been measured from 100 to 1500 keV. Measurements were made on two samples. One was on loan from the Atomic Energy Research Establishment, Harwell, England. The other, a much thicker sample, was prepared here several years ago.

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[b] W. P. Poenitz, WASH-1136, page 4 (1969).

The results were compared with measurements made on the former sample at Harwell. The agreement is good in absolute cross section but the energy of the resonance near 250 keV is ~7 keV higher in the ANL measurements.

b. The total cross section of ^{7}Li and carbon from 100 to 1500 keV[c]
(J. W. Meadows and J. F. Whalen)

A precise determination of the neutron total cross section of ^{7}Li and carbon has been made in the energy region 100 to 1500 keV. The parameters of the prominent ^{7}Li resonance in the laboratory system are E = 261 keV, Γ = 36.5 keV and γ_λ^2 = 594 keV. Corresponding parameters for the principal bound state resonance in carbon are E = -2020 keV and γ_λ^2 = 540 keV. The carbon data is fitted by $\sigma_T = 4.830 - 3.55E + 1.587E^2 - 0.305E^3$ where σ_T is in barns and E is in MeV. Above 500 keV the ^{7}Li data is fitted by $\sigma_T = 6.929 - 27.018E + 42.721E^2 - 27.210E^3 + 6.139E^4$.

4. (n;n'γ) and (n;γ) Processes

a. Spin determination of resonances in ^{165}Ho(n,γ) from low level occupation probability ratios
(W. P. Poenitz and J. R. Tatarczuk[d])

The dependence of the low level occupation probabilities on the compound state spin has been used to assign spin values to fourteen resonances in the reaction ^{165}Ho(n,γ)^{166}Ho within the neutron energy range from 18 to 86 eV. The low level occupation probabilities were determined from the intensities of γ-rays de-exciting these levels. These intensities have been measured in a time-of-flight experiment at the Rensselaer electron linear accelerator using a Ge(Li) detector. The spins assigned in the present experiment agree with those of the seven resonances where spin values have been recommended in BNL-325. A report of this work has been accepted for publication in Nuclear Physics.

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[c] Accepted by Nuclear Science and Engineering.

[d] From Rensselaer Polytechnic Institute.

b. Gamma rays from inelastic neutron scattering of U-238
(W. P. Poenitz)

Measurements of the γ-spectrum associated to the inelastic neutron scattering process in U-238 have been carried out at incident neutron energies of 800—1600 keV. A Ge(Li)-detector has been used to detect the γ-spectra. The time-of-flight technique has been employed to separate the n,n'γ-spectra from effects caused by fast neutrons in the detector material and from background events. The results provide ^{238}U level scheme information and cross section values to supplement inelastic neutron cross section measurements employing direct detection of the scattered neutrons.

c. $^{23}Na(n;n'\gamma)$ reaction
(D. L. Smith)

A Ge(Li) detector and pulsed-beam time-of-flight techniques were employed to measure the relative yields of the 439-keV (n'n'γ) gamma ray from ^{23}Na. Data was accumulated at 25-keV neutron intervals from 750 keV—1500 keV at a 90° reaction angle. Angular distribution measurements were made at neutron energies of 780, 910, 1070, 1150 and 1230 keV. Reported values[e] of the production cross section for the 670-keV gamma ray from ^{63}Cu were used to determine the cross section for production of the 439-keV gamma ray from ^{23}Na. The results are in excellent agreement with the fast neutron inelastic scattering data reported by J. P. Chien and A. B. Smith.[f]

5. Facilities (Applied Physics Division)

The Fast Neutron Generator has been in operation for several hundred hours. Stability is good and beam currents delivered on target have exceeded 50 microamps in tandem mode. The focus is particularly good and, combined with the high currents, has led to the destruction of several beam stops, slit assemblies, and a magnet box. Initial research measurements are underway intermittently with continued acceptance testing.

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[e] BNL-325; Neutron Cross Sections, Vol. I. (May 1964).

[f] J. P. Chien and A. B. Smith, Nucl. Sci. and Eng. 26 (1966) 500.

The on-line computer complement of the new facility is now installed and operational. Interfacing has been tested and software is under development. The main computer system is based upon two 24 bit machines with up to 16k of core with two 12 bit machines in special purpose and supporting roles.

6. Facilities (Physics Division)

A nanosecond beam-pulsing system to be used in the high-voltage terminal of the 4-MV Dynamitron was purchased from ORTEC and installation of the equipment is almost complete. Preliminary tests of the source system have indicated that the optical matching of the source to the accelerator tube is satisfactory. The crossed-field analyzer has undergone preliminary tests. Several pressure-sensitive leaks in the source have prevented tests from being run under operating conditions, but repair of the leaks will allow final acceptance tests to be run in the near future. The initial planned uses of the pulsed-beam facility will be in (p,n) reaction studies, in studies of spontaneously fissioning isomers in neutron-induced reactions, and in triple-scattering measurements.

B. Charged Particle Physics

1. Study of $^{10}B(^{3}He,d)^{11}C$ Reaction
(J. R. Comfort, H. T. Fortune, J. V. Maher, and B. Zeidman)

The spin of the 8.11-MeV level in ^{11}C (and its presumed mirror level at 8.57 MeV in ^{11}B) has long been assigned $J \leq \frac{5}{2}$. Data previously obtained at the Argonne cyclotron from the $^{12}C(^{3}He,\alpha)^{11}C$ reaction showed that this level is populated by $\ell = 1$; this limits the spin to either $J = \frac{1}{2}$ or $\frac{3}{2}$ (with negative parity). The present data showed that the level is also populated by $\ell = 1$ in the $(^{3}He,d)$ reaction. In view of the $J^{\pi} = 3^{+}$ assignment of the ^{10}B ground state, a unique assignment of $J^{\pi} = \frac{3}{2}^{-}$ is thus established for the 8.11-MeV state of ^{11}C. A paper reporting these results has been submitted for publication.

2. A Study of the Energy Levels of ^{29}Si
(D. Dehnhard and J. L. Yntema)

The $^{30}Si(^{3}He,\alpha)^{29}Si$ reaction was investigated with the 12-MeV ^{3}He beam of the ANL tandem. The results obtained with the magnetic spectrograph have been compared with those of the (d,t) and $(^{3}He,\alpha)$

reactions on the same nucleus with beams from the ANL cyclotron, and also with the predictions of the Nilsson model. It is found that the relative excitation strength of the $\frac{5}{2}^+$ levels is not in agreement with the model. However, indications are that band mixing due to the Coriolis force can account for discrepancies between the experiment and the simple model. A suggestion that the 4.90-MeV $\frac{5}{2}^+$ state of ^{29}Si would have a different deformation from the ^{29}Si ground state appears quite unlikely in view of our experimental results and the much improved agreement with theory when band mixing is used.

3. The $^{90}Zr(^3He,t)^{90}Nb$ Reaction
(R. C. Bearse, J. R. Comfort, J. P. Schiffer, M. M. Stautberg, and J. C. Stoltzfus)

This reaction has been studied with the 21-MeV ^3He beam from the Argonne tandem Van de Graaff and a position-sensitive semiconductor detector in the focal plane of a split-pole spectrograph. Nine states, apparently belonging to the $(g_{9/2})^2$ configuration, were identified. The multipole coefficients extracted from this spectrum seem to be almost identical to those extracted from the $(f_{7/2})^2$ ^{48}Sc spectrum, the only other completely known two-body spectrum in which the two orbits are identical. The quadrupole coefficients from both spectra are substantially larger than those extracted from all other known two-body spectra.

4. J Dependence of $^{54}Fe(d,p)^{55}Fe$ and $^{50}Ti(d,p)^{51}Ti$
(J. L. Yntema, H. Ohnuma, H. T. Fortune, and R. C. Bearse)

The experimental data have been extended to 15 MeV with the Minnesota tandem and additional data have been taken with the Argonne tandem. It appears now that it is quite feasible to obtain good fits to the $p_{3/2}$ and $p_{1/2}$ experimental angular distributions for

^{54}Fe(d,p)^{55}Fe reaction in the 8—12-MeV range with either surface or volume absorption in the deuteron potential. However, potentials such as the one used by Haeberli et al. do not fit the Fe data at 14—18 MeV. It is much easier to fit the ^{50}Ti(d,p)^{51}Ti angular distributions over the entire energy range. The extraction of absolute spectroscopic factors depends on the DWBA technique and on the potential types that are used, and at this point it is not evident that one can experimentally determine the appropriate procedure for the extraction of strength from distorted-wave calculations.

5. Possible Spin Dependence in Proton Inelastic Scattering
(J. C. Legg and J. L. Yntema)

An anomaly, apparently a final-state spin dependence, has been observed in proton inelastic scattering from ^{63}Cu, ^{65}Cu, and ^{67}Zn. The excited-core model of inelastic scattering cannot produce such an effect. Indeed, no current theory of inelastic scattering based on the distorted-wave Born approximation can even qualitatively predict such an effect. Subsequent experiments with deuterons have exhibited a similar result.

6. Energy Levels of ^{181}W Observed with the (d,t) and (p,t) Reaction
(J. R. Erskine)

The energies and single-particle excitations of ^{181}W were investigated with the split-pole magnetic spectrograph and the automatic plate scanner. This is a continuation of the earlier (d,p) studies on ^{183}W, ^{185}W, and ^{187}W. Angular distributions of the ^{182}W(d,t)^{181}W reaction were recorded at 14 MeV. These data (resolution width = 10 keV FWHM) allowed ℓ values to be determined for most of the observed levels. Excitation energies and differential cross sections derived from the (d,t) data were sufficient to identify the hole states $\frac{9}{2}$+[624] , $\frac{5}{2}$-[512] , $\frac{1}{2}$-[521] , and $\frac{7}{2}$-[514] at 0, 365, 386, and 408 keV, respectively. However, the particle state $\frac{1}{2}$-[510] , expected on the basis of systematics to lie at an excitation of 200—400 keV, was not observed in the (d,t) data. Consequently, the ^{183}W(p,t)^{181}W reaction was studied at 17 MeV bombarding energy. A strong peak with an ℓ = 0 angular distribution

was seen at 457 keV excitation, the presumed band head of the $\frac{1}{2}$-[510] state.

7. Study of Levels in ^{182}Ta with the ^{181}Ta(d,p)^{182}Ta Reaction
(J. R. Erskine)

New data have been taken with the ^{181}Ta(d,p)^{182}Ta reaction to try to understand the discrepancy between recent results of ^{181}Ta(n,γ) studies and an old investigation of the ^{181}Ta(d,p)^{182}Ta reaction by the author. The split-pole magnetic spectrograph and the automatic plate scanner were used to obtain these data. In the original study made at 7 MeV bombarding energy, states at 99 and 115 keV were assigned $J^{\pi} = 4^-$ and 5^-, respectively. These assignments were made by comparing calculated differential cross sections with the measured cross sections. The angular distributions gave no information on the ℓ value. Recently, however, the ^{181}Ta(n,γ)^{182}Ta reaction has been studied at Argonne as well as at other laboratories. These studies indicated that both the 99- and 115-keV states were $J^{\pi} = 4^-$, in conflict with the earlier (d,p) assignments. The previous 4^- and 5^- assignments were traced to an obscure error in sign in the old calculations. Further studies of odd-odd deformed nuclei, including ^{180}Ta, ^{166}Ho, and ^{164}Ho, are planned.

C. Photonuclear Physics

1. Threshold Photonuetron Spectra
(H. E. Jackson)

A new experimental high-resolution photoneutron facility is now in operation at Argonne. It consists of an experimental area below grade of $\sim$900 ft^2 which adjoins the new high intensity electron linear accelerator, used as a source of bremsstrahlung. A shielding wall 7 ft thick separates the linac pit from the experimental area. Photoneutrons travel along flight tubes placed at 90°, 135° and 155° to the direction of the bremsstrahlung beam, and are detected in banks of Li glass neutron detectors at the end of each flight tube. In experiments to date, the linac has operated with a 5-nanosecond pulse at a repetition rate of 720 sec^{-1} and an intensity corresponding to average currents in excess of 20 μA. A test photoneutron spectrum for lead is shown in Fig. 1. The maximum bremsstrahlung energy (7.4 MeV) was chosen to permit excitation only of states in ^{207}Pb. A thin target (1/8 in.) of natural lead was used. Such a spectrum requires about 5 hr of beam at the above conditions. To data spectra have been observed for ^{208}Pb, ^{207}Pb, ^{138}Ba, and ^{53}Cr.

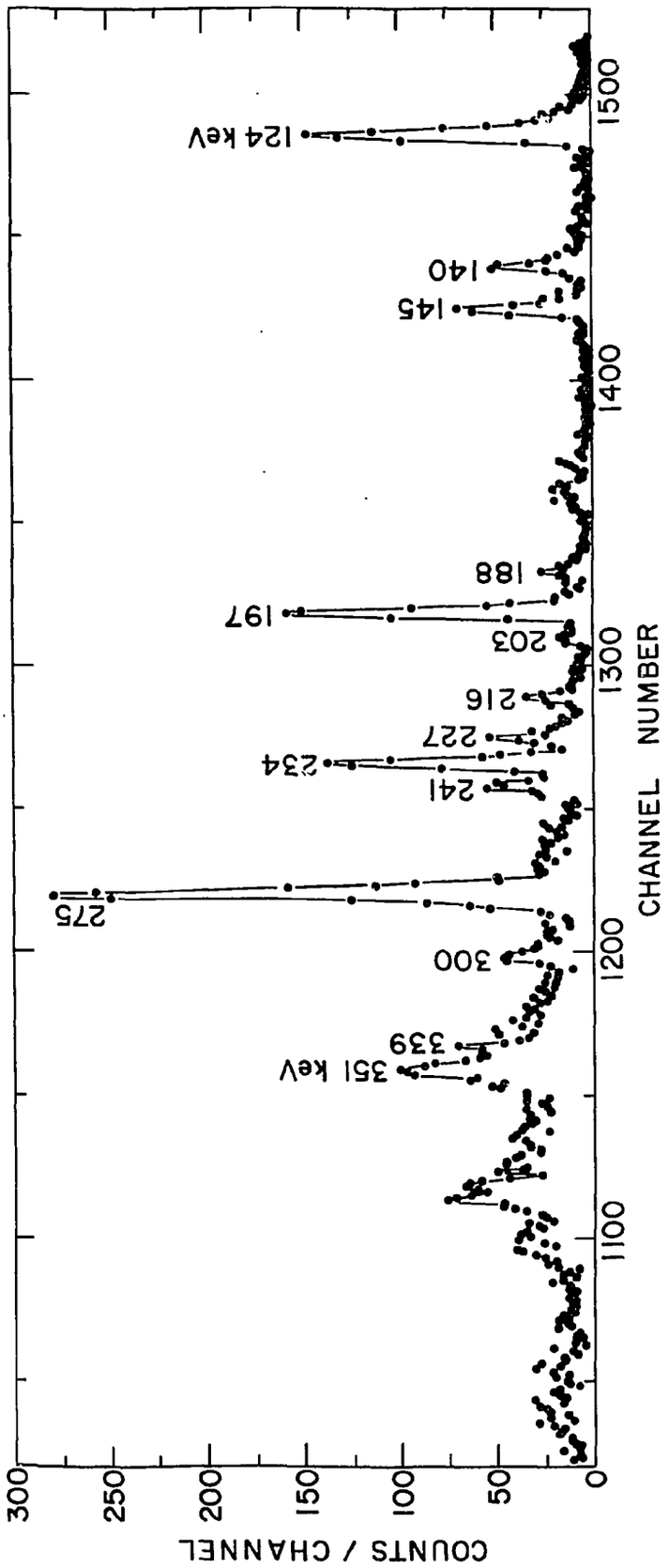

Fig. C-1. (Neg. No. 209-735, PHG-9450)

PILE NEUTRON PHYSICS

The CP-5 reactor is currently shut down for extensive modification and rehabilitation. A return to full power is expected in the next few months. Consequently research activity has been limited to analysis of data obtained before the shutdown.

A. Structure in the Strength Function of M1 Transitions in $^{105}Pd(n,\gamma)^{106}Pd$

(L. M. Bollinger and G. E. Thomas)

An average-resonance-capture measurement for $^{105}Pd(n,\gamma)^{106}Pd$ shows that a plot of the reduced width $\Gamma_\gamma E_\gamma^{-3}$ vs E_γ for M1 transitions forms a smooth giant-resonance-like curve that has a maximum at about 7.8 MeV and a width (FWHM) of roughly 2.5 MeV.

The observed high-energy γ-ray lines are formed by three components—M1 and E2 transitions following s-wave neutron capture and E1 transitions following p-wave capture. In order to obtain information about the M1 component, the E1 and E2 contributions have been subtracted.

The intensity of the M1 component cannot be accurately determined because of uncertainties in the s-wave and p-wave neutron strength functions of ^{105}Pd. Nevertheless, the calculations and the data show that the derived giant-resonance-like structure in the M1 strength function is real, although its properties are not well determined. The small intensities of transitions to the 0^+ states show that the observed structure cannot result from anomalies in either the E1 or E2 transitions.

The observed structure for the M1 γ-ray strength function is qualitatively similar to that calculated for heavy deformed nuclei by Shapiro and Emery[g] on the basis of a two-quasiparticle model.

NUCLEAR THEORY AND ANALYSIS

A. Analysis of the Distribution of the Spacings Between Nuclear Energy Levels

[g] C. S. Shapiro and G. J. Emery, Phys. Rev. Letters 23, 244 (1969).

(J. E. Monahan and N. Rosenzweig)

An empirical spacing distribution is always based on a finite, and usually small, number of observed levels. Thus, even if the spacing of levels were described exactly by Wigner's random-matrix model, the observed distribution would necessarily fluctuate about the theoretical mean—the Wigner distribution. A statistic $\Lambda(n)$ has been defined to enable one to judge whether the magnitude of the observed fluctuations about the Wigner distribution is compatible with the random-matrix model. It is found that the correlations between the spacings implied by the model tend to reduce the expected fluctuations significantly. The statistical properties of $\Lambda(n)$ were studied by means of a Monte Carlo calculation with matrices of order 100 sampled from the Gaussian orthogonal ensemble. An illustrative analysis of the very long series of neutron resonances observed in ^{238}U by Garg *et al.* reveals no obvious discrepancy between theory and experiment up to neutron kinetic energies of about 2 keV. The statistic $\Lambda(n)$ permits a significant test of Wigner's model also for relatively short series of 10—15 neutron resonances. It is therefore planned to subject the extensive experimental material (obtained during the past decade or so) to a suitable analysis.

B. Theory of Nuclear Level Density for Periodic Independent-Particle Energy-Level Schemes (P. B. Kahn and N. Rosenzweig)

Accurate formulas were derived for the density of states of a degenerate system of any number of types of fermions moving in arbitrary periodic single-particle energy-level schemes. The results are of the standard exponential form with the modification that the excitation energy is to be replaced by an "effective energy." The effective energy contains an additive correction which depends explicitly on the structure and ground-state occupation of the periodic level sequences. The spin-dependent level-density formula for two kinds of particles should be useful in a rough correlation of observed nuclear level densities with shell-model level sequences. The present work generalizes, unifies, and simplifies earlier treatments of related problems.

BROOKHAVEN NATIONAL LABORATORY

A. NEUTRON PHYSICS

1. Fast Chopper (R. E. Chrien, O. A. Wasson, M. R. Bhat,* S. F. Mughabghab,* R. G. Graves,** M. Beer,* S. Dritsa,† and J. B. Garg††)

a) Instrumental

A new drive system consisting of an AC induction motor and oil flow lubrication for the thrust bearings was installed in the fast chopper in January. This variable speed system permits the chopper to be operated either at its designed speed of 15,000 RPM for optimum resolution or at slower speeds down to 1500 RPM for thermal neutron measurements. Routine operation has been obtained since February 1.

Development of a spectrometer to measure the resonant neutron capture γ rays in the fissile nuclei continues. A special Ge(Li) γ-ray detector is surrounded by an annular liquid scintillator, which detects fission neutrons, and thereby separates capture from fission events. Preliminary tests of the pulse shape discrimination efficiency of the liquid scintillator were performed using the fission neutrons from resonant neutron absorption in U^{235}.

b) Experimental

1) Resonant neutron capture γ ray measurements in Dy^{163}. The spins of 23 resonances in a target of 93% dysprosium-163 were determined from measurements of both the high- and low-energy γ ray spectra for each resonance. The high energy γ ray spectrum from the sum of several resonances is shown in Fig. A-1. The deduced spin assignments from the intensity ratio of the two low-energy γ rays are shown in Fig. A-2 where the circles and triangles represent resonances of 3^- and 2^- respectively. In addition strong correlations between individual γ ray intensities and the reduced neutron widths of the capturing states were observed. This type of correlation was first

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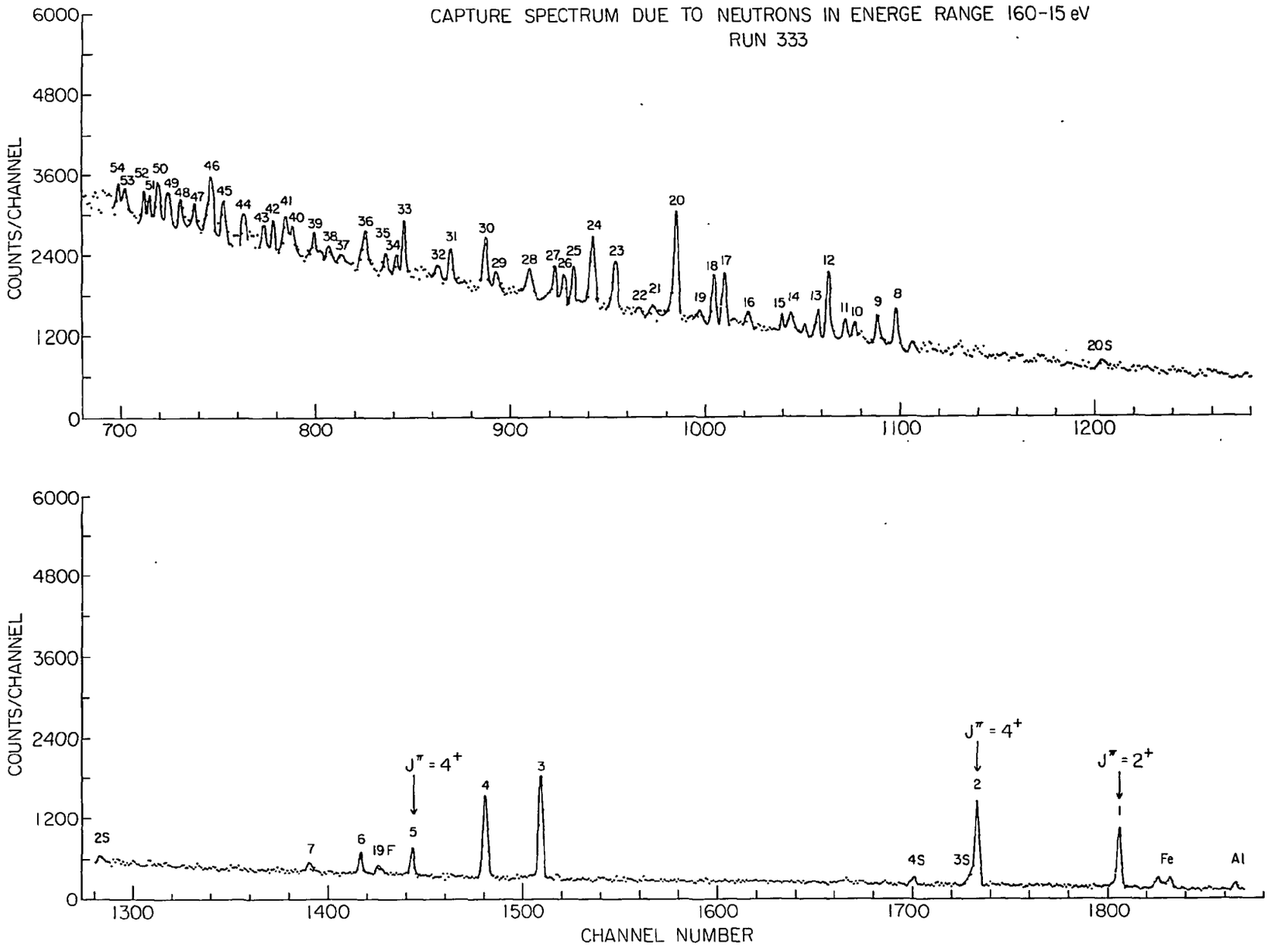

FIGURE A - 1

Resonance capture γ-rays from $^{163}Dy(n,\gamma)^{164}Dy$ over a broad energy range.

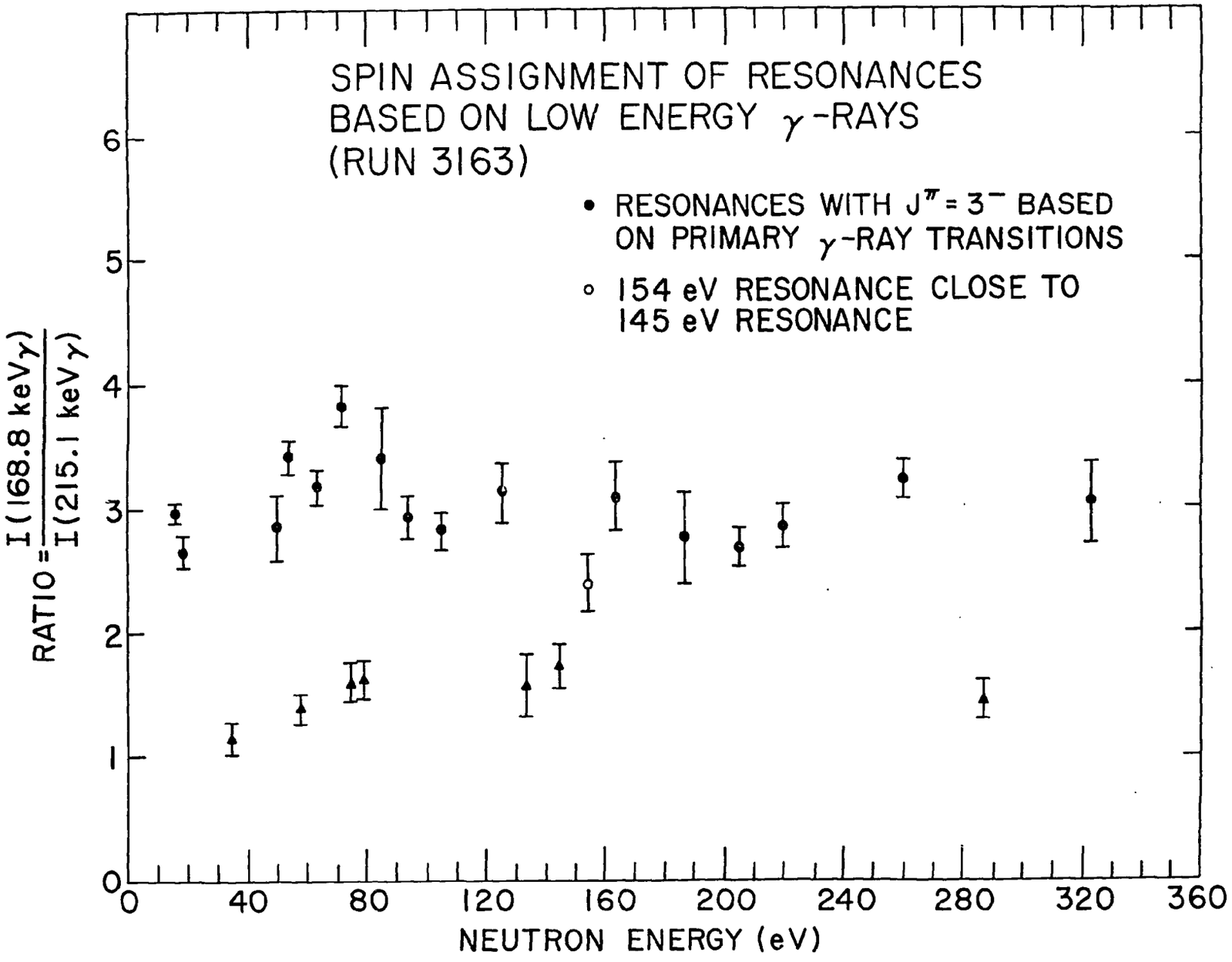

FIGURE A - 2

Spin assignments for ^{163}Dy resonances based on the observation of the ratio of the 168.8 keV to 215.1 keV transitions. The 154 eV and 145 eV resonances, shown as the open circle, are not completely resolved.

observed in thulium and is an indication of departure from the purely statistical decay of the compound nuclear resonances.

(Pertinent to Requests 292, 293, WASH 1144)

2) Resonant neutron capture in cesium. The high-energy γ rays from neutron capture in 6 resonances of Cs were measured. Typical results are shown in Fig. A-3. The observation of the weak 6892 keV M1 ground state transition established the neutron binding energy as 6891.6 ± .2 keV.

The distribution of the reduced partial γ ray widths from 6 resonances is consistent with the Porter-Thomas Distribution, although no account was taken of the lack of knowledge of resonance opens. No correlations among the γ ray intensities or between the partial γ ray widths and the reduced neutron widths was observed. In addition the average γ ray widths were seen to follow an E_γ^3 dependence. These facts are all consistent with a statistical decay of the resonant state.

(Pertinent to Requests 239, 240, WASH 1144)

3) Gamma rays from thermal and resonance capture in Sb^{121} and Sb^{123}. Prompt high energy γ rays resulting from neutron capture at thermal energies and in the resonances of Sb^{121} and Sb^{123} have been studied. Typical spectra are shown in Fig. A-4. The binding energy, B_n, of the last neutron in Sb^{122} and Sb^{124} has been determined to be 6807±2 keV and 6468±2 keV respectively. Based on prompt capture γ-ray data, we have assigned a spin of 4 to the 21.6 eV resonance of Sb^{123}. Energy levels populated by the neutron capture γ rays are given up to an excitation energy of 2475 keV in Sb^{122} and up to 2221 keV in Sb^{124}. These data are compared with the existing (d,p) data on Sb^{121} and Sb^{123}. We have also studied the low energy (< 511 keV) γ rays originating in neutron capture in the different resonances. For Sb^{121}, the observed spectra are found to fall into two classes, each having its own characteristic intensity distribution depending on the spin of the capturing state. By comparing these spectra with those originating from the 6.24 eV resonance (3^+) and the 15.4 eV resonance (2^+) we have assigned the following spins to the resonances in Sb^{121}: 29.7 eV (3), 53.5 eV (2), 64.5 eV (3), 73.8 eV (2), 111.4 eV (2), and 126.8 eV (3). The low energy spectra have also been used to measure the half-life of the 61.6 keV isomeric state in Sb^{122} by a new method. The half-life of the isomeric state is found to be 2.3±.6 μ sec, and is derived from an analysis of the time dependence of individual γ-rays in the time-of-flight spectrum.

4) Resonance neutron capture in Rh^{103}. The γ-ray spectra following slow neutron capture in a target of ^{103}Rh have been measured. A total of 145 levels in ^{104}Rh, populated by transitions directly from

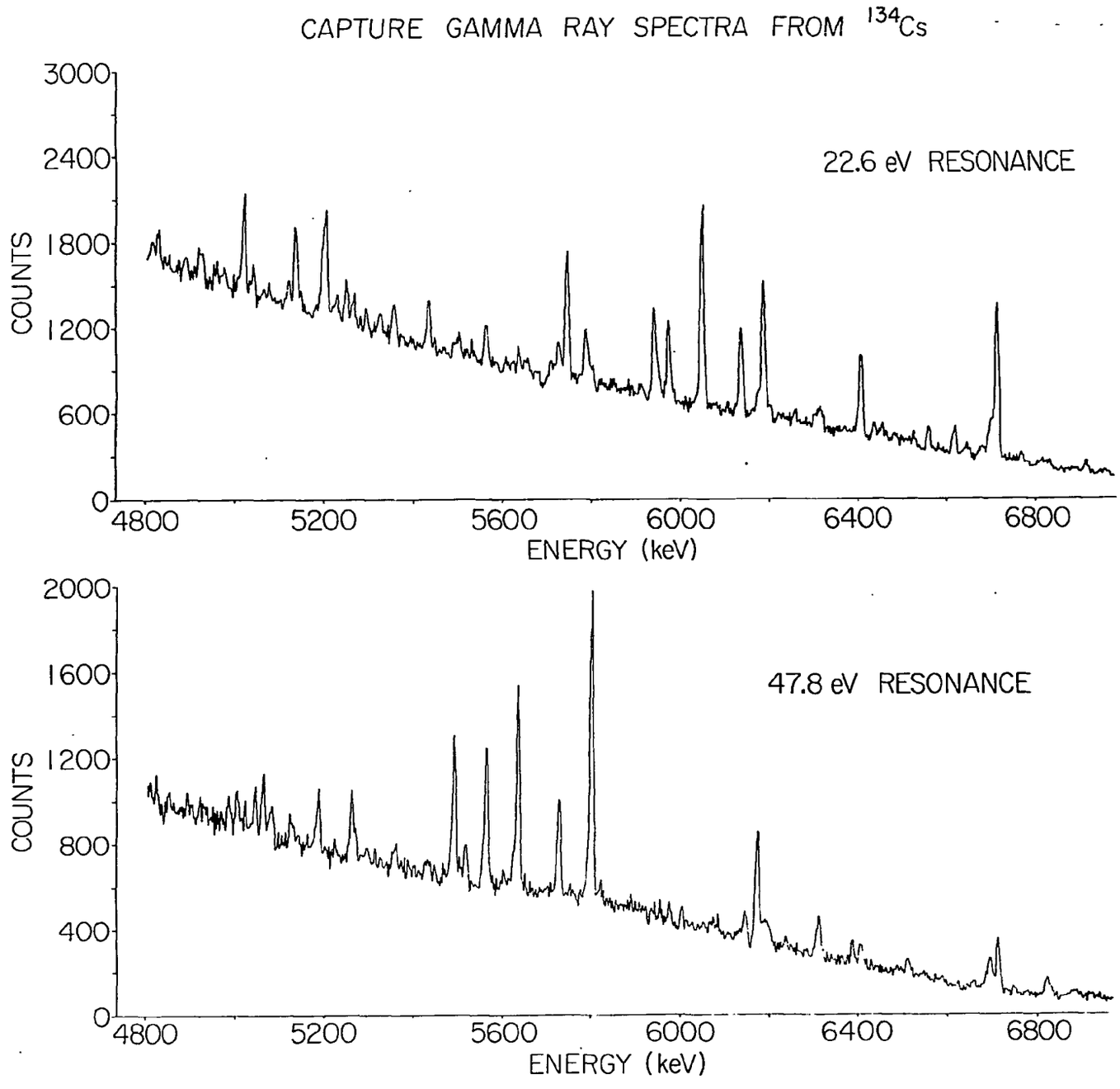

FIGURE A - 3

Capture spectra from the 22.6 and 47.8 eV resonances of cesium.

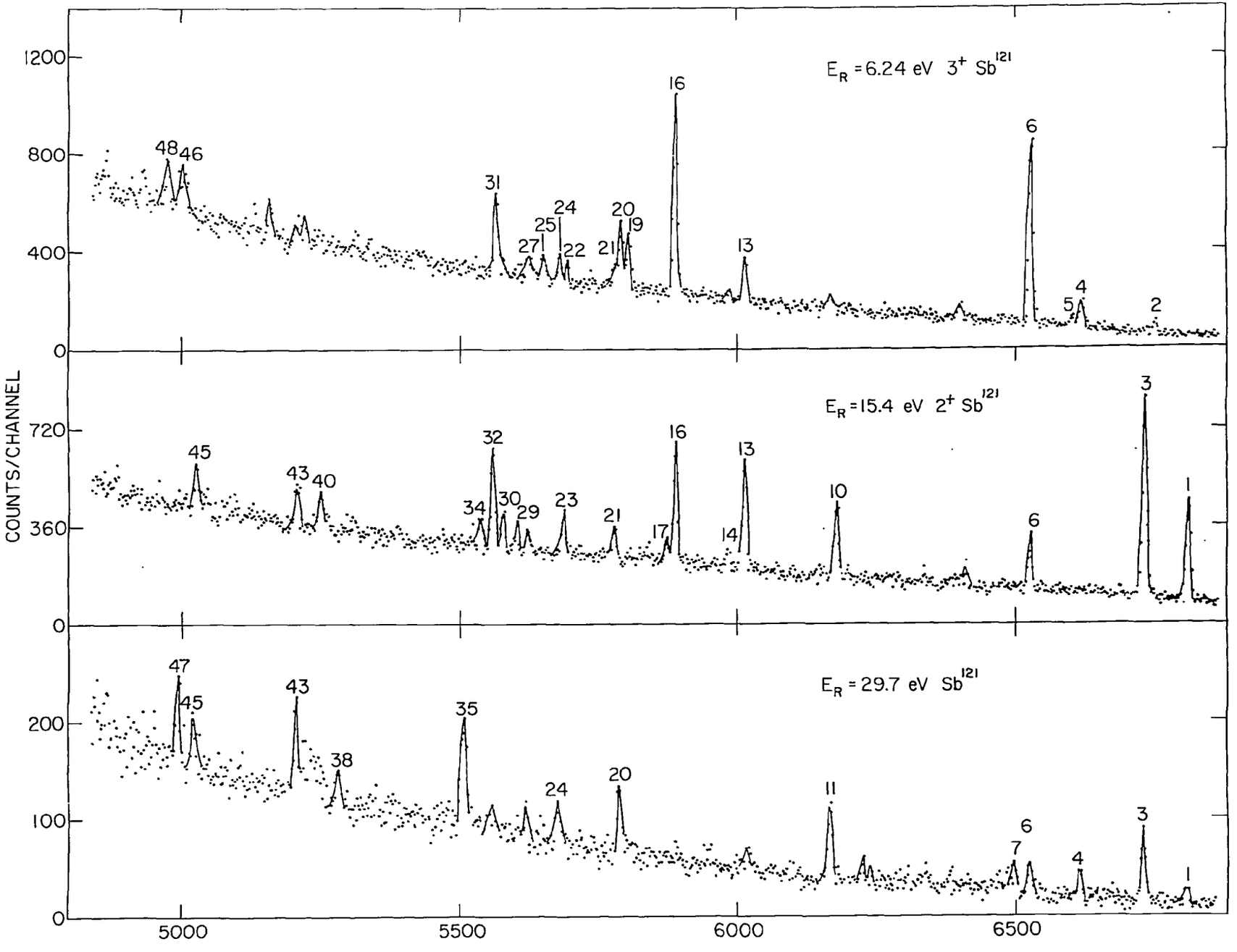

FIGURE A - 4

Capture spectra from resonances in antimony.

16 capturing states, was recorded. A neutron binding energy of 6999.3±1.5 keV is obtained. From these high energy γ-ray data several spin assignments for levels in ^{104}Rh are made. The distribution of transition probabilities in rhodium is not consistent with the Porter-Thomas distribution; values of $\nu = 2.70 \begin{smallmatrix}+0.53\\-0.40\end{smallmatrix}$ and $\nu = 2.45 \begin{smallmatrix}+0.38\\-0.40\end{smallmatrix}$ are obtained as best fits to the class of chi-square distribution functions to spin 0 and spin 1 resonances, respectively. The gross shape of the γ-ray spectrum shows an enhancement of strength to states near 1 MeV in excitation energy, both for thermal and resonance capture. It is shown that this enhancement is not due to a direct reaction process, and it is suggested that the presence of doorway states may be responsible for this enhancement.

(Pertinent to Request 228, WASH 1144)

5) High energy γ rays following neutron capture in Pu^{239} and U^{235}. Gamma rays following neutron capture in ^{235}U and ^{239}Pu have been examined. In ^{235}U the radiative transitions are weak and not readily observable above the fission γ-ray background. There is, however, considerable structure in the spectrum of delayed γ-rays following fission. This structure is seen to be similar to the structure observed for a target of ^{239}Pu (see Fig. A-5). In the latter case, however, the radiative transitions are stronger and are seen to dominate the spectra of several resonances. Several transitions to known states of ^{240}Pu and the assignment of spins in two ^{239}Pu resonances. The partial widths of the stronger transitions were measured by correcting the detector for the fission γ-ray component and standardizing against a known transition in ^{195}Pt. These widths are listed in Table A-1. Several γ-ray lines in ^{241}Pu, resulting from capture in the 1.056 eV ^{240}Pu impurity resonance, were also observed. The relative intensities are listed in Table A-2.

(Pertinent to Requests 392, 448, 449, WASH 1144)

Table A-1

Partial Radiative Widths

$^{239}Pu(n,\gamma)^{240}Pu$

10^{-6} eV

E_γ(keV)	0.3	7.85	10.95	11.9	14.68	17.7	22.2	41.7	52.7	58
6491.2±1.5	65							66		
5936.3	80	726		120	28			48	126	93
5674.6	96							76		

Table A-1 (continued)

E_γ(keV)	0.3	7.85	10.95	11.9	14.68	17.7	22.2	41.7	52.7	58
5597.3		227		286	25	192	72	76		
5575.2	295	64	156		38		136		103	99
5292.3					78			110		
5095.4				344	44			160	96	

Table A-2

Relative Intensities

1.054 eV resonance, ^{240}Pu

E_γ	I
5170.4	110±22
5076.5	140
4298.7	259
4279.8	208
4273.8	230
3942.6	601
3882.3	641
3874.2	368±56

6) Resonant neutron capture in Lu^{175}. A study of the neutron capture reaction mechanism for radiative capture of resonant energy neutrons has been made for $^{175}Lu(n,\gamma)^{176}Lu$. The statistical distribution of the partial radiation widths over 11 neutron resonances is inconsistent with a chi-squared distribution with 1 degree of freedom. A value of $\nu = 1.56\ ^{+0.3}_{-0.23}$ is obtained. No correlations are observed between the γ-ray partial widths and the reduced neutron widths of either the capturing or final states. Neither is there any significant correlation among the individual γ-ray widths. Such facts indicate that neither channel capture nor doorway states contribute strongly to the neutron capture process in the region above the neutron binding energy. Final states unreported in previous experiments are observed. In addition the spins of 11 resonances as well as limitations on the spins of the low-lying final states are determined. The resonance spins are listed in Table A-3.

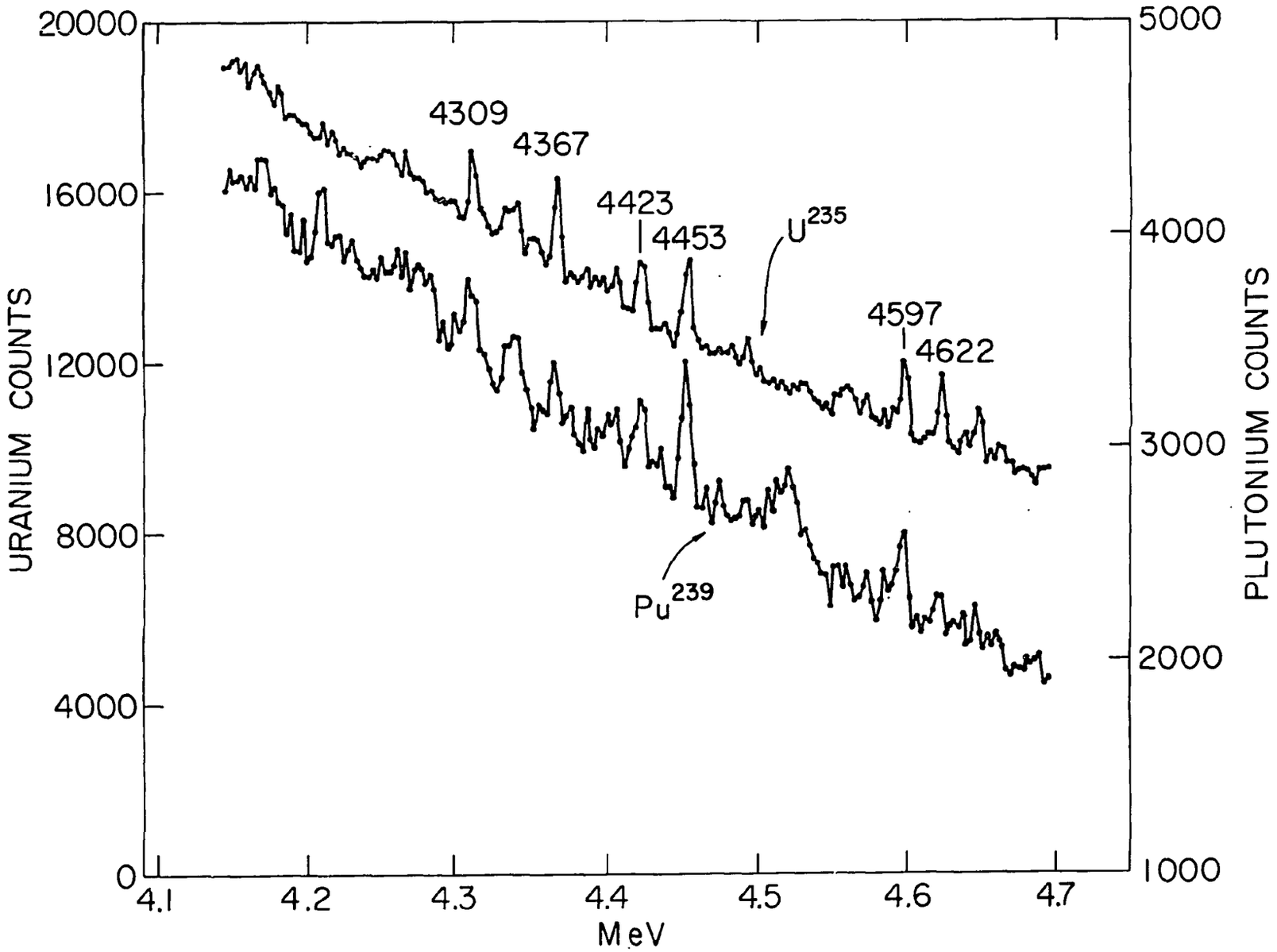

FIGURE A - 5

A portion of the delayed (> 10 μsec) γ-ray spectra from ^{235}U and ^{239}Pu. The γ rays which are labeled by energy are those which are seen in both spectra. The energy scale is constructed by assuming that these are 2-escape peaks.

Table A-3

Resonance Spin Assignments

Resonance Energy, eV	Resonance Spin	
	High Energy γ Rays	Low Energy γ Rays
2.6		4
4.8	4	4
5.2		3
11.2		3
13.8	3	3
15.4	4	4
20.7	3	3
23.7	3	3
27.9		4
36.5	3	3
40.6		3

2. Nuclear Cryogenics

a) Spin assignment of Dy^{161} and Dy^{163} neutron resonances by nuclear polarization (G. Brunhart, Hans Postma, D. C. Rorer, V. L. Sailor, and L. Vanneste)

The total angular momenta, J, of the compound states corresponding to the first several neutron resonances in Dy^{161} and Dy^{163} have been determined by the polarization method (transmission of polarized neutrons through polarized targets). Quantitative results at two resonances of opposite spin make the assignments absolute. Results were, listing $E_0(J)$ where E_0 is in eV: Dy^{161}: 2.72(3); 3.69(2) 4.35(2); 7.75(3); 10.40(2); 10.87(3); 12.65(2); 14.3(2); 16.7(?); 18.5(2); and Dy^{163}: 1.71(2); 16.25(3). The hyperfine interaction constants for Dy^{163} were found to be $A/k=0.100\pm0.005^{o}K$, and $P/k=0.008 \pm0.001^{o}K$ where A is the magnetic interaction and P the electric quadrupole interaction constant.

(Pertinent to Request 292, WASH 1144)

b) Factors in the precision of slow neutron capture cross section measurements using a simple Moxon-Rae detector (S. S. Malik, G. Brunhart, F. J. Shore, and V. L. Sailor)

The practicality of using relatively simple apparatus for precise measurements of slow neutron capture cross sections has been explored. The capture gamma-ray production rate was measured by means

of a very simple detector of the type invented by Moxon and Rae which consisted of a thick graphite converter placed next to a thin plastic scintillator mounted on a two-inch photomultiplier tube. All cross sections were measured relative to Au. It was found that cross sections can be obtained to a precision in the range of 1-2% provided that proper attention is given to sample purity, geometry, and corrections for multiple scattering and self-absorption. A variety of elements were tested covering a cross section range from < 0.2 to > 150 barns. Results are given for the elements Ni, Cu, Zr, Nd, Tb, and Er at neutron energies of 0.033, 0.075, 0.115, and 0.270 eV and for Al, Ag, and Ta at 0.070, 0.115, 0.364, and 0.835 eV. The measured values are consistent with 1/v dependence of the capture cross section for those elements having no nearby resonances.

c) Absolute determination of spins of neutron resonances and the hyperfine coupling constant in Er^{167} (G. Brunhart and V. L. Sailor)

The spins of the lowest four neutron resonances in Er^{167} have been determined by measuring the transmission of polarized neutrons through a sample of polarized erbium nuclei. The determination of the spins depends solely on the transmission effect and is independent of any assumption about the sign of the nuclear magnetic moment or the direction of the effective field at the target nuclei. The spins were found to be $J = I + 1/2 = 4$ for the 0.460 eV resonance and $J = I - 1/2 = 3$ for the resonances at 0.584 eV, 6.10 eV, and 9.6 eV. The nuclear polarization of the sample, obtained as function of the sample temperature at a fixed energy, was fitted to a theoretical curve using the magnetic and electric hyperfine splitting constants as fitting parameters. The values found for the magnetic and electric hfs constants are, respectively, $A/k = -0.085 \pm 0.0005^{o}K$ and $P/k = -0.005 \pm 0.001^{o}K$. Taking the nuclear magnetic moment of Er^{167} to be $-0.56\mu_N$ the corresponding effective magnetic field at the nucleus is 7.26×10^6 Oe.

d) Spin dependence of the neutron capture cross section of vanadium and the internal magnetic field at vanadium nuclei (H. Postma, L. Vanneste, and V. L. Sailor)

The spin dependence of the neutron capture cross section of vanadium at 0.115 eV has been measured with the aid of polarized neutrons and polarized vanadium nuclei. It is concluded that the capture cross section of V^{51} is mainly related to spin $J = I - 1/2$. In addition it is shown that the internal field at the vanadium nuclei is less than 4 kOe in very pure vanadium, which apparently does not become ferromagnetic down to 0.06 K.

e) Parahydrogen total cross section (T. L. Houk and R. Wilson, Harvard University)

A measurement is underway on the total cross section of parahydrogen at a few selected energies in the range from 0.003 to 0.02 eV in effort to reduce the uncertainty in this quantity. The gaseous target at about 1 atmosphere pressure is maintained at constant temperature by a liquid hydrogen bath. Temperatures, pressures, and neutron energies are selected which should minimize corrections for finding effects, molecular excitation, and ortho/para ratios. Difficulty has been experienced in achieving equilibrium ortho/para ratios in reasonable lengths of time.

3. Nuclear Structure

a) The level structure of Ag^{110} (W. R. Kane and G. S. Goldhaber)

After decades of research in nuclear physics, the level structures of almost all nuclides lying near the valley of stability have been thoroughly established. Ag^{110}, however, has remained an exception to this statement. In particular, until now the first excited state of Ag^{110} has remained hidden. The existence of this state had been inferred from studies of the decay of 253 day Ag^{110m}, where only one transition, with M4 character, is observed, while the isomeric and ground states are known to have 6+ and 1+ spin and parity respectively. In an effort to resolve the question of the "missing" first excited state of Ag^{110}, extensive studies of the $Ag^{109}(n,\gamma)Ag^{110}$ reaction have been carried out. Since Ag^{110} is odd-odd, the density of low-lying states is high, the capture gamma ray spectrum very complex, and accordingly, high precision and resolution were essential to the experiment. The work was carried out in three stages: 1. Measurements on high energy capture gamma rays, both of thermal energy and on the 5.19 eV resonance, established 15 levels populated directly from the capture state. 2. Low energy gamma ray and Ge-Ge coincidence measurements provided a detailed level scheme, with strong evidence for the first excited state at 1.28 keV. Part of this level scheme is shown in Fig. A-6(b), with previously existing information shown in Fig. A-6(a). In order to demonstrate directly the existence of the first excited state, Ge-Ge coincidence measurements were made at a resolution sufficient to split the 1.28 keV gamma-ray doublets expected for transition populating the ground state - first excited state level doublet. The results of these measurements are shown in Fig. A-7(b), where the gamma-ray doublets are shown in both singles and coincidence measurements, showing conclusively that both members of the doublet are populated from a single initial state.

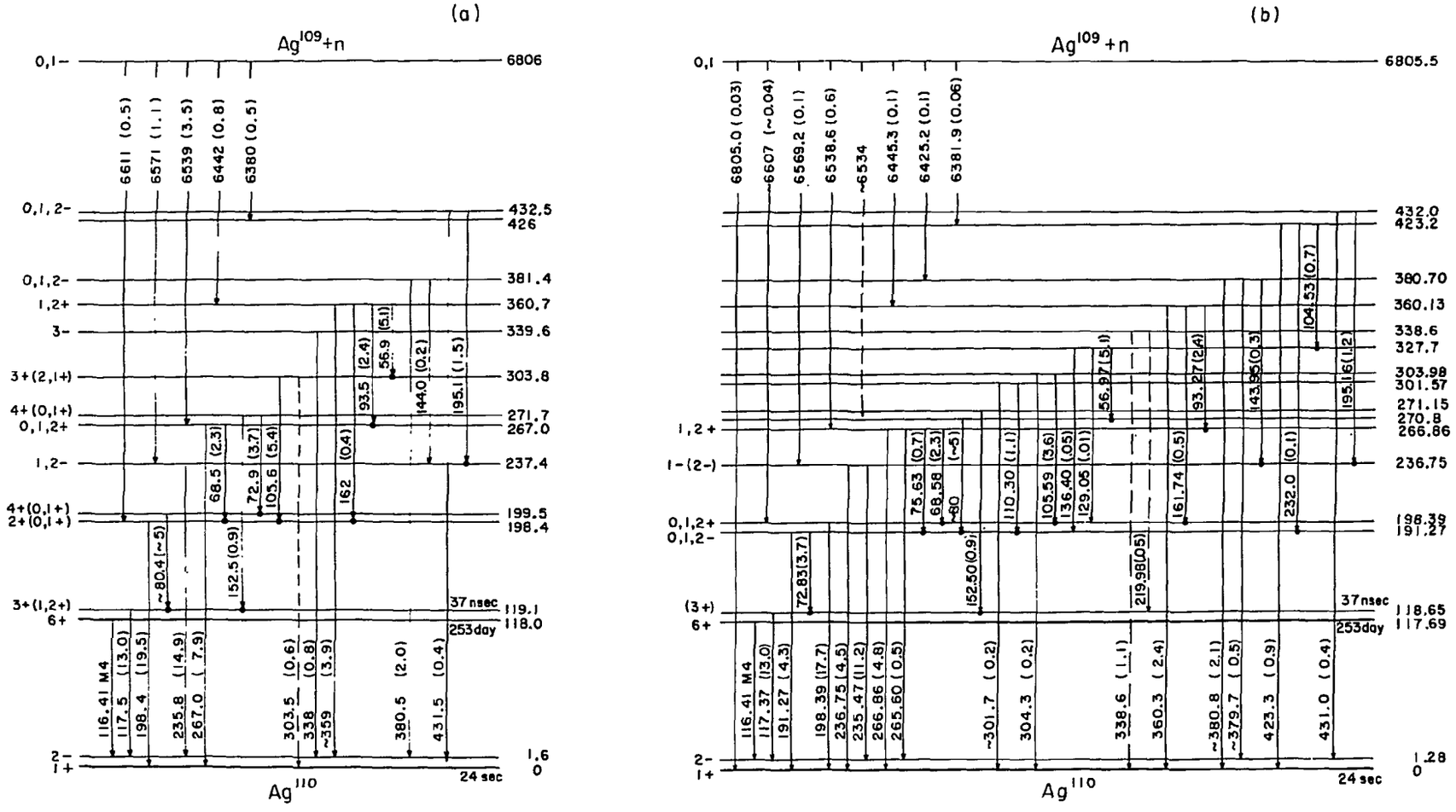

FIGURE A - 6

Partial level schemes of Ag^{110} showing evidence for the first excited state obtained in the $Ag^{109}(n,\gamma)Ag^{110}$ reaction. (a) Evidence existing in the literature. (b) Evidence obtained in the present work.

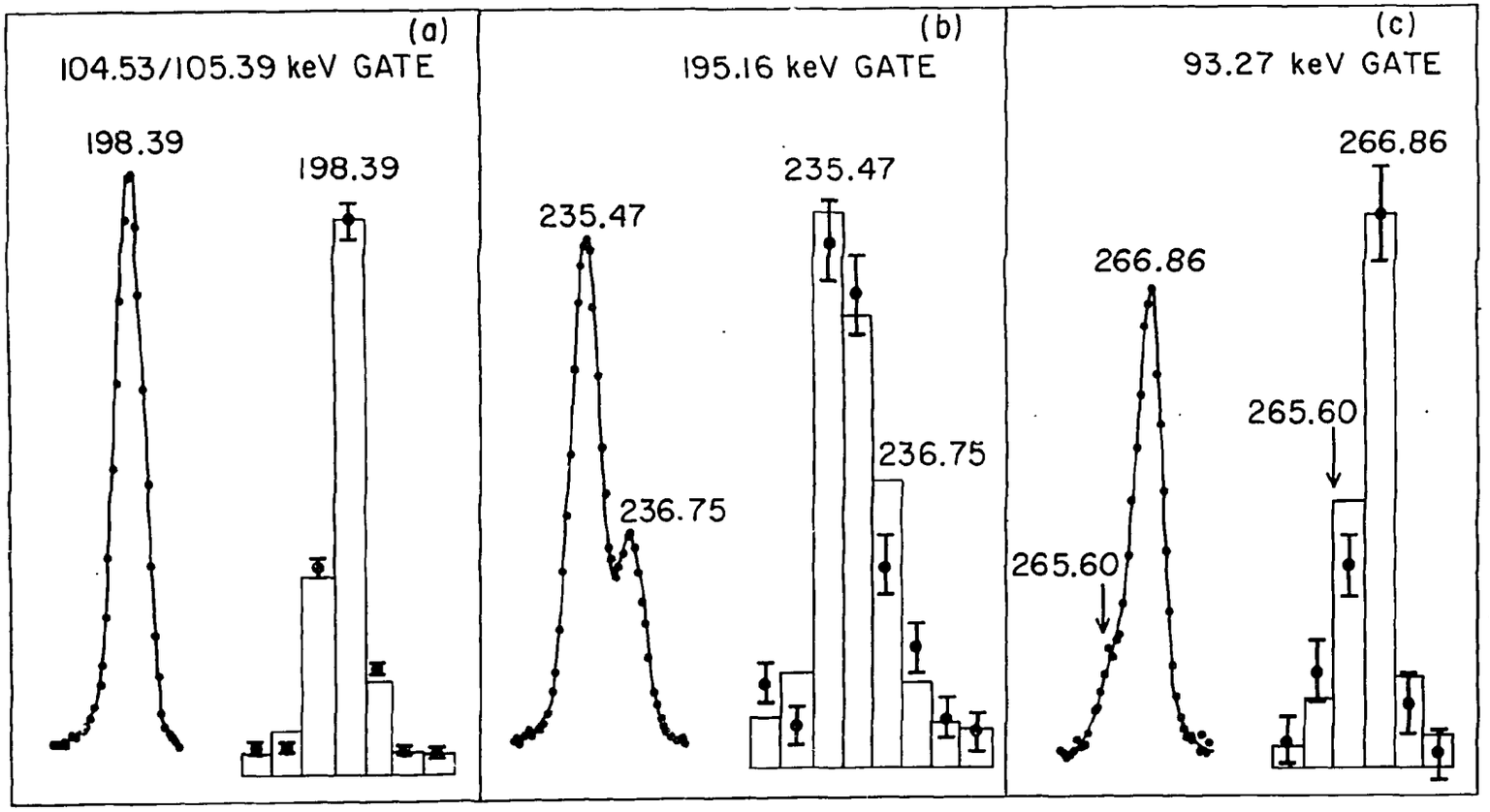

FIGURE A - 7

Gamma-ray singles and coincidence peaks demonstrating the existence of the 1.28 keV ground state - first excited state level doublet in Ag^{110}. (a) For comparison, the single 198.39 keV peak. (b) The 235.47-236.75 keV doublet. (c) The 265.60-266.86 keV doublet.

b) Neutron capture by Xenon isotopes in the resonance region (W. Gelletly, D. R. MacKenzie, and W. R. Kane)

With the aid of a neutron monochromator designed for capture gamma ray investigations, the gamma rays from neutron capture in low-lying resonances of Xe^{124}, Xe^{129}, and Xe^{131} are being studied. In this work a target of solid Na_4XeO_6 is used. Since charged particle reactions and radioactive decay populate largely high spin levels in the product nuclei, while the (n,γ) reaction favors low spin levels, this work should extend considerably knowledge of the level structure of these nuclei. Xe^{125} is particularly interesting since it lies on the edge of a region of deformation. From measurements on the 14.1 eV resonance of Xe^{131}, 18 levels in Xe^{132} have been established. The neutron spearation energy is 8936.3±1.0 keV. The spin of the resonance is probably 2.

B. NATIONAL NEUTRON CROSS SECTION CENTER (S. Pearlstein, M. D. Goldberg, M. K. Drake, D. E. Cullen, T. J. Krieger, J. R. Stehn, H. Bauman, M. R. Bhat, H. R. Connell, D. I. Garber, W. H. Kropp, B. A. Magurno, V. May, S. F. Mughabghab, A. Prince, F. Scheffel, T. E. Stephenson, A. Z. Livolsi)

Final agreement among the 4-Centers (at BNL, Saclay, Vienna, and Obninsk) has been reached with regard to EXFOR---the inter-Center data exchange format---and up-to-date versions of the keyword dictionaries are now available. The test example, selected for inter-comparison of interpretation of EXFOR by the 4-Centers, has been sent from the NNCSC to the other three Centers, along with a selection of other examples already coded for our files. A tape has been received from the Nuclear Data Section (the IAEA Center in Vienna) containing that Center's preparation of the test example.

Volume I ($Z = 1$-20) of the new edition of BNL-400 is in publication. All necessary additions and corrections to the tape library for the content of Volume II ($Z > 20$) are about complete, and preparation of publication output for this volume will begin shortly.

The formats for the ENDF/B-II neutron cross section library have been established and corrections to preliminary data determined. The ENDF/B-II library will be released on several magnetic tapes. The first tape, containing the heavy isotopes, should be distributed by the end of April. Tapes containing other isotopes will be distributed in May and June.

The ENDF/B-II library will contain re-evaluated data sets for certain materials, revised data sets for some materials, and data sets for some Version-I materials (i.e., the ENDF/B library released in July

1968). A summary of the materials that have been approved for release is given in Table I. This list will be expanded to include additional materials as they are reviewed by the Data Testing Subcommittee of the Cross Section Evaluation Working Group and approved by CSEWG. The data sets for moderating materials (scattering law data) will also be available upon request.

The effort to obtain evaluated data sets for fission product nuclei was continued. This effort is divided into two areas: (An attempt is being made to obtain a better understanding of nuclear systematics so that the radiative capture cross section for the fission product nuclei can be estimated reliably, and (2) complete evaluations are being made of the cross sections for specific fission product nuclei--Tc-99, Rh-103, Ag-107, Ag-109, and Cs-133---which are important to applications other than reaction burnup calculations.

The PDP-10 computer has been operating under the 10/50 swapping system, although the 10/40 multiprogramming system is available upon request. The two disk-pack units are scheduled for arrival sometime in May. These units will increase the NNCSC on-line fast storage capacity to sixty (60) million bytes. After the disk-packs arrive, the two swapping drums and two magnetic tape units that are now being used will be returned to the Digital Equipment Company. A 9-track tape drive is also scheduled to arrive in May, allowing the Center to improve its services to IBM-360 customers.

Table B-1

Contents of the ENDF/B-II Library

Material	MAT	Comments
H	1001	
H_2O	1002	Scattering law
H in ZrH	1097	Scattering law
D	1120	Revised MAT=1003
D_2O	1004	Scattering law
Li-6	1115	Revised MAT=1005
Li-7	1116	Revised MAT=1006
He	1088	
Be	1007	
Be	1064	Scattering law
B-10	1009	
Graphite	1065	Scattering law
Polyethylene	1011	Scattering law
Benzene	1095	Scattering law
O	1013	
Na	1059	
Mg	1014	
Al	1015	
Ti	1016	
V	1017	
Cr	1121	Revised MAT=1107
Mn	1019	
Fe	1122	Revised MAT=1108
Ni	1123	Revised MAT=1109
Cu	1087	
Cu-63	1085	
Cu-65	1086	
Nb	1112	Revised MAT=1024
Mo	1111	Revised MAT=1025
Xe-135	1026	
Sm-149	1027	
Eu-151	1028	
Eu-153	1029	
Gd	1030	

Material	MAT	Comments
Dy-164	1031	
Lu-175	1032	
Lu-176	1033	
Ta-181	1035	
W-182	1060	
W-183	1061	
W-184	1062	
W-186	1063	
Re-185	1083	
Re-187	1084	
Au-197	1037	
Th-232	1117	
U-233	1041	
U-234	1043	
U-235	1102	
U-236	1046	
U-238	1103	
Pu-238	1050	
Pu-239	1104	
Pu-240	1105	
Pu-241	1106	
Pu-242	1055	
Am-241	1056	
Am-243	1057	
Cm-244	1058	
Fiss. Prod. U-233	1042	Rapidly saturating
" " U-235	1045	" "
" " Pu-239	1052	" "
" " U-233	1066	Slowly saturating
" " U-235	1068	" "
" " Pu-239	1070	" "
" " U-233	1067	Non-saturating
" " U-235	1069	"
" " Pu-239	1071	"

CASE WESTERN RESERVE UNIVERSITY

A. NEUTRON PHYSICS

1. Absolute Normalization of Neutron Cross Sections Using an Organic Scintillator as a Scatterer (P. Boschung, J. T. Lindow and E. F. Shrader*)

A method of normalizing neutron scattering cross section data has been developed which uses an organic scintillator (NE 102) as a hydrogen scatterer in the same geometry as the unknown. Scattering from carbon nuclei is discriminated against by observing the light output produced by the recoil proton in coincidence with the scattered neutron. A Monte-Carlo code, which is capable of simulating time-of-flight spectra corresponding to the actual experimental conditions, has been written to take into account the finite size and light output of the scintillator. A comparison of a calculated spectrum with an experimental distribution is shown in Figure 1. Combining the H(n,n) cross section error with statistical uncertainties and other estimated systematic errors gives a total error of less than 2% for the normalization constant which converts yields to absolute cross sections. A paper describing the method will be published in Nuclear Instruments and Methods.

2. Elastic and Inelastic Scattering of Neutrons by $^{54,56}Fe$, $^{58,60}Ni$ and Carbon (J. T. Lindow, P. Boschung, and E. F. Shrader*)

The reduction of data to absolute differential cross sections for the scattering of neutrons by ^{56}Fe, ^{58}Ni and ^{60}Ni at energies of 5.1 and 5.6 MeV and for ^{54}Fe and C (elastic scattering only) at 4.0, 5.1 and 5.6 MeV is nearly complete. A total of nine angular distributions for the elastic cross sections will be reported; forty-two inelastic angular distributions are being reduced. A Monte-Carlo code FNMUL produces, through an iterative process, angular distributions corrected for finite geometrical effects, neutron attenuation, and multiple interaction. Normalization of the data to absolute cross sections is determined with respect to the H(n,n) cross section using the techniques described above in section 1.

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* Harshaw Chemical Company, Solon, Ohio

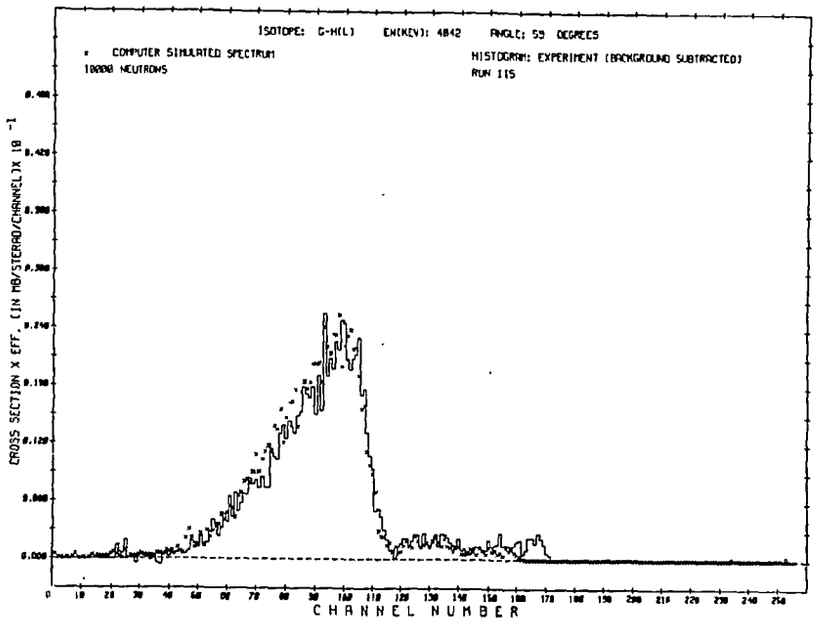

Fig. 1. Comparison of measured (histogram) and calculated (crosses) time-of-flight spectrum. Incident neutron energy is 4.04 MeV, scattering angle 59°. Scintillator (NE 102) dimensions: radius 0.95 cm, height 1.94 cm. Time calibration is 1.031 ns/channel. Time increases to the left.

3. Investigation of Gamma-Rays from ^{54}Fe (D. E. Velkley, J. T. Lindow, and P. Boschung)

Evidence was observed in the measurement of neutron inelastic scattering by ^{54}Fe described above in section 2 for neutron groups corresponding to levels in ^{54}Fe near 1.95 and 2.15 MeV. Gamma rays from levels near these energies had been observed in one previous measurement.[1]

In order to obtain more definite results, the yield of gamma rays following inelastic scattering of 4.4 MeV neutrons by ^{54}Fe was

[1] Shapiro and Higgs, Phys. Rev. 108, 760 (1957).

investigated with a 25 cc Ge(Li) detector. Neutrons were obtained from the $D(d,n)^3He$ reaction using a pulsed deuteron beam. Time-of-flight techniques were used to discriminate against events in the detector other than prompt gamma-rays from the sample. The sample was $\sim$ 1 mole of 97% enriched ^{54}Fe.

No gamma rays were observed which could be attributed to ground state transitions from the two levels in question or cascades to the well known 1.408 MeV state. The lower limit on gamma-ray production cross sections which would have been observed was estimated to be $\sim$ 2 mb/sr.

B. STRIPPING REACTIONS AND POLARIZATION

1. Polarization of Neutrons from the $^{13}C(d,n)$ Reaction (W. W. Lindstrom* and E. F. Shrader**)

Polarization angular distributions for neutrons from the $^{13}C(d,n)$ reaction leading to the ground and first five excited states of ^{14}N have been obtained for incident deuteron energies of 1.7, 2.3, and 2.5 MeV. Relative yield excitation functions at 20° and 90° (Lab) have been determined over this energy range in 50 keV steps, and polarization excitation functions were obtained at 20° (Lab) for neutrons leading to the third, fourth and fifth excited states of ^{14}N.

The polarization distributions for the ground state and the first, third, and fifth excited states were found to be slowly varying with energy even though considerable compound-nucleus contributions were indicated by yield fluctuations. Polarization predictions may therefore be possible by simple addition of an unpolarized background contribution, varying slowly with energy, to optical-model direct-reaction calculations. A paper is being prepared for publication based on the dissertation of W. W. Lindstrom.[1]

2. Polarization of Neutrons from the $^{16}O(d,n)^{17}F$ Reaction (B. D. Anderson, D. E. Velkley, R. Nerbun and H. B. Willard)

Measurements are now in progress of the polarization of neutrons from the $^{16}O(d,n)$ reaction leading to the ground and first

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**Harshaw Chemical Company, Solon, Ohio.

[1] W. W. Lindstrom, Ph.D. dissertation, CWRU, 1970, unpublished.

excited states of ^{17}F. Angular distributions will be determined for incident deuteron energies of 3.05, 3.34, and 3.6 MeV, and the excitation function will be investigated at 20° (Lab) over the range of deuteron energies from 3.0 to 3.7 MeV. Targets of Ta_2O_5, made by anodizing tantalum, are up to 184 keV thick for 3.5 MeV deuterons. Preparation for the measurements is essentially complete, and no major obstacles appear to remain at this time. The most recent effort has been in reducing background and refining the experimental apparatus for the polarization measurements. A measurement of the neutron polarization from the $T(p,n)^3He$ reaction was in excellent agreement with the results of Walter et al.[1]

Work is continuing on computer programs to determine the effective analyzing power of the He polarimeter.[2] Recent work has concentrated on the determination of neutron detection efficiencies for the particular geometry used in the above experiment. Relative efficiencies were measured with neutrons from the T(p,n) reaction and then converted to absolute detection efficiencies by comparison with a Monte-Carlo computer program which simulates the detection process in a proton-recoil neutron detector.[2] These results will be used in the calculations of effective analyzing power, considering finite geometry and multiple scattering in the polarimeter, and geometrically correct absolute efficiencies for the detector.

3. Cross Section Measurements of the (^3He,n) Reaction for s-d Shell Nuclei (S. K. Bose, A. Kogan, and P. R. Bevington)

Work is in progress for an investigation of the cross sections for the (^3He,n) reaction from selected nuclei in the s-d shell. A computer program RATE (Reaction Analysis of Time-of-flight vs. Energy), which simulates the time-of-flight spectrum for a given reaction, has been used to select experimentally feasible target nuclei and to optimize conditions such as detector size and distance, target thickness, etc. A gas target assembly and gas filling system for ^{20}Ne, ^{35}Cl and ^{36}Ar gases have been constructed. The shielding of the standard LiOH collimator, which presently has a 6 in. diameter central shaft, is being improved by the fabrication of a paraffin snout with a conical interior, designed to minimize contributions to background from multiple scattering in the collimator. Measurements for incident $^3He^+$ energies up to 4 MeV are expected to start this summer, with extended energies from doubly charged $^3He^{++}$ ions later this year.

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[1] R. L. Walter, W. Benenson, P. S. Dubbeldam, and T. H. May, Nuclear Physics 30, 292-299 (1962).

[2] W. W. Lindstrom, Ph.D. dissertation, CWRU, 1970, unpublished.

4. Polarization of Neutrons from (^{3}He,n) Reactions on s-d Shell Nuclei (R. Nerbun, V. Burke, and P. R. Bevington)

The feasibility of using doubly charged $^3He^{++}$ ions to measure the polarization of neutrons from (^{3}He,n) reactions on s-d shell nuclei for incident ^{3}He energies up to 8 MeV is being investigated. A test-bench duplicate of the accelerator ion source is being used to maximize the average He beam and a pickup loop has been constructed to extract a timing signal from the (more intense) $^3He^+$ beam accompanying the $^3He^{++}$ beam before the analyzing magnet of the accelerator. New side detectors for neutrons scattered from the ^{4}He polarimeter are being designed to increase the detection efficiency by an order of magnitude without seriously degrading the effective analyzing power of the polarimeter or increasing background contributions.

C. CHARGED PARTICLE PHYSICS

1. An Investigation of the ^{13}C + d System (P. Liebenauer,* E. A. Silverstein,** K. G. Kibler,*** and K. F. Koral)

Excitation functions and angular distributions in the energy interval 1.0 to 2.7 MeV have been obtained for most of the kinematically available exit channels from the ^{13}C + d system, including $^{13}C(d,p)^{14}C$ (g.s., 6.09, 6.72, 6.89), $^{13}C(d,d)^{13}C$ (elastic), $^{13}C(d,t)^{12}C$ (g.s), and $^{13}C(d,\alpha)$ ^{11}B (g.s., 2.14, 4.46). The data show that the reaction mechanism does not proceed solely via compound nucleus, but that direct processes must be considered. Resonances in the excitation functions were used to obtain values for the energy levels in the compound nucleus ^{15}N in the range of excitation energies between 17.1 and 18.5 MeV. The results are in good agreement with previous work. A discussion of the results was presented at the spring A.P.S. meeting in Washington and a paper is being prepared for publication based on the dissertation of P. Liebenauer.[1]

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* State University College, Oswego, N. Y.

** Bendix Aerospace, Ann Arbor, Michigan.

*** General Dynamics Corporation, Fort Worth, Texas

[1] P. Liebenauer, Ph.D. dissertation, CWRU, 1969, unpublished.

D. LIGHT NUCLEI

1. Gamma Ray - Neutron Branching Ratio in the Triton-Deuteron Reaction (A. Kosiara, P. Boschung and H. B. Willard)

The cross section for the $T(d,\gamma)^5He$ reaction has been measured to determine the branching ratio of gamma rays and neutrons [from the $T(d,n)^4He$ reaction] leading to the ground states of ^5He and ^4He, respectively. Separation of the gamma rays from the intense neutron flux produced by the t+d reaction was accomplished with time-of-flight techniques, using a hydrogen-free scintillator (NE 226) as a detector. Absolute values of the $T(d,\gamma)^5He$ cross section were determined by comparison with the yield of gamma rays from the mirror reaction $^3He(d,\gamma)^5Li$ for which the cross section is known.[1] At an incident deuteron energy of 1.025 MeV and a reaction angle of 90° (Lab) the cross section obtained was 0.44 ± 0.12 μb/sr. The corresponding gamma ray - neutron branching ratio is 2.3×10^{-5}. This work is complete and a paper has been submitted for publication in Physics Letters B.

2. Search for the Bound Trineutron (K. F. Koral and P. R. Bevington)

According to preliminary analysis, no evidence has been found for the production of a bound trineutron from the reaction $^7Li(^1n,^3n)^5Li$ or $^7Li(^1n,^3n)^4He,^1p$. The general method used in the search was outlined in WASH 1127.

In the final geometry, the ^4He gas scintillation detector was placed on the zero degree line from source to target and a tungsten shadow cylinder was used to reduce the flux of direct neutrons. Scattering angles ranged from 10° to 40° (Lab) because of the large Li target, 4 in. in diameter by 3-1/4 in. long. The forward angles from 0° to 10° (Lab) were also briefly investigated by removing the shadow cylinder. Data were accumulated in a two-dimensional array of time-of-flight versus detector pulse height.

Comparison of the counting rate in the trineutron region for the Li runs with that for the background runs with a C target indicates that no measurable number of trineutrons was detected. Upper limits for the production cross sections are yet to be obtained from the data. The number of direct neutrons detected in the ^4He scintillator, together with transmission measurements for the target and shadow cylinder, will determine the flux of incident

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[1] W. Buss et al., Nuclear Physics A112, 47 (1968).

neutrons. Trineutron binding energies from .5 to 3.0 MeV will be assumed and individual cross sections will be calculated for each hypothetical binding energy. The reliability of these cross sections will depend mainly on our theoretical estimate of $^4He(^3n,^3n)^4He$ elastic scattering, which will be used in determining the detector efficiency for the trineutron region.

E. INSTRUMENTATION

1. Van de Graaff Accelerator (L. H. Hinkley)

The operating range of the Van de Graaff accelerator has been extended from the previous upper limit of 3 MeV by installing a new HVEC "stainless steel" accelerator tube with improved breakdown characteristics, and by the addition of SF_6 to the insulating gas. The new tube is now operational, permitting maximum machine voltages of 4 MeV or more. It has been necessary to effect a compromise between maximum voltage capability and optimum beam focus by decreasing the voltage gradient across the top four sections of the tube by a factor of 2.

A 2 MHz terminal pulsing system has been developed, to replace the existing 1 MHz unit, and is now ready to be installed.

2. Real-Time Computer System

a. Hardware (P. R. Bevington and R. A. Leskovec)

The CWRUNCH (Case Western Reserve University Nuclear Computation Handler) system consists of a PDP-9/L computer (installed May, 1969) with 16K of 18 bit memory, two magnetic tape decks, card reader, teletypewriter, storage oscilloscope, light pen, and IDIOT (Indicating Digitizer for Input/Output Transformations) switch panel. Interfacing to existing paper tape reader and punch and multichannel pulse-height analyzer is being developed.

A remote computer terminal is being installed in the accelerator control room. The terminal consists of a teletypewriter, IDIOT switch panel and a Tektronix 611 storage oscilloscope equipped with light pen. Interfacing for the storage scope includes remote control of the storage mode and expansion of both x and y axes by a factor of 1-8 with variable offset. Development of a radically new, completely solid state light pen which works reliably with the Tektronix 611 storage oscilloscope is nearing completion.

b. Software

The CWRUNCH PDP-9/L computer system has been used extensively for reduction of multichannel analyzer pulse-height spectra, using non-linear least-squares fitting procedures and interaction with light pen to control the fit. Additional use has been made of it for computing experimental parameters, such as kinematic corrections, energy loss, or NMR frequency vs. energy; and for simulating effective average parameters, such as detection efficiency, analyzing power for a polarimeter, pulse-height distributions from a neutron detector, or time-of-flight spectra.

A library of Fortran subprograms has been developed for interaction with the oscilloscope, light pen, and IDIOT switch panel, especially for displaying multichannel pulse-height analyzer spectra in two or three dimensions. Additional subprograms provide standard computations for Wigner 3j 6j and 9j functions, kinematics, random numbers, and matrix inversion.

3. Photomultiplier signal processing (R. A. Leskovec and P. R. Bevington)

A transistorized stacked emitter follower (based on the White cathode follower circuit) has been devised for feeding low level linear signals into a 50 Ω coaxial line. Output signal swing is ± 2 volt with a gain of .99, input impedance of 100 k, and rise time of less than 4 ns.

Constant fraction pulse height discriminators based on a design of D. A. Gedcke and W. K. McDonald[1] have been constructed and successfully used in several of the experiments reported here.

Renewed interest in an n-γ discriminator designed previously[2] has resulted in an improved circuit to be built directly into new PM tube bases.

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[1] D. A. Gedcke and W. J. McDonald, Nucl.Inst. and Methods 58, 253 (1968).

[2] E. F. Shrader and B. M. Shoffner, CWRU, unpublished.

COLUMBIA UNIVERSITY

A. FAST NEUTRON SPECTROSCOPY

1. Total Neutron Cross Section of ^{16}O at 2.37 MeV (J. Kalyna, I. J. Taylor and L. J. Lidofsky)

A minimum in the total neutron cross section of ^{16}O occurs at 2.37 MeV. This interference dip is being measured by the transmission of neutrons through a 5 foot sample of liquid oxygen. The Van de Graaff accelerator is pulsed to produce 5 nanosecond neutron bursts via the $^{7}Li(p,n)^{7}Be$ reaction. An eight inch diameter by one inch thick liquid scintillator (NE213) together with a pulse shape discriminator, comprises the neutron time-of-flight system.

Samples of the oxygen are now being analyzed by mass spectroscopic methods to accurately determine traces of Argon, CO_2 and ^{17}O and ^{18}O. Using published total neutron cross sections for these elements, corrections to the measured transmission will be made to obtain as much precision as possible in the final measurement.

Data are now being taken in a series of six independent runs to check for reproducibility of results. Target thickness will be made progressively smaller during each and every run and hopefully, the final results can then be made independently of target thickness.

Preliminary data which measure the neutron yield versus neutron energy have been taken. Background and inscattering corrections have not been made.

Following the series of intensive runs the data will be carefully analyzed and corrected for inscattering (using a Monte Carlo computer code MONCAR, described in the 1967 and 1968 annual reports).

2. Pulse Shape Discrimination: An Investigation of n-γ Discrimination with Large Diameter Size of Liquid Scintillators (J. Kalyna and I. J. Taylor)

In neutron time-of-flight work it is often necessary to discriminate against background gamma rays. This is especially true for the measurement of neutron cross sections where backgrounds must be subtracted and ideally should therefore be made very low.

The technique of n-γ discrimination in organic scintillators depends on utilizing the differences in the decay times of the slow component of the light flash produced by different ionizing particles (elec-

trons vs. recoil protons). Such pulse shape discrimination (p.s.d.) has been mainly limited in the literature to systems using scintillators whose diameters are small in comparison to the 8 inch diameter NE213 and NE218 (Nuclear Enterprises) liquid scintillators typically required for fast neutron time-of-flight work on the Van de Graaff accelerator and as used in the total neutron cross section measurement of ^{16}O, mentioned elsewhere in this report.

A pulse shape discrimination circuit has been constructed to enable optimum n-γ discrimination using the double differentiation and crossover detection technique and to permit direct comparison of p.s.d. performance of various scintillator and detector arrangements.

Using this circuit it was evident that p.s.d. performance worsened with the use of larger diameter scintillators, and an attempt has been made to find a satisfactory explanation for this effect and whether or not it can be corrected. This has led to the investigation of the transit time properties of several 5 inch diameter photomultipliers.

To date, the 5 inch diameter Amperex 58 AVP, XP 1040, and bi-alkali type 58 DVP photomultipliers, and with type A and type B standard voltage dividers, have been used with 4 inch and 8 inch diameter NE213 and NE218 liquid scintillators to study the overall performance of a zero cross over p. s. d. system in obtaining maximum suppression of γ-rays for an experiment measuring a fast neutron total cross section.

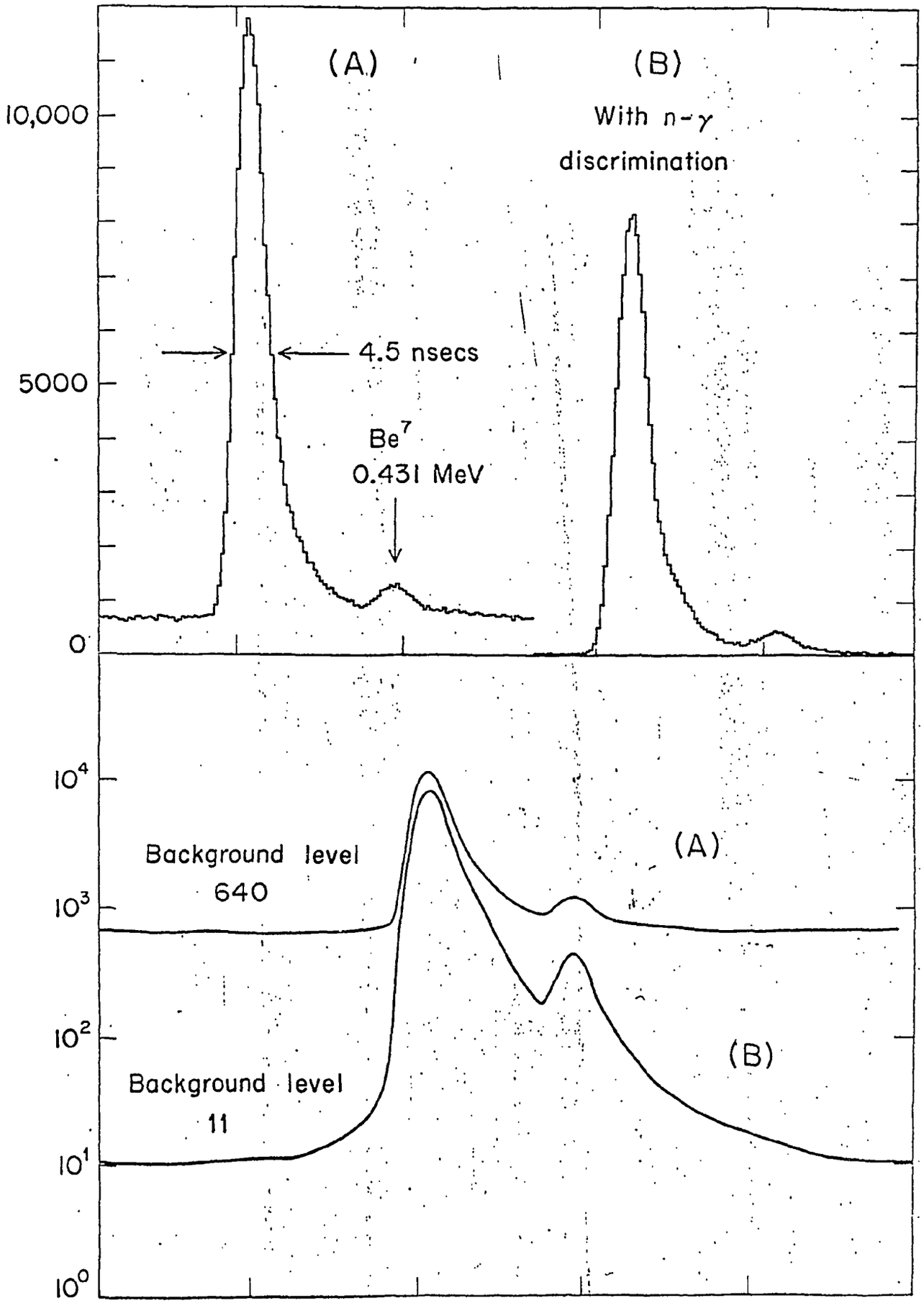
The extent of gamma ray suppression achieved with 8 inch diameter NE213 using the p.s.d. is illustrated in Figure A-1, which shows a neutron time-of-flight spectrum in the experiment on oxygen mentioned above. The primary group corresponds to 2.37 MeV neutrons from the $^{7}Li(p,n)^{7}Be$ reaction and the secondary group to neutrons form the reaction leading to the first excited state of ^{7}Be at 431 keV. The effect of background suppression is seen more clearly in the logarithmic plot of the data. The peak to background ratio is improved by a factor of 44 on application of the n-γ discrimination.

A paper describing the work presented above is being submitted for publication.

B. SLOW NEUTRON PHYSICS

1. Neutron Resonance Cross Section Measurements (H. Camarda, G. Hacken, F. Rahn, H. I. Liou, S. Wynchank, M. Slagowitz, W. W. Havens, Jr. and J. Rainwater)

Figure A-1



DATA NOT FOR QUOTATION

a. Analysis of Results

The neutron spectrometer run in 1968 using an EMR6050 on-line computer data acquisition system to provide 8192 histogram channels resulted in an unusually large amount of high quality data. Most of the resonances observed in $^{86,87,88}Sr$, $^{151,153}Eu$, $^{154,158}Gd$ and ^{177}Hf have not previously been reported. Separate isotopes of ^{235}U, ^{115}In, ^{63}Cu, $^{142\ 143\ 144\ 145\ 146\ 148}Nd$, $^{160\ 167\ 168\ 170}Er$, $^{171\ 172\ 173}Yb$ $^{174\ 176}Yb$, ^{139}La, $^{182\ 184\ 186}W$ were investigated. Natural Na, Al, Fe, Cu, Co, Mn, Ta, La, Pr, Nd, In, Er, Yb were also studied.

In the past year much of the final analysis of this data has been completed. An improved data acquisition system using the faster EMR6130 computer has been developed. Complete reports on the analysis and results of the investigations will be given in a series of papers. A brief summary and some illustrative results are given below.

In most cases the use of smaller separated isotope sample area (1 1/4" x 5") allowing a greater thickness extended the energy range which could be investigated. The thicker samples improved the detection of small resonances.

Analysis of transmission and self-indication measurements for $^{86,87,88}Sr$ have been completed covering the energy range from 1 eV to >20 keV. The useful energy range is several times larger than has been previously reported for these nuclei. The distributions of level spacings and neutron widths along with the correlation of various parameters have been presented.[1]

Levels have been identified and $g\Gamma n$'s extracted: 24 levels from 588 eV to 23087 eV in ^{86}Sr, 37 levels from 3.53 eV to 9974 eV in ^{87}Sr, and 7 levels from 12389 eV to 88329 eV in ^{88}Sr.

Graphs of level number vs. En for $^{86,88}Sr$ and $\Sigma g\Gamma n°$ for ^{87}Sr are presented in Figure B-1 and Figure B-2.

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[1] F. Rahn et al., "Neutron Resonance Spectroscopy IV: Eu^{151} and Eu^{153}," presented at the Spring 1969 Meeting of the American Physical Society, Washington, D. C. (BAPS 14, no. 4); F. Rahn et al, "Neutron Resonance Spectroscopy, $Sm^{152,154}$, $Sr^{86,87,88}$," presented at the Fall 1969 Meeting of The American Physical Society, Boulder, Colorado (BAPS 14, no. 12, 1935).

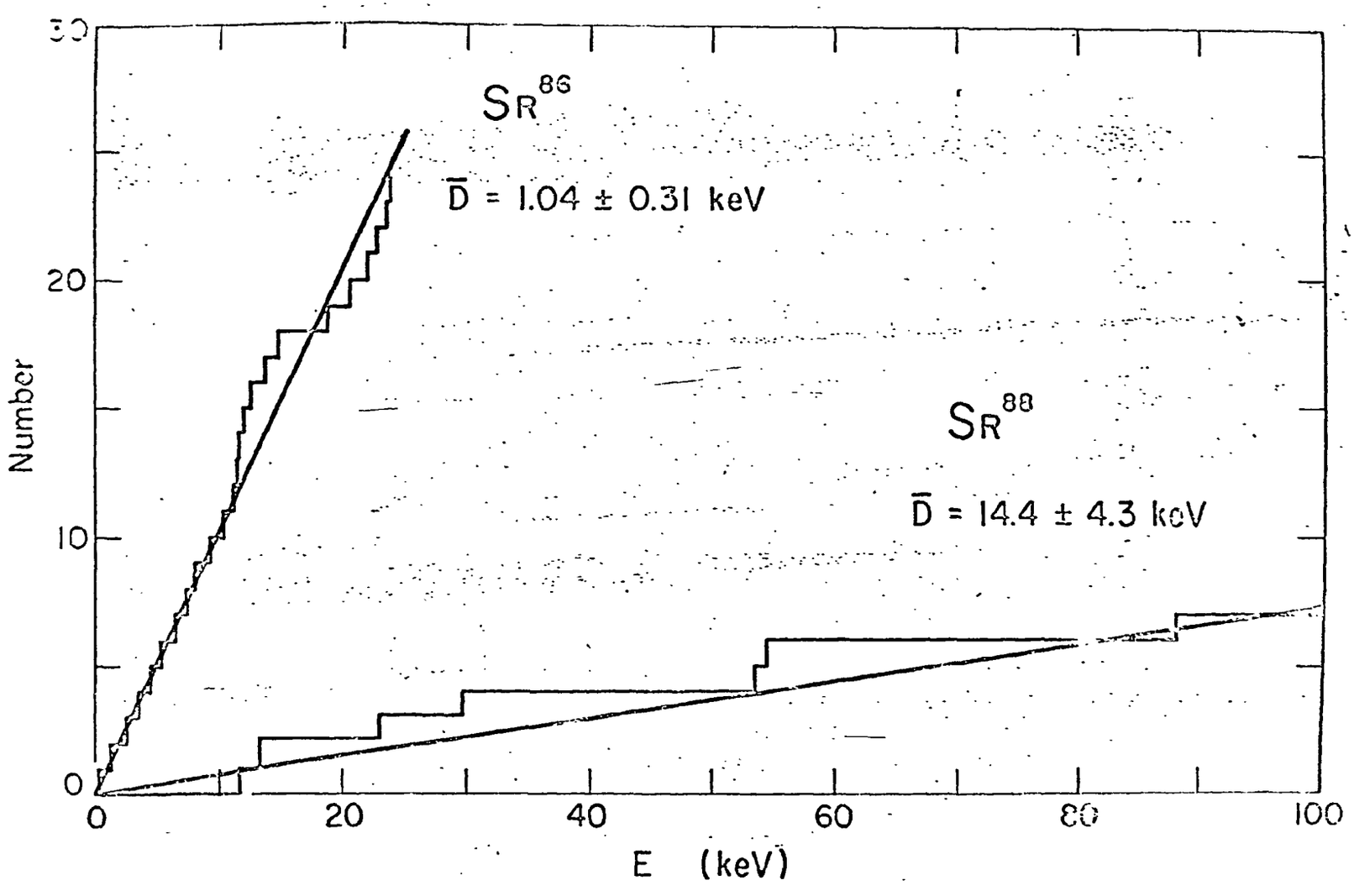

Figure B-1

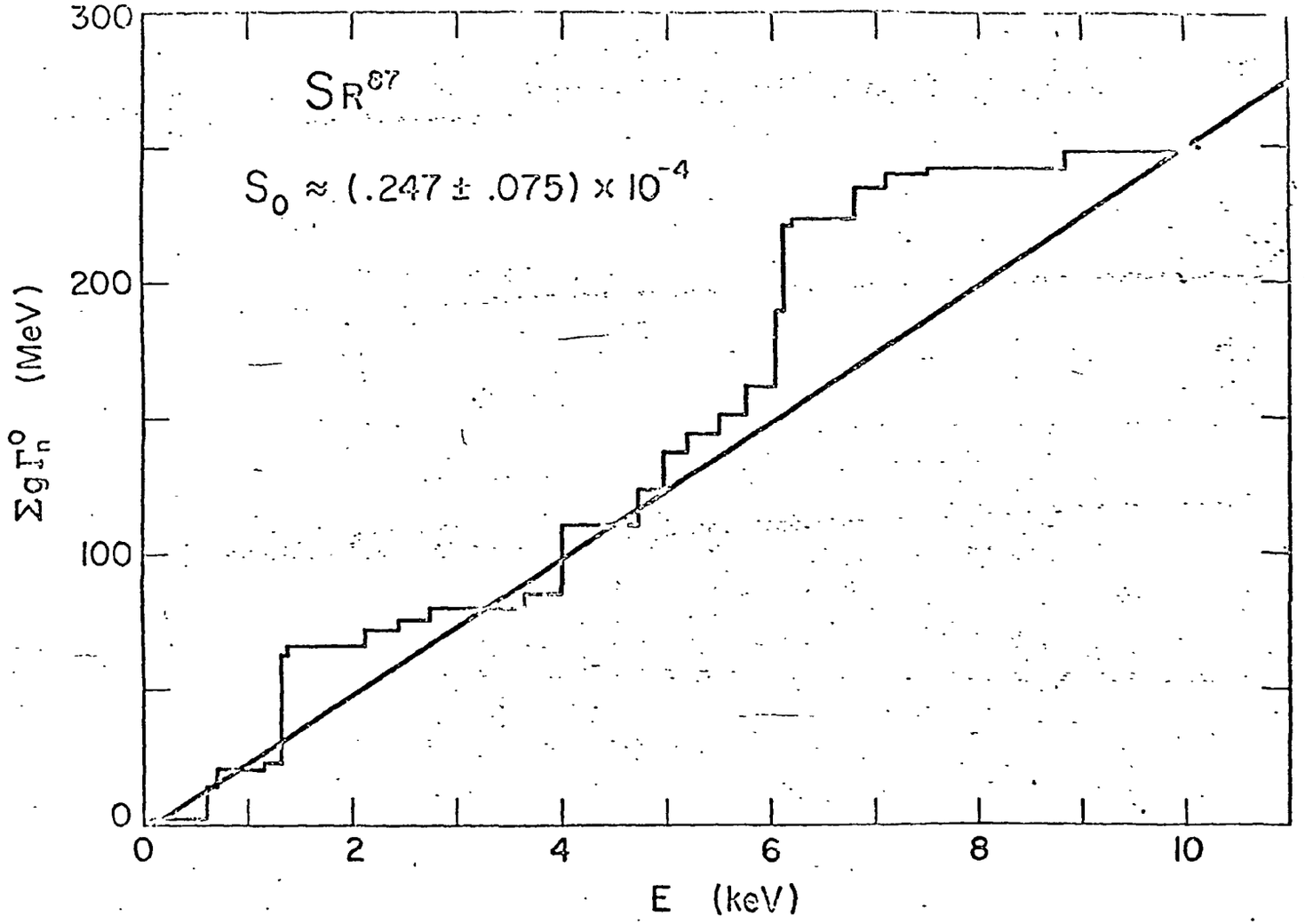

Figure B-2

The resonance energies and parameters for 90 levels in ^{151}Eu, 68 levels in ^{153}Eu, 29 levels in ^{152}Sm and 20 levels in ^{154}Sm were analyzed for the energy region up to 100 eV for ^{151,153}Eu, 1500 eV for ^{152}Sm and 2500 eV for ^{154}Sm.

Most of the above mentioned levels had not previously been reported including two in the previously reported range up to 27 eV in ^{151}Eu and 2 in the previously reported range up to 23 eV in ^{153}Eu.

$\overline{\Gamma}_\gamma$ is 96 meV and 94 meV for ^{151,153}Eu and 68 meV, 78 meV for ^{152,154}Sm.

Table B-1 gives values of observed average resonance spacing, $\overline{D}$, s-wave strength function, s_o, and total resonance integral above .414 eV, I. The resonance integral determined from the data is compared with the resonance integral above the cadmium (0.55 eV) cut off measured by others. These results have been reported at the meeting of the American Nuclear Society.[1]

Data from 1 eV to 1700 eV for ^{171}Yb, ^{167}Er and to 20 keV for ^{172,174,176}Yb, ^{166,168,170}Er have been analyzed yielding resonance parameters for over 1000 levels. The large number of analyzed levels, many previously unreported, allow for an improved statistical study of these nuclei.

Some of the results[2] are presented in Table B-2. Isotopic identification and resonance parameters[3] were determined for ^{182,184,186}W over an energy range $0.0 \lesssim E \lesssim 15$ keV. From these parameters quantities of physical interest were determined. For example, the strength function, S., and average level spacing, D, found for ^{182,184,186}W are respectively: $S^\circ = 2.43 \pm .29$, $D = 68.0 \pm 4.4$ eV, $S^\circ = 2.33 \pm .30$, $D = 90.0 \pm 6.4$ eV, $S^\circ = 2.29 \pm .32$, $D = 120.0 \pm 7.2$ eV.

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[1] F. Rahn et al., "Neutron Resonance Spectroscopy IV: Eu^{151} and Eu^{153}," presented at the Spring 1969 Meeting of the American Physical Society, Washington, D. C. (BAPS 14, no. 4); C. Ho, F. Rahn, Measurement of the Cross Section Resonance Parameters and Integral of Eu^{157}, Eu^{153}, Sm^{152} and Sm^{154}, ANS, Winter Meeting, December 1969, San Francisco.

[2] H. Liou et al., "Neutron Resonance Spectroscopy V: Argon and the Isotopes of YB and Er, " presented at the Spring 1969 Meeting of the American Physical Society, Washington, D. C. (BAPS 14, no. 4, 495).

[3] H. Camarda et al., "Neutron Resonance Spectrosocopy II: W^{182}, W^{184}, W^{186}," Washington APS Meeting, April 1969 (BAPS 14 no. 4).

TABLE B-1

Resonance Parameters and Capture Integrals for $Eu^{151,153}$ and $Sm^{152,154}$

Isotope	$g\,\overline{\Gamma_n^o}$ (MeV)	D(eV)	So($\times 10^4$)	$Ic^{.414}$ calculated	$Ic^{.55}$ calculated	$Ic^{.55}$ measured
Eu^{151}	.359 ± .053	1.04 ± .07	3.25 ± .51	6559 ± 687	3300	3741[2*]
Eu^{153}	.355 ± .059	1.45 ± .12	2.42 ± .47	2332 ± 205	2198	1833[2*]
Sm^{152}	142 ± 37	52.7 ± 7.6	2.72 ± .83	2644 ± 604	2635	3100[4], 3162[4], 2850[6]
Sm^{154}	238 ± 75	125 ± 20	1.90 ± .66	154 ± 40	150	-----

2* J. Rogers, Trans. Am. Nucl. Soc. 10, 259 (1967).

TABLE B-2

Gross Structure Parameters of Yb and Er Isotopes

Isotope	Examined (keV) Interval	No. of Levels	<D> (eV)	So x 10^4
Yb^{171}	0.0 - 1.7	165	7.0 ± 0.9	1.83 ± 0.28
Yb^{172}	0.0 - 10.7	95	64.7 ± 9.4	1.45 ± 0.30
Yb^{174}	0.0 - 29.3	105	188 ± 21	1.24 ± 0.28
Yb^{176}	0.0 - 26.2	77	236 ± 36	1.88 ± 0.37
Er^{166}	0.0 - 9.5	152	48.5 ± 2.9	1.89 ± 0.31
Er^{167}	0.0 - 1.7	263	4.2 ± 0.4	2.07 ± 0.29
Er^{168}	0.0 - 15.0	96	118 ± 10	1.50 ± 0.28
Er^{170}	0.0 - 24.0	87	201 ± 22	1.47 ± 0.32

Previously reported resonance parameters extended to 22 keV. The new results represent a significant improvement in quality and energy range covered.

Measurements were also made on natural W over the range 21.0 $< E \lesssim$ 82,000 eV providing the highest quality total cross sections available.

Transmission measurements for ^{113,115}In and ^{139}La were made up to 89 keV and self indication measurements up to 3200 eV. The resonances analyzed in natural In numbered 193 (a much larger number were observed) in the range 20-2000 eV; of these, 145 were attributed to ^{115}In and 48 to ^{113}In. The resonances analyzed in ^{139}La numbered 56 from 701.9 eV to 10217 eV yielding $\langle D \rangle$ = 11.7 1.2 eV, S = (.34 .12) x 10^{-4}.

Previous available data on ^{175}Lu described only 20 resonances below 42 eV. In the present work 312 resonances have been observed and their resonance parameters measured, below 5000 eV.

No previous data were available on resonances of ^{154}Gd and only 18 resonances were previously known below 900 eV in ^{158}Gd. Analysis of the last run has produced 40 resonances in ^{158}Gd below 5000 eV and 107 resonances ^{154}Gd below 3200 eV.

An R-matrix analysis system has been developed and used to study ^{23}Na. The system utilized the EMR 6130 computer and a computer driven 5" display in a feedback mode. A sample result which identified the 2850 eV ^{23}Na resonance with J=1 is presented in Figure B-3. This method of analysis yields resonance energy, resonance widths, J, and ℓ (0 or 1)

Three Ph.D. theses using the results from the last run are being completed.

b. System Improvements

A great many experimental changes have been made in the system for the next run. The four 11" NaI 200 m detectors had a fairly large dead time (due to self blocking effects) at high counting rates. The 200 m system now combines ten 6" NaI detectors in addition to the four 11" ones which are gated off during high counting rates, each with its own Single Channel Analyzer. The new system decreases dead time and improves statistics at lower energies where the counting rates are low. The old time of flight system (TOF) provided 6 words of buffering with an 80 nsec dead time and a minimum channel width of 25 ns. The new TOF

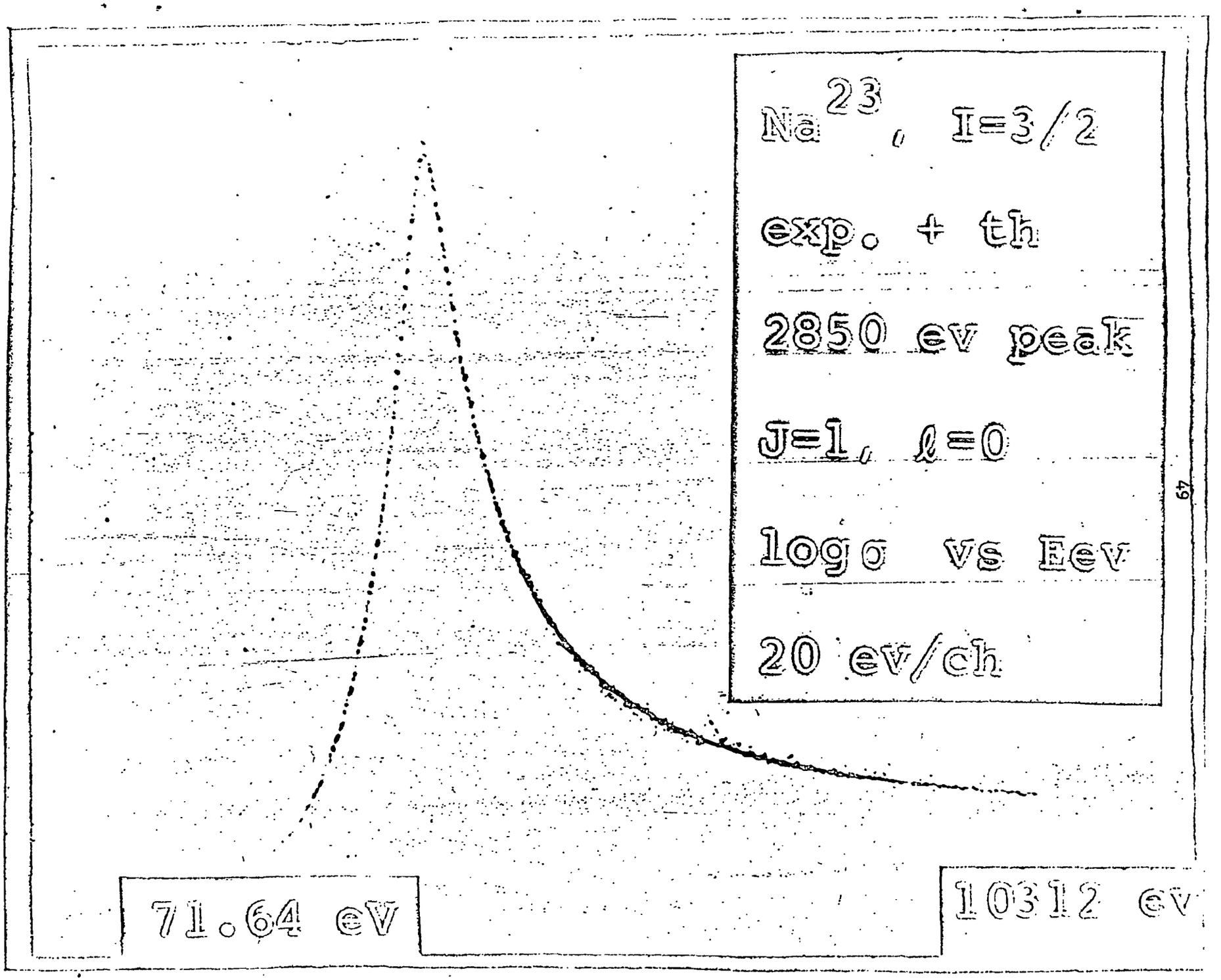

Figure B-3

system [1] has 8 data quantizers (with < 40 ns dead time each) feeding 16 words of buffering with a 20 ns read-in (and transfer time) and minimum channel width of 20 ns. The 6130 computer provides 16,000 timing channels as well as a 775 ns read-in time or buffer emptying (compared to 1.9 μ seconds for the 6050). The 16000 channels allow for the data acquisition in one run over a range of energies that in the past required 2 runs, thus providing more information for the same amount of cyclotron time. The histogram is broken up into 32 groups (512 channels each) with independently variable widths (20 ns, 40 ns, 80 ns, etc.) provided by a pin board matrix at the TOF. The TOF also provides a switch selectable "T = 0" thus the program no longer has to do the arithmetic to handle channel widths and "T = 0". Therefore, more data can be processed for each burst.

In the past valuable cyclotron time was wasted while the necessary histogram plots and data listings were made. The new system provides for simultaneous data acquisition and CRT display. The data from previous runs are stored on a disc and the plotting and printing out of the data can be done while data are being taken. The emphasis is on taking more useful data per unit cyclotron time.

Further improvement of the single turn deflection system has been made providing a 100 kV pulse with a rise time < 15 ns, a back-up system of nearly identical characteristics and an electronic feedback system that automatically adjusts deflection delays to account for the slow drifts of the hydrogen thyratron. In the past, this slow drift was monitored visually (via an oscilloscope) and corrected manually when detected.

The next run will start in the near future and will entail the study of different separated isotopes as well as a re-study of some isotopes where improved statistics might be valuable. Some of the separated isotopes to be studied are ^{110,112,114,116}Cd, ^{140}Ce, ^{160,161,162,163,164}Dy, ^{158,160}Gd and ^{203,205}Tl.

2. Radiative Capture Cross Section Measurements in the Low keV Region (J. Arbo, C. Ho, J. Felvinci, F. Rahn, E. Melkonian, W. W. Havens, Jr., and J. Rainwater)

The run at the Nevis synchrocyclotron which had been planned for summer 1969 has been rescheduled for April 1970. Preparations for this run are largely complete.

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[1] M. Slagowitz, J. Hahn, J. Rainwater, W. W. Havens, Jr., Neutron Velocity Spectrometry Data Acquisition on Analysis, Skytop Conf. on Computer Systems, March 1969; J. Hahn, L. Cucancic, C. Gillman, A. Zidon, "A 16,000 Channel 50 MHz Time-of-Flight Analyzer for High Data Rates," IEEE Trans. on Nucl. Sci. NS-17, No. 1 (February 1970).

The modified three-stage Moxon-Rae detectors described in the 1968 Progress Report have been calibrated up to a gamma energy of 4 MeV. The detection efficiency vs. energy curve was found to be linear over this range. A high-energy calibration of the detectors is planned using the 7.367 MeV capture gamma line from a Pb-207 target in a thermal neutron beam at the HFBR. This measurement should reliably establish the detector efficiency curve over the entire energy region of interest.

As a result of the April 1968 test of the detector system at Nevis, extensive attention has been given to preparation of a new 35-meter neutron flight path which will provide good shielding and neutron beam definition at the detector station. The design also provides a contiguous helium path from the inside face of the cyclotron shielding wall, past the capture sample, up to the beamstop.

Samples for which capture cross section measurements will be made include Rh-103, Tm-169, Mn-55, Cs-133, Np-237, and U-238. Au-197 will be used as the reference standard. An attempt will be made to measure $\sigma(n,\gamma)$ of Th-232 despite the anticipated high gamma background from Th-228 decay products.

Earlier limitation of the data handling rate has been relieved by use of a new 20 nsec/channel time-of-flight buffer and the addition of a magnetic disk memeory to the PDP-8 computer. The entire time-of-flight system is described in the Electronics Instrument Development part of this report.

3. Gamma Ray Spectra from Radiative Capture in the Resonance Region (M. Derengowski, J. Felvinci, C. Ho, E. Melkonian, F. Rahn and W. W. Havens, Jr.)

Equipment has been set up and tested for use in the NVS run scheduled for early 1970 at the Nevis cyclotron. The experiment involves measurement of the energies of the neutron capture gamma rays emitted by a ^{235}U target, as well as the time-of-flight of the captured neutrons.

In order to take advantage of the high energy resolution of the lithium drifted germanium detector, we are using an 8192 channel ADC with a built in stabilizer (Northern Scientific NS-627) for the gamma ray measurements. The ADC is interfaced to the PDP-8 computer. A program has been written to store the contents of the 8192 channels on the Digital magnetic disc, while allowing 512 channels at a time to be displayed on the oscilloscope.

The time-of-flight of the neutrons will be measured by means of a time-of-flight analyzer and buffer system.

The timing pulse from the germanium detector is obtained from a time pickoff unit placed between the charge sensitive preamp and the linear amplifier. The output of the time pickoff unit is shaped and fed into one of the inputs of the buffer system.

A block diagram of the system is shown in Figure B-4. As was mentioned in a previous Progress Report (NY-72-191, p. 19) the system includes two NaI detectors for operation in a pair spectrometer mode to reduce the background and simplify the spectrum.

Because of the low counting rates expected in the individual gamma peaks, it seemed impractical to stabilize the ADC on a peak in the stored spectrum. Therefore, an external precision pulser was built to provide a peak for gain stabilization. The pulser for zero stabilization is internal to the stabilizer itself. The ADC was modified to prevent storage of the external pulser pulse upon reception of a tag input provided by the pulser. Another modification was made to allow the use of the stabilizer in the ADC coincidence mode. This involved taking out a tag pulse from the zero pulser circuit in the stabilizer and using it in the external coincidence circuit.

We are now taking test runs of various targets using neutrons from plutonium beryllium sources in order to check the operation of the system during long term runs.

4. Fission Fragment Mass Distributions from Correlated Energy and Time-of-Flight Measurements (M. Derengowski and E. Melkonian)

Further analysis of the data subsequent to the last Progress Report (NYO-72-227) has revealed the existence of a rounding-off error in the computer calculations. The only part of the results affected by this error is the neutron number distributions at fixed mass, which had previously been reported as peaking at zero neutrons at all values of fragment mass. Upon correction of the error, we find that the peak at zero neutrons occurs only for about half the heavy masses, predominantly on the light end of the heavy mass peak. A paper covering this research has been submitted to the Physical Review. The abstract is as follows:

An experiment has been performed on the thermal neutron induced fission of ^{235}U, in which the energies of complementary fission fragments and the time-of-flight of one fragment were measured. Fragment masses after neutron emission were obtained directly from this information. Pre-neutron masses and kinetic energies were deduced by means of a reflection method which simulates a double time-of-flight experiment. Subtraction of postneutron from primary fragment masses then gave the number of neutrons emitted by single fragments in each event. Among the results presented are the distributions of the numbers of neutrons emitted by single fragments of

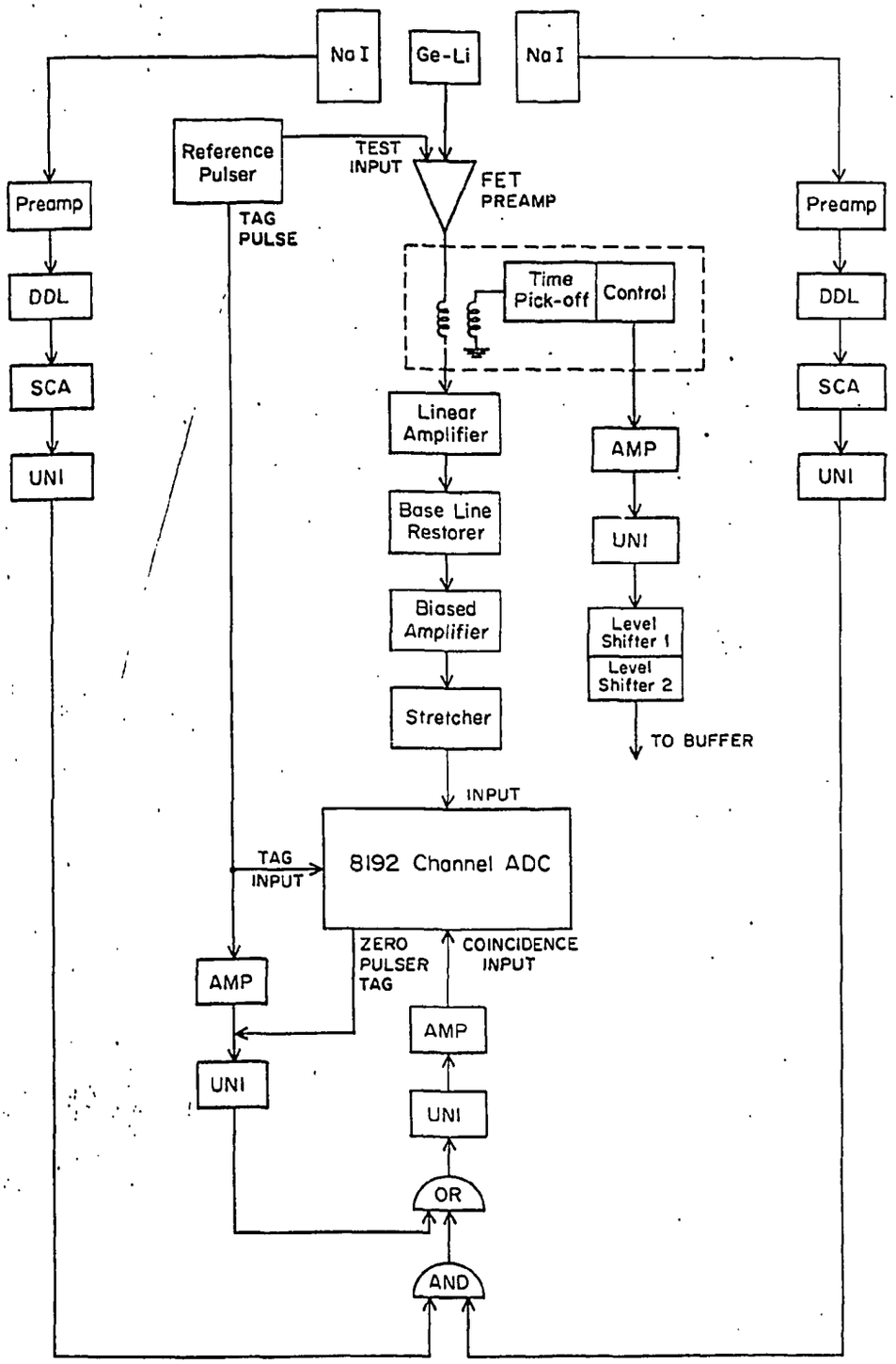

Figure B-4

Na I	5-inch sodium iodide crystal
DDL	Double delay line amplifier
SCA	Single channel analyzer set on 511 keV
UNI	Univibrator
AMP	Gain – 10 amplifier

fixed mass. This information is very difficult to obtain from other types of experiments, and there has been no previous publication of such results for any fissioning nucleus. The results also include the average number of neutrons emitted as a function of mass and total kinetic energy, as well as mass distributions in fixed kinetic energy intervals, and total kinetic energy distributions at fixed fragment masses.

5. Comparison of Mass Distributions of Fission Fragments from Spontaneous and Induced Fission of Compound Nucleus ^{240}Pu (J. R. Toraskar and E. Melkonian)

This experiment was performed to investigate the effects of the spin and the excitation energy of the compound nucleus on the fission process. The experiment consisted of measuring simultaneously the energies of the complementary fission fragments and then deriving the mass and kinetic energy distribution from these data.

A complete description of this experiment, including the experimental method, data analysis and the results has been given in a thesis entitled: Mass Distributions of Fission Fragments for the Compound Nucleus ^{240}Pu: Comparison between Spontaneous Fission and Fission Induced by Neutrons of Several Energies Below 1 eV by Jayashree R. Toraskar, Columbia University, 1969.

Some additional experimental work was done which further confirmed that there was no contamination in the target used in the study of spontaneous fission of ^{240}Pu.

Two papers based on the results of this experiment are now ready to be published. The titles and the abstracts follow:

a. "Effect of Pu-240 Compound Nucleus State on the Fission-Fragment Mass and Kinetic Energy Distributions."

Abstract:

Fission-fragment mass and kinetic energy distributions have been obtained for fission of Pu-239 induced by neutrons filtered through beryllium and by neutrons filtered through samarium. The beryllium filter enhances the contribution of the negative enrgy resonance level to the fission cross-section and the samarium filter enhances the contribution of the 0.297 eV level. Surface barrier detectors were used for simultaneous measurement of both the fragment energies. Absolute fragment energies were calculated by using mass dependent pulse-height-energy relations. The average total kinetic energy of the fragments produced in the fission induced by samarium-filtered neutrons was observed to be 0.75 ± 0.05 MeV greater than in the case of fission induced by beryllium-filtered neutrons. Combining this result with the results of other experiments implies $J = 0^+$ for the negative

energy level and J = 1^+ for the 0.297 eV level of Pu-239. The two mass distributions are similar except for a difference in the symmetric fission yield. This difference again implies the same spin assignments as above. The absolute average total kinetic energies were determined with somewhat less accuracy and are found to be 173.0 ± 1.5 MeV and 173.7 ± 1.5 MeV for fissions induced by beryllium-filtered and samarium-filtered neutrons respectively as directly measured, and 175.8 ± 1.5 MeV and 176.5±1.5 MeV respectively after correction for neutron emission.

b. "Spontaneous Fission of Pu-240"

Abstract:

Fission fragment mass and kinetic energy distributions have been obtained for the spontaneous fission of Pu-240 and compared with those for the thermal neutron induced fission of Pu-239. Surface barrier detectors were used for the simultaneous measurements of both fragment energies. Absolute fragment energies were calculated by using mass dependent pulse-height-energy relations. The average total kinetic energies were measured to be 177.25 ± 1.56 MeV and 172.98 ± 1.47 MeV for the spontaneous and the induced fission respectively. This higher value of the total kinetic energy for the spontaneous fission is rather surprising, because in the thermal neutron induced fission of Pu-239, the compound nucleus Pu-240 has about 6.3 MeV more excitation energy than in its ground state. The measured total kinetic energy and mass distributions for the spontaneous fission also appear to be significantly different in shape from those in the case of induced fission.

6. Variation of Fission Fragment Kinetic Energy Distribution and Yield (J. Felvinci and E. Melkonian)

The analysis of the U-233 data reported in the previous report (NYO 72-227) continued. The method of subdividing single fragment kinetic energy curve into groups was extended from four to seven groups. A statistical test (the Kolmogorov-Smirnov method) was applied at selected resonances to three different groups to ascertain whether there is significant deviation among the shapes. Definite differences were found among groups for the 22.1 eV and 22.5 eV double peak and also in the region of the 15-16 eV complex. Further significant differences between groups were evident at the low energy shoulder of the 1.78 eV resonance (there is a supposedly 2^+ resonance at 1.55 eV).

The fact that no appreciable difference was found in the single fragment mean kinetic energy from resonance to resonance, but that the deviations were significant between different groups may indicate that the shape and not the position of the single fragment kinetic energy distribution is varying. If speculation is correct and the 2^+ levels have higher symmetric fission yield and wider mass distribution, this effect could cause some of the observed differences.

The preparations for the run in 1970 have been completed. We expect to measure Np-237 subthreshold fission and compare this a.) with earlier measurements by Paya et al.[1] and b.) with the spin values obtained from the multiplicity experiment. (See Section 8) The method of measurement will be the same as in previous runs except we will use the new 20 ns/ channel TOF buffer developed by the Pegram Electronics group. The method of measurement will be the same as in previous runs except we will use the new 20 ns/channel TOF buffer developed by the Pegram Electronics Group. The events will be stored on magnetic tape event-by-event and a TOF histogram will be developed for monitoring purposes on the disk memory unit attached to the PDP-8 computer.

7. Determination of the Spin of Slow Neutron Resonances in Fissionable Nuclei by Measuring the Yield of Gamma Rays (J. Felvinci and E. Melkonian)

The measurements described in the previous Progress Report used an NaI detector to record γ-rays above 3 MeV as a function of neutron time-of-flight. After further study of this preliminary experiment, it was decided that the method holds enough promise to be included in the 1970 run, using several fissile targets (U-233, U-235, Np-237). This time two NaI detectors will be used to allow observation of coincidences between cascade captive γ-rays. Great care will be taken to reduce the background, and statistics will be improved. This experiment, like the others to be performed during this run, will use the new 20 ns/ channel TOF buffer built by the Pegram Electronics Group. (This system is described in the Electronics Instrument Development part of the report.) The entire system has been set up and tested in the laboratory.

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[1] Paya et al., Dubna Conference, 1968, SMNF 624/68.

It is expected that the better results to be obtained in the U-233 measurements will enable us to assign spins to several levels and we will correlate these results with the fission fragment energy distribution. In the U-235 experiment the many discrepancies in spin assignment between Asghar et al.[1] and Bowman et al.[2] will hopefully be resolved. The Np-237 spin values might give a clue to the nature of the levels excited in the subthrehold fission. The fact that in this experiment the energies of the γ-rays are also recorded made it possible to calculate mean energies as a function of neutron time-of-flight. The background mean energy was high due to the large amount of Fe 7.64 MeV γ-rays from the beam stop. The mean γ-energies of resonances were all significantly lower than background except the 4.8, 11.5 and 10.3 eV resonances which are believed to have 2^+ spin.

8. Precision Measurement of the 2200 m/sec Neutron-Proton Capture Cross Section (D. Cokinos, E. Melkonian and W. W. Havens, Jr.)

This experiment which was reviewed in the previous report has now been completed and a paper with this title has been prepared for submission to The Physical Review for publication.

9. Slow Neutron Scattering by Hydrogeneous Compounds (T. I. Taylor, J. Markisz, and W. W. Havens, Jr.)

Without the availability of a reactor, the major part of the past year was devoted to the moving of the crystal spectrometer and its related components to the TRIGA reactor, reassembling it and getting it into operating condition. A baseplate was designed and built, which allowed the spectrometer to be assembled on a set of heavy duty casters so that it could easily be moved around while the reactor was inactive, and could be wheeled away from the reactor face with a minimum of time and effort, should that be necessary when the reactor is operating. An

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[1] Asghar et al., Physics Letters 26B, 664 (1968).

[2] Private communication.

adjustment of four leveling screws and four bolts into a pair of I-beams are all that are necessary to deteach the spectrometer physically from the fact of the reactor. The adjustable collimator from the Brookhaven Graphite Research Reactor, which had been used in conjunction with the crystal spectrometer, was pulled from that reactor and brought into Columbia after sufficient decontamination. Suitable shielding and adapting apparatus are being constructed. Shielding for the entire spectrometer, along with mounting equipment, is being constructed.

Calculations of cross sections from data taken on methane, ethane, dimethylacetylene, and methylammonium chloride before the closing of the Brookhaven Graphite Reactor have been completed and considerations have been given to additional measurements needed to complete the research when the facilities are available. Theoretical calculations of total cross sections as a function of temperature have been continued with special emphasis on suitable models and equations for methane at the low temperatures.

Manuscripts have been prepared for publication of the results of measurements on polymers and related materials involving methyl groups and large molecules.

C. NEUTRON AND GAMMA RAYS

1. Sensitivity of Transport Calculation to Microscopic Cross Sections (C. Weisbin, L. J. Lidofsky and H. Goldstein)

The moments code described in the last Progress Report (NYO-72-227, p. 81) has been made much more powerful and versatile with the addition of two major features during the past year. The first of these is a variable dimensioning technique which permits rapid generation of moments codes efficiently dimensioned in proportion to the input parameters of the problem. Where needed, it is possible for example, to use virtually the entire available core of Columbia's IBM 360/91 ($\sim 1.2 \times 10^6$ bytes) for large scale transport calculations (e.g. one with 2,000 or more energy points). On the other hand, another version of the code can be prepared tailored to small

scale investigations, e. g. involving only one element, elastic scattering only and, say, 200 energy points. The advantages in computing efficiency are obvious.

The second addition is the capability to read input cross section data directly from ENDF/B files. This provision is in line with the desire of the AEC to standardize on ENDF/B format for evaluated cross section data. In the sensitivity studies, the present "first round" sets of ENDF/B data are used for the initial calculations and as a point of departure for investigating the effects of cross section changes. (Our studies have had the incidental effect of revealing gross inadequacies in these "first-round" ENDF/B evaluations of Be, Fe and Li, at least as regards shielding calculations.

All of the series of programs related to the moments calculations have been linked together. It is, therefore, possible to carry out as a single computer "job", a calculation which starts with an ENDF/B tape of cross sections, introduces specified changes in these cross sections, computes the spatial moments of the spectrum, reconstitutes the flux from the moments, and finally produces tabulations and plots of the output results. Work has been also initiated to incorporate the recently acquired SEL computer into the input preparation and output analysis sections of the chain of moments-programs.

The investigation of neutron transport in beryllium oxide, previously reported, has been continued. Present indications are that the transport of fission neutrons is remarkably insensitive to variations in the cross section data within the uncertainty limits now known. In addition, similar calculations have been started for pure beryllium, for which the following preliminary results have been obtained:

	Fission source	14 MeV source
Fast effect	1.075	2.97
Age ($\sim$1.4 eV) p= 1.85 gm/cm^3	73.68 cm^2	144.18 cm^2

The transport of neutrons in carbon under specified conditions of source and geometry had been proposed by the Radiation Shielding Information Center as a "benchmark" problem for shielding studies. Moments calculations for nearly identical conditions have therefore been carried out for carbon and compared with previous discrete ordinates calculations (GGA) and Monte Carlo calculations (ORNL). The scalar flux so computed agrees with these other predictions to 10% or better, except in the highest energy group where the discrepancy is a factor of two. The source of discrepancy is presently being investigated.

The moments computational procedure as of June 1969 and the preliminary results for BeO have been described at length in a doctoral thesis (C. Weisbin) which has subsequently been issued as a report, NYO-268.

2. The Effect of Cross Section Fluctuations on Fast Neutron Transport (W. Preeg and H. Goldstein)

The study of the effect of isolated minima in the total cross section (discussed in the previous report, p. 82) has been continued. A semi-quantitative model has been developed which agrees reasonably well with rigorous calculations in oxygen and iron. Neutrons born above the energy of the minimum are slowed down in the vicinity of the source; some fraction slow down into a small energy band centered around the exact minimum point. These, plus the source neutrons born in the band, then travel far either without collision or with only very small-angle elastic collisions. They then act as a virtual, nearly monoenergetic, source distributed through the medium. The flux spectrum below the minimum is determined solely by local slowing down from this virtual source, irrespective of the nature of the actual source.

When the cross section exhibits minima that are close together (relative, say, to $\bar{\xi}$) and arise as the result of rapid but relatively shallow cross section fluctuations, the phenomena are more complex. Iron is a convenient nucleus for which these effects can be studied as the fluctuations persist into the MeV range, and there are at least two high resolution measurements of the total cross section in this region (from Gulf General Atomic and Karlsruhe). By a series of moments calculations, ranging up to a "monster" 2500 energy point problem, it has been possible to show that the characteristics of the nucleus interactions at the minima of the total cross sections still determine the nature of the deep penetration. It appears important to include fluctuations in both the total and the differential elastic cross sections, but preliminary results seem to show fluctuations in the inelastic cross section are not significant.

In the usual multigroup transport calculation a single group may include 20 or so of these fluctuation minima. It is, therefore, important that the weighing spectrum used to calculate the multigroup cross sections should suitably emphasize the minima in the cross section. The customary 1/E weighing with the GAM II group structure has been shown to give fluxes incorrect by a factor of 10 or more through 80 cm of iron. Various weighting "prescriptions" have been developed, none of which gives exactly the correct result throughout the entire energy spectrum. However, it has been found that a weighting spectrum derived on the assumption that the collision density varies smoothly as 1/E gives adequate accuracy and is a simple recipe to apply.

The investigations summarized here will be described at length in a doctoral thesis by W. Preeg.

3. High Energy Gamma Ray Production by 14 MeV Neutrons (M. Stamatelatos, B. Lawergren, L. J. Lidofsky)

The object of the research has been to measure spectra of gamma radiation from 14 MeV neutron interactions, in particular, neutron capture in medium to heavy elements (copper, antimony, zirconium).

The source of neutrons was a Texas Nuclear Corporation Cockroft-Walton-type neutron generator, and the detector a specially built coincidence-anticoincidence telescope pair spectrometer composed of three thin and one inch thick NE-102 plastic scintillators.

The spectrometer was calibrated against gamma radiation in the range of 12-21 MeV from proton and deuteron reactions $H^3(p,\gamma)$ He , $B^{11}(p,\gamma)C^{12}$, $B^{11}(d,n\ \gamma)C^{12}$. The protons and the deuterons were accelerated with the Pegram Van de Graaff. A spectrometer response function has been generated using these calibration spectra and a specially written non-linear least squares program. The function will be used in the final unfolding of the data obtained from the neutron capture reactions. Since the (n,γ) spectra are continuous rather than strongly peaked, an iterating unfolding technique, based on that of N. Scofield, has been adopted. The unfolding of the data for copper, antimony and zirconium has been completed. The spectra and cross sections are being compared with various predictions of theoretical calculations including "semi-direct" capture. ABACUS II, a nuclear optical model code written by Auerbach for the CDC 6600 computer has been modified to run on the IBM 360/91 Columbia computer and will be used in the comparisons.

4. Response of GeLi Detectors to Gamma Radiations (A. Tavitian and L. J. Lidofsky)

A Monte Carlo code has been completed and is applicable to the energy range 0.1 MeV to 10.00 MeV, for the geometrical configurations listed below. The processes taken into account are: Compton effect, photo-electric effect, and pair production.

The output for each case consists of the generated gamma-ray spectrum and the peak-to-total ratio. Calculation of the single or double escape peak-to-total ratio, and the intrinsic efficiency can be inserted with a minimal amount of work.

The following source-crystal geometrical configurations are considered in the code:

a. Regular

1) Point isotropic source on the axis of a solid cylindrical crystal.

2) Point isotropic source on the axis (perpendicular to the plane of the front face) of a solid rectangular crystal.

3) Point isotropic source on the axis of a cylindrical shell crystal with a vacuum core.

4) Point isotropic source on the axis of a cylindrical shell crystal with an absorbing core.

5) Point isotropic source on the axis of a solid cylindrical crystal attached to a cylindrical shell (of the same radius) with an absorbing core.

b. Special

1. Point isotropic source on the axis of a solid cylindrical crystal; the total energy deposited in the detector as a function of the energy deposited in the front portion of the crystal. The front portion considered can be varied. The aim is to test means of reducing non-full energy events.

2. Point isotropic source on the axis (perpendicular to the plane of the front face) of a solid rectangular crystal; narrow in one direction, the azimuthal angle of the scattered photon in a Compton interaction is picked by considering polarization. The aim is to calculate the polarization sensitivity of the detector.

Machine Time: 14 sec for 1000 histories.

GULF GENERAL ATOMIC INCORPORATED

SAN DIEGO, CALIFORNIA

A. NEUTRON AND GAMMA-RAY CROSS SECTIONS

1. Fast Neutron Capture (M. P. Fricke, W. M. Lopez,* S. J. Friesenhahn, A. D. Carlson and D. G. Costello)

Absolute average capture cross sections have been obtained at continuous neutron energy intervals from ~1-1000 keV for Mo, Rh, Gd, Ta, W, Re, Au and ^{238}U. These include some new results for cross sections reported previously to NCSAG. The cross sections are measured relative to $^{10}B(n, \alpha)$ from 1-80 keV and relative to the hydrogen scattering cross section from 80-1000 keV. In most cases the cross sections are normalized to saturated resonances. Overall uncertainties in the capture cross sections are typically 10-15% over the full energy range. These results have been accepted for presentation at the IAEA Helsinki Conference on Nuclear Data for Reactors, June 15-19, 1970. Our capture cross sections for Au and ^{238}U are in very good agreement with the data of Poenitz et al.[1] and Menlove and Poenitz,[2] respectively. They do not, however, support previous indications[1] that Au capture data based on the ^{235}U fission cross section are systematically higher above 200 keV than data obtained in other ways. (These measurements are pertinent to request Nos. 223, 228, 274, 318, 331, 413 and 414 in WASH-1144.)

2. Resonance Parameters and Average Capture Cross Sections of Gadolinium (S. J. Friesenhahn, M. P. Fricke, D. G. Costello, W. M. Lopez and A. D. Carlson)

Analysis of the average resonance parameters for ^{155}Gd and ^{157}Gd between 3 eV and 200 eV has been completed. These average parameters, together with those deduced from average capture cross sections measured to 20 keV, have been used to calculate resonance

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[1] W. P. Poenitz, et al., J. Nucl. Energy 22, 505 (1968).

[2] H. O. Menlove and W. P. Poenitz, Nucl. Sci. and Eng. 33, 24 (1968).

integrals from 0.5 eV to 100 keV. We obtain 1538^{+14}_{-24} barns for ^{155}Gd and 765^{+17}_{-24} barns for ^{157}Gd. When these results are combined with the parameters obtained by Karschavina et al.,[3] a value of $390.9^{+6.3}_{-8.9}$ barns is obtained for the resonance integral of natural gadolinium.

The s-wave strength functions obtained for ^{155}Gd and ^{157}Gd are significantly higher than those predicted from the collective model generalization of the optical model. The total radiation widths for resolved resonances are found to have a much larger variance than that predicted by the statistical model, provided the widths are assumed to be spin-independent. The average capture cross section at higher energies is also found to deviate from conventional statistical-model predictions. The results of our gadolinium measurements have been transmitted to the SIGMA center, and the experiment is described in an article accepted for publication in Nuclear Physics. (These measurements are pertinent to request Nos. 274, 276, 278, 279, 280, 284, 285 and 286 in WASH-1144.)

3. Rhodium Resonance Parameters (A. D. Carlson, S. J. Friesenhahn, M. P. Fricke and W. M. Lopez)

Rhodium capture and self-indication measurements in the resolved resonance region are being analyzed for neutron resonance parameters. These data combined with the average capture cross-section measurements from 1 to 1000 keV should allow an accurate determination of the rhodium resonance integral. The large difference in the statistical weighting factors for the two possible states which can be formed by s-wave neutron capture ($g = 0.25$ for $J = 0$ vs. $g = 0.75$ for $J = 1$) has allowed the spin, as well as the neutron and radiation widths, to be determined for a number of suitably strong resonances. The method employed for spin determinations involves an area analysis of capture and self-indication data for a given resonance for $J = 0$ and then again for $J = 1$. In addition a shape fit is made to the experimental data. For relatively strong resonances there is good agreement between the shape analysis and the area analysis only for one value of J. Capture data for the 154.2-eV rhodium resonance are shown in Fig. A-1 together with the shapes calculated from the resonance parameters obtained from area analysis of capture and self-indication data for the two spin values. The shape fit to the data indicates $J = 0$.

Determinations have been made of the parameters describing the resolution function and their dependence on neutron energy so that

[3] E. N. Karschavina, et al Report No. JINR-P3-3882 (1968)

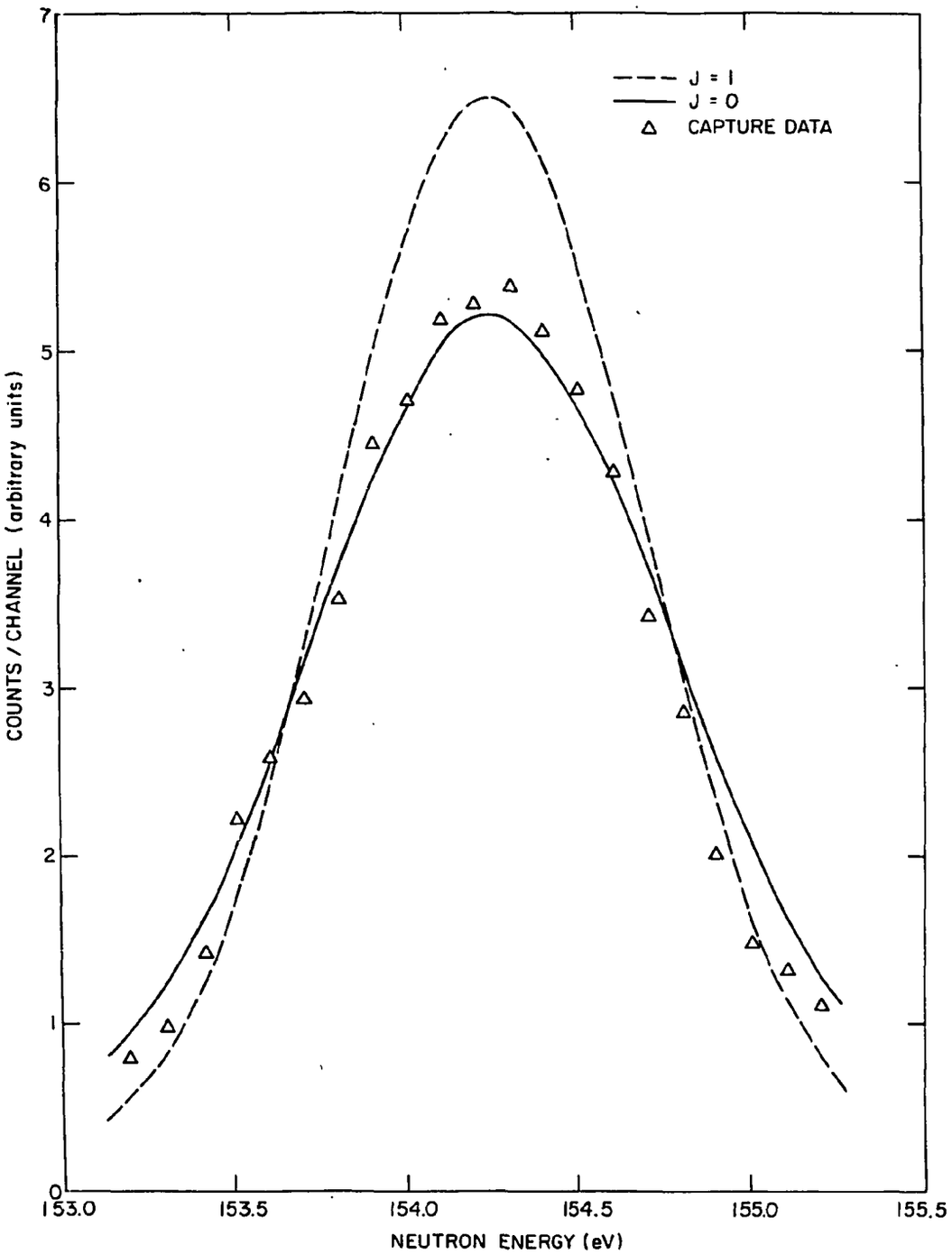

Figure A-1. Rh capture data vs calculations for different spins. The dashed curve was calculated with parameters deduced by area analysis with J = 1, and the solid curve was produced by the parameters for J = 0.

the shape fit can be reliably employed at high neutron energies. The combined area-shape analysis is being examined further to establish the sensitivity of spin determinations as a function of resonance strength and energy. Preliminary resonance parameters obtained in this investigation are shown in Table A-1. Combining these data with those from previous experiments[4] indicates that the spin dependence (if any) of the radiation width for s-wave levels is very weak. Further analysis will provide more information on this dependence and also that of the spin dependence of the s-wave neutron strength function.

Rhodium has a relatively large p-wave strength function which at present is not very well known. There is concern over the tehniques employed in assigning p-wave resonances, and it would be useful to have a more definite means of identification. A method similar to that employed by Coceva[5] has been considered for the identification of p-wave resonances. This technique depends on the difference in detection efficiency for p-wave vs. s-wave capture when our scintillator is used in a special mode. In this mode, only the logs (the outer part of the detector) are employed, and coincidences are required between signals from the two halves. The detector is then more sensitive to any difference in the gamma-ray de-excitation process that occurs with s- vs. p-wave neutron capture. Measurements are also made employing the entire detector, for which the efficiency is essentially independent of the details of the decay process. By comparing the two sets of data, relative differences in efficiency from resonance to resonance can be determined. Preliminary results indicate that the "logs-only detector" has a slightly lower efficiency for p-wave capture compared to s-wave capture. No difference in efficiency was observed for s-wave capture into states having spin 0 compared to those with spin 1. This technique was applied to the resonances from 90-130 eV. The results confirm the assignments of Ribon.[6] (This work is pertinent to request No. 228 in WASH-1144.)

4. Gamma-Ray Production Cross Sections for Iron and Aluminum
(V. J. Orphan, C. G. Hoot and Joseph John)

Measurements of the gamma-ray spectra resulting from neutron interactions in natural iron and aluminum for the energy range .85 MeV ≤

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[4] BNL-325, Vol. IIB, Suppl. No. 2(1966).

[5] C. Coceva, F. et al, Nucl. Phys. A117, 586 (1968).

[6] P. Ribon, et al, Antwerp Conf. Paper 165 (1965) and J. Phys. Radium (Orsay Conf.) 24, 987 (1963).

$E_n \leq 16$ MeV have been made with the facility described in Ref. 7. An 80-cm^3 Ge(Li) detector, sectioned to operate as a total-absorption spectrometer (DUODE), was used to measure the γ-ray spectra. The two-parameter data (neutron energy, γ-ray energy) have been sorted into γ-ray spectra at 25 intervals of neutron energy that span the full range. Analysis of the spectral data to obtain γ-ray production cross sections for both resolved and continuum γ-rays is currently in progress. (These measurements are pertinent to request Nos. 64, 104, 105 and 106 in WASH-1144.)

5. Gamma-Ray Spectra from the $^{238}U(n, \gamma)^{239}U$ Reaction
(Joseph John, V. J. Orphan and C. G. Hoot)

The large amount of two-parameter (gamma-ray pulse-height vs. neutron time-of-flight) data accumulated in this experiment have been sorted into 31 pulse-height spectra. These spectra correspond to various neutron energy groups covering the range 0.02 eV to 100 keV. Spectral unfolding techniques developed in this laboratory have been used to provide preliminary estimates of the contribution of "continuum" gamma rays to the gamma-ray production cross section. The yields of gamma rays will be grouped into γ-ray energy intervals of 250-500 keV over the range 1 to 5 MeV. (Pertinent to request No. 415, WASH-1144.)

6. Numerical and Experimental Studies of Spectral Unfolding
(M. Sperling, L. Harris, H. Kendrick, G. Borgonovi)

Neutron and γ-ray cross sections may be obtained by unfolding pulse-height data. Studies are underway to determine whether ambiguities in unfolded spectra are inherent or due primarily to faulty methods. Monte Carlo techniques are used to generate pulse-height pseudo-data from assumed spectra and spectrometer responses. The spectra include smooth continua and discrete lines; the responses include recoil and Gaussian responses. For each method that is studied, pseudo-data are generated and unfolded, and the unfolded spectra are compared with the assumed spectra. The program began with tests of several published methods, all of which were found to contribute method-dependent ambiguities. A series of new methods is now being studied in which the method-dependent ambiguities are being eliminated stage-by-stage. At the same time and unintentionally, the ability to resolve structure is evolving to the point where order-of-magnitude improvements of

[7] V. J. Orphan, et al., Nucl. Inst. and Methods 73 (1969) 1.

Gaussian resolution of discrete lines becomes attainable when large numbers of counts are available. The program will conclude with a measurement of neutron flux from a LINAC source obtained simultaneously by pulse-height unfolding and time-of-flight techniques.

7. Threshold Photoneutron Measurements (R. E. Sund, V. V. Verbinski, D. G. Costello, L. A. Kull and R. L. Bramblett)

An experimental facility for the measurement of threshold photoneutrons has been developed. A one-section electron accelerator is used in conjunction with an energy-analysis system with 1% to 3% resolution. The bremsstrahlung converter consists of a 0.005-cm-thick gold foil followed by a 2.5-cm-thick aluminum block to stop the electrons. Neutrons from (γ, n) reactions in a target are detected by three ~ 14-cm-diameter ^{10}B-loaded liquid scintillators at the end of a 19.5-m flight path. As a check on the performance of the system, preliminary measurements were done with $^{56}Fe(\gamma, n)$ reactions. Exploratory runs have been made on ^{235}U, ^{238}U, and ^{239}Pu and other measurements are planned in the near future.

TABLE A-1

Rhodium Resonance Parameters

E_0(eV)	$2g\Gamma_n$ (meV)	Γ_γ(meV)	J
1.259	.774 ± .01	154 ± 3	-
46.8	.80 ± .05	143 ± 30	-
68.4	.30 ± .02	---	-
95.7	3.6 ± .2	146 ± 20	-
125.6	11.0 ± .5	141 ± 25	-
154.2	Γ_n = 210 ± 25	140 ± 10	0
187.0	Γ_n = 36 ± 3	133 ± 18	1
253.9	Γ_n = 36 ± 4	138 ± 12	1
272.2	Γ_n = 60 ± 10	141 ± 10	1
319.5	Γ_n = 100 ± 15	135 ± 15	1

IDAHO NUCLEAR CORPORATION

A. CROSS SECTION MEASUREMENTS

1. Total Neutron Cross Section of ^{243}Am from 0.5 eV to 1 keV Using the ORELA (F. B. Simpson, O. D. Simpson, INC; J. A. Harvey, G. G. Slaughter, ORNL; R. W. Benjamin, C. E. Ahlfeld, SRL)

Transmission measurements have been made on oxide samples of ^{243}Am from 0.5 eV to 1 keV. Samples having inverse thicknesses of 1288.2 and 279.3 b/atom of ^{243}Am were used. The atom percent isotopic enrichment of the sample material was as follows: ^{243}Am, 99.73%; ^{241}Am, 0.15%; ^{244}Cm, 0.03%; and isotopes of Pu 0.09%. Data were taken using channel widths ranging in size from 10 - 320 nsec. Electron bursts of 20 - 30 nsec and a flight path of 18.576 meters were used.

An Automatic Cross Section Analysis Program (ACSAP)[1] was used to analyze the data below 60 eV. Most levels below 20 eV were analyzed using shape analysis. Above 20 eV the Doppler width was too large to permit shape analysis, therefore, above this energy resonances were analyzed using a subroutine in ACSAP called peak fitting. When peak fitting was used, values of E_o and Γ_γ were assumed and values of the reduced scattering widths were obtained by adjust Γ_n^o until the Doppler and resolution theoretically broadened data described the measured experimental data. Table A-1 shows a listing of the Breit-Wigner single level resonance parameters obtained using the above techniques. For all assumed values of Γ_γ = 45 meV, Γ_n^o was obtained using the peak fitting method. The solid line shown in Figure A-1 was obtained by Doppler and resolution broadening the Breit-Wigner single level curve obtained from the resonance parameters of Table A-1.

The theoretical total, capture and scattering cross sections for a temperature of 320°K were calculated using the parameters of Table A-1 and are shown in Figures A-2 through A-4. No instrumental resolution broadening is included in these data. The potential scattering cross section was obtained using the equation $\sigma_p = 0.2641 \times A^{2/3}$ barns, where A is the atomic weight of the nucleus. The scattering cross section below 10 eV was determined by omitting the -2.0 eV level and reflecting all measured positive resonances about zero eV into the negative energy region. The scattering cross section above 10 eV was obtained using the resonance parameters of Table A-1. Resonances above 60 eV were omitted in the theoretical calculations.

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[1] N. H. Marshall and O. D. Simpson "An Automatic Fitting Technique for Obtaining Neutron Cross Section Resonance Parameters", ANS Annual Meeting, Seattle, Washington, June (1969).

The average level spacing between resonances is shown in Figure A-8 and was found to be 0.69 eV. The neutron strength function from the levels below 60 eV was found to be 0.93×10^{-4}, see Figure A-9.

Only a brief summary of the data has been presented at this time; a more complete report will be published in the literature at a later date. The final report will include the area analysis of resolved resonances above 60 eV. The tabulated total cross section data from 0.5 eV to 1 keV will be published.

2. The Total Neutron Cross Section of ^{243}Am Below 1 eV (J. R. Berreth)

The total neutron cross section of ^{243}Am below 1 eV was measured using the MTR fast chopper and is shown in Figure A-6. After minor corrections were made to the data a total cross section value of 85 ± 4 barns at 0.0253 eV was determined. The data are presently being fitted and the thermal partial cross sections will be presented in the next NCSAC report.

3. Analysis of the 290 eV ^{203}Tl Resonance (T. Watanabe)

The 290 eV resonance in ^{203}Tl has been analyzed. A reduced neutron width (Γ_n^o) of 265 meV was determined assuming a value for Γ_γ of 250 meV. A fit to the experimental data is shown in Figure A-11.

4. Analysis of ^{238}Pu Fission Data from "Persimmon" (T. E. Young and M. G. Silbert*)

Fission cross section data from the nuclear explosion Persimmon have been analyzed for 46 resonances below 500 eV. A plot of the data is shown in Figures A-8 and A-9 Values of $\Gamma_n^o\ \Gamma_f/\Gamma$ for the 46 resonances and values of Γ_f and Γ_n^o for 12 resonances for which total cross section measurements are available are given in Table A-2. The average fission width for these resonances is 6.4 meV. An autocorrelation technique indicates an intermediate structure in the fission cross section with a level spacing of 1350 eV, see Figure A-14. This implies a secondary minimum in the fission barrier at about 3 MeV above the bottom of the primary well. Examination of running averages of the fission cross section yielded inconclusive results for any intermediate spacing, since the spacing depended strongly on the averaging width used.

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5. Total Neutron Cross Section of ^{94}Nb (T. E. Young and M. R. Serpa

Analysis of the ^{94}Nb data is nearly completed. Figures A-11 and A-12 show the experimental data. The resonance parameters that were used to obtain the solid line fits to the above data are given in Table A-3. The thermal absorption cross section of ^{93}Nb was found to be 1.2 ± 0.2 barns. A thermal absorption cross section of 23 ± 7 barns was calculated for ^{94}Nb. The observed resonances contribute only 1.2 barns to this value. With reasonable certainty an upper limit of 50 barns can be assigned to the thermal cross section of ^{95}Nb.

6. ^{242}Pu Total Neutron Cross Section Below 1 eV (T. E. Young, F. B. Simpson, and R. E. Tate*)

Comparison of metal and oxide measurements of the total neutron cross section of ^{242}Pu has been carried on using the MTR fast chopper. The results of a measurement of the total neutron cross section of ^{242}Pu using a metal sample are shown in Figure A-13. Also shown are the results of a previous measurement made using a $^{242}PuO_2$ sample[1]. At 0.0253 eV the uncorrected oxide sample data shows a neutron total cross section of 39 barns; the same value was obtained by Auchampaugh, et al[2]. Below 0.01 eV the total cross section varies approximately as A/E_n, where E_n is the neutron energy.

The oxide data were corrected for H_2O contamination and for scattering by the oxide particles. The forms of these corrections were determined by analysis of previous measurements[3,4] of oxide and metal samples. Uncorrected and corrected total cross sections at 0.0253 eV are 39 barns and 26.9 barns, respectively. The corresponding absorption cross section values are 28 barns and 18.5 barns. As shown in Figure A-13, the neutron total cross section measured with the metal sample is essentially identical to the corrected value obtained from the oxide sample. This identity requires that the absorption cross section calculated from the data also be the same as the 18.5 barns given by the corrected oxide data.

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[1] T. E. Young and S. D. Reeder, To be published in Nucl. Sci. and Engr.

[2] Auchampaugh, Bowman, Coops, and Fultz, Phys, Rev. 146(3), 840 (1966)

[3] Simpson, Moore, and Berreth, Nucl. Sci. and Engr. 29, 415 (1967)

[4] MTR unpublished

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Satisfactory extraction of total and absorption cross sections from the oxide data depended on the correctness of the following assumptions:

(1) The proper value of the potential scattering cross section was assumed, in this case the 10.7 barns calculated from the optical model.

(2) The absorption cross section of the isotope is very nearly 1/v from 0.001 eV to 1 eV.

(3) The shape of the "correction cross sections" obtained from measurements of other oxide samples, and used to correct for H_2O and for scattering by the oxide particles, are appropriate for use in this case. If any of these assumptions were to be invalid the corrected cross section would be in error.

From these measurements it can be concluded that cross section measurements below 0.5 eV are most likely in error when oxide samples are used. If precise measurements are to be made in the low energy region then good metalic sample should be used.

B. LOW ENERGY ETA MEASUREMENTS OF ^{233}U, ^{235}U AND ^{241}Pu (J. R. Smith and S. D. Reeder)

During June 1969, the value of eta for ^{233}U was measured at 0.095eV relative to its value at 0.06 eV, using the MTR 20" diameter manganese bath. During the Phoenix core, additional measurements were made on ^{233}U, ^{235}U and ^{241}Pu at 0.16 eV, and ^{233}U and ^{241}Pu at 0.26 eV. In addition, the calibration point at 0.06 eV was repeated for all three nuclei. Data reduction is not complete. In particular, the ^{241}Pu data analysis is complicated by decay to ^{241}Am. Some preliminary results for ^{233}U and ^{235}U, however, are shown in Table B-1.

C. SEARCH FOR THE SUGGESTED 0.3-YEAR ISOMERIC STATE OF ^{241}Pu (C. W. Reich, D. K. Oestreich, S. D. Reeder, L. D. McIsaac, and L. A. Kroger)

Two recent experimental results give what now appears to be definitive evidence that the 0.3-year isomeric state of ^{241}Pu, if it indeed exists, does not have an appreciable spontaneous-fission decay mode. Chemical analysis of a group of shavings machined from the original sample of Nisle and Stepan before irradiation has failed to detect any appreciable amount of ^{137}Cs. Studies of one sample failed to reveal the presence of any significant amount of 287-d ^{144}Ce, another fission product that should be present had there been spontaneous fission in the sample. Measurements of the spontaneous fission rate have been made on the sample irradiated inside a thick-walled (~ 1/4") Cd slug for one cycle (~ 6 weeks) in the ETR core. This sample was chemically purified; and then a 0.08-mg portion was electroplated onto a metallic foil and counted in a fast gas scintillation detector. The first measurement of the spontaneous fission rate from this sample revealed no

significant number of fissions that could not be accounted for in terms of the known amount of ^{240}Pu and ^{242}Pu. These two experimental results convince us that there is no appreciable spontaneous fission associated with the suggested ^{241}Pu isomer.

With this finding, we conclude either that the isomer does not in fact exist or that it has a very large thermal fission cross section. To investigate this latter possibility, we are now preparing a ∿ 0.4-g portion of the ETR-irradiated sample as a fast chopper sample. An attempt will be made to look at the low-energy portion of the total cross section of this sample before the shut-down of the MTR to see if there exists an observable anomaly that can be associated with the existence of an isomer. In addition, another ∿ 0.4-g portion of the sample will be prepared for measurement in the ARMF.

D. VERY INTENSE NEUTRON SOURCE VINS (R. M. Brugger, G. J. Russell, B. W. Johnson*, and G. P. De Vault†)

A report has been issued (INC 1304) describing the concept of the pulsed neutron source called VINS.

E. A NON-DESTRUCTIVE ANALYTICAL TECHNIQUE (D. K. Oestreich and F. B. Simpson)

A non-destructive analytical technique has been developed[1] which employs the MTR fast chopper as an analytical tool. Transmission of neutrons through irradiated and unirradiated fuel samples is used in the the quantitative determination of fuel burnup. The areas of resonances which are characteristic of the nuclei of interest are a function of concentration. With this technique it is possible to determine fissile isotopes, fissile isotope capture products, and those fission products which have large neutron resonances with a relatively high degree of accuracy.

To demonstrate the technique, transmission measurements as a function of time-of-flight were made on unirradiated and irradiated samples of uranium. Figure E-1 shows the experimental data and Table E-1 shows the results of the analysis.

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[1] Simpson, Oestreich, and Berreth, "Isotopic Assaying of Samples by a Non-Destructive Technique", to be presented at the Hannover Meeting June (1970).

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† Montana Tech., Bozeman

The advantages of the transmission technique are many:

1. This technique is non-destructive. Consequently the fuel may be returned to the reactor for further irradiation.

2. This technique is quite accurate for a non-destructive method. Even though in most cases resonance parameters are not known to better than 10% further careful work in calibrations of standards could reduce this uncertainty considerably. It is not necessary to know absolute concentrations when determining burnup. A simple ratio of concentrations found in irradiated and unirradiated samples will cancel systematic errors.

3. This technique is not subject to interference by gamma rays.

4. It is possible to measure the concentrations of many isotopes simultaneously.

F. NEUTRON BURNUP OF ETR HAFNIUM CONTROL RODS (L. G. Miller and T. Watanabe)

Using the shielded neturon radiography facility at the Materials Testing Reactor (MTR), the burnout of the high neutron cross-section isotopes in the Engineering Testing Reactor (ETR) hafnium control rods has been measured directly. With these and subsequent measurements, in-pile nuclear residence limits for hafnium control rods in ETR and the Advanced Test Reactor (ATR) can be predicted with good accuracy. Theoretical calcualtions showing hafnium burnup are difficult to obtain due to the inadequacy of the theoretical models to predict self-shielded effective cross sections of the numerous hafnium isotopes, and the neutron energy and flux distributions in and above the reactor core. There is a pressing need to develop in-pile residence limits for hafnium control rod sections in ETR and ATR since the world's knowledge of irradiated hafnium will soon be surpassed by ATR. The percent burnup of a hafnium control rod for a reactor neutron spectrum has been measured directly using an MTR neutron radiograph. Figure F-1 shows the percentage burn-up for two ETR hafnium control rods. With the use of the MTR neutron radiography facilities accurate burnup can now be measured for hafnium control rods.

G. NEUTRON FILTERED BEAMS

1. Flux Spectrum Measurements of the 25 keV Beam (J. W. Rogers)

The iron filter has been moved from the HG-5 to the down beam hole DB-2 of the MTR. The size of the beam can be varied from 0.5 to 4.0 inches by a simple selection of one of the many available collimators.

Two peaks occur in the spectrum, the major one at 25 keV and a minor one at 137 keV, see Figure G-1. These measurements extended from 5 keV to 270 keV and indicate that 98.5% of the beam flux in this energy region is due to the 25 keV window. A usable flux of 1×10^6 neutron/cm^2/sec is available from the iron filter in the DB-2 hole of the MTR.

2. Activation Cross Sections Using the 25 keV Fe Filtered Neutron Beam (R. L. Tromp)

Both the physical and nuclear characteristics of the MTR 25 keV filtered beam, and preliminary results of foil-activation cross section determinations, have been described in the two previous NCSAC status reports.

During the extended shutdown for structural modifications in the MTR in late 1969, this iron filtered beam was moved from HG-5 to DB-2 beam hole. A series of various stacked foil irradiations has been completed,with data analysis still in progress. Studies of specific activation versus cumulative thickness of samples of ^{115}Tn, ^{181}Ta, ^{198}Au, and ^{238}U have been made (1) to determine the general self-shielding, energy degradation and scattering characteristics of these convenient targets, (2) for comparison with previous work, and (3) for useful data in a cooperative study of neutron resonance prediction theory, by the U. of Wisconsin Nuclear Engineering Department. Initial results show that expected self-shielding attenuation due to preferential shielding of resonance neutrons by the front foils is usually less than either theoretical predictions or earlier results in HG-5. Analysis of the data is continuing.

3. Neutron Scattering Cross Sections at 2 keV (J. R. Smith and O. D. Simpson)

A study of neutron scattering at 2 keV was carried out on the 2 keV filtered beam facility at the MTR during the Phoenix core run. The detector system utilized two separate sets of BF_3 counters mounted concentrically about the scattering sample.

Different amounts of polyethylene surrounded the two detectors so as to make them preferentially sensitive to 2 keV and fission neutron respectively. Data were taken as a function of sample thickness. A Ce-Mn filter was used to remove the 2 keV neutrons from the beam and reveal the effects of the higher energy background. Measurements were made on ^{239}Pu, ^{235}U, Pb, Al, and C, in various sample thicknesses and combinations. The data are in process of being analyzed.

4. Capture Gamma Rays Produced by 2 keV Neutrons (R. C. Greenwood and C. W. Reich)

Neutron capture gamma-ray measurements using the 2 keV neutrons from the scandium-filtered beam facility of the Materials Testing Reactor has continued. Because of the anticipated shut-down of the MTR, the major emphasis of this work to date has been in data accumulation rather than in data analysis. Elements for which 2 keV neutron capture gamma-ray spectra have been measured include: sodium, potassiam, chromium, iron, cobalt, nickel, copper, zirconium, niobium, molybdenum, terbium, dysprosium, lutetium, hafnium, tungsten, rhenium, iridium, platinum, gold, mercury, thallium, lead, bismuth, thorium, and depleted uranium, together with a number of separated isotope samples.

In the measurements with the lead sample the experiment was specifically designed to obtain an absolute cross section for capture of 2 keV neutrons by ^{207}Pb. A preliminary value for this cross section is (1.5 ± 0.6)mb. Analysis of the above measurements will continue over the next several months.

H. MEASUREMENT OF RELATIVE INTEGRAL REACTION RATES IN THE CFRMF (R. G. Nisle and J. J. Scoville)

An integral reaction rate may be defined as follows:

$$\overline{\sigma\phi} = \int_0^\infty \sigma(E)\ \phi(E)\ dE \qquad 1.$$

where the cross section $\sigma(E)$ is that for the (n,γ) reaction. Upon termination of an irradiation period of duration T, the gamma activity is given by

$$R_i = (\overline{\sigma\phi})_i \frac{Mi\ No}{A_i} \left[1 - \exp(-\lambda_i T)\right] \qquad 2.$$

where M_i is the weight of isotope i
N_o is Avogadro's number
A_i is the atomic weight of isotope i
λ_i is the decay constant of the daughter product in the (n,γ) reaction

and the burnup of M_i has been neglected. R_i was measured for several isotopes with a gamma-ray spectrometer using a NaI detector. A 5-mil Au foil was irradiated simultaneously with each isotope and the Au reaction rate was used as the reference. The relative reaction rate is then given by

$$\frac{(\overline{\sigma\phi})_i}{(\overline{\sigma\phi})_{Au}} \approx \frac{R_i}{R_{Au}} \frac{A_i}{A_{Au}} \frac{M_{Au}}{M_i} \left[\frac{1 - \exp(-\lambda_{Au} T)}{1 - \exp(-\lambda_i T)} \right] \qquad 3.$$

All irradiations were made in the Coupled Fast Reactivity Measurement Facility (CFRMF) which has a spectrum similar to that expected for the FBR.

For comparison purposes a calcualted reaction rate was obtained by use of cross sections from BNL-325 and from CCDN-NW/10 and a spectrum in the CFRMF measured by recoil-proton and by foil activation methods. If the integral in equation 1. is approximated by a summation, the corresponding reaction rate ratio is given by:

$$\frac{(\overline{\sigma\phi})_i}{(\overline{\sigma\phi})_{Au}} \approx \frac{\left[\sum_1^n \sigma_n \, \phi_n \, \Delta E_i \right]}{\left[\sum_1^n \sigma_n \, \phi_n \, \Delta E_{Au} \right]} \qquad 4.$$

The results of these measurements and calculations are shown in Table H-1.

TABLE A-1

^{243}Am Resonance Parameters

E_o(eV)	Γ_n^o(meV)	Γ_γ(meV)	E_o(eV)	Γ_n^o(meV)	Γ_γ(meV)
-2.0 *	0.84	42	27.690	0.0083	45
0.420 *	0.0013	39	28.734	0.1960	45
0.983	0.0143	36.5	29.299	0.1412	45
1.356	0.9505	43	30.113	0.1040	45
1.744	0.1815	38.7	31.056	0.1440	45
3.140	0.0065	30.8	31.455	0.0330	45
3.424	0.1566	35.9	32.397	0.0290	45
3.845	0.0070	48.3	32.966	0.0173	45
5.125	0.1400	41	33.194	0.1661	45
6.554	0.3894	37.8	33.931	0.3183	45
7.067	0.0268	39.6	34.979	0.1654	45
7.863	0.4856	41.8	36.434	0.0189	45
8.377	0.0025	45	36.680	0.1409	45
8.770	0.0409	30.4	37.020	0.3348	45
9.314	0.0506	40.8	37.553	0.0150	45
10.314	0.1467	52.0	37.912	0.1103	45
10.877	0.0049	45	39.487	0.1080	45
11.278	0.0890	47.0	40.461	0.0192	45
11.693	0.0310	31.0	40.951	0.0617	45
12.122	0.0508	44.0	41.269	0.1649	45
12.873	0.6761	37.9	41.532	0.3820	45
13.152	0.4197	48.6	42.938	0.4420	45
15.143	0.0192	45	44.089	0.0797	45
15.404	0.3526	45.7	45.330	0.1874	45
16.210	0.1424	50.1	47.108	0.0496	45
16.583	0.0485	33.6	48.546	0.0665	45
17.874	0.0533	45.6	49.275	0.1170	45
18.158	0.0143	45	50.220	0.0226	45
19.533	0.0482	49.4	51.273	0.1550	45
19.915	0.0205	45	53.024	0.2893	45
20.974	0.1224	45	53.582	0.0264	45
21.120	0.2285	45	54.005	0.1020	45
21.872	0.0325	45	54.539	0.2315	45
22.011	0.0092	45	54.934	0.0231	45
22.608	0.1177	45	55.860	0.2473	45
22.741	0.2660	45	57.213	0.0165	45
24.454	0.1820	45	57.708	0.0160	45
25.429	0.0332	45	58.680	0.0519	45
26.227	0.0070	45	59.076	0.1237	45
26.749	0.3184	45	59.936	0.0912	45
27.343	0.1065	45			

* Determined by J. R. Berreth MTR Fast Chopper

Note: All values of Γ_γ = 45 meV were assumed.

TABLE A-2

Resonances Between 15 and 500 eV in ^{238}Pu

Energy of Resonance (eV)	$\frac{\Gamma_n^o \Gamma_f}{\Gamma}$ (meV)	Γ_n^o (meV)	Γ_f (meV)
18.6	.036	.041	2.05
32.2	.0014		
36.5	.0005		
59.8	.0038	.20	.67
70.2	.050	.29	7.7
77.7	.0009		
83.0	.137	2.1	3.8
96.1	.001		
99.6	.005		
110.1	.052	.53	4.7
111.5	.005		
113.6	.115	.95	6.3
118.6	.067	3.0	1.5
122.4	.294	2.3	8.8
139.7	.0009		
132.3	.010		
129.7	.036		
151.1	.29	1.2**	16
164.8	.005		
171.0	.030	4.9	.61
176.7	.100		
182.8	.210	2.2	6.5
192.4	.798	3.8**	22.5
202.8	.018		
216.1	.35		
220.9	.052		
224.9	.17		
251.6	.51		

** A significant discrepancy exists between these values and those obtained from analysis of fission and capture cross sections. This discrepancy is being investigated.

TABLE A-2 (continued)

Energy of Resonance (eV)	$\frac{\Gamma_n^o \Gamma_f}{\Gamma}$ (meV)	Γ_n^o (meV)	Γ_f (meV)
281.0	.44	(.44)*	(5500)*
284.9	1.31	(1.3)*	(1500)*
289	.49		
300	1.72		
305	.31		
320	.26		
326	.29		
336	.13		
361	.008		
368	.072		
382	.006		
391	.038		
408	.042		
419	.37		
426	.29		
448	.20		
460	.20		
465	.21		
473	.042		
496	.049		

* Large Γ_f required to fit fission data.

TABLE A-3

Breit-Wigner Single Level Resonance Parameters for ^{94}Nb

E_o(eV)	Γ_n^o(meV)	Γ_γ(meV)
11.58	1.8 ± 0.1	165 ± 20
22.78	0.19 ± 0.02	165*

* Assumed

TABLE B-1

Relative Values of Eta

Energy (eV)	$\eta(^{233}U)$	$\eta(^{235}U)$
0.060	1.000	1.000
0.095	0.993 ± .005	
0.160	0.966 ± .005	0.997 ± .005
0.260	0.993 ± .013	

TABLE E-1

A non-destructive analysis of an irradiated uranium fuel sample

Nuclide Observed	Energy of Resonance Used	Unirradiated Sample mg/cm^2 Found From Computer Fit of Resonance Parameters To Data	Irradiated Sample mg/cm^2 Found From Computer Fit of Resonance Parameters To Data
^{234}U	5.14 eV	1.25 mg/cm^2	1.25 mg/cm^2
^{235}U	8.77 eV	90.4 mg/cm^2	39.8 mg/cm^2
^{236}U	5.44 eV	----------	8.52 mg/cm^2
^{239}Pu	7.76 eV	----------	17.8 mg/cm^2
^{240}Pu	1.059 eV	----------	2.79 mg/cm^2
^{147}Pm	5.35 eV	----------	0.674 mg/cm^2
^{99}Tc	5.61 eV	----------	1.16 mg/cm^2
^{133}Cs	5.83 eV	----------	2.94 mg/cm^2
^{152}Sm	7.98 eV	----------	0.221 mg/cm^2
^{131}Xe	14.3 eV	----------	1.03 mg/cm^2

Transmission measurement on the sample was started only 18 days after completion of the irradiation. Consequently, there was insufficient time, in many cases, for the fission products of interest to arrive at their maximum concentrations from the radioactive decay of their precursors. [illegible]ately half the fissions in the sample were in ^{239}Pu [illegible] irradiation. Since fission yields are different for ^{239}[illegible], fission product concentrations are a rather complex [illegible]. Samples contained 430.5 mg of ^{238}U and 27.8 mg of ^{235}U originally. The sample was irradiated for 39.3 days at a flux of 4×10^{14} neutrons/cm^2/sec, or an integrated flux of 1.36×10^{21} neutrons/cm^2.

TABLE H-1

Summary of Relative Integral Reaction Rates

A. Measurements Completed - Ratios not Calculated

Reaction	Ratio Relative to Gold	Comments
$Cu^{63}(n,\gamma)Cu^{64}$	0.085 (5 mil foil)	secondary reference
$Y^{89}(n,\gamma)Y^{90m}$	8.8×10^{-4}	metal chips
$Mo^{98}(n,\gamma)Mo^{99}$	0.033	metal powder
$Rh^{103}(n,\gamma)Rh^{104m}$	0.081	10 mil wire
$Rh^{103}(n,\gamma)Rh^{104g}$	0.86	10 mil wire
$Ce^{140}(n,\gamma)Ce^{141}$	2.2×10^{-3}	oxide
$Ce^{142}(n,\gamma)Ce^{143}$	0.046	oxide
$Gd^{160}(n,\gamma)Gd^{161}$	0.23	2 mil foil

B. Measurements Completed - Ratios also Calculated

Reaction	Ratio Relative to Gold		Comments
	Measured	Calculated	
$Nb^{93}(n,\gamma)Nb^{94}$	0.42	0.36 (BNL-325) 0.33 (CCDN-NW/10)	Powder
$Nb^{93}(n,\gamma)Nb^{94}$	0.46		5 mil foil
$La^{139}(n,\gamma)La^{140}$	0.046	0.061 (BNL-325) 0.055 (CCDN-NW/10)	oxide
$Gd^{158}(n,\gamma)Gd^{159}$	0.45	0.53 (BNL-325)	2 mil foil
$Ta^{181}(n,\gamma)Ta^{182}$	1.23	1.00	metal powder
$W^{186}(n,\gamma)W^{187}$	0.36	0.23	5 mil foil

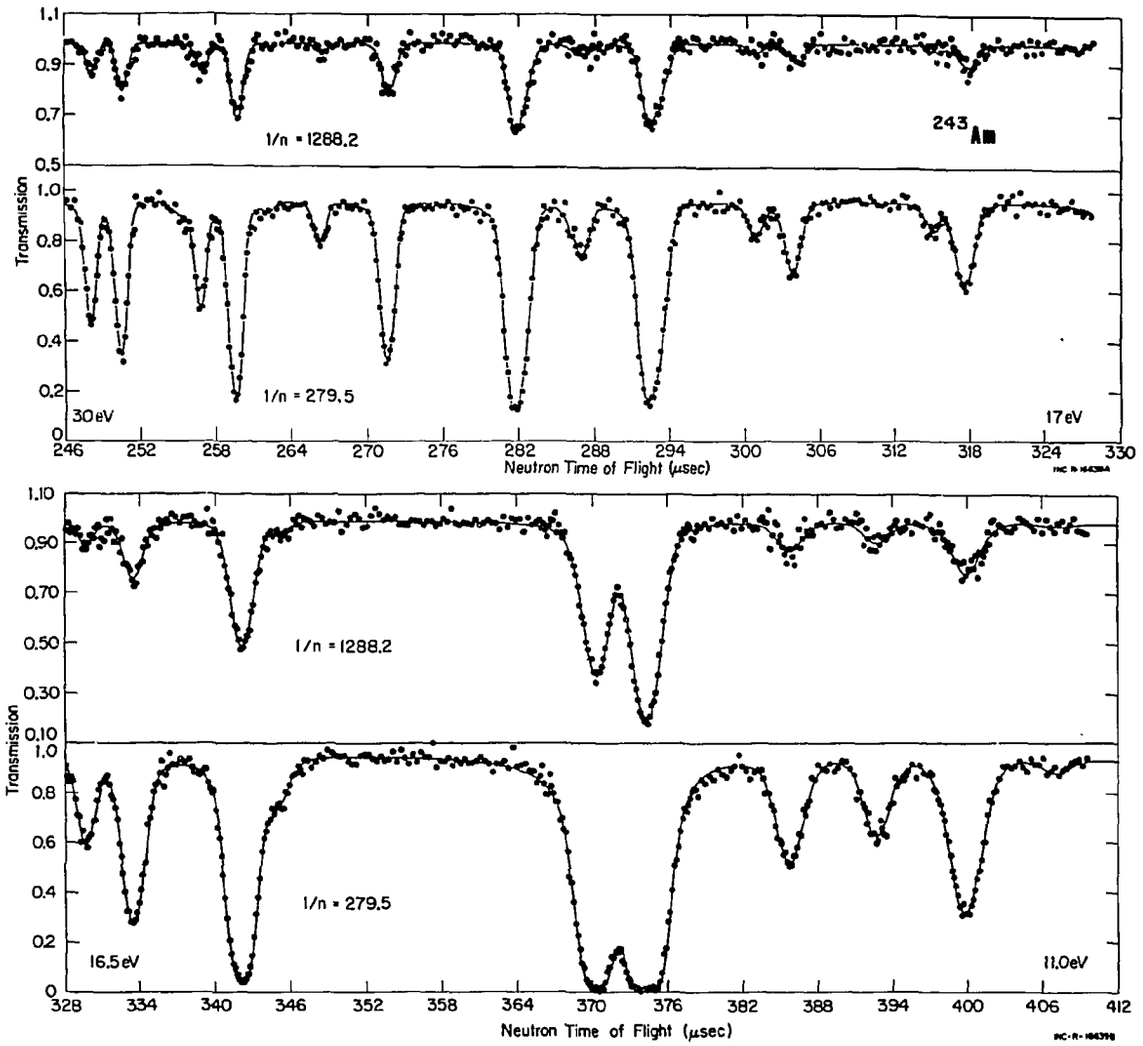

Figure A-1. Neutron transmission as a function of time of flight. The solid line was determined by Doppler and resolution broadening the Breit-Wigner single level data which was obtained from the resonance parameters of Table A-1. An effective sample temperature of 320°K was used. The data cover the energy range from 30-10 eV.

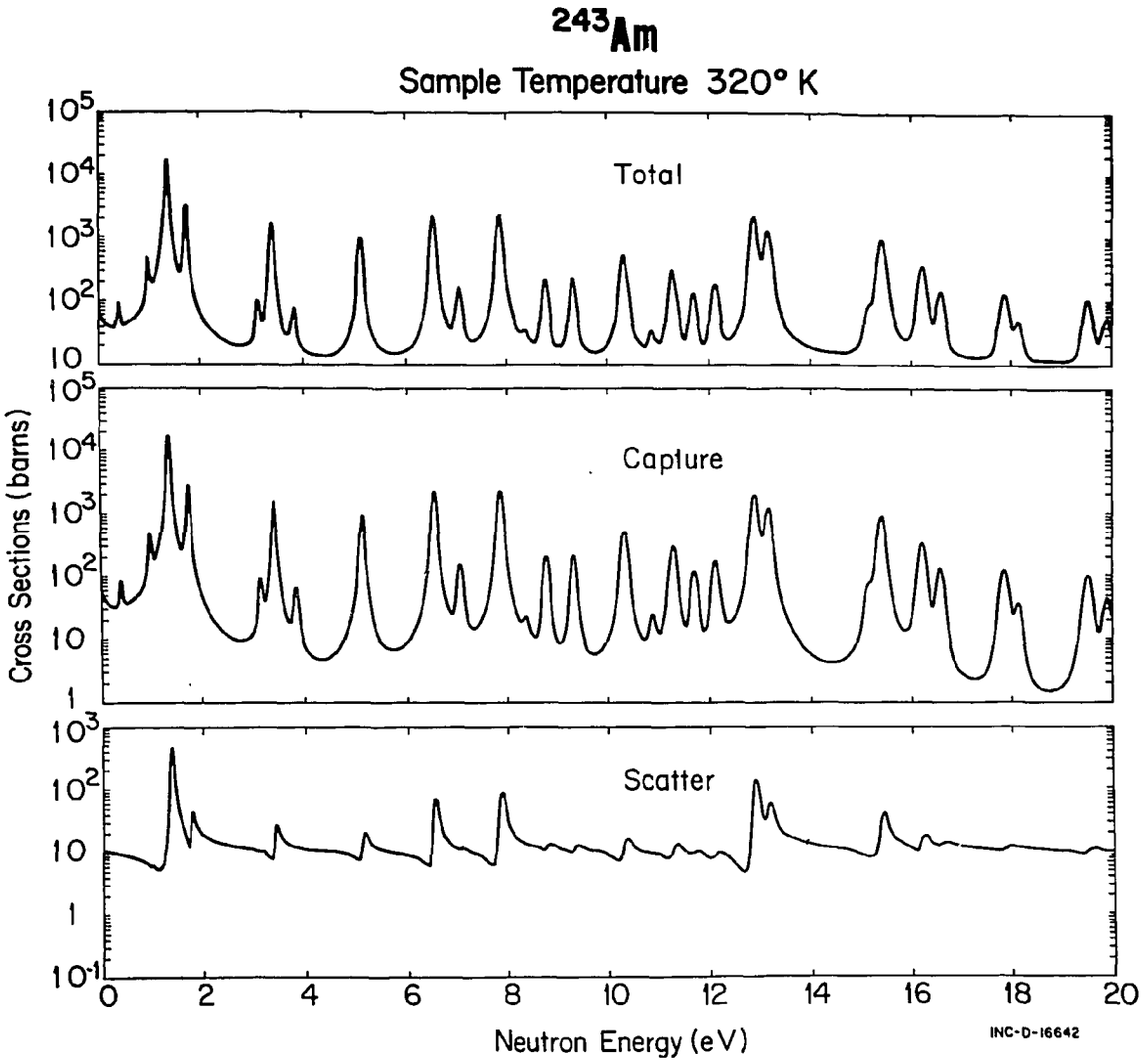

Figure A-2. The neutron total capture and scattering cross sections as a function of neutron energy. The theoretical curves were calculated, assuming an effective sample temperature of 320°K and using the Breit-Wigner single level equation and the resonance parameters of Table A-1. No instrumental resolution broadening is included in these data.

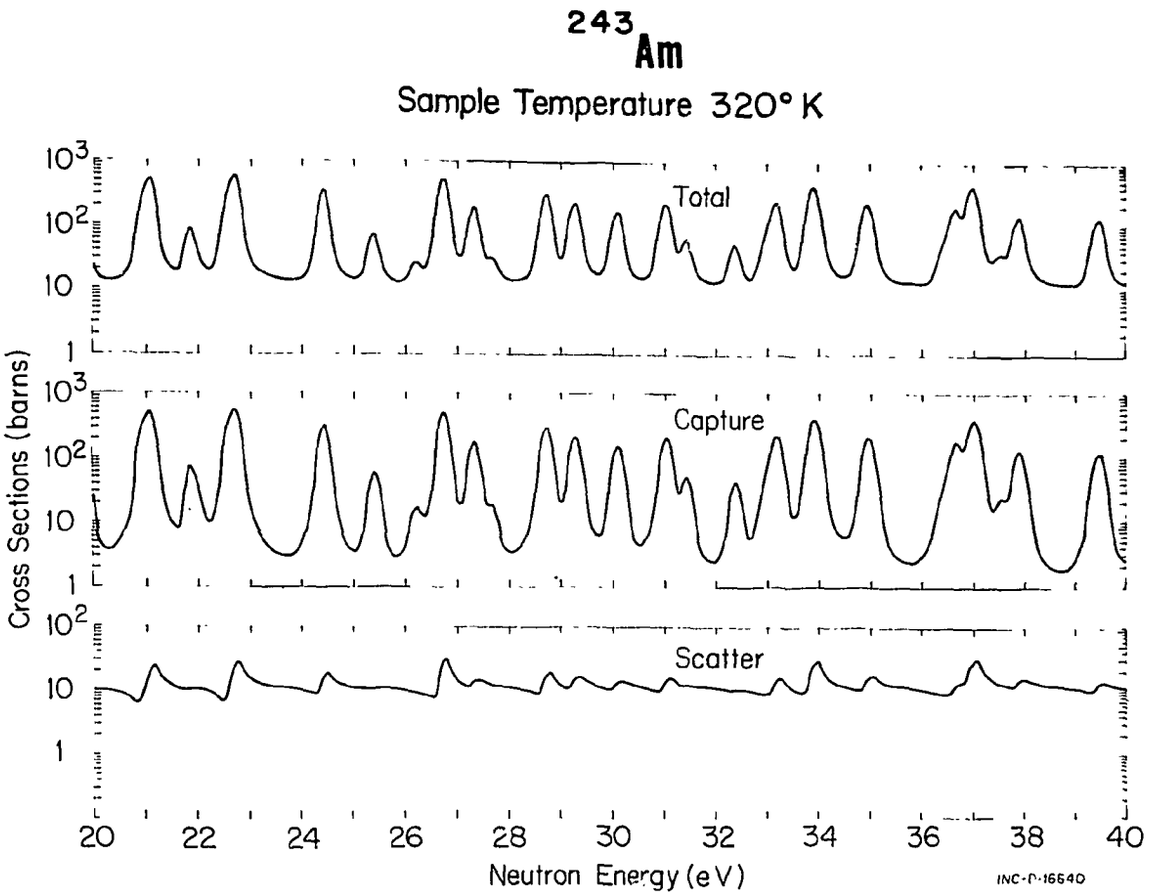

Figure A-3. The neutron total capture and scattering cross sections as a function of neutron energy. The theoretical curves were calculated, assuming an effective sample temperature of 320°K and using the Breit-Wigner single level equation and the resonance parameters of TableA-1. No instrumental resolution broadening is included in these data.

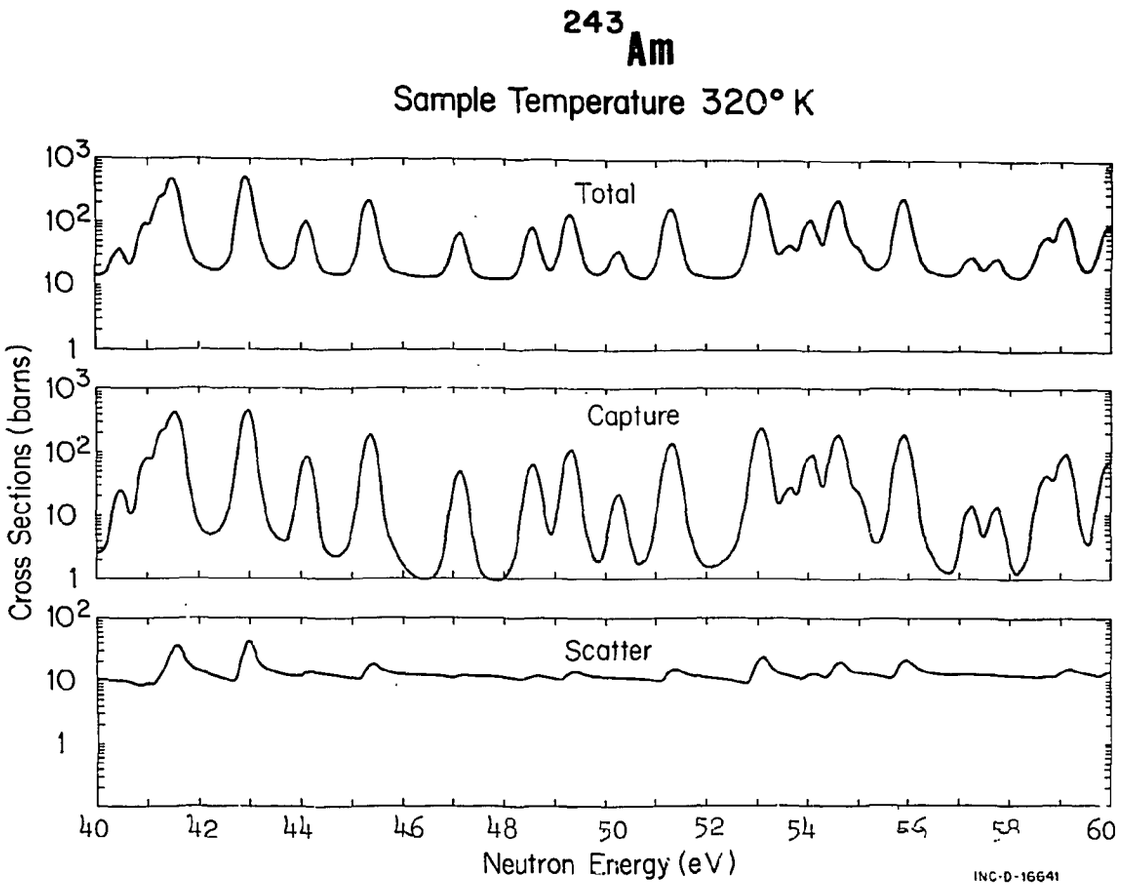

Figure A-4. The neutron total capture and scattering cross section as a function of neutron energy. The theoretical curves were calculated, assuming an effective sample temperature of 320°K and using the Breit-Wigner single level equation and the resonance parameters of Table A-1. No instrumental resolution broadening is included in these data.

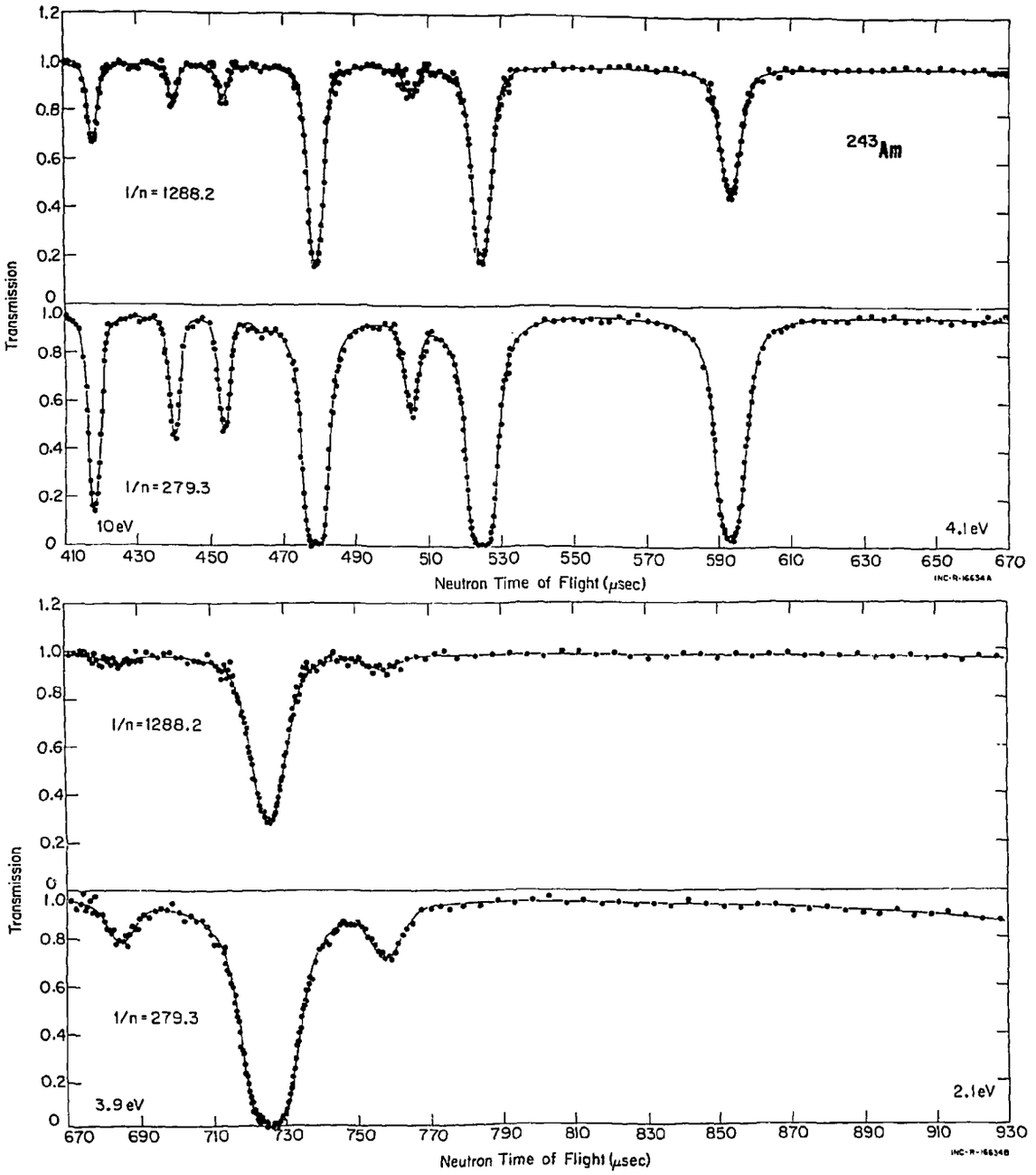

Figure A-5. Neutron Transmission as a function of time of flight. The solid line was determined by Doppler and resolution broadening the Breit-Wigner single level data which was obtained from the resonance parameters of Table A-1. An effective sample temperature of 320°K was used. The data cover the energy range from 10-2 eV.

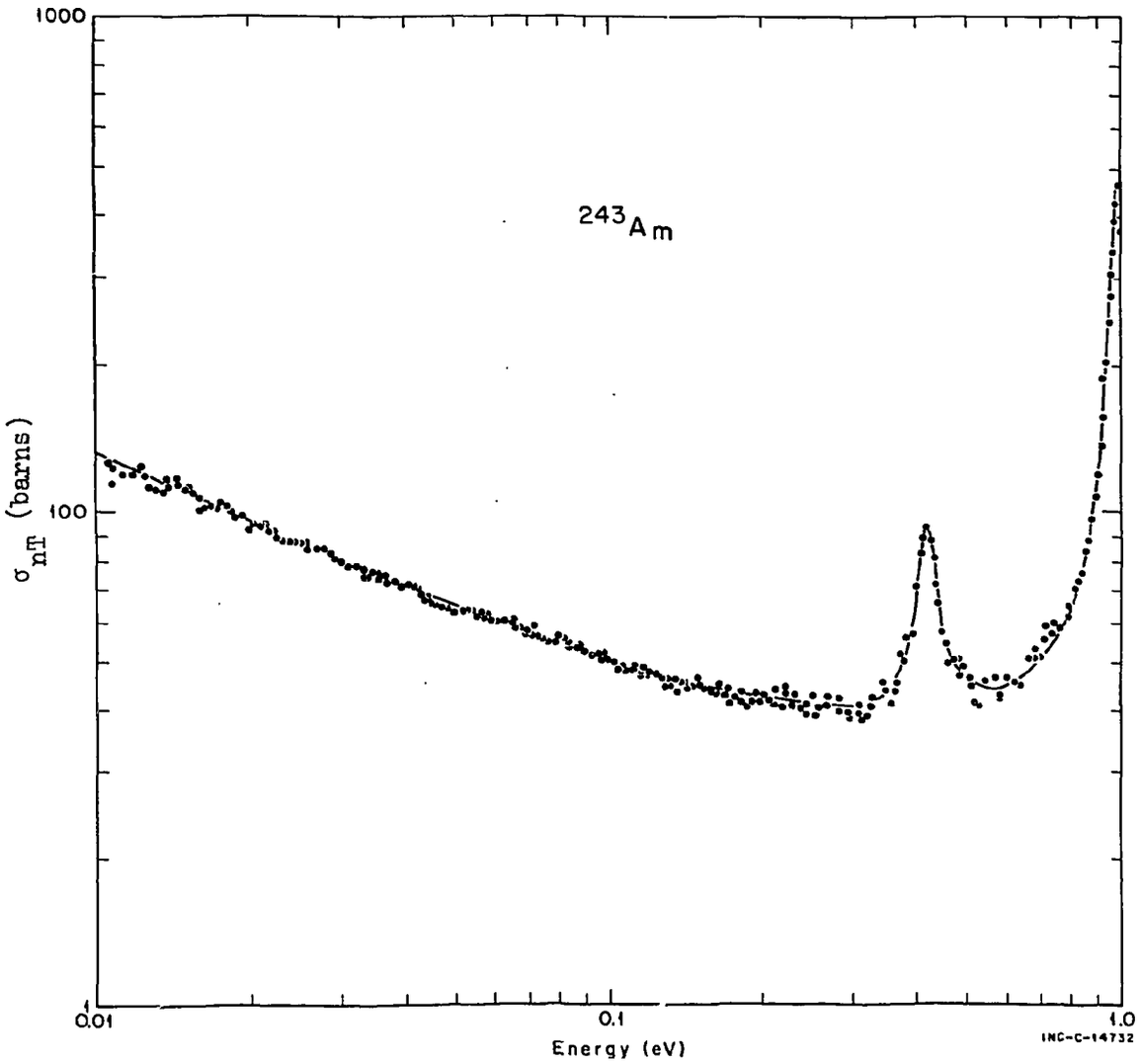

Figure A-6. The total neutron cross section of ^{243}Am below 1 eV. The solid line is an "eyeball" fit to the data.

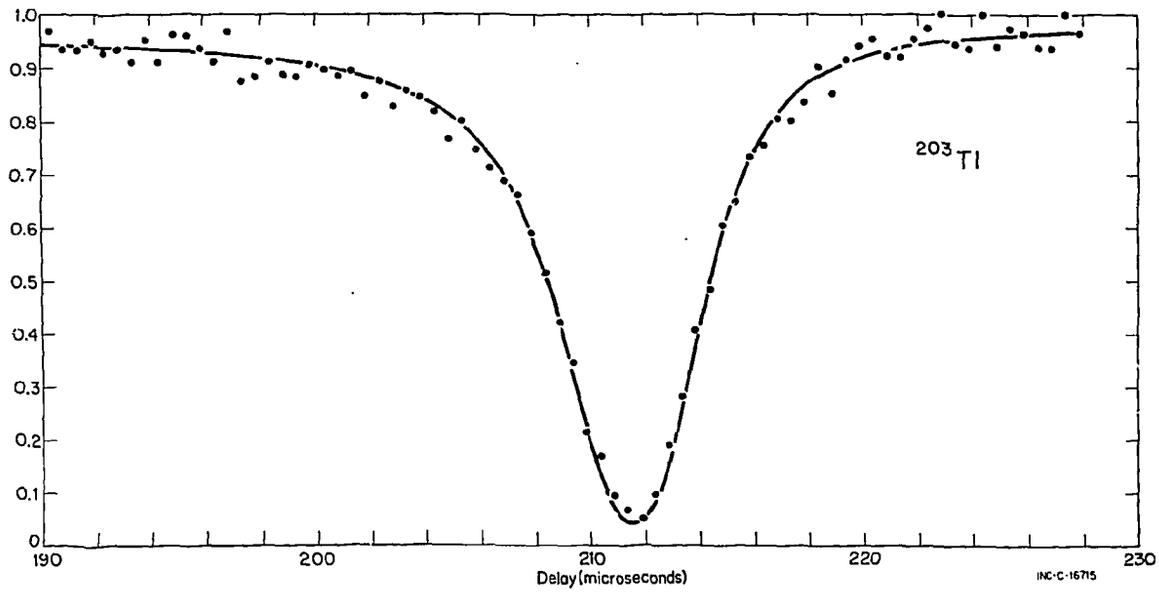

Figure A-7. Transmission data of ^{203}Tl. An inverse sample thickness of 1145 b/a was used. The solid line is a Breit-Wigner single level fit to the data. The following resonance parameters were obtained: E_o = 290 eV, Γ_n^o = 265 meV for an assumed Γ_γ of 250 meV.

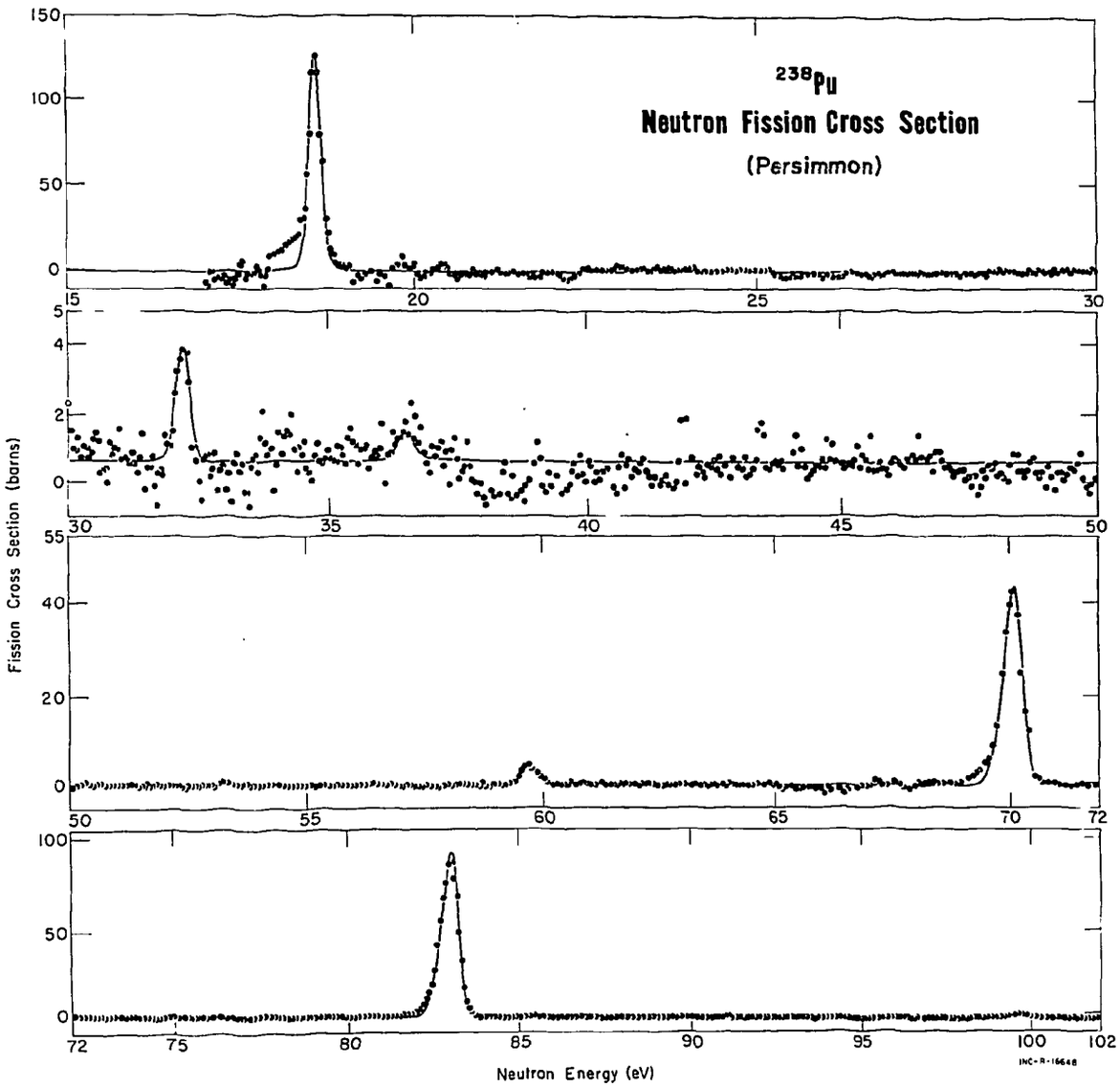

Figure A-8. Fission cross section of ^{238}Pu from 15 eV to 102 eV. The solid line shows the fission cross section calculated using the Breit-Wigner single level formula. Values of $\Gamma_n^o \Gamma_f/\Gamma$ were adjusted to fit the data.

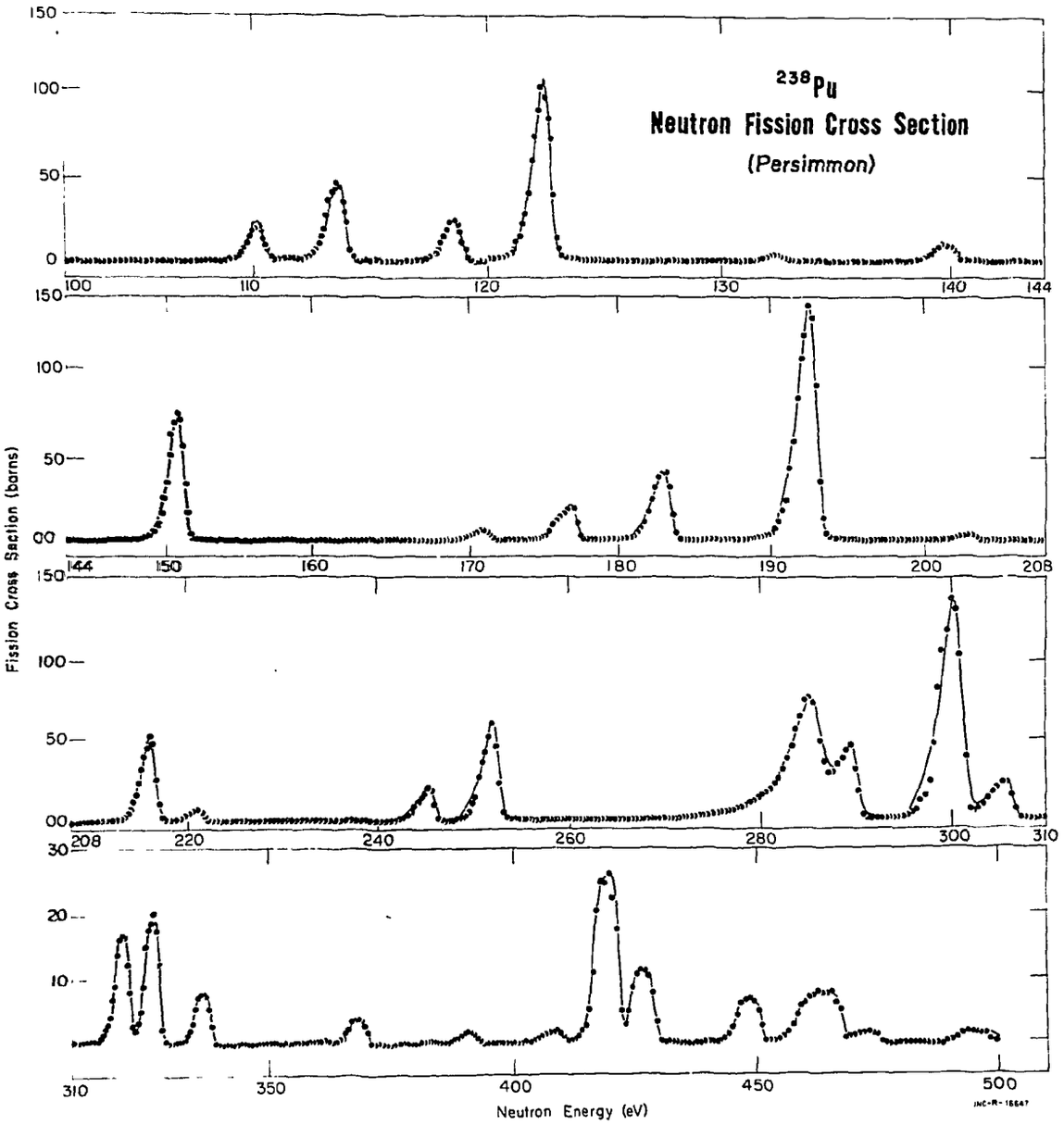

Figure A-9. Fission cross section of ^{238}Pu from 102 eV to 500 eV. The solid line shows the fission cross section calculated using the Breit-Wigner single level formula. In addition to adjusting $\Gamma_n{}^o\Gamma_f/\Gamma$ as with the resonances in Figure 1(a) it was necessary to use fission widths of 5500 meV and 1500 meV to fit resonances at 281 eV and 285 eV.

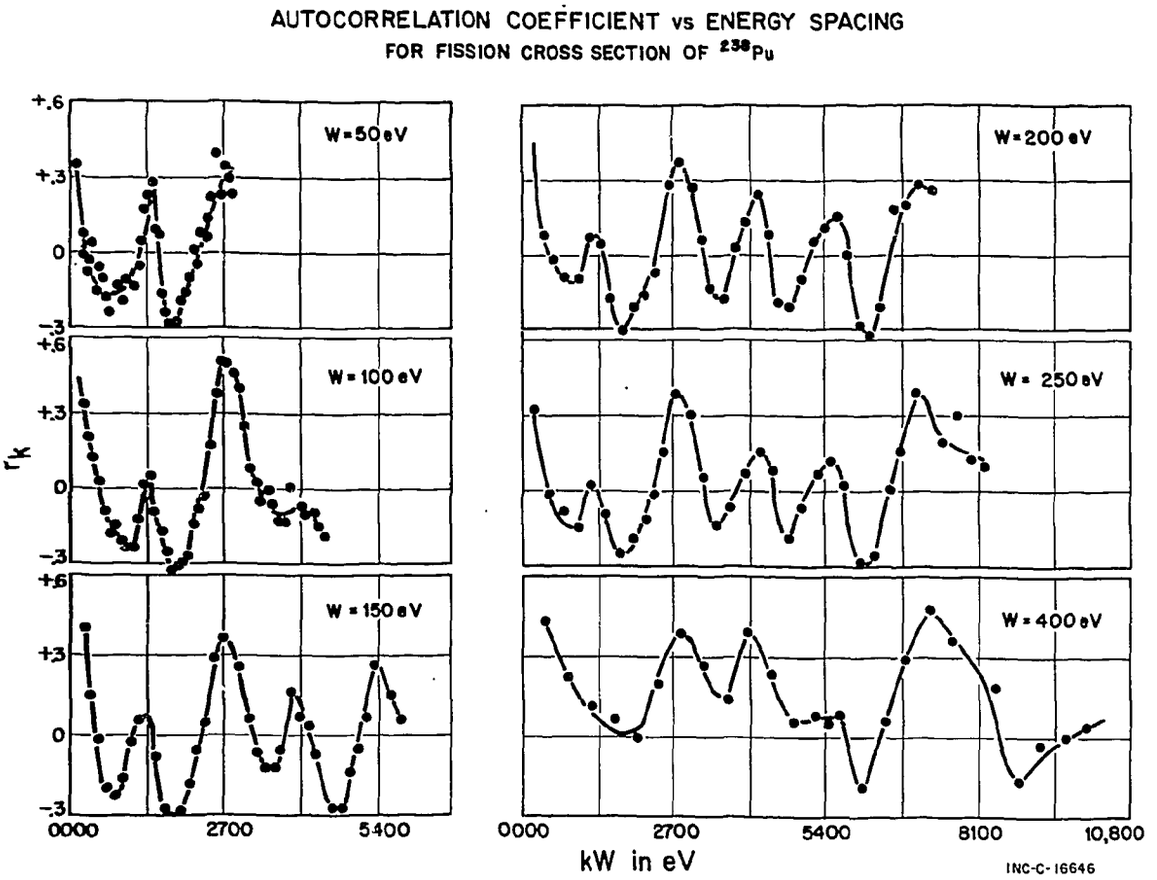

Figure A- 10. Autocorrelation coefficients versus energy spacing for sampling widths from 50 eV to 400 eV. Intermediate structure in the fission cross section gives maxima in this plot at intervals of 1350 eV. Further investigation of the significance of these plots is planned.

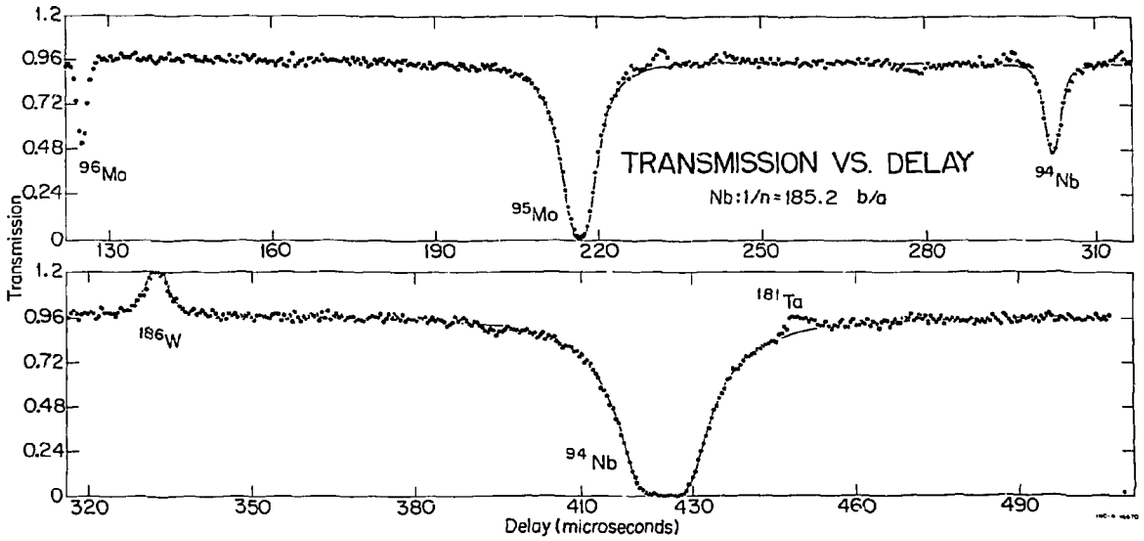

Figure A-11. The neutron transmission as a function of time of flight. A sample having an inverse thickness of 185.2 b/a was used. The solid line is a single level Breit-Wigner fit to the data.

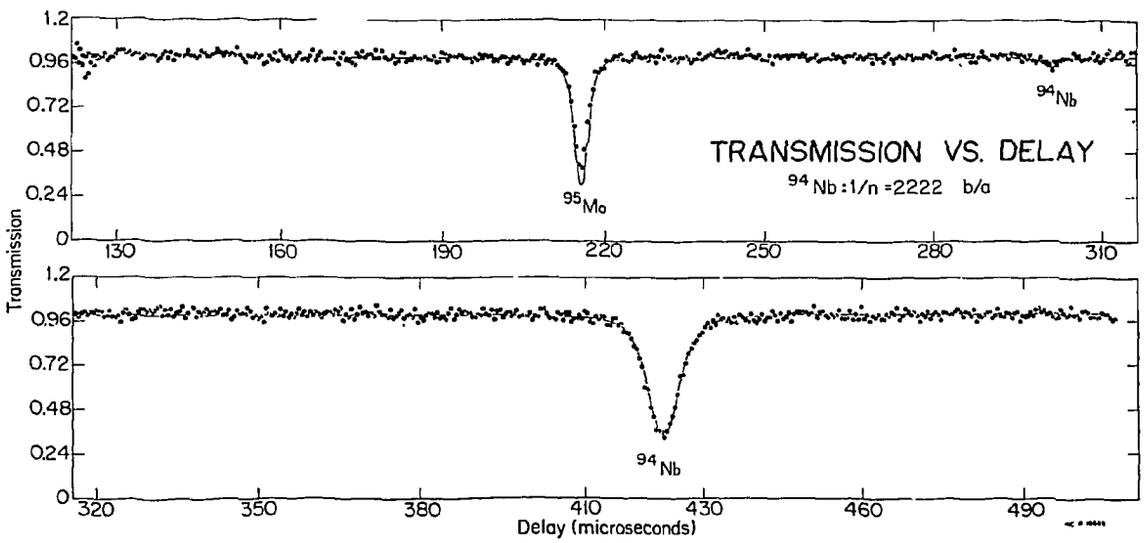

Figure A-12. The neutron transmission as a function of time of flight. A sample having an inverse thickness of 2222 b/a was used. The solid line is a single level Breit-Wigner fit to the data.

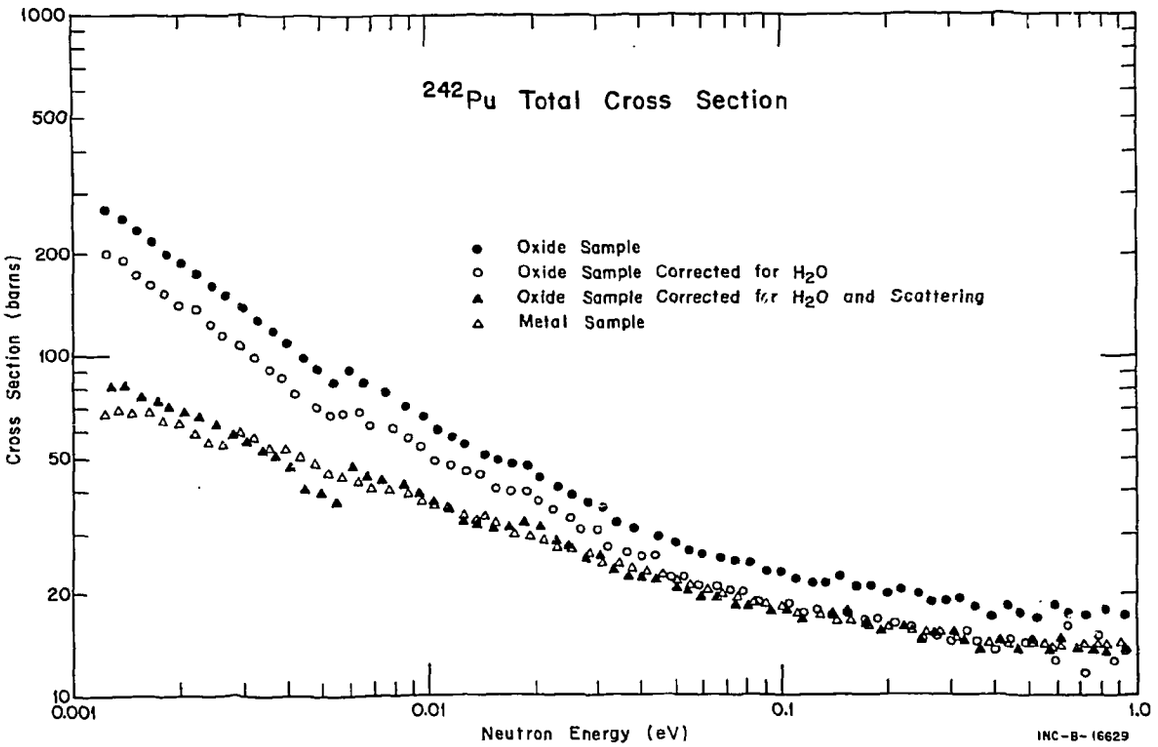

Figure A-13. Neutron total cross section of ^{242}Pu from 0.0012 eV to 1.0 eV. Original data from a $^{242}PuO_2$ sample is shown as well as the results of two successive corrections. Validity of such corrections requires a 1/v absorption cross section, knowledge of σ_p, and consistency of the scattering by H_2O and small particles from one oxide sample to another.

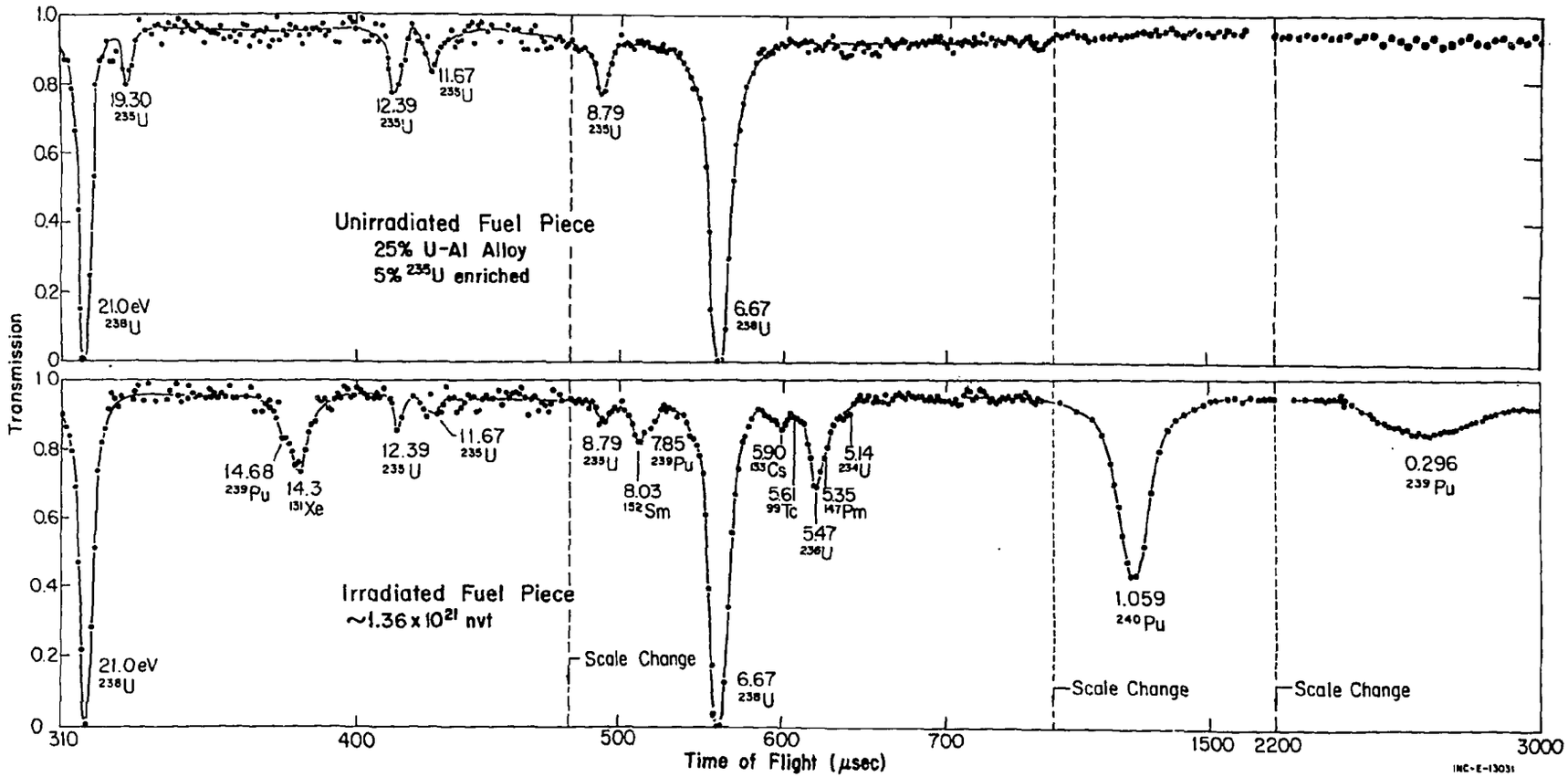

Figure E-1 Neutron transmission measurements as a function of time of flight for an unirradiated and irradiated fuel piece. The top curve is for the unirradiated sample and the bottom curve represents data for an identical sample irradiated at a flux of 4×10^{14} n/cm^2/sec for 39.9 days.

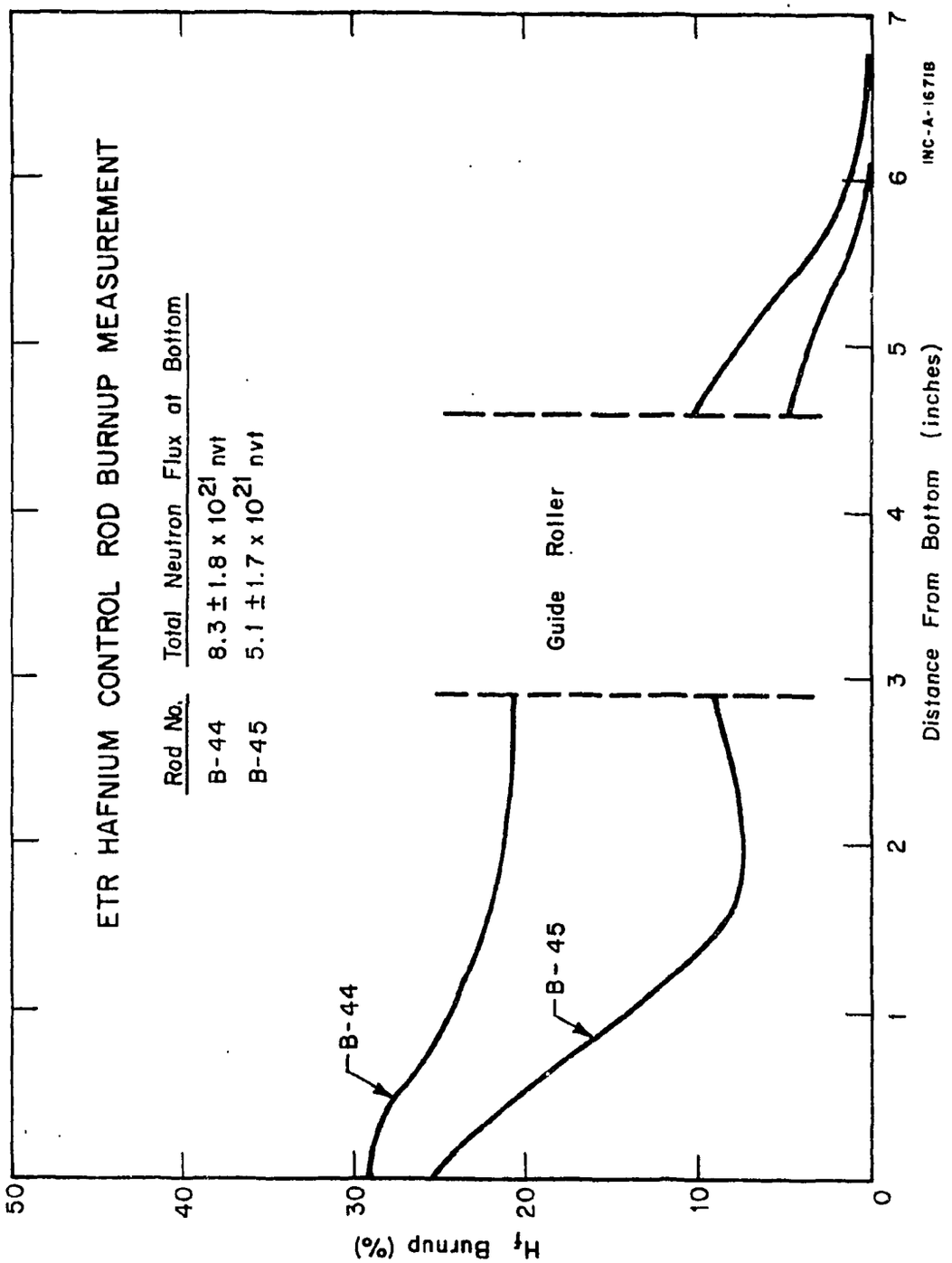

Figure F-1. Percentage burnup of hafnium vs. position in inches from the bottom of the rod. During normal operation the B-45 rod was located above the reactor core with its bottom end adjacent to the fuel. The B-44 rod was initially located above the core but was lowered approximately 2 inches into the core as a control rod during the latter part of its use.

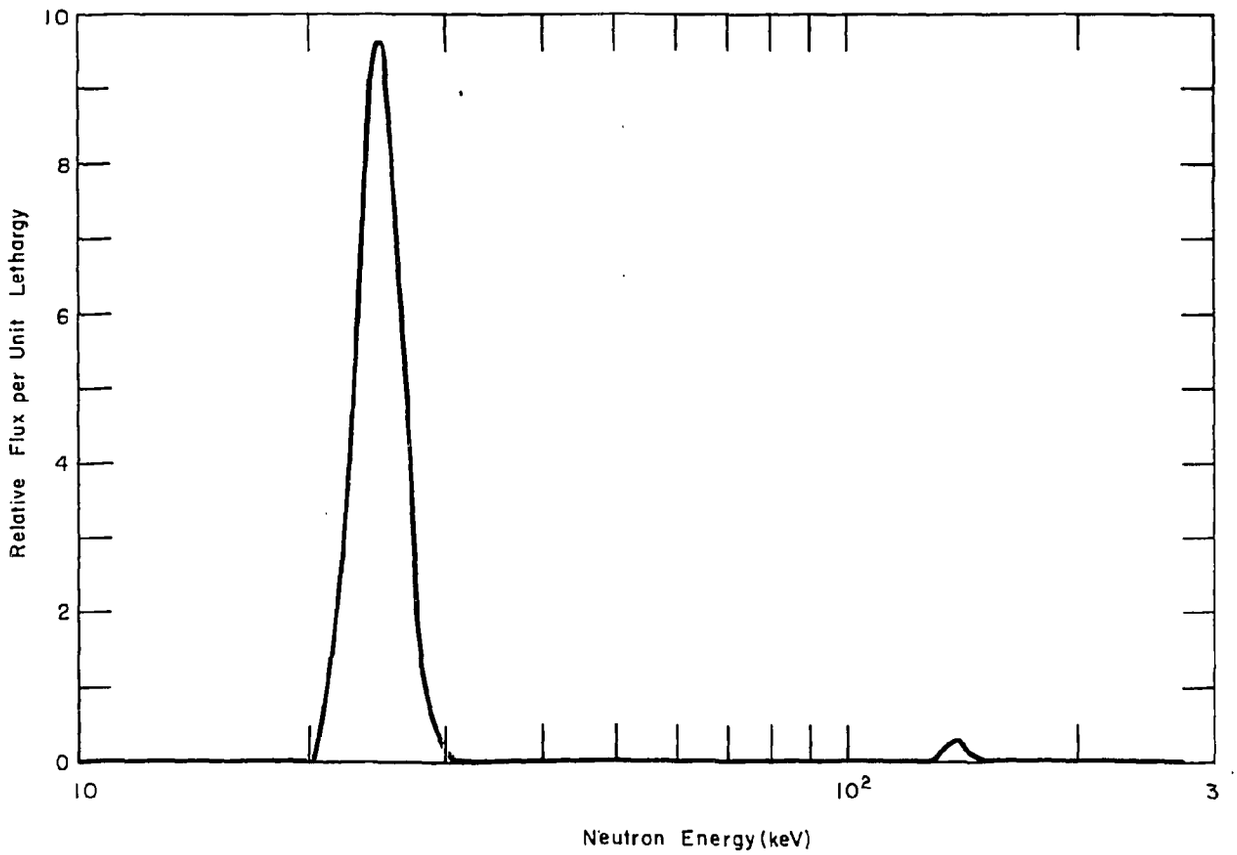

Figure G-1 Neutron flux spectrum in the iron filtered beam.

LAWRENCE RADIATION LABORATORY

A. NEW FACILITIES

1. Progress on the 100 MeV Livermore Electron Accelerator Facility (C. D. Bowman and S. C. Fultz)

Acceptance tests revealed in October 1969 that the accelerator could not meet specifications regarding beam steering owing to a few parts per thousand radial component in the solenoids surrounding three of the accelerating sections. The three defective solenoids have been replaced and the accelerator is now reassembled. Acceptance tests show that the trouble has been eliminated. Barring any new major problems, the tests should be completed by June, 1970.

The installation of the neutron time-of-flight facilities is essentially complete. Targets for neutron production have been installed for both the above and below ground portion of the time-of-flight facility. The targets are designed for 70 kW of electron beam. Magnets for beam delivery to the targets are in position. All flight tubes (from 4 to 250 meters in length) are complete.

The construction of a target and rabbit facility for the production of neutron deficient isotopes is under way. For this purpose, this facility compares very favorably with the most intense presently available 14 MeV neutron generators. The yield of an isotope via linac induced (γ,n) reactions will exceed that available from the Livermore ICT induced $(n,2n)$ reactions by a factor of ~ 500.

B. DETECTOR DEVELOPMENT

1. Detection of Transition Radiation or Visible Bremsstrahlung (L. A. Page* and C. D. Bowman)

Radiation in the visible spectrum is produced when an electron beam enters or leaves a conducting medium.[1] The radiation intensity is roughly one photon per 100 electrons. The radiation is of interest since fast timing might be possible (in the sense that Cerenkov radiation is useful) by avoiding scintillator decay times and, if intensity allows, using a fast photodiode instead of photomultiplier tubes. The radiation, appearing as bluish-white light, has been detected in the intensity expected. The possibility of radiation owing to heating of the foil has definitely been eliminated. However there still is a possibility that the radiation is visible bremsstrahlung from the "skin depth" of the foil, although the effect appears not to be strongly Z dependent. Measurements of angular distribution, etc. are planned which should pin down the source of the radiation.

C. NEUTRON PHYSICS

1. Doorway State in Cr^{53} for γ-Rays (R. J. Baglan and C. D. Bowman)

Threshold photoneutron measurements have been carried out on a Cr^{53} target which allows neutron emission primarily to the ground state of Cr^{52}. The resulting (γ,n) cross section as a function of photon energy can be converted to an (n,γ) cross section simply by reciprocity. The upper portion of Fig. C-1 shows the differential (γ,n) cross section measured at 135° to the photon direction plotted against neutron energy. The lower portion shows the neutron total cross section for Cr^{52} (same compound nucleus for comparison). The resonances in the total cross section are $\ell = o$ and therefore $1/2^+$ states. The cluster of resonances around 90 keV are clearly of a different spin. On the basis of the level spacing of s-wave resonances (which has been measured over a wider energy range than shown here) and the 2J + 1 rule, a level density can be calculated for any spin. If one assumes a spin of 3/2 for the cluster, the probability that such a cluster would occur accidentally is less than 1/1000. Another cluster was found at higher energies. Such effects also have been detected at Livermore in Fe^{57} (γ,n) and in p- or d-wave resonances in Cr^{52} total cross section work

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* Visiting scientist from University of Pittsburgh.

1. F. G. Bass and V. M. Yakouenko, Soviet Physics-USP 8, 420 (1965).

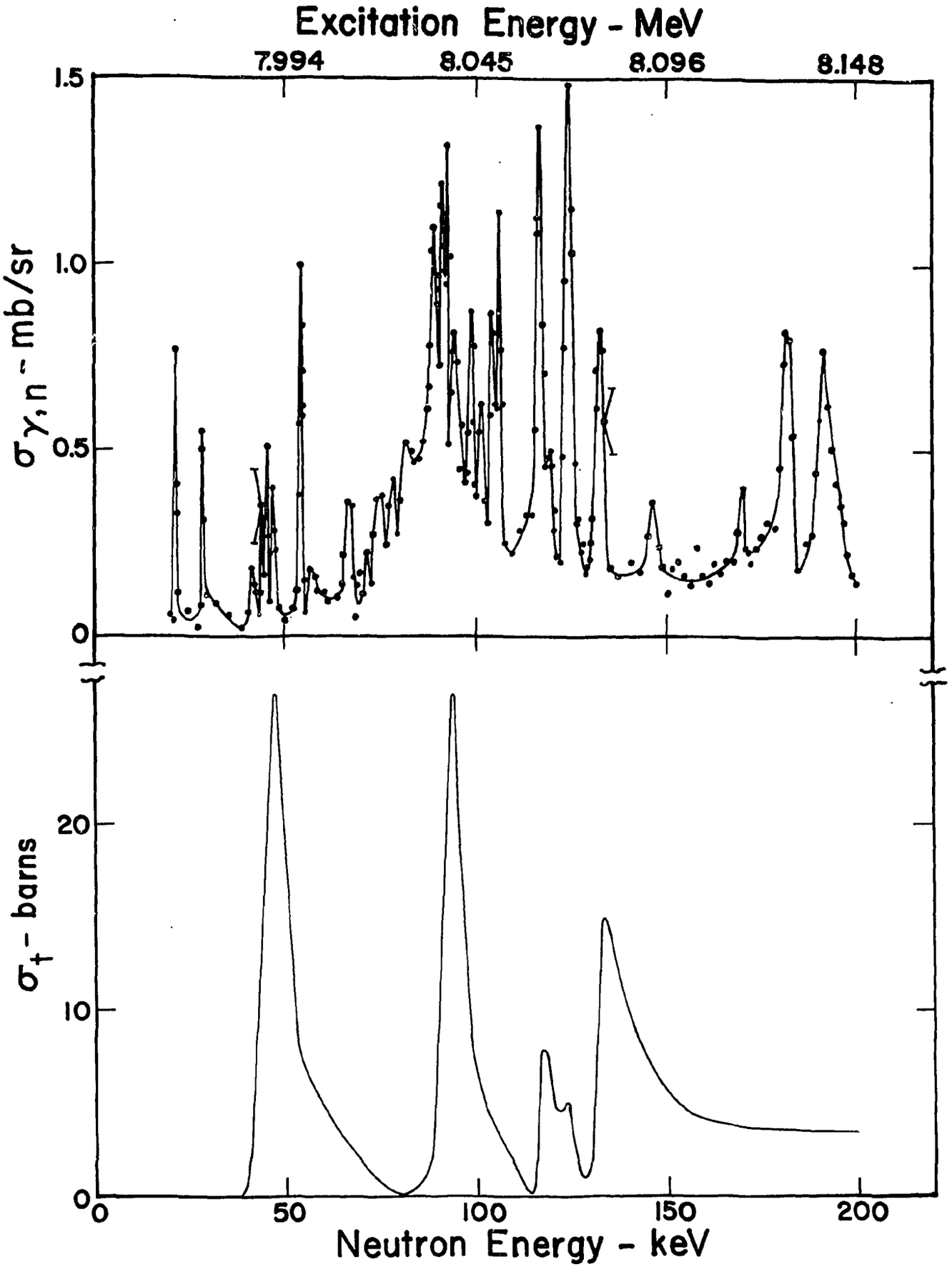

Fig. C-1

DATA NOT FOR QUOTATION

2. Theory For Direct (γ,n) Processes in Pb^{208} (M. S. Weiss)

In collaboration with C. M. Shakin,* several attempts have been made to secure a theoretical understanding of the source of "background" cross section observed in $Pb^{208}(\gamma,n)$ at threshold. By "background" we mean the weakly energy dependent cross section that manifests itself between resonances and by interference with resonances. We have considered only dipole transitions from the Pb^{208} ground state.

The observations consist of an asymmetry in a resonance at neutron energy 41 keV[1], from which a background cross section can be derived and thermal[2] neutron capture on Pb^{207}. So far, we have identified three contributing sources of background $\sigma(\gamma,n)$: a direct process which ejects a bound nucleon into the continum, the tail of photo-nuclear giant resonance (ground state branch) and the tail of the highest lying sub-threshold resonance seen in gamma ray scattering experiments[3].

The theoretical prescription for extrapolating the tails of these two resonances is not simple and is discussed in a forthcoming paper[4]. The giant resonance dominates but the other two mechanisms are also important. We require, in this theory, two quantities which have not been experimentally determined: the relative amount of s-wave neutron emission in the ground state branch of the giant resonance and the neutron width of the sub-threshold resonance. Making reasonable assumptions for these quantities, we can secure 2.5m.b. at neutron energy 41 keV and agreement with the thermal capture rate, 2.5m.b., while on the low side experimentally, is still consistent with the data[4].

The conclusions of this analysis would be altered by the presence of another doorway state. As there is evidence for one in neighboring nuclei at neutron energy ∿500 keV, it would be desireable for experiments on Pb^{208} at this energy. Also, more precise measurements of the background cross section below 100 keV would permit a more definitive test of the theory.

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* Physics Department, MIT, Cambridge, Massachusetts

1. C.D. Bowman, R.J.Baglan, B.L. Berman, Phys. Rev. Lett. 23 796 (1969).
2. H. Pomerantz, Phys. Rev. 88 412 (1952).
3. P. Axel, K. Min, N. Stein, and D.C. Sutton, Phys. Rev. Letter 10 299 (1963).
4. C.M. Shakin and M.S. Weiss (in preparation).

3. ^{165}Ho, ^{151}Eu and Natural Europium Capture Cross-Section Measurements (J. B. Czirr)

The neutron capture cross sections of ^{165}Ho, ^{151}Eu and natural Eu have been measured in the 200-eV to 12-keV energy range. Data were obtained in approximately 150 energy bins over this range. The Livermore 33-MeV linear accelerator was used as a pulsed source of neutrons at a repetition rate of 360 pps. The neutrons were generated by bremsstrahlung photons striking a natural uranium target, and then were moderated into a 1/E spectrum by a moderator located next to the source. Neutron velocities were measured by time-of-flight, with a resolution of 15 nsec/m.

The capture samples were viewed by a deuterated-benzene-based 1-liter liquid scintillator detector. This scintillator was used to reduce the background resulting from the capture of foil-scattered neutrons in the detector. The detected capture-γ events were pulse-height weighted on-line to provide data which are essentially independent of variations in the de-excitation spectrum. The electron-energy bias of the detector was set at approximately 0.1 MeV, a value low enough to accept almost all of the expected prompt-γ spectrum.

Table C-1. Experimental conditions.

	^{165}Ho (foil)	$^{151}Eu_2O_3$ (powder)	Eu(natural) (foil)
Sample Thickness[a] (atoms/cm^2)	1.238×10^{21}	1.261×10^{21}	1.254×10^{21}
Running time (hr)	15	7.5	8.3
Counts/0.5-μsec channel at 10 keV	18,000	25,000	28,000
^{153}Eu:^{151}Eu atomic ratio	-	0.0327	1.093

(a) The samples were placed at 45 deg to the beam direction so these numbers should be multiplied by $\sqrt{2}$ to obtain the effective thickness.

Table C-1 lists the capture-sample characteristics, together with other pertinent data.

The absolute efficiency of the detector system was measured at the energy of a "black" resonance to normalize the relative cross sections measured at higher energies. The resonance at 3.92 eV was used for this purpose in the case of Ho, and the ^{151}Eu resonance at 7.44 eV was used for Eu. The natural Eu foil data were also normalized by comparison of the detection rate with that of the Ho foil in identical geometry. This latter method (after correction for differences in energy release) yielded a 10% higher cross section than the black resonance technique applied directly to the Eu data. The results tabulated in this report represent the average of these two methods.

Figure C-2 shows the values of $\sigma_c(E)$ when grouped into 0.5-μsec time-of-flight bins. The sample thicknesses are such that a 100-b cross section results in an 8.5% self-shielding correction for all samples. This correction, which is small over most of the energy range, has not been made to the data. With the exception of this correction, the data yield the proper averaged capture cross sections at all listed energies, in spite of the limited resolution employed.

The capture resonance integrals, defined as $RI = \int_{E_{min}}^{E_{max}} \sigma_c(E) \frac{dE}{E}$, are as follows for E_{max} = 10 keV and E_{min} = 200 eV: ^{165}Ho—48.4 b; ^{151}Eu 149 b; Eu(natural)—131 b.

The statistical uncertainties of the data are less than ±1% throughout. For the Ho data, the normalization uncertainty is approximately ±2%. Because of the 10% discrepancy between the two normalization methods for the Eu data, this uncertainty is increased to ±5% in these cases. Imperfect knowledge of the background levels and neutron spectra lead to a total estimated uncertainty of ±5% for ^{165}Ho and ±7% for Eu and ^{151}Eu. These estimates also apply to the errors on the quoted resonance integrals.

A listing of the data and a more complete description of the experiment are found in UCRL-50804.

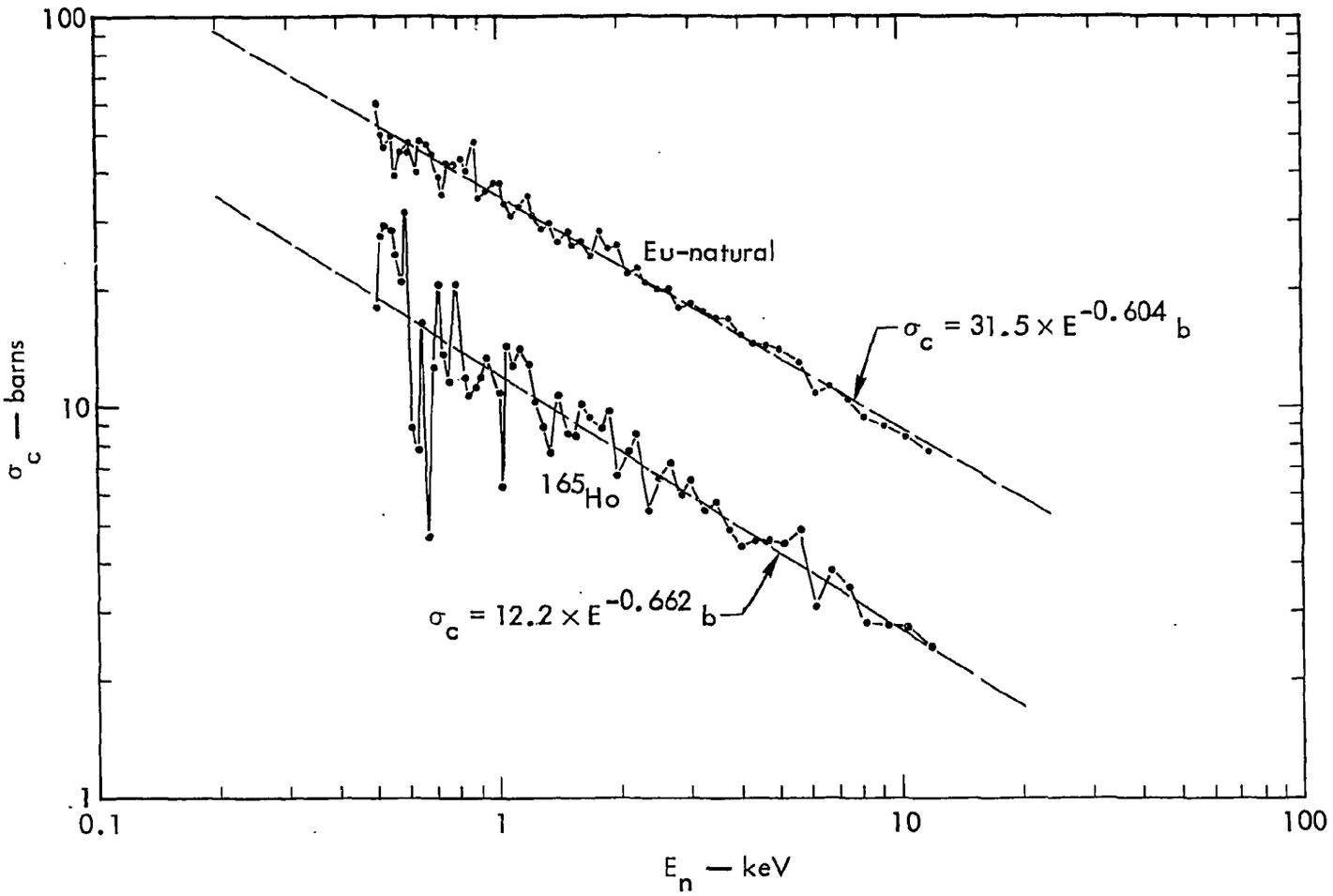

Fig. C- 2 Capture cross section of ^{165}Ho and natural Eu versus neutron energy. The dashed curves represent an estimated average slope over this energy range.

4. ^{235}U α Measurements from 50 eV to 28 keV (J. B. Czirr)

Measurements of α for ^{235}U have been carried out in the 50 eV to 28 keV range. The technique is the same as that used for the ^{239}Pu measurements described in WASH-1136. The results of the measurement are listed below.

E_{max}	E_{min}	$\langle\sigma_c\rangle/\langle\sigma_F\rangle$
28.0 keV	23.1 keV	0.43
10.9	7.3	0.37
7.3	4.3	0.30
4.3	2.6	0.28
2.6	1.6	0.33
1.6	0.96	0.37
0.96	0.59	0.39
0.59	0.36	0.30
0.36	0.21	0.37
0.21	0.13	0.54
0.13	0.079	0.56
0.079	0.048	0.42
10.2	0.10	0.40

The statistical plus systematic errors are approximately ± 6% for the above energy bins.

5. Thermal Neutron Cross-Sections of the Calcium Isotopes (F. P. Cranston, D. H. White and R. E. Birkett

The thermal neutron cross sections of all the stable calcium isotopes have been determined by direct measurements using a modified Moxon-Rae type detector, and by detailed analysis of the neutron-capture gamma-ray spectra, of several mixed isotope samples.

The Moxon-Rae detector was calibrated against several materials (Al, Ag, Au) of known cross-section, covering a wide dynamic range. Measurements were then taken with several thin $CaCO_3$ samples, of known

enrichments in the isotopes 42, 43, 44, as well as natural composition. Results are shown in Table C-2. Our results for σ(Ca-42) are in good agreement with a previously determined value (0.61 ± 0.12 b) taken by comparing with decay γ-rays in V-51. However, the value listed in BNL-325 is in gross disagreement.

Additional information was obtained through a detailed analysis of the neutron-capture gamma-ray spectra[2] of several calcium isotope samples of various known composition. Knowledge of the energy levels, decay schemes, and the β-decay in the case of Ca-49, has permitted additional cross section values to be deduced. See Table C-2.

These results are consistent with the Moxon-Rae results as well as with the accepted value for natural calcium. However, the value for Ca-42 (and therefore also for Ca-40) listed in BNL-325 appear to be in error.

Table C-2

Summary of Calcium Cross Sections

		σ(barns)		
Isotope	Natural Abundance %	From BNL-325	Moxon-Rae Detector	Decay Scheme (Assuming σ_{44} = 1.1)
Natural		0.44 ± 0.02	0.41 ± 0.08	
^{40}Ca	97.01	0.22 ± 0.04		0.41 ± 0.11
^{42}Ca	.67	42 ± 3	0.70 ± 0.16	
^{43}Ca	.15		6.2 ± 1.1	6.2 ± 1.7
^{44}Ca	2.01	0.67 ± 0.07	1.1 ± 0.2	
^{46}Ca	.003	0.25 ± 0.10		0.70 ± 0.19
^{48}Ca	.16	1.1 ± 0.1		1.1 ± 0.3

1. F. P. Cranston, P. B. Snow and D. H. White, Bull. Am. Phys. Soc. 11 909 (1966).
2. D. H. White and R. E. Birkett, UCRL 71676 (unpublished).
3. F. P. Cranston, R. E. Birkett, D. H. White, and J. A. Hughes, UCRL-72237 (to be published).

6. Calculation of (n,γ) Cross Sections (D. G. Gardner and C. Gatrousis)

In the Newton-Lang level density formalism the sum of the single particle level densities is calculated from the mean spin values of the neutrons and protons, j_n and j_p. The spin values proposed by Newton in 1956 often disagree with values extracted from the currently available experimentally determined level densities. Because of this disagreement we have extracted a new set of spin values. Using our spins we have computed the level density parameter and nuclear level densities. Figure C-3 compares our calculated values with experimentally observed level spacings. We have calculated (n,γ) excitation functions for a number of nuclei using our calculated values for radiation widths and level densities, and the general optical model parameters of Moldauer. Some typical results are shown in Figures C-4 and C-5.

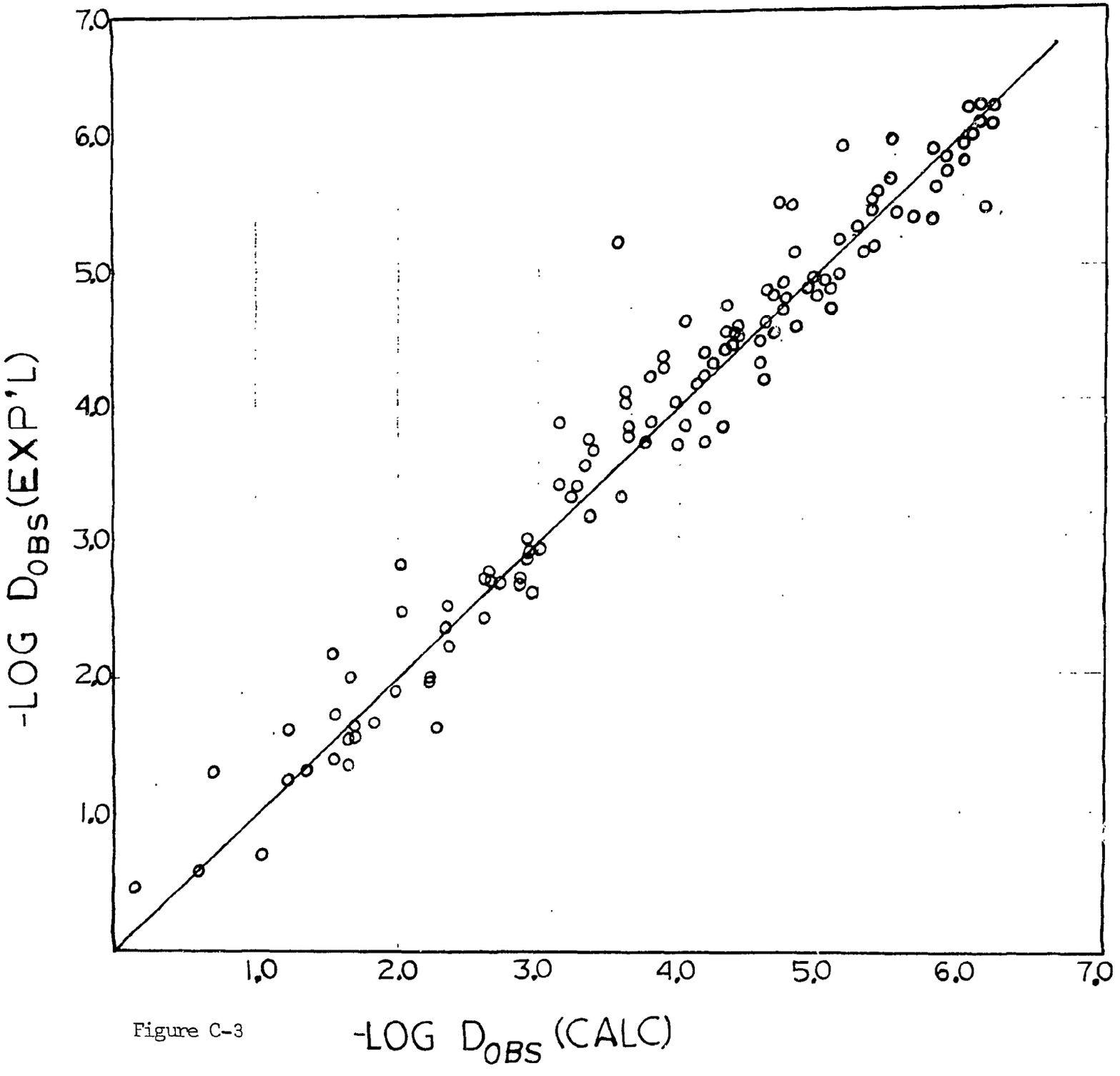

Figure C-3

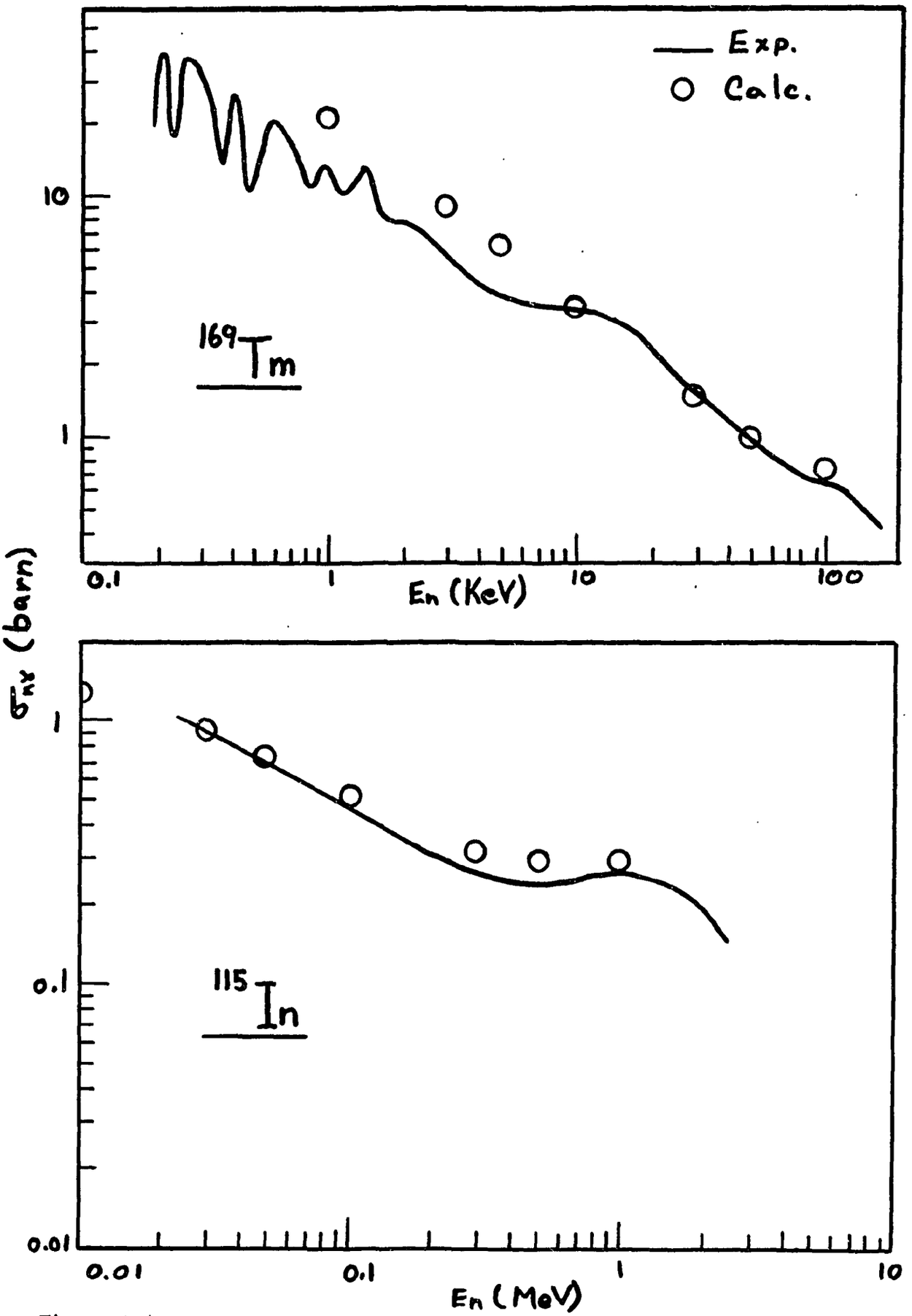

Figure C-4

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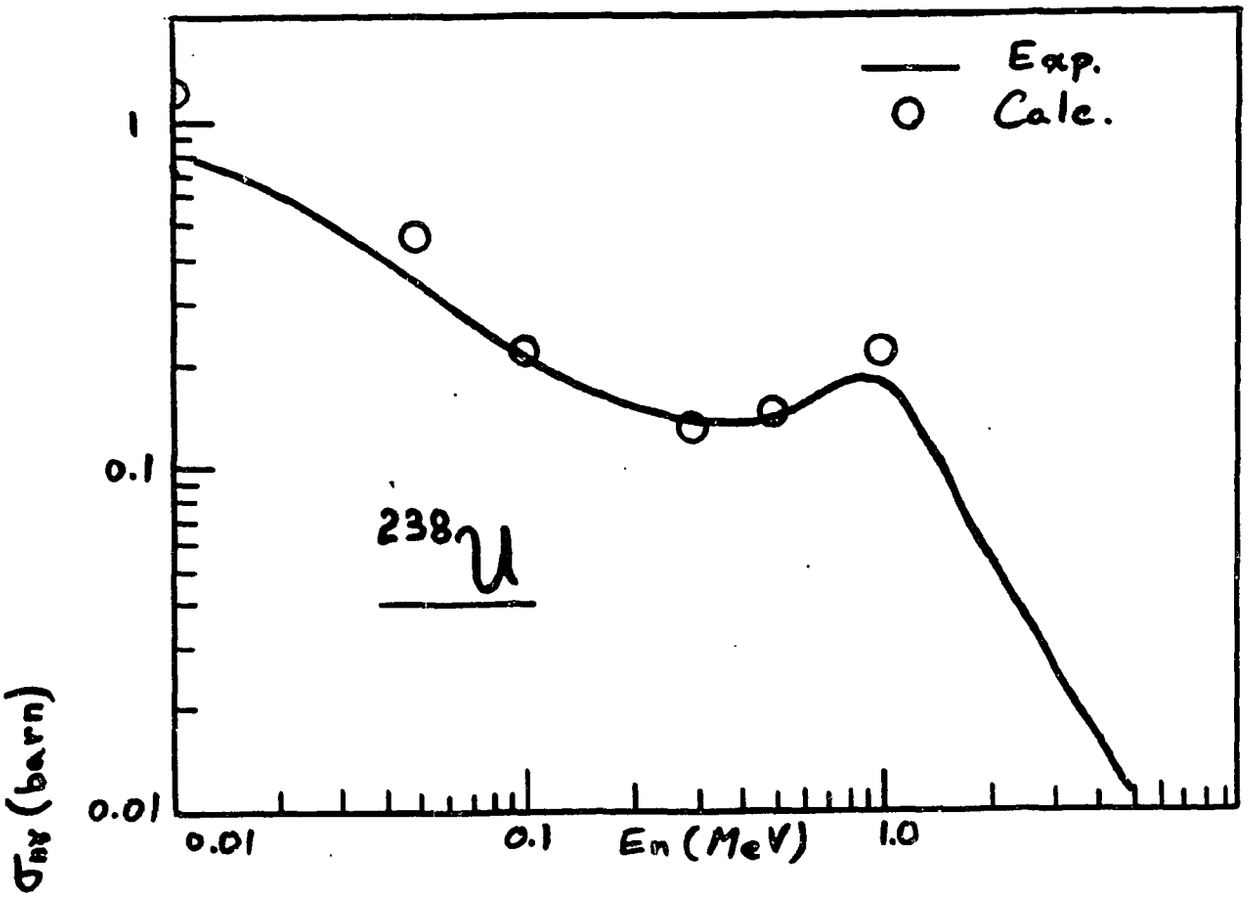

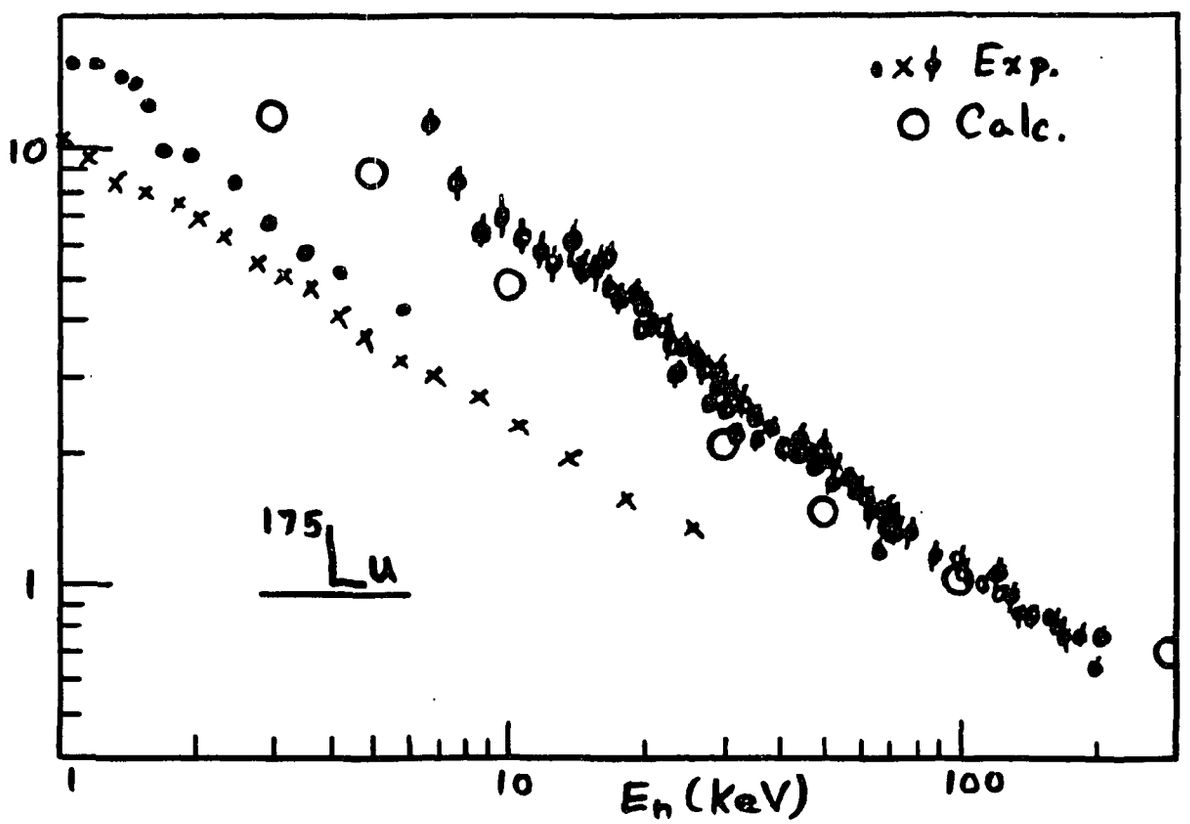

Figure C-5

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7. Evaluation of Effective Interactions (S. D. Bloom)

Work is in progress and nearing completion on evaluation of effective interactions based on (p,n) and (p,p') reactions as well as gamma spectroscopy which bears on the prediction of neutron production cross sections in connection with analog reactions and reactions to analog related states. The practical applications have to do not only with neutron production, but also with gamma production. In this work we have acquired and are using the shell model code developed by McGrory and collaborators at Oak Ridge.

D. FISSION PHYSICS

1. An Attempt to Assign Resonance Spins of U^{235} (C. D. Bowman, G. D. Sauter* and B. L. Berman)

A preliminary report in WASH-1127 described our attempts to assign resonance spins of U235 by measuring the ratio of double to triple γ-ray coincidences following neutron capture. A more detailed analysis of this work corroborated by a second measurement has forced us to withdraw our earlier set of suggested spins. An attempt was made to obtain an improved set from the results shown in Figure D-1. The revised analysis was based on a comparison of the efficiency for detecting a resonance by a double coincidence of neutron capture gamma rays. The % deviation from the average efficiency is shown as the ordinate. The upper and lower flags on the points show the results of the two separate measurements for each resonance and the circles represent the average.

There is clearly no strong tendency for the points to cluster into distinct groups. We conclude that the experiment has failed; the data of Figure D-1 simply show no strong tendency to cluster into two distinct groups. One might therefore suggest that in U^{235} there is no correlation between resonance spin and neutron capture gamma ray multiplicity. In examining the Saclay and Geel measurements, we find that the point scatter within a spin group can be correlated with α and suggest that incomplete elimination of fission gamma rays might be responsible for the observed grouping in those experiments. We feel that future efforts along these lines should be abandoned in favor of the methods which determine the spin directly.

* Applied Science Dept., University of California at Davis.

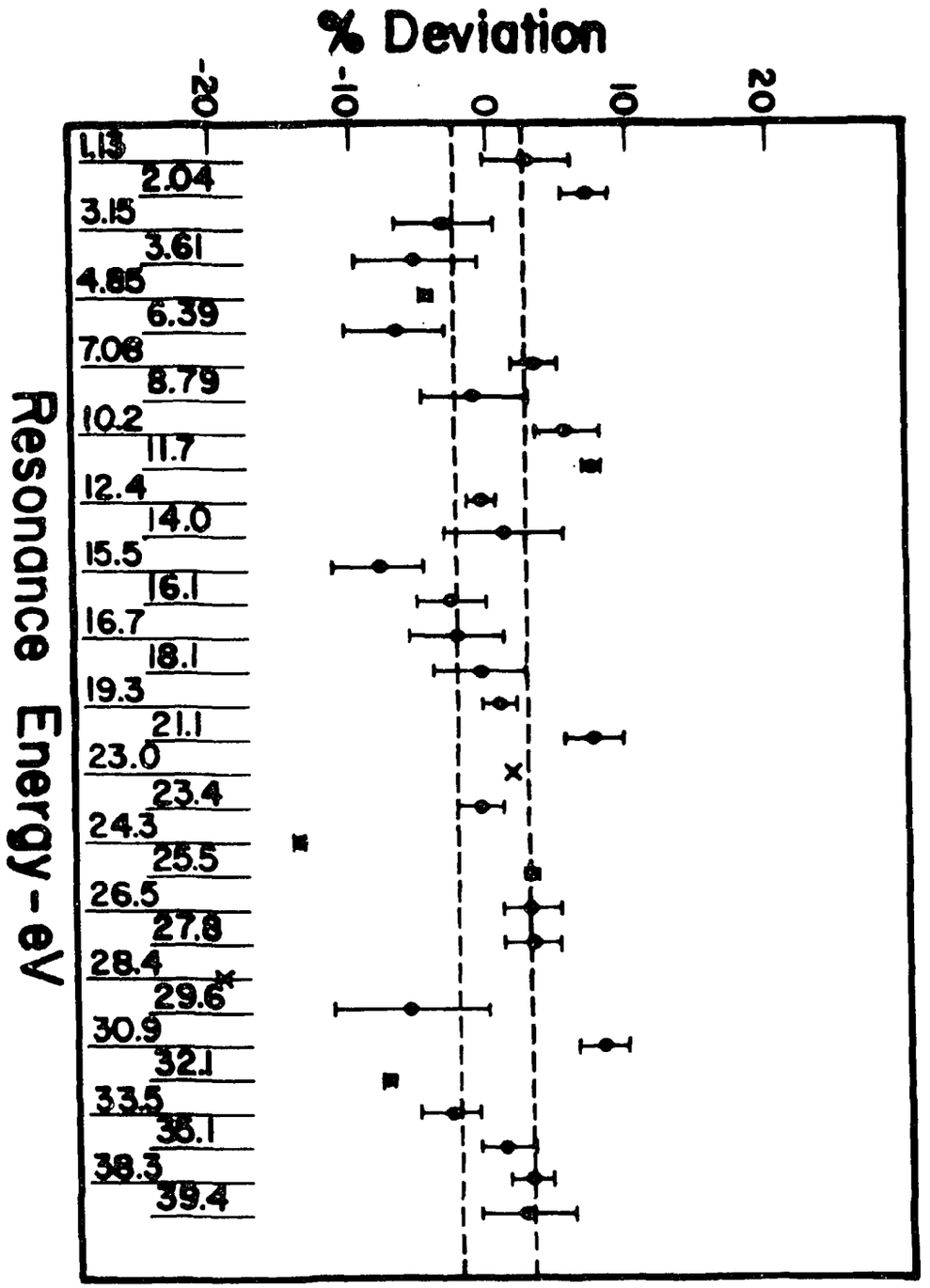

Figure D-1

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2. keV Fission Cross Section of U^{235} (C. D. Bowman, M. L. Stelts and R. J. Baglan)

An abstract has been submitted to the Helsinki meeting on recent "high resolution" measurements carried out at the Livermore 30 MeV electron linac. The data is shown in Figures D-2, D-3, and D-4. The abstract is given below.

The importance of the keV fission cross section of U^{235} to reactor design and its increasing use as a standard for measurements in the keV and MeV region have brought about high priority requests for cross sections with an accuracy of 1% throughout the keV and MeV range. Earlier attempts at standard measurements have been carried out at a relatively few points using monoenergetic neutron sources. The possibility of fine structure in the U^{235} fission cross section in the keV region clearly could introduce point scatter into such experiments, and also influence the usefulness of U^{235} as a standard. In fact the concept of a double-humped fission barrier implies the existence of such structure at much higher energies than was expected previously.

An experiment was undertaken to measure the U^{235} fission cross section with both high resolution and good statistics to search for such structure. No attempt was made to compete with earlier experiments in terms of accuracy in absolute cross section. A time-of-flight measurement was carried out at the Livermore 30 MeV electron linac using a 20 meter flight path. The detector was of a unique design which allowed detection of fission with high efficiency via detection of triple coincidence between prompt fission gamma rays. The U^{235} sample was a disk 0.125 cm thick and 25 cm in diameter, weighing about 1300 grams. The large mass allowed good statistics to be obtained easily. The time uncertainty of 13 nsec was determined by the 8 nsec beam burst and the 10 nsec resolution of the detector. The resolution was 0.7 nsec/meter, about a factor of three better than previous measurements. The measurements extended from 2. to 400. keV. Peak-to-valley fluctuations of 20% were observed between 10 and 30 keV and 10% between 30 and 150 keV.

In spite of the considerable structure, a closer examination shows that the resolution in the earlier measurements was wide enough to average out fine structure such that the errors from fine structure effects in those measurements is less than 3%.

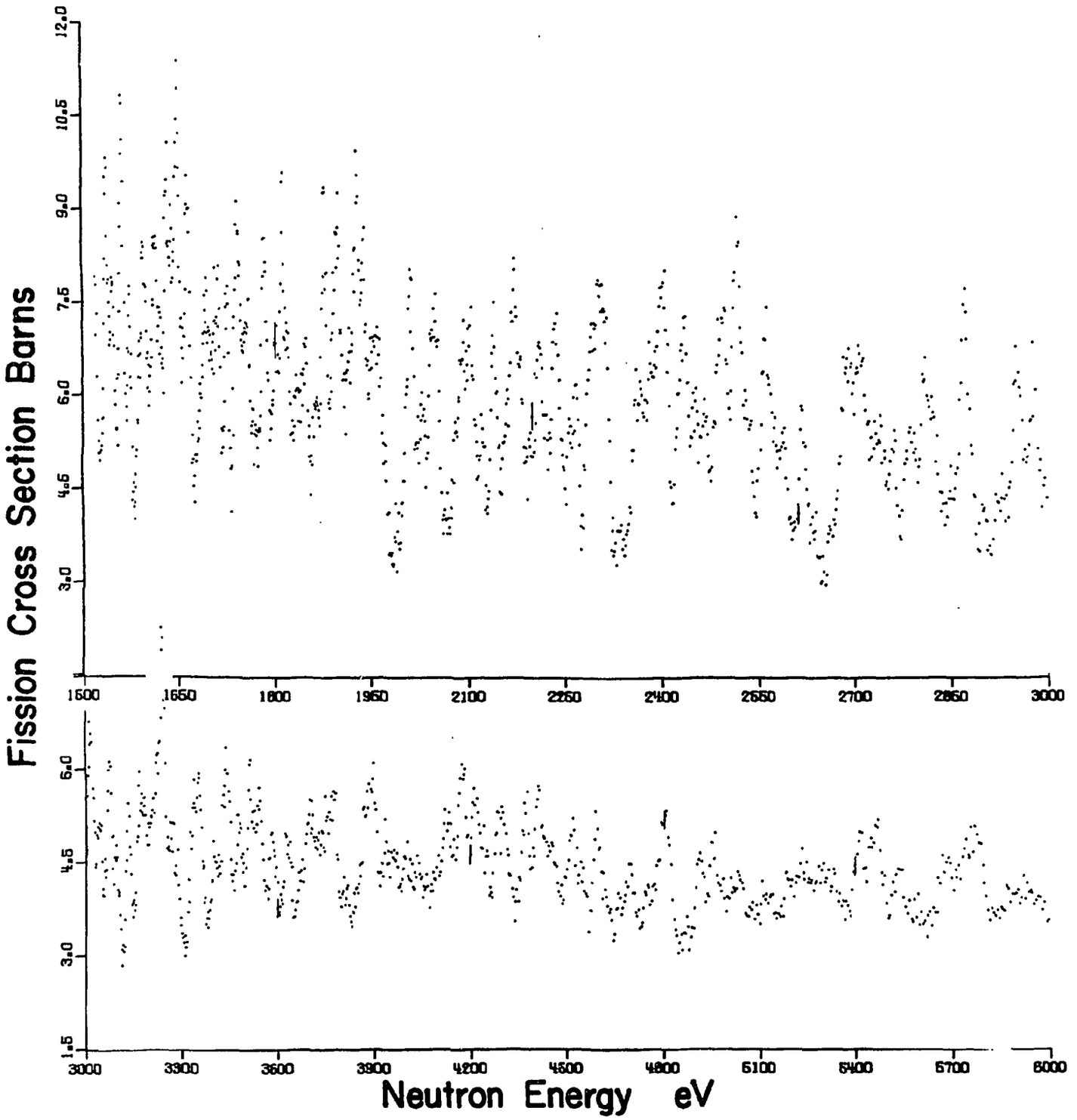

Figure D-2

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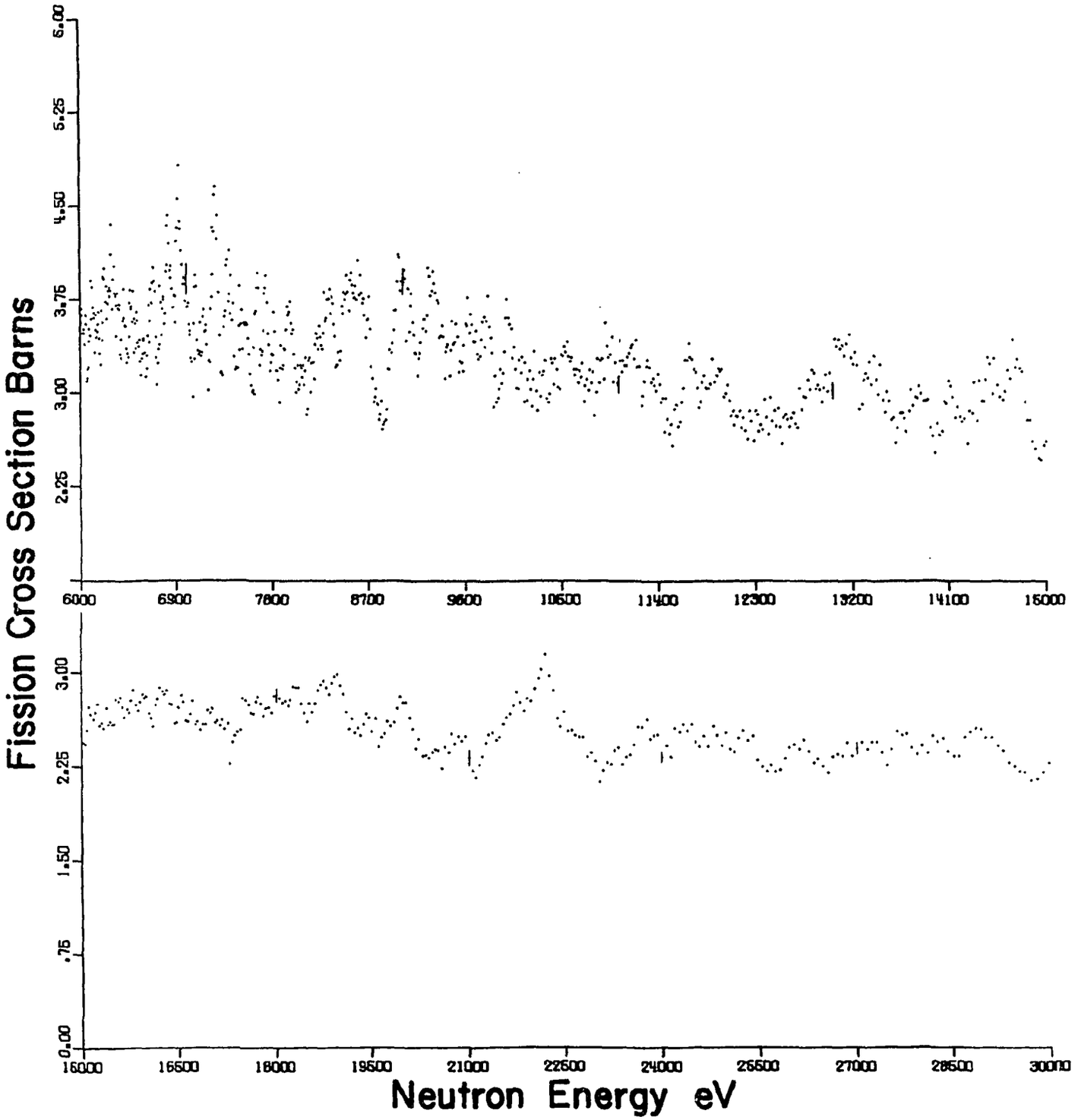

Figure D-3

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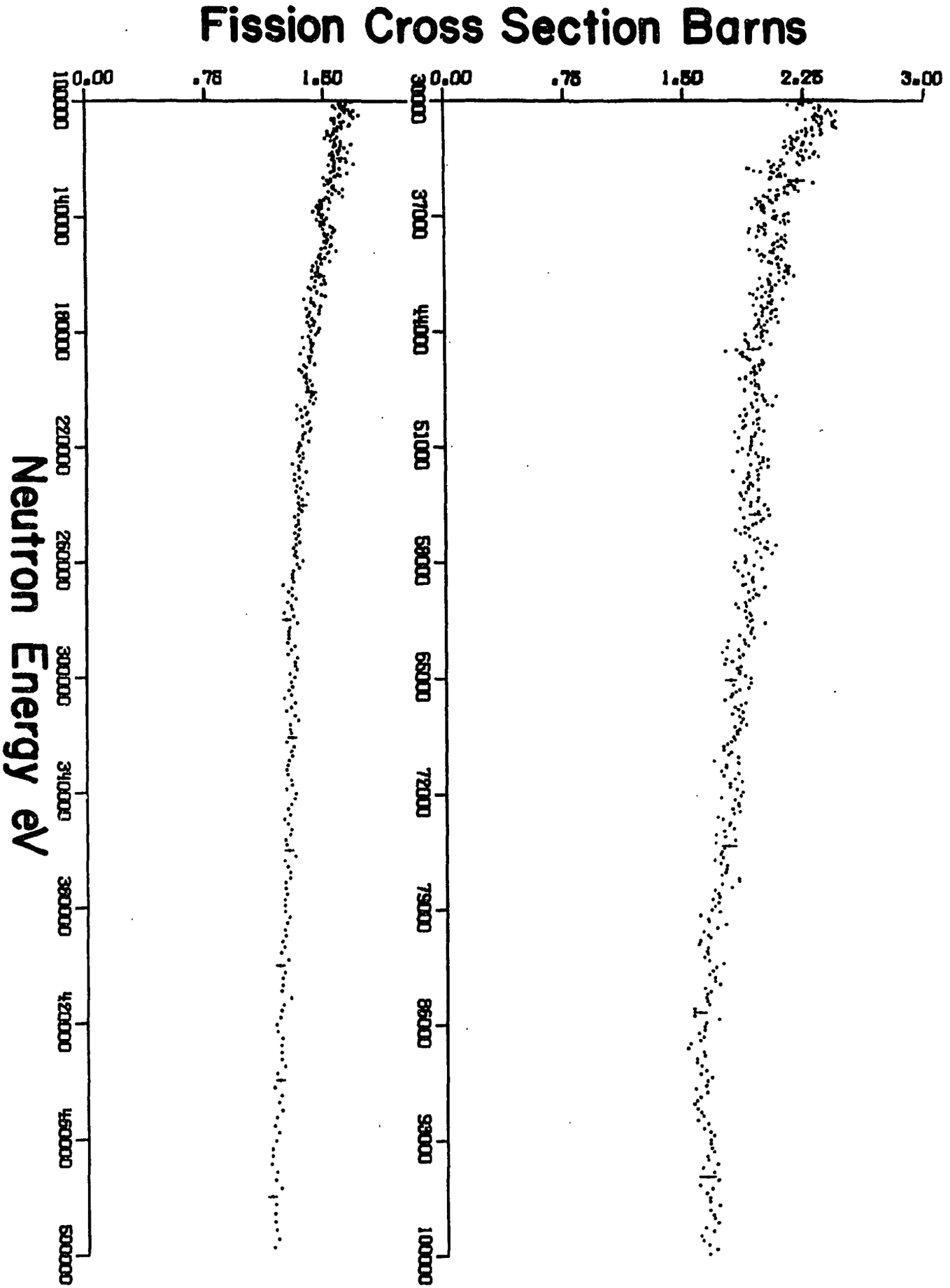
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2.25
3.00
Neutron Energy eV
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Figure D-4

LOCKHEED PALO ALTO RESEARCH LABORATORY

A. NEUTRON PHYSICS

1. The $^{197}Au(n,\gamma)^{198}Au$ Activation Cross Section (H. A. Grench and F. J. Vaughn)

The promise of the $^{197}Au(n,\gamma)^{198}Au$ cross section as a potential secondary fast-neutron-flux standard has prompted continuing experimental activity and has elicited many review papers on the subject at reactor- and neutron-physics conferences.

Measurements of this cross section using two different experimental techniques[1,2] have been performed at the Lockheed Palo Alto Research Laboratory. The first[1] used a rather unique application of the so-called associated-activity method to measure the neutron flux. Accurate flux measurements have traditionally been the most difficult part of $^{197}Au(n,\gamma)^{198}Au$ and many other kinds of neutron-cross-section experiments. In this first method, the neutrons were produced by means of the $^{51}V(p,n)^{51}Cr$ reaction using a thin V target. A gold spherical shell was placed so that the neutrons were produced at its center. The reaction rate was measured by counting the 412-keV γ rays of ^{198}Au(2.7d), while the neutron flux was determined by counting the associated ^{51}Cr activity (27.7d), produced in the target. The ^{51}Cr activity is characterized by the emission of a 320-keV γ ray. Thus, this technique resulted in an absolute measurement of the Au cross section in the sense that it did not rely upon a normalization to another cross section.

The second experimental method used at Lockheed[2] for obtaining $^{197}Au(n,\gamma)^{198}Au$ cross sections was based on relative measurements. During an investigation of the $^{89}Y(n,\gamma)^{90}Y$ fast-neutron cross section, the neutron flux was determined using an ionization chamber which responded to fissions occurring in a thin deposit of ^{235}U. Therefore, the results obtained were relative to the $^{235}U(n,f)$ fast-neutron cross section. The $^{197}Au(n,\gamma)^{198}Au$ cross section was employed as a secondary standard in that experiment by simultaneously activating Au foils. Thus, a planned secondary result of the Y measurements was a number of values of the Au cross section relative to the fission cross section. The $^{197}Au(n,\gamma)^{198}Au$ cross sections obtained from these two sets of measurements differed by an average of about 20%, an amount greater than the sum of the assigned uncertainties.

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[1] Harris, Grench, Johnson, Vaughn, Ferziger, and Sher, Nucl. Phys. 69, 37(1965).

[2] Reports to the AEC Nuclear Cross Sections Advisory Group, WASH-1068.

The subsequent work at Lockheed has consisted of four major parts. The first part was a re-evaluation of the two sets of experiments performed in this laboratory, trying to consider all those facets of the experiments which might be in error. The second part consisted of performing selected new experiments[3] to try to resolve the discrepancies. The third part was a re-analysis and renormalization of the work of Harris et al.,[1] incorporating new information and using analysis techniques developed since that work was done. Finally, all published information concerning the $^{197}Au(n,\gamma)^{198}Au$ cross section for fast neutrons is being analyzed and combined in order to obtain a "best" curve of the cross section versus energy between about 10 keV and 5.5 MeV.

As mentioned above, a re-evaluation of the two sets of results obtained at Lockheed for the neutron capture cross section of gold has been carried out. The results obtained in this laboratory for the $^{197}Au(n,\gamma)^{198}Au$ cross section relative to the $^{235}U(n,f)$ cross section were in very good agreement with similar results from other laboratories. Therefore, it seemed that errors associated with operation of the fission counter, Au counting, scattering corrections, etc. were relatively unimportant, and that the only possible significant source of error in the Au cross section must be attributed to errors in the $^{235}U(n,f)$ cross section. Since work was going on elsewhere on remeasurement of the $^{235}U(n,f)$ cross section, it was decided to re-examine the Lockheed experiments of Harris et al. These experiments had also undergone careful scrutiny at Lockheed; in fact, they had been completely re-analyzed starting from the raw data after a report was written on the subject but prior to publication. However, since the ^{51}Cr associated-activity technique had not been used elsewhere and since $^{51}V(p,n)^{51}Cr$ had rarely been used as a neutron-source reaction previously, it was decided to make some new cross-section measurements, using the basic technique of Harris et al. but incorporating several improvements. It should be emphasized that, in principle, this technique is very accurate; the measurements had an average quoted absolute uncertainty of $\pm$ 4.7% from all known sources of error. Therefore, the various uncertainties in the new measurement had to be held to $\lesssim$ 1% each in order to obtain an overall error comparable to that of Harris et al. and commensurate with what was believed to be the inherent precision of the technique. A great deal of effort was expended on refining some of the experimental and analytical techniques. However, attempts to measure the cross section at 30.8 and 573.2 keV were beset with experimental difficulties which will not be described in detail here. Nevertheless, the results at these energies are not inconsistent with those of Harris et al.

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[3] Reports to the AEC Nuclear Cross Sections Advisory Committee, WASH-1124.

The third part of our effort was an updating of the results of Harris et al. They were first renormalized in accordance with recent information[4] on the ^{198}Au and, particularly, the ^{51}Cr decay schemes. The recently adopted values are 0.9553 ± 0.0005 412-keV γ rays per decay of ^{198}Au and 0.099 ± 0.001 320-keV γ rays per decay of ^{51}Cr. This newer information leads to a factor of 1.024 by which the results should be multiplied. Harris et al. also performed a measurement at one energy using the $^{65}Cu(p,n)^{65}Zn$ reaction as a neutron source. Newer decay-scheme information[5] for the ^{65}Zn decay, and the small change in the ^{198}Au branching ratio leads to a multiplying factor of 1.037.

Our re-evaluation of the crystal-efficiency data which Harris et al. used did not lead to any change in the ratio of efficiencies for 0.320- to 0.412-keV γ rays but did give an uncertainty of ± 2% rather than the ± 0.5% assigned earlier. In the case of the ^{65}Zn point, the crystal-efficiency ratio did change; the resulting correction factor is 0.982 with a ± 2% uncertainty. Thus, the ^{65}Zn value of Harris et al. must be multiplied by 1.018 to give an updated value.

The average neutron energies were also recalculated in accordance with new information. The V target thicknesses for the points of Harris et al. were obtained by weighing V-Pt targets before and after the V layer was evaporated on the platinum and from a measurement of the area of the V deposit. The Pt-backing holders for evaporation had holes in them to define the evaporated area. Early in the course of that work, these holders were remachined but in a way which was not intended to change the evaporated area. The original hole size was therefore used in calculating target thicknesses. We have remeasured these holes and have found that the areas were increased by ~ 20% in machining. The targets were accordingly ~ 20% thinner than originally calculated, an effect which, when taken into account, tends to increase the average neutron energy slightly. Our recent experiences with target weighing indicate also that the uncertainty in target thickness was underestimated by Harris et al.

There is also information on the $^{51}V(p,n)^{51}Cr$ total yield[6] as a function of proton energy more recent than that used in analyzing the data of Harris et al. This information has been used in place of the 0-deg yield information which was previously employed in the calculations of the average neutron energies. A new computer code was very useful in determining the effects of uncertainties in yield curves, target thickness, proton energy, etc. on the average neutron energy. The relative uncertainties in average neutron energy from point to point using the $^{51}V(p,n)^{51}Cr$

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[4] M. J. Martin and P. H. Blichert-Toft, Radioactive Atoms (to be published).

[5] Nuclear Data 2, Sec. B, B2-6-16 (1968).

[6] J. H. Gibbons and R. L. Macklin, Nucl. Instr.and Meth. 37, 330(1965).

neutron source ranged from ± 1.4 to ± 1.9 keV and the absolute uncertainties were between ± 1.7 and ± 2.1 keV. The neutron energy for the point measured using the $^{65}Cu(p,n)^{65}Zn$ reaction had ± 1.6-keV error relative to the ^{51}V points but only ± 1.3-keV absolute error. These energy uncertainties were translated into cross-section uncertainties using the slope of a smooth curve drawn through the points. Table A-1 gives the renormalized results and updates Table 1 in the paper of Harris et al. The changes from both cross-section renormalization and neutron-energy recalculation tend to make the new curve higher than the older one. Figure A-1 shows the two sets of Lockheed results. It is seen that the results of the two sets of measurements differ in magnitude by an average of about 12% and may also exhibit minor differences in shape. Between approximately 220 and 430 keV the agreement between the two sets seems best.

Table A-1. Cross sections for the $^{197}Au(n,\gamma)^{198}Au$ reaction; updating Table 1 of the work of Harris et al.

E_n (keV)	ΔE_n (keV)	σ (mb)	$\delta\sigma_{rel}$ (mb)	$\delta\sigma_{abs}$ (mb)
13.1	9.7	1252	134	161
23.2	12.9	761	56	64
36.0	14.9	623	42	46
41.6	13.9	548	26	26[a]
53.5	16.3	440	18	22
69.7	20.4	384	13	17
89.4	24.1	359	10	14
129.3	29.8	290.8	7.2	11
168.8	35.4	278.7	9.7	12
232.3	34.8	267.2	9.0	12
284.2	42.1	222.3	5.8	8.4
372.1	50.1	181.5	5.3	7.2
508.6	60.5	130.0	3.1	4.7
555.2	61.2	115.5	3.6	4.8
691.2	67.9	92.8	2.0	3.2

[a] Measured using the $^{65}Cu(p,n)^{65}Zn$ source reaction.

The fourth part of the Lockheed work on this cross section, which is the compilation of all available data in order to obtain a "best" curve, is in progress.

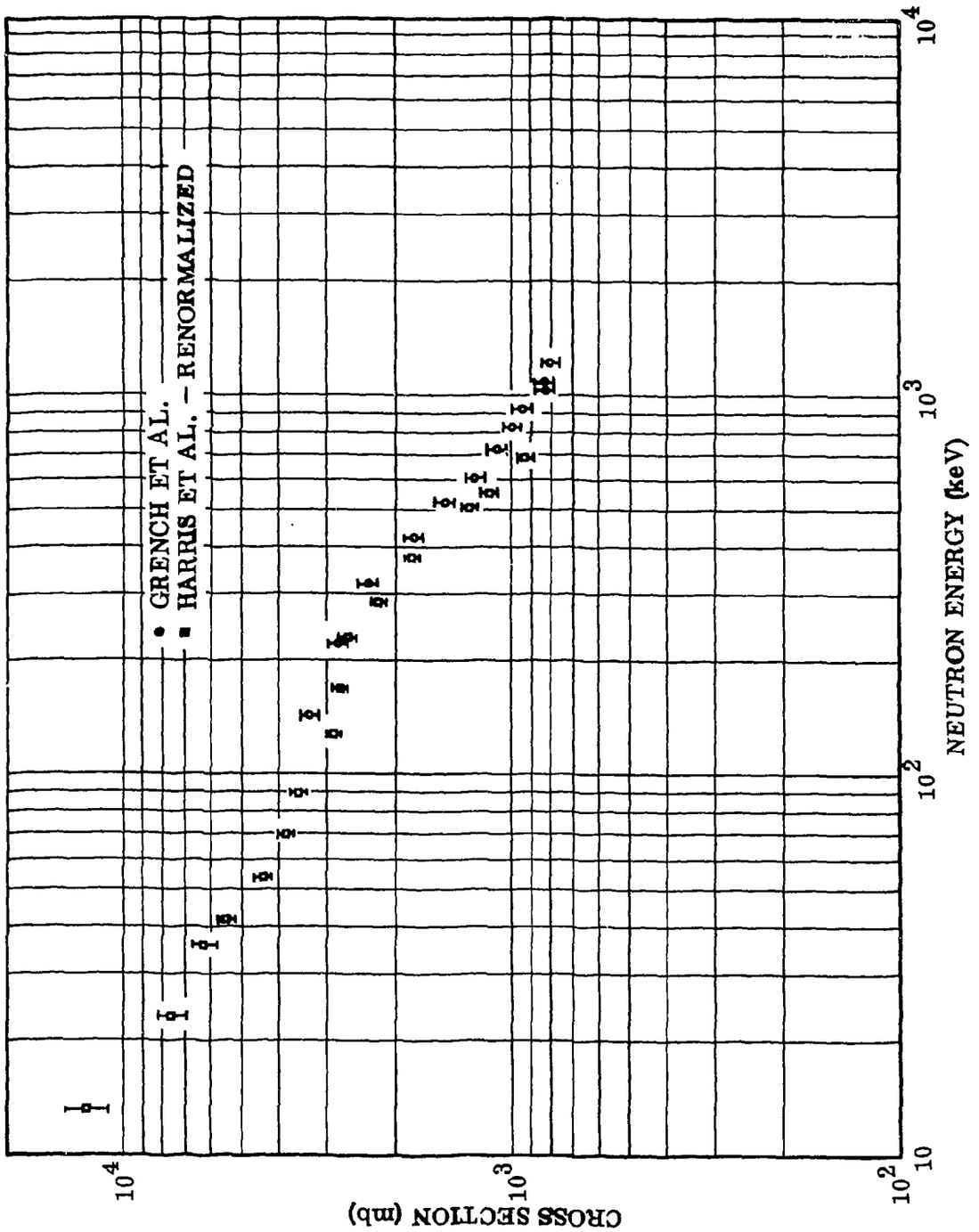

Fig. A-1. The $^{197}Au(n,\gamma)^{198}Au$ Cross-Section Results of Lockheed.

2. Gross-Fission-Product Gamma-Ray Spectroscopy (W. L. Imhof, L. F. Chase, Jr., R. A. Chalmers, and F. J. Vaughn)

High-resolution γ-ray spectroscopy of fission products has been performed using highly enriched ^{235}U and ^{238}U targets with fission produced by both 5- and 15-MeV neutrons. Irradiations of 5 min, 40 min, and 5 hours have been made for both target materials, with counting intervals ranging from 30-sec long after 2-min cooling to 4-hour counts as much as a week later. Enriched ^{239}Pu targets have been obtained and will be similarly irradiated and counted. A set of irradiations is also planned for the ^{235}U and ^{239}Pu targets using 0.5-MeV neutrons.

New computer programs are being developed to aid in the comparisons of the yield of individual γ rays as a function of neutron energy and isotope. Lines numbering upwards of a hundred or more are automatically measured in each spectrum; their half-lives, and in some cases their parent's half-lives, are obtained; and the relative amounts produced in the runs being compared are calculated.

Figure A-2 illustrates some of the results obtained. Four spectra of fission-product activity from ^{238}U at each of 2 neutron energies and each of 2 delay times are compared. Arrows identify 3 of the γ rays in the ^{128}Sn-^{128}Sb decay chain at 314, 480, and 753 keV. Note the large difference of yield as a function of neutron energy, typical of fission fragments of mass close to $\frac{1}{2}$ the mass of the fissioning nucleus.

3. Spin-spin Effect in the Neutron Total Cross Section of ^{59}Co (T. R. Fisher, J. McCarthy,* D. C. Healey,* and D. Parks*)

In our last report,[7] progress on the construction of a polarized ^{59}Co target for use in fast-neutron-scattering experiments was described. This target is now operational and has been used to study the "spin-spin effect"[8] in the neutron total cross section of ^{59}Co for neutron energies from 0.3 to 8.0 MeV. The target consists of 32 g of polycrystalline Co metal and has an average nuclear polarization of 35%.

The neutron-energy region from 0.3 to 1.1 MeV was covered with good energy resolution (10 keV) using the $^{7}Li(p,n)^{7}Be$ neutron-source reaction; the energy region from 1.1 to 1.8 MeV was covered with intermediate energy resolution (50 keV) using the $^{3}H(p,n)^{3}He$ reaction; and

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[7] Reports to the AEC Nuclear Cross Sections Advisory Committee, WASH-1136.

[8] T. R. Fisher, D. C. Healey, and J. A. McCarthy, Nucl. Phys. A130,609(1969).

* Stanford University, Stanford, California.

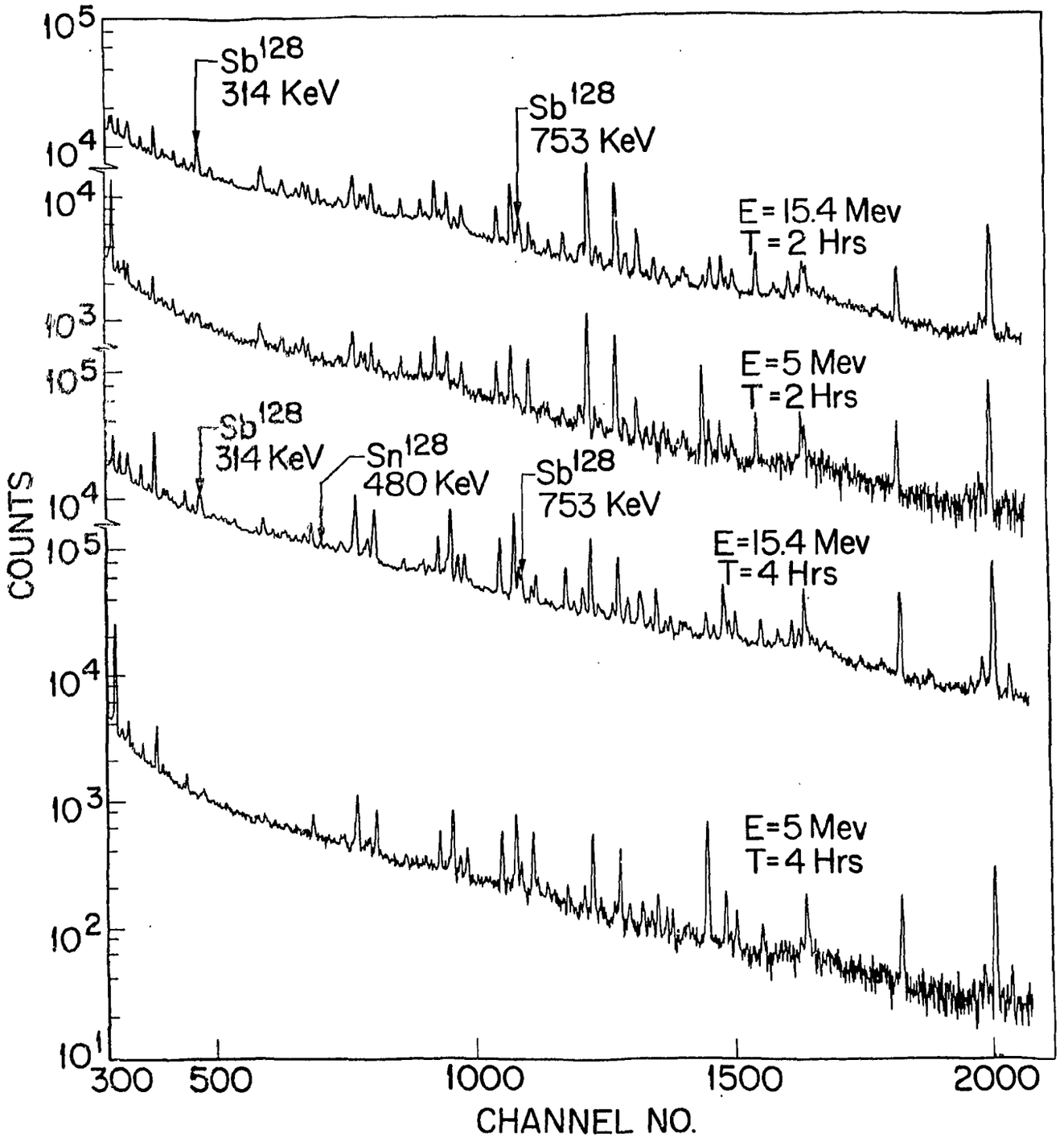

Fig. A-2. Partial fission-product spectra from the irradiation of ^{238}U with 5- and 15.4-MeV neutrons. A 30-cc Ge(Li) detector was used to obtain these spectra after cooling times of 2 and 4 hours.

additional points at 3.35 and 7.75 MeV were obtained with the $^{9}Be(\alpha,n)^{12*}C(4.43)$ and $^{9}Be(\alpha,n)^{12}C$ reactions. The spin-spin cross section σ_{SS} shows fine structure with amplitude fluctuations up to 1.5 b; this effect can be explained by the statistical theory of Carlson and Barschall.[9] The gross structure, however, is probably of more physical significance and is shown in Fig. A-3. The data have been averaged over energy intervals of 300 keV. The calculated curve was obtained using an optical potential containing an additional term

$$-V_{SS} \frac{\underset{\sim}{I} \cdot \underset{\sim}{\sigma}}{I} F(r)$$

with V_{SS}= -1.4 MeV. The quantity F(r) is the Woods-Saxon form factor, and the optical parameters of Rosen et al.[10] were employed in the calculation. Further calculations and experiments are in progress.

4. Studies of the Decay of ^{30}Al Produced by the $^{30}Si(n,p)^{30}Al$ Reaction (A. D. W. Jones, H. A. Grench, and R. W. Nightingale)

The γ rays following β-ray decay of ^{30}Al(3.27 sec) have been studied using a 30-cc Ge(Li) detector. The ^{30}Al was produced by 14-MeV neutron bombardments of both natural silicon and SiO_2 enriched in ^{30}Si. The neutrons were produced by means of the $^{2}H(t,n)He^{4}$ reaction using a gas cell filled to 2 atm of deuterium. Gamma rays emitted in conjunction with β-ray decays to the 4.81- and 4.83-MeV levels in ^{30}Si have been found in addition to those found previously for the 2.23- and 3.51-MeV states. No evidence for a 72.5-sec ^{30m}Al activity[11] has been found.

B. CHARGED-PARTICLE REACTIONS

1. Angular Correlation Studies in ^{29}Si and ^{33}S (T. T. Bardin, J. A. Becker, T. R. Fisher, A. D. W. Jones, and R. G. Hirko*)

The $(\alpha,n\gamma)$ reaction has been used to investigate the decay of excited states in ^{29}Si and ^{33}S. Each individual state was populated in turn, with bombarding energies chosen sufficiently near threshold that s-wave neutrons were preferentially emitted. The γ-ray angular distributions obtained were analyzed according to angular-correlation theory to yield level-spin and γ-ray-mixing-ratio information. These experiments have yielded unambiguous spin assignments and γ-ray-multipole-mixing ratios for states up to ~ 5-MeV excitation in both nuclei. An article concerning this work will soon be submitted for publication; some results have already been presented.[12]

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[9] A. D. Carlson and H. H. Barschall, Phys. Rev. 158, 1142(1967).
[10] L. Rosen, J. G. Beery, A. S. Goldhaber, and E. H. Auerbach, Ann.Phys. (New York) 34, 96(1965).
[11] E. Peeters, Phys. Lett. 7, 142 (1963).
[12] R. G. Hirko and A. D. W. Jones, Bull.Am. Phys. Soc. 15, 566(1970).
* Stanford University, Stanford, California.

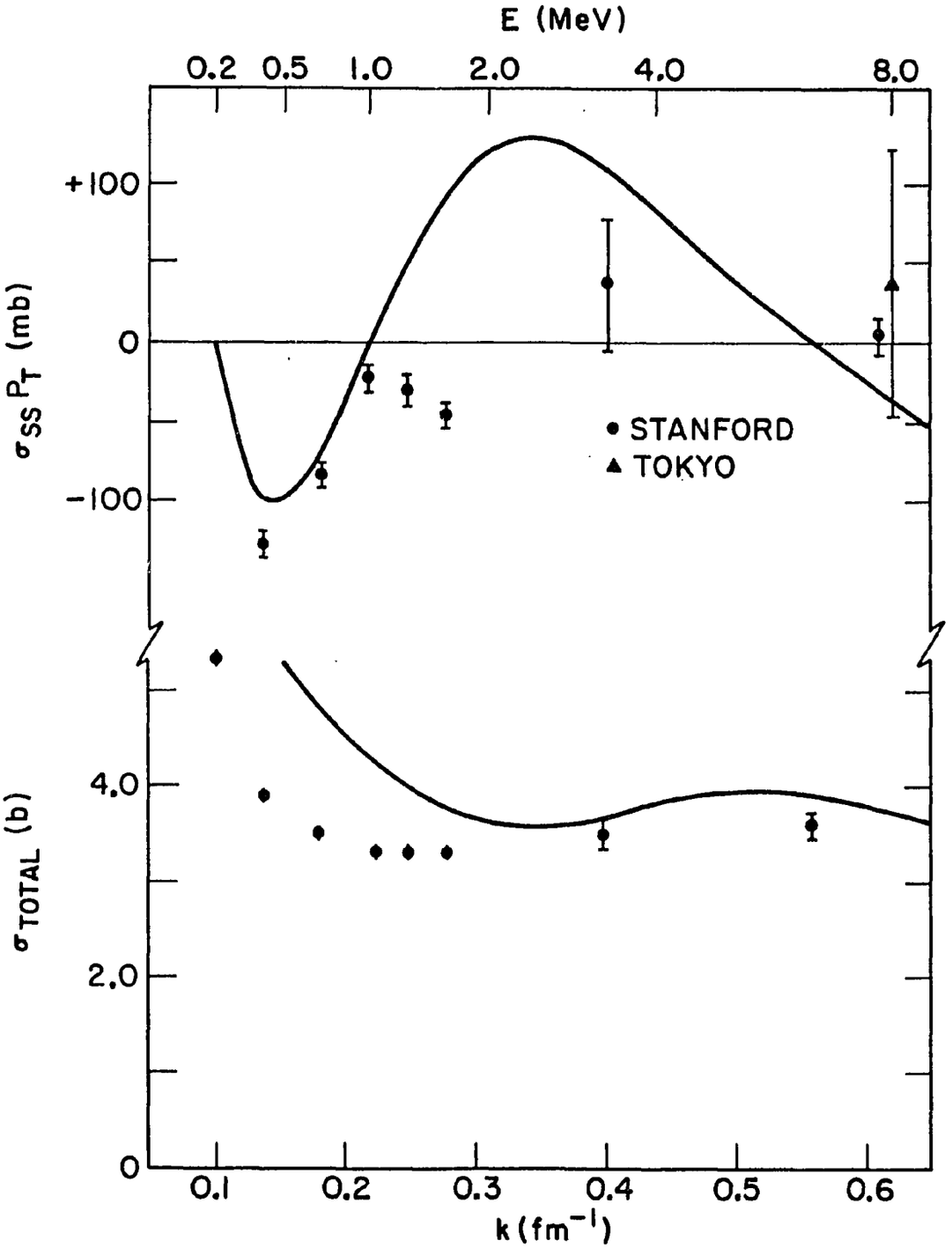

Fig. A-3. Experimental measurements of σ_{SS} P_T and the total cross section as functions of neutron energy. The quantity σ_{SS} is defined by $\sigma_{SS}=(\sigma_{\uparrow\uparrow}-\sigma_{\uparrow\downarrow})/2P_N P_T$ where $\sigma_{\uparrow\uparrow}$ and $\sigma_{\uparrow\downarrow}$ are the total cross sections for parallel and anti-parallel orientations of the beam and target polarization vectors. P_N and P_T are the magnitudes of the beam and target polarizations. The Tokyo point is from a group at the University of Tokyo. Uncertainties are statistical.

2. Lifetimes of Excited States in ^{29}Si (T. T. Bardin, J. A. Becker, T.R. Fisher, and A. D. W. Jones)

Lifetimes or lifetime limits for states up to 6.4-MeV excitation in ^{29}Si have been obtained employing the $^{26}Mg(\alpha, n)^{29}Si$ reaction. The lifetimes were deduced from observation of the attenuation in different stopping materials of the Doppler-shifted γ rays originating from the states of interest. The information obtained, together with angular-correlation data, has made it possible to make theoretical predictions relating to the nuclear structure of ^{29}Si.

3. A $K^{\pi} = 7/2^{-}$ Band in ^{29}Si (T. T. Bardin, J. A. Becker, T. R. Fisher, and A. D. W. Jones)

The properties of the 5.256-MeV state in ^{29}Si, namely, $J = 9/2$, parity odd, and $\tau_m = 0.95 \pm 0.15 \times 10^{-13}$ sec, as determined by the investigations reported in (1) and (2) above, are consistent with the state being the second member of a $K^{\pi} = 7/2^{-}$ band built on the 3.624-MeV state of ^{29}Si. This is the first such band identified in the 2s-1d shell. A report of the work has been published.[13]

4. The β-Ray Decay of ^{25}Na and ^{29}Al (A. D. W. Jones, J. A. Becker, R. E. McDonald, and A. R. Poletti)

The work is completed and an article concerning it has been accepted for publication in the Physical Review.

5. The β-Ray Decay of ^{33}Cl (T. T. Bardin, J. A. Becker, and R. E. McDonald)

This work is complete and an article describing it has been submitted for publication.

6. Studies of ^{25}Na (J. A. Becker, R. E. McDonald, L. F. Chase, Jr., and D. A. Kohler)

This work is complete and an article describing it has been published in the Physical Review.

7. Studies of ^{24}Na (J. A. Becker, R. E. McDonald, and R. W. Nightingale)

The analysis of the results of the experimental investigation of ^{24}Na are nearing completion. Some time is being devoted to theoretical interpretation of the ^{24}Na level scheme in terms of rotational bands based on Nilsson orbitals.

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[13] T. T. Bardin, J. A. Becker, T. R. Fisher, and A. D. W. Jones, Phys. Rev. Letters 24, 772(1970).

8. Lifetime Measurement in ^{29}Al (A. D. W. Jones, R. E. McDonald, and J. A. Becker)

This work is nearing completion and the final draft of a report on the experiment is underway.

9. Spin of the 1.67-MeV Level in ^{20}O (R. W. Nightingale, J. A. Becker, D. A. Kohler, and R. E. McDonald)

A J=2 assignment for the ^{20}O, 1.67-MeV level has been deduced from a measurement of the angular correlation of the 1.67-MeV γ radiation. The level was populated via the $^{18}O(t,p)^{20}O$ reaction using 2.0-MeV tritons incident on an ^{18}O gas target. This work has been accepted for publication.

LOS ALAMOS SCIENTIFIC LABORATORY

A. TIME OF FLIGHT WITH NUCLEAR EXPLOSIONS

1. Resonance Parameters of ^{238}Pu (M. G. Silbert; A. Moat (AWRE); and T. E. Young (INC) Relevant to WASH-1144, Requests 432, 433.

Measurements on the Persimmon event included the fission fragment yield from a thin ^{238}Pu sample and the gamma-ray yield from a thick ^{238}Pu sample. The fission cross section has been reported in preliminary form.[1] The gamma-ray yield (by modified Moxon-Rae detectors) was proportional to $(\sigma_{n,\gamma} + K\sigma_{n,f})$. Assuming $\Gamma_\gamma = 34$ meV for each resonance and using single-level area analysis, the gamma and fission[1] areas for each resonance were combined to yield values for Γ_n^o and Γ_f. The preliminary values below have errors ranging upward from ±10% for Γ_n^o and ±20% for Γ_f. Small resonances in particular have large errors in their derived widths.

E_o(eV)	Γ_n^o(meV/√eV)	Γ_f(meV)	E_o(eV)	Γ_n^o(meV/√eV)	Γ_f(meV)
18.6	0.84	1.8	216.0	1.2	21.0
32.2	0.011	5.9	221.0	3.3	1.3
36.5	0.004	5.8	232.0	0.037	0.82
59.7	0.17	0.79	245.0	0.39	27.0
70.1	0.28	8.3	252.0	0.88	58.0
77.7	0.004	5.0	285.0	1.5	>500.0
83.0	2.0	4.0	289.0	2.1	23.0
96.1	0.009	5.6	300.0	2.7	135.0
99.6	0.020	13.0	306.0	0.43	83.0
110.2	0.55	4.1	321.0	6.2	6.2
111.4	0.005	27.0	327.0	1.2	19.0
113.6	1.1	5.7	337.0	0.73	10.0
118.6	2.4	1.7	361.0	0.043	13.0
122.4	2.3	8.9	368.0	0.89	4.7
129.0	0.035	1.7	382.0	0.021	25.0
132.3	0.073	5.5	391.0	0.71	2.8
139.7	0.23	7.0	409.0	0.94	2.6
151.2	2.2	9.5	419.0	2.8	27.0
165.0	0.013	17.0	427.0	2.0	13.0
171.1	3.2	0.76	448.0	0.31	68.0
176.8	0.21	36.0	(461.0 *	3.0	7.0
182.9	2.0	7.2	(463.0 *	3.0	7.0
192.5	1.4	71.0	473.0	0.96	3.1
203.0	0.31	2.4	496.0	0.49	7.9

*Unresolved doublet, analysis assumed two identical resonances.

[1] M. G. Silbert, "Fission Cross Section of ^{238}Pu from Persimmon," Los Alamos Scientific Laboratory Report, LA-4108-MS (1969).

The fission widths exhibit enhanced fission strength near 300 eV, indicative of a corresponding level in the second well. The unusually wide level peaking at 285 eV[1] has been analyzed in the fission cross section with the multilevel search routine MULTI of G. F. Auchampaugh.[2] This resonance has Γ_n^o of 1.5 meV and Γ_f of 3 to 4 eV. For comparison the average value of Γ_n^o is about 1.2 meV and the average value of Γ_f for all the other resonances listed is ~20 meV.

The capture cross section of ^{238}Pu, derived by subtraction of the fission cross section[1] from the gamma-ray production cross section, is illustrated in Fig. A1. Contributions from 0.6% ^{239}Pu and 0.2% ^{234}U in the sample have not been removed from these figures.

2. Neutron Cross Sections from the Pommard Event (Physics-7)

The reduction of data from the Pommard event has been completed. All data sets show a gap above a few keV, where noise interference occurred. At the lower energies, the cross sections were determined relative to the ^{6}Li(n,α)H^3 cross section. Above ~100 keV, cross sections were determined relative to the ^{235}U fission cross section as evaluated by W. G. Davey.[3] A Los Alamos report, LA-4420, is in preparation. This report gives a description of the following measurements and a listing of the fission cross-section data obtained:

a. ^{232}U (J. A. Farrell)

The ^{232}U fission cross section below 30 keV.

b. ^{233}U (D. W. Bergen) Relevant to WASH-1144, Requests 353, 354.

The ^{233}U fission cross section below 5 keV and the cross section between 50 keV and 3 MeV.

c. ^{235}U (J. D. Cramer)

The ^{235}U fission cross section, relative to ^{6}Li(n,α), below 5 keV. The ^{235}U data from 70 keV to 3 MeV served as the reference for other fission measurements in this energy region.

d. ^{236}U (J. D. Cramer and D. W. Bergen)

The ^{236}U fission cross section below 2 keV.

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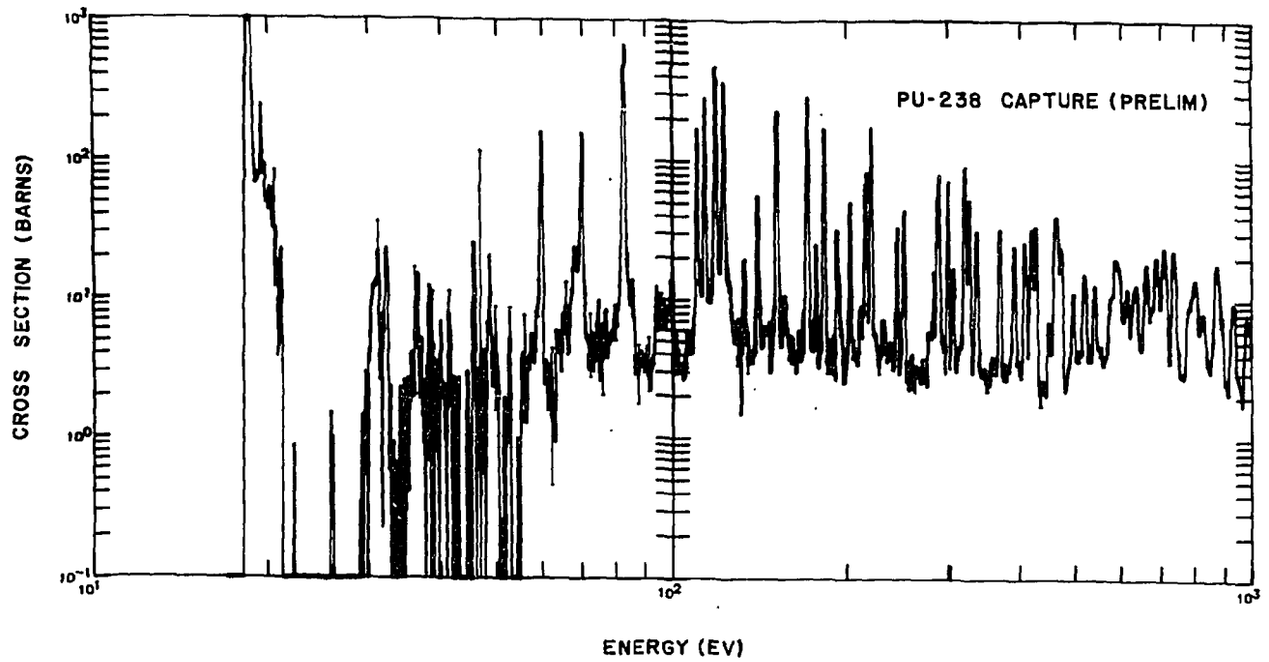
[2] G. F. Auchampaugh, "Multilevel Code for Analyzing Cross Section Data for Resonance Parameters Using a CDC 6600 Computer," WASH-1071 (1966).

[3] W. G. Davey, Nucl. Sci. Eng. 32, 35 (1968).



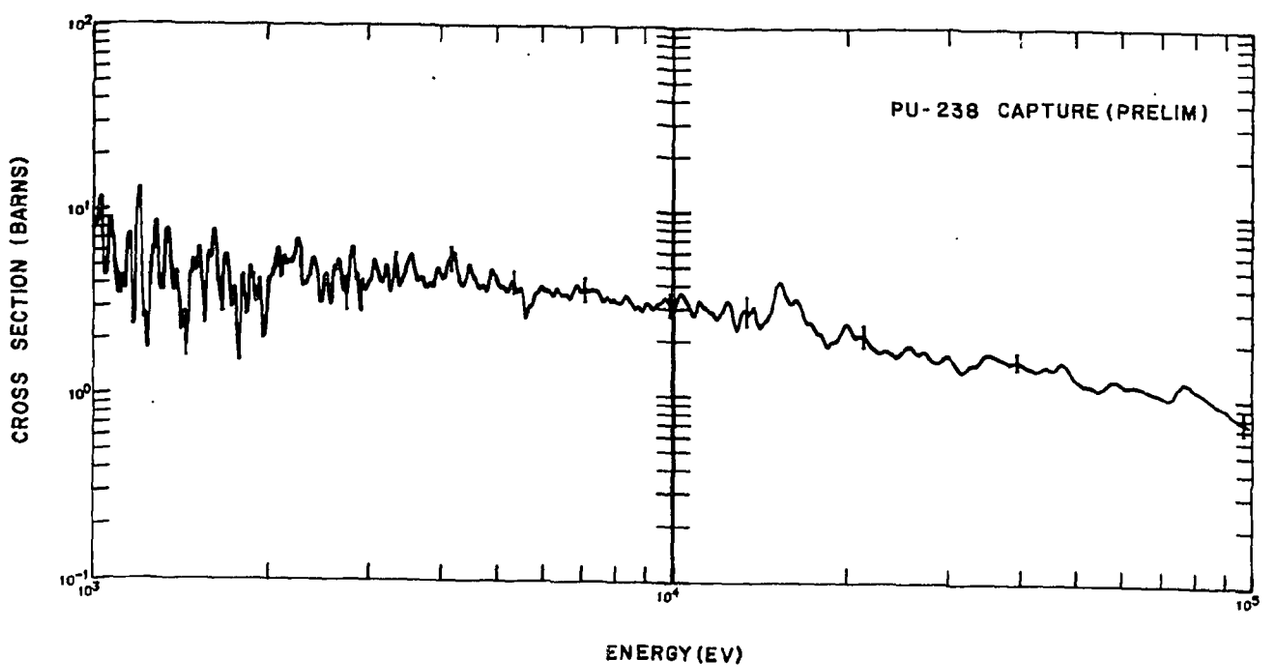


Fig. A1. Preliminary capture cross section of ^{238}Pu from 10 eV to 100 keV, as measured on the Persimmon event (Physics-6).

e. ^{237}U (J. H. McNally, J. W. Barnes, B. J. Dropesky, P. A. Seeger, and K. Wolfsberg) Relevant to WASH-1144, Requests 403, 404

The ^{237}U fission cross section below 1 keV and (Fig. A-2) the fission cross section from 0.1 to 2 MeV (Fig. A-3).

f. ^{238}Pu (D. M. Drake; C. D. Bowman, M. S. Coops, and R. W. Hoff, LRL-Livermore) Relevant to WASH-1144, Requests 428, 436

The ^{238}Pu fission cross section below 10 keV and the fission cross section from 0.1 to 2.5 MeV.

g. ^{242}Pu (D. W. Bergen and R. R. Fullwood)

The preliminary ^{242}Pu fission cross section below 5 keV and the fission cross section from 0.1 to 3 MeV.

h. ^{243}Am (P. A. Seeger)

The ^{243}Am fission cross section below 10 keV and the fission cross section from 0.1 to 3 MeV.

i. ^{243}Cm (R. R. Fullwood; D. R. Dixon, BYU; and R. W. Lougheed, LRL-Livermore)

The fission cross section of ^{243}Cm from 0.1 to 3 MeV.

3. Fission Cross Sections of ^{237}Np from Pommard (W. K. Brown; D. R. Dixon, BYU; and D. M. Drake)

A Los Alamos report, LA-4372, contains listings of the fission cross section of ^{237}Np, as determined on the Pommard event, and a description of the experiment. Figures A-4 and A-5 show the cross section below 2.2 eV; Figure A-6 shows the cross section from 100 keV to 3 MeV.

4. Preliminary ^{232}Th Capture Results from the Physics-8 Event (L. Forman, A. D. Schelberg, J. H. Warren, M. V. Harlow, and N. W. Glass) Relevant to WASH-1144, Requests 343, 344

Neutron capture in ^{232}Th has been investigated utilizing time-of-flight techniques with a beam of neutrons from the Physics-8 underground

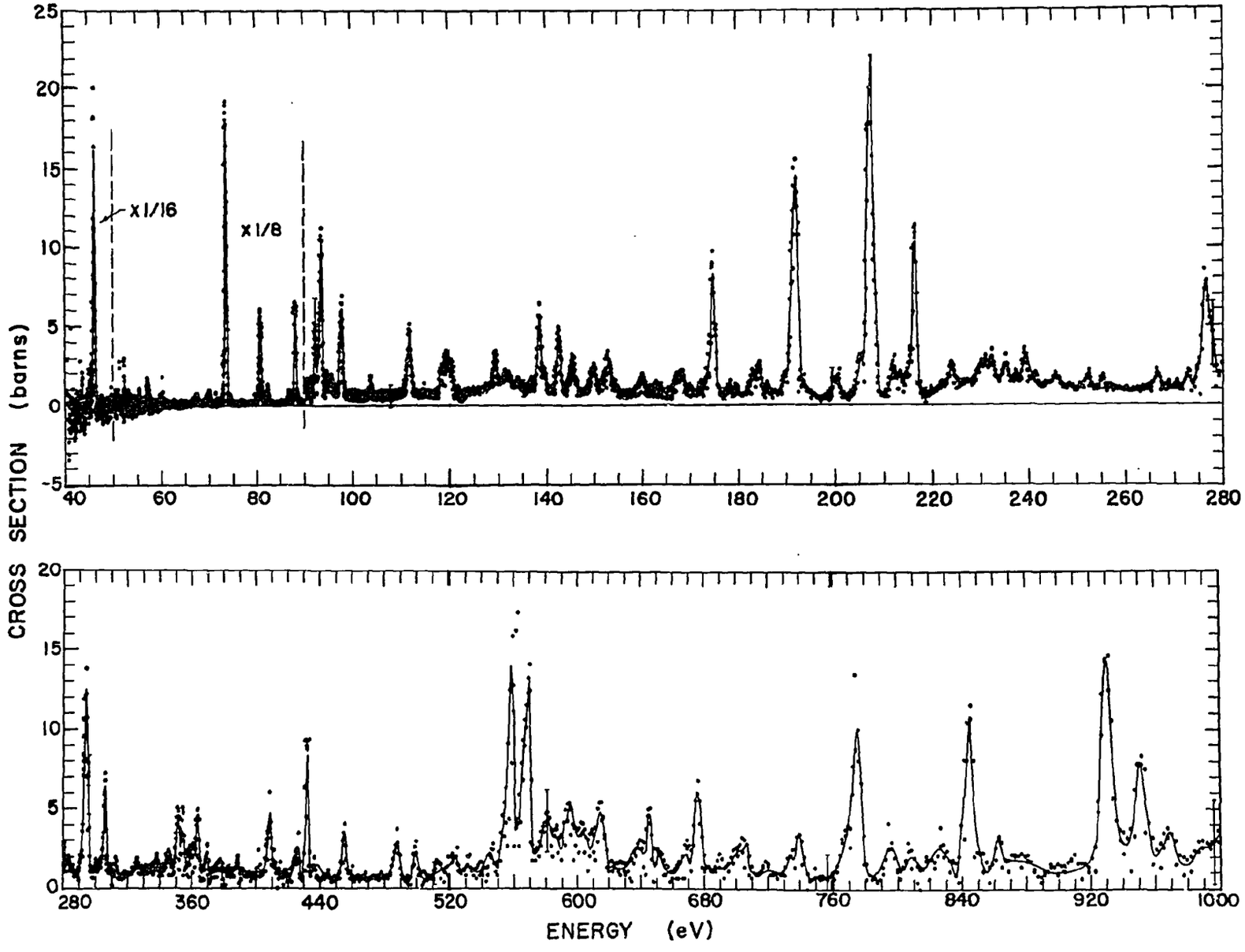


Fig. A-2. Fission cross section of ^{237}U, from 40 eV to 1 keV, from the Pommard event (Physics-7).

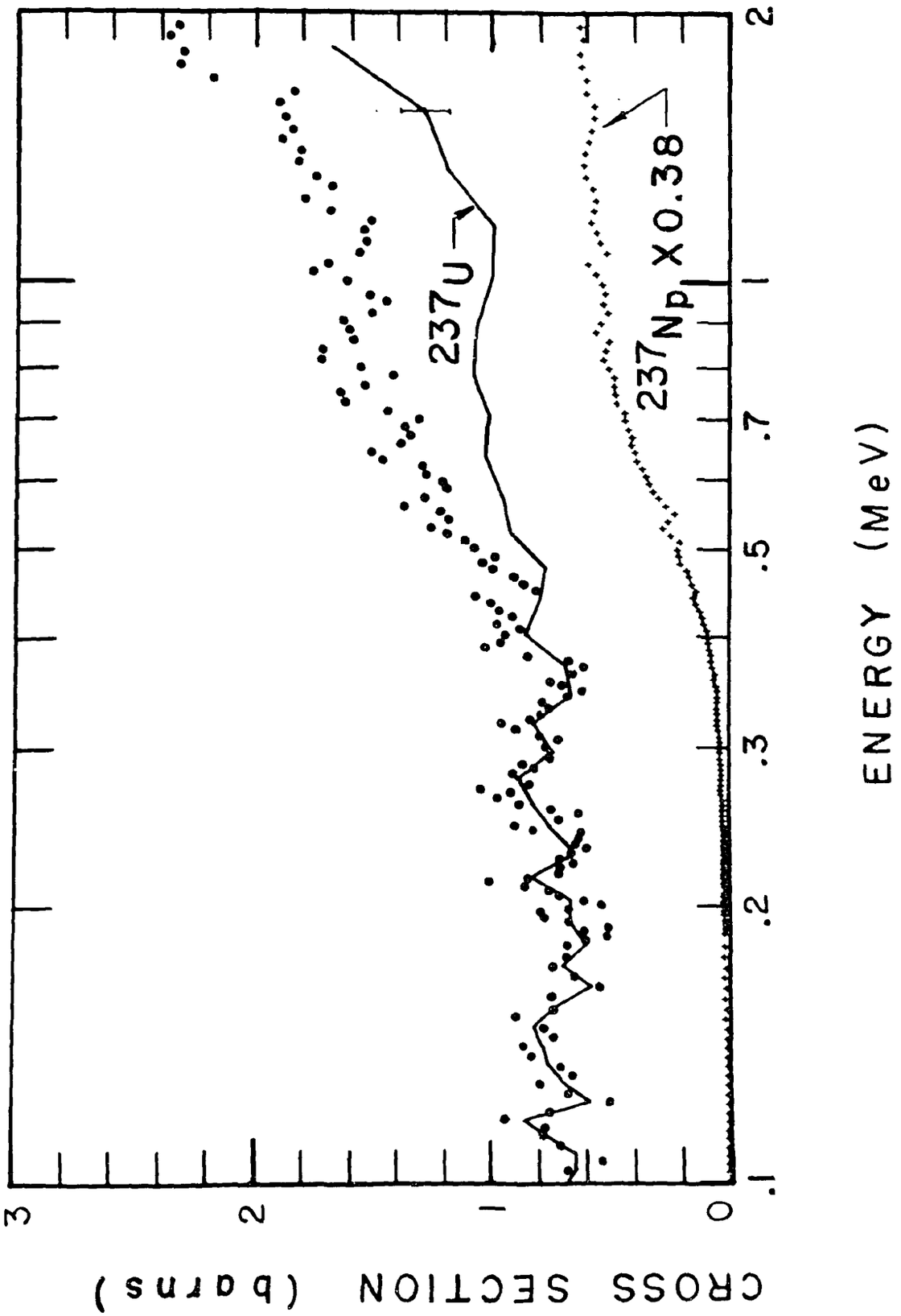


Fig. A-3. Fission cross section of ^{237}U, from 100 keV to 2 MeV, from the Pommard event (Physics-7).

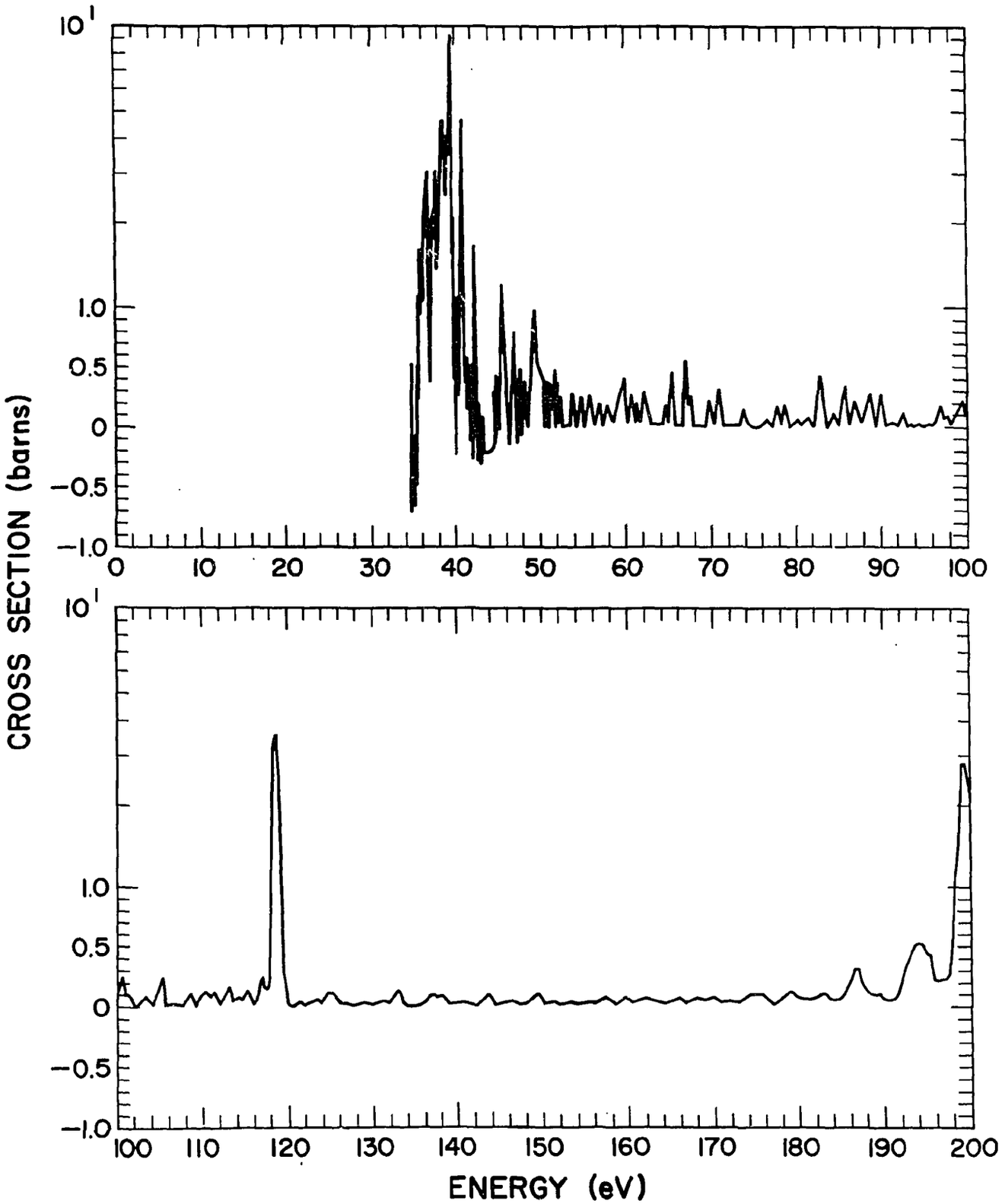


Fig. A-4. Fission cross section of ^{237}Np, from 35 eV to 200 eV, from the Pommard event (Physics-7).

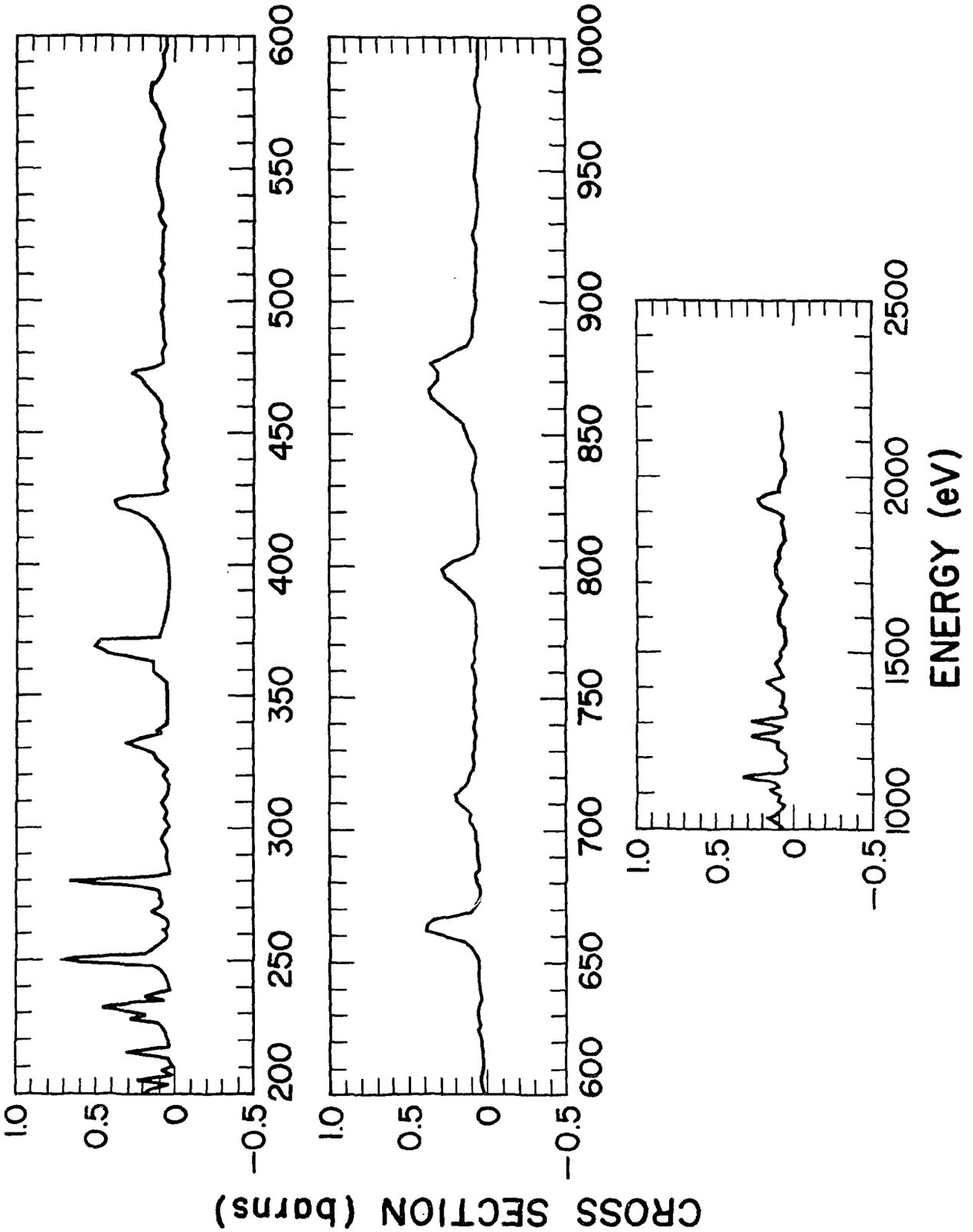


Fig. A-5 Fission cross section of ^{237}Np, from 200 eV to 2.5 keV, from the Pommard event (Physics-7).

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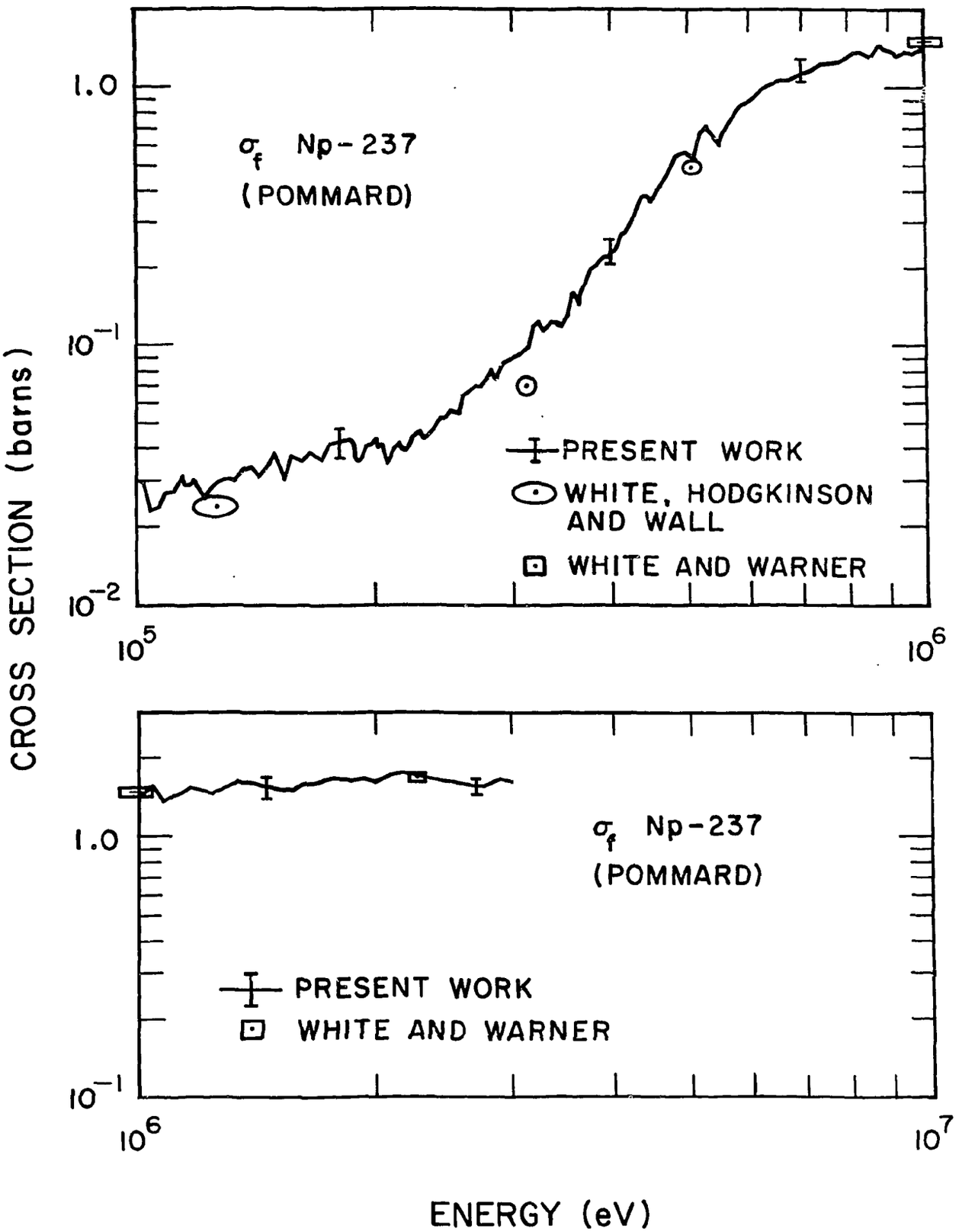

Fig. A-6. Fission cross section of ^{237}Np, from 100 keV to 3 MeV, from the Pommard event (Physics-7).

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nuclear detonation. Capture gamma cascades from three samples were monitored with Moxon-Rae detectors. Figure A-7 shows the preliminary "measured" capture cross section from the first sample (1000 barns/atom) without corrections for self-absorption, multiple scattering, etc. Resonance parameters may be derived from matching the area under the resonances with corrected theoretical predictions as a function of $g\Gamma_n$ and Γ_γ.

Figure A-8 shows detector current as a function of energy. The larger resonances have been listed by Garg, et al[4] and shown to belong to a set of resonances whose Γ_n^o values can be fitted with a Porter-Thomas distribution. This theoretically indicates that most small s-wave resonances have been accounted for within this listing. The smaller peaks which appear in Fig. A-8 are therefore presumed p-wave. Their level spacing is consistent with the $\sim(2J+1)^{-1}$ theoretical prediction.

The quality of the data is encouraging for area analysis; this will allow investigation of the $E^{(\ell+1/2)}$ dependence of the barrier penetration coefficient, and should have sufficient accuracy to determine whether there is any energy dependent variation of the radiation width as observed in the ^{238}U capture results of Glass, et al.[5]

5. Fission and Capture Cross Sections of Cm (Moore, Brown, Ennis, Fullwood, Keyworth, McNally; Simpson, Berreth, INC; Baybarz, ORNL; and Thompson, SRL) Relevant to WASH-1144, Requests 499, 503-518, 526

In the Physics-8 event, fission cross sections were measured for ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm, and ^{252}Cf from 20 eV to several MeV. Radiative capture cross sections were determined for ^{244}Cm and for several resonances in ^{246}Cm and ^{248}Cm. Low resolution (20 nsec/m) recordings have been processed completely. These give resonance-region cross sections between 20 and 300 eV, as shown in Figs. A-9 - A-14.

The even target data were analyzed by single-level area analysis. Preliminary resonance parameters for ^{244}Cm are listed in Table A-I; those for ^{246}Cm and ^{248}Cm also in Table A-I; and those for ^{252}Cf in Table A-II. Fission data on ^{245}Cm required multilevel analysis. These data are being analyzed between 20 and 150 eV by the least-squares multilevel routine developed by Auchampaugh.[2] Preliminary analysis of ^{247}Cm resonances was done by a single-level least-squares routine; multilevel analysis is also being carried out. Preliminary parameters for both ^{245}Cm and ^{247}Cm are given in a paper submitted to the Helsinki conference on Nuclear Data for Reactors.

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[4] J. B. Garg, J. Rainwater, J. S. Petersen, and W. W. Havens, Jr., Phys. Rev. 134, B985 (1964).

[5] N. W. Glass, A. D. Schelberg, L. D. Tatro, and J. H. Warren, "Proc. of Second Conf. on Neutron Cross Sections and Technology," (March 1968).

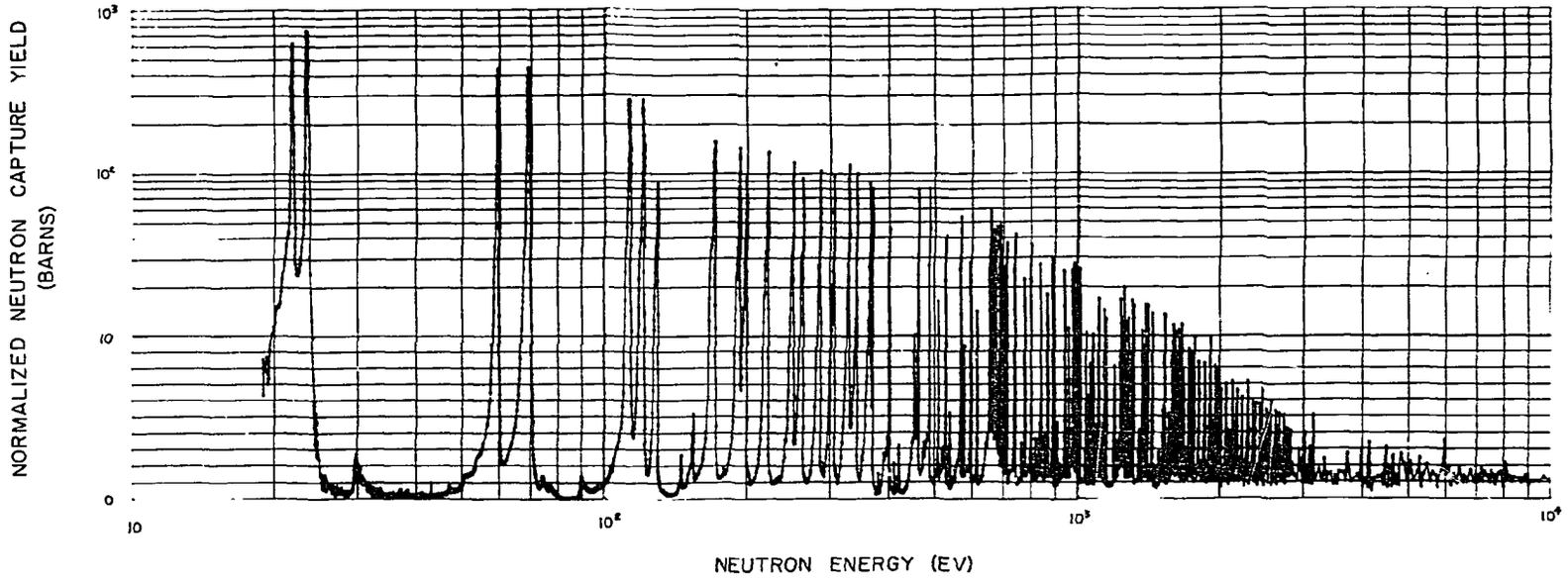


Fig. A-7. Preliminary capture cross section of ^{232}Th, from 20 eV to 10 keV, from the Physics-8 event.

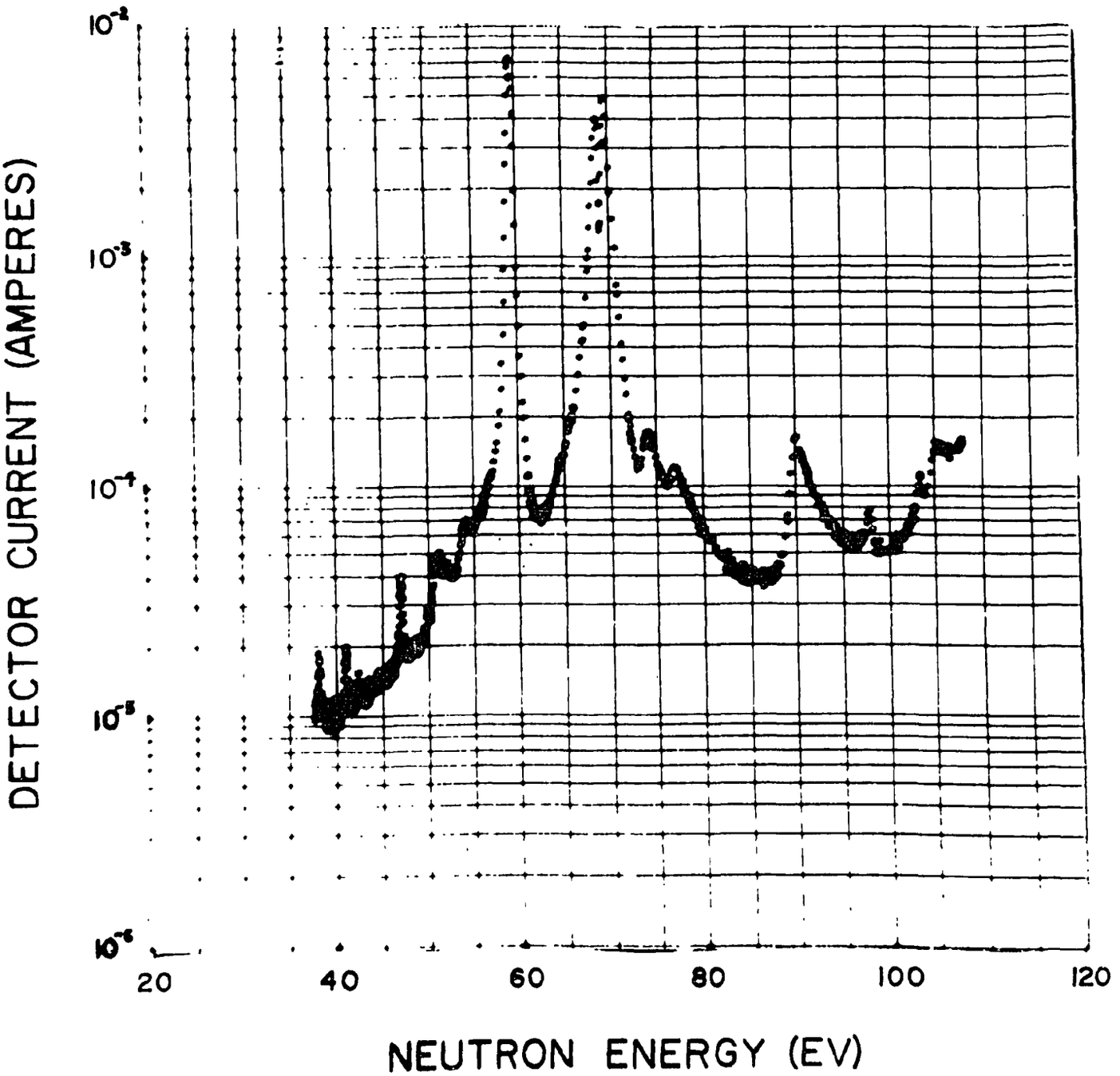
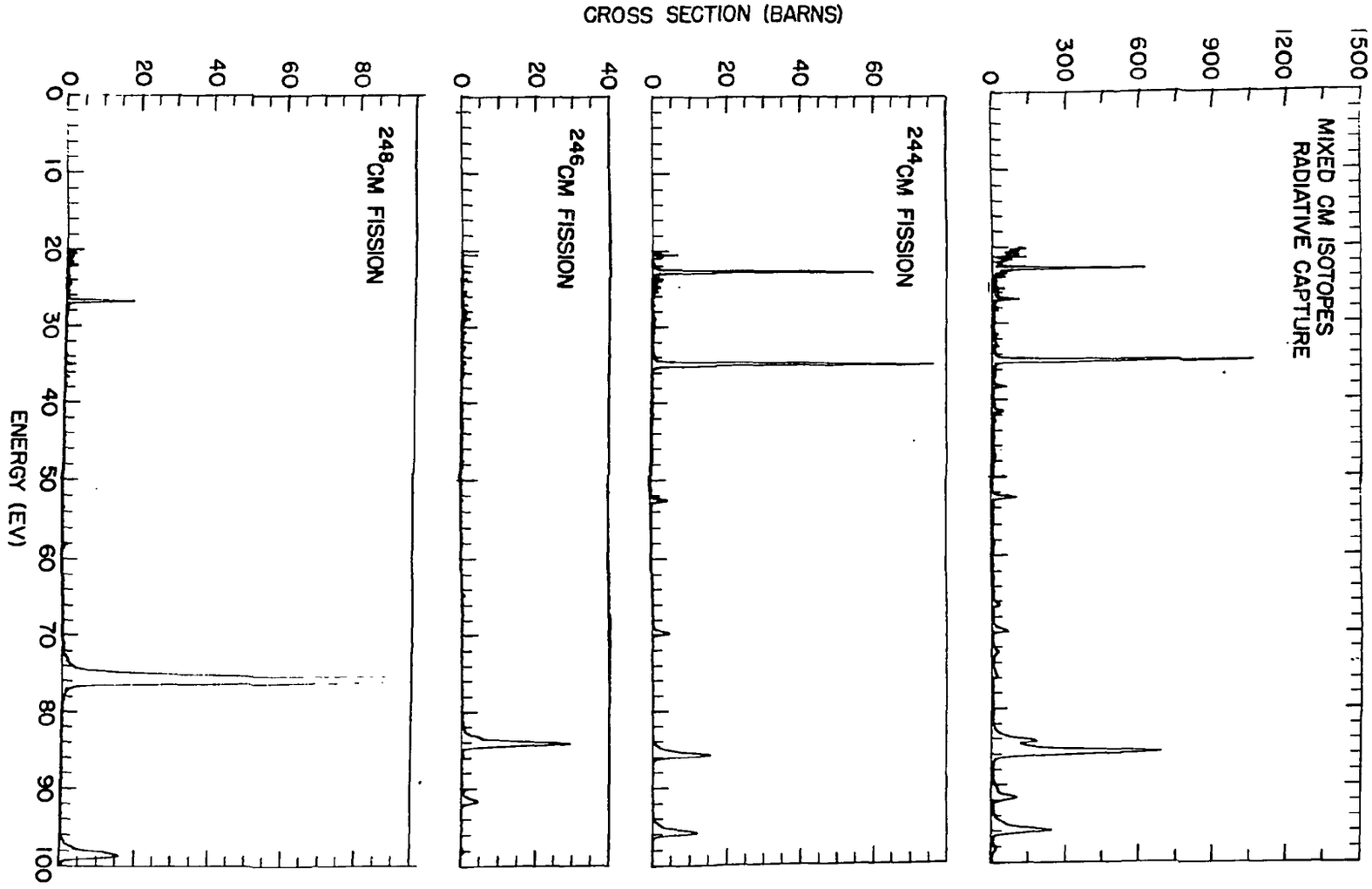


Fig. A-8. Detector current from the modified Moxon-Rae detector viewing the ^{232}Th sample, from 37 to 108 eV. The small spikes are attributed to p-wave resonances.

Fig. A-9. Radiative capture cross section of a sample of mixed Cm isotopes, and fission cross sections of ^{244}Cm, ^{246}Cm, and ^{248}Cm, between 20 and 100 eV from the Physics-8 event. While the capture sample contained predominantly ^{244}Cm and the cross section shown corresponds to the ^{244}Cm content, resonances also are seen which are due to ^{246}Cm and ^{248}Cm. Isotopic identification was made possible by the fission data shown.



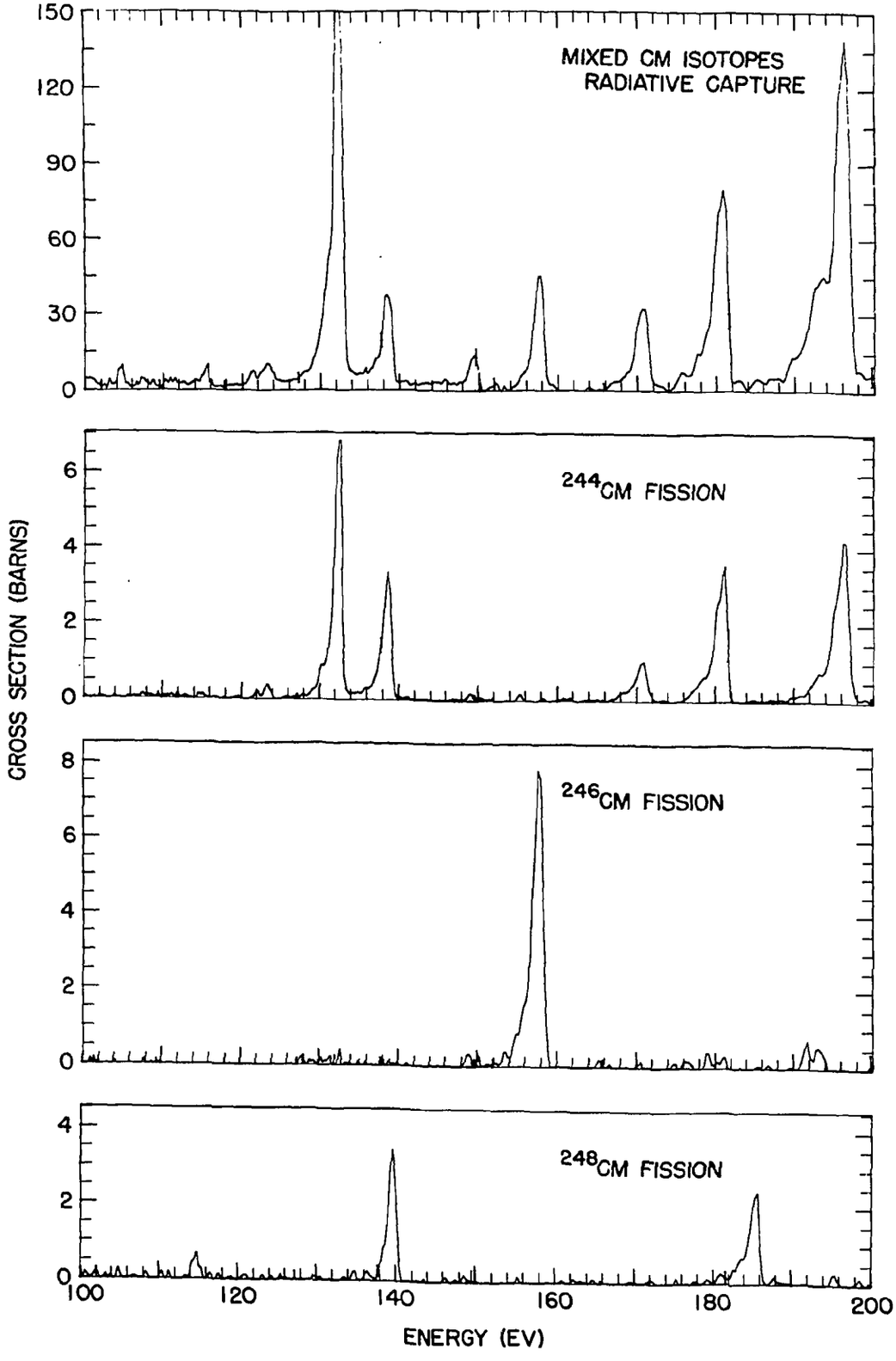


Fig. A-10. Radiative capture cross section of a sample of mixed Cm isotopes, and fission cross sections of ^{244}Cm, ^{246}Cm, and ^{248}Cm, between 100 and 200 eV from the Physics-8 event. While the capture sample contained predominantly ^{244}Cm and the cross section shown corresponds to the ^{244}Cm content, resonances also are seen which are due to ^{246}Cm. Isotopic identification was made possible by the fission data shown.

Fig. A-11. Radiative capture cross section of a sample of mixed Cm isotopes, and fission cross sections of ^{244}Cm, ^{246}Cm, and ^{248}Cm, between 200 and 300 eV from the Physics-8 event. While the capture sample contained predominantly ^{244}Cm content, resonances also are seen which are due to ^{246}Cm. Isotopic identification was made possible by the fission data shown.

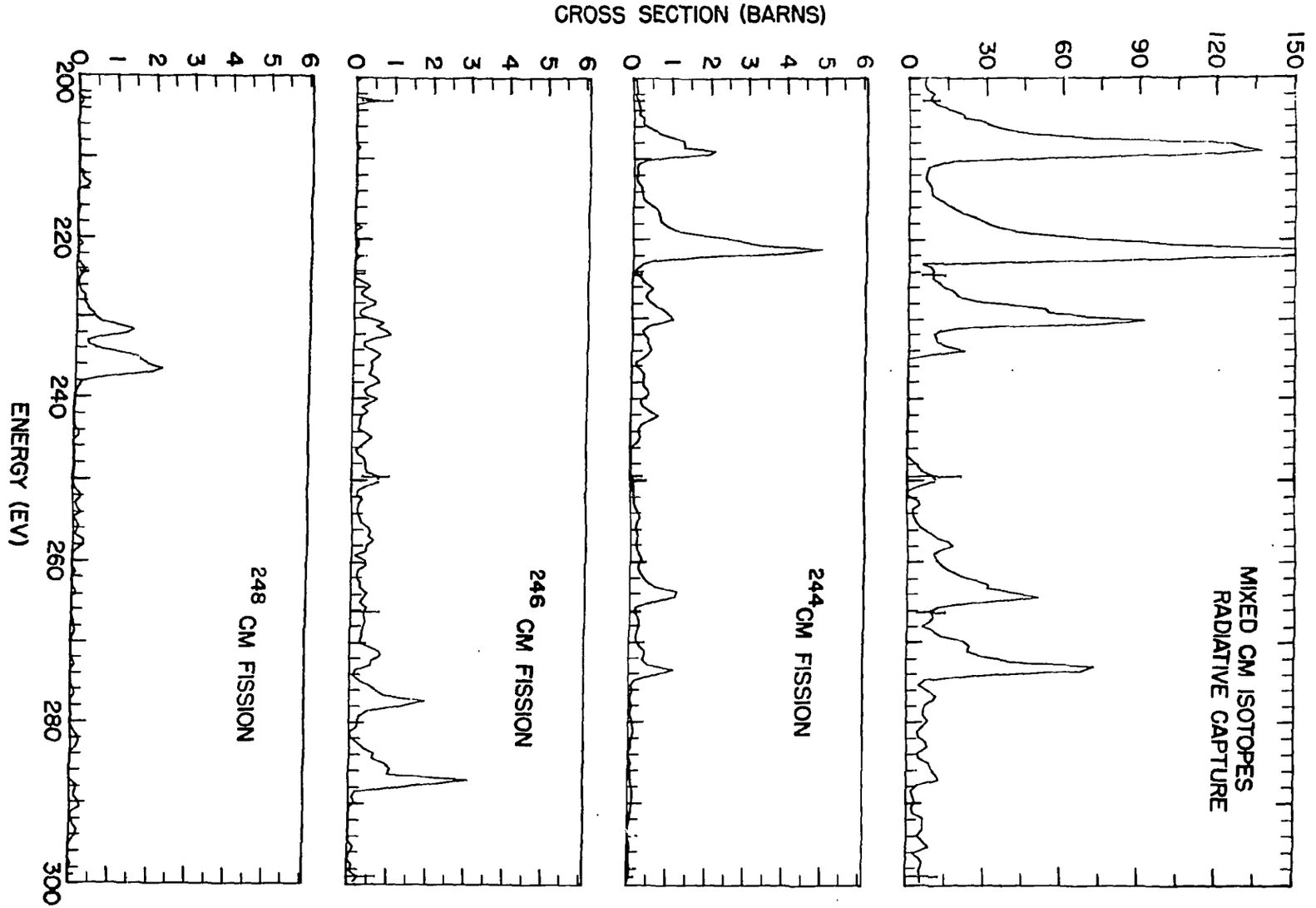


Fig. A-12. The fission cross sections of ^{245}Cm and ^{247}Cm between 20 and 150 eV, from the Physics-8 event. Differences in the interference and in the average fission width for the two isotopes are readily apparent.

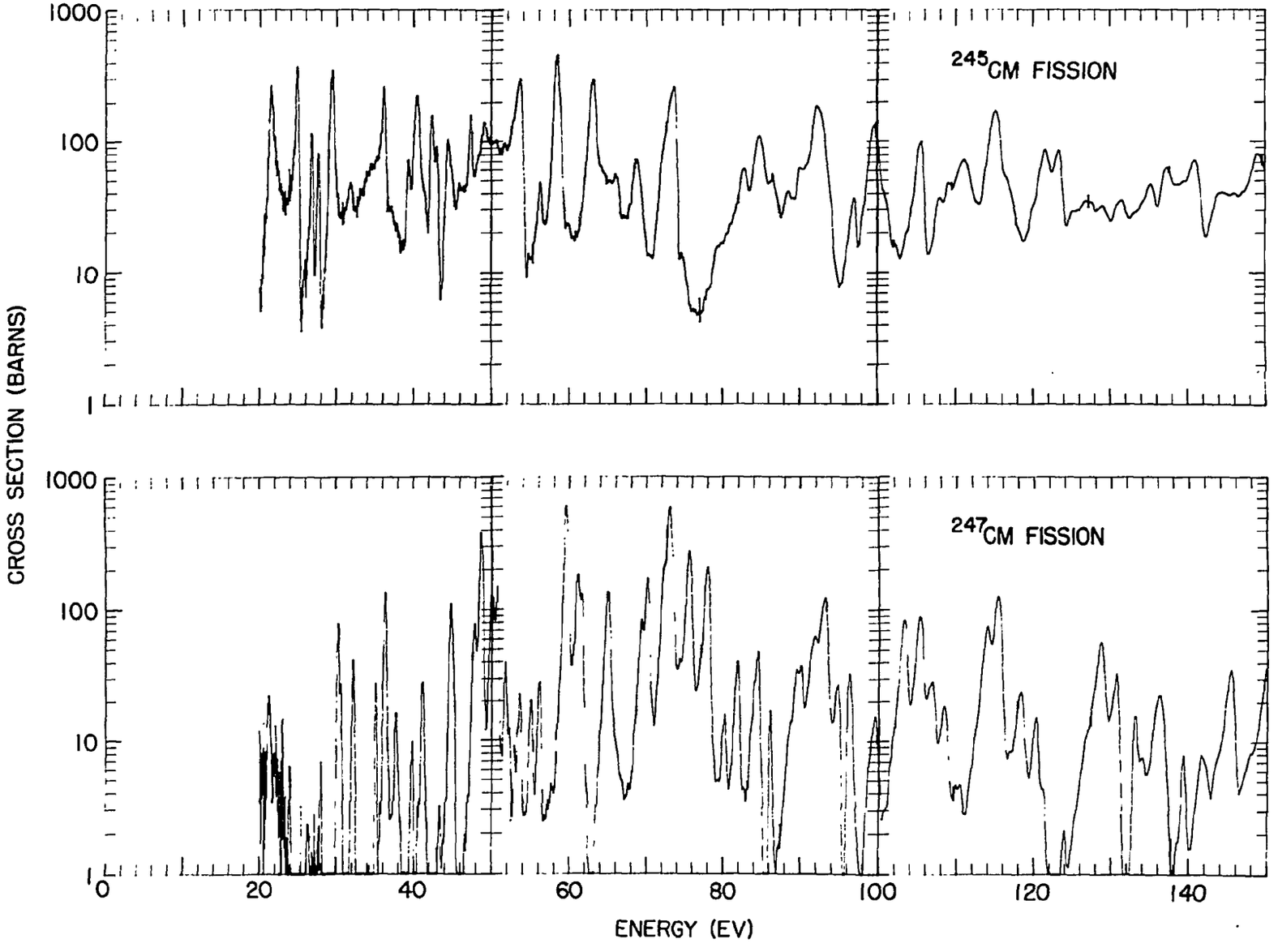
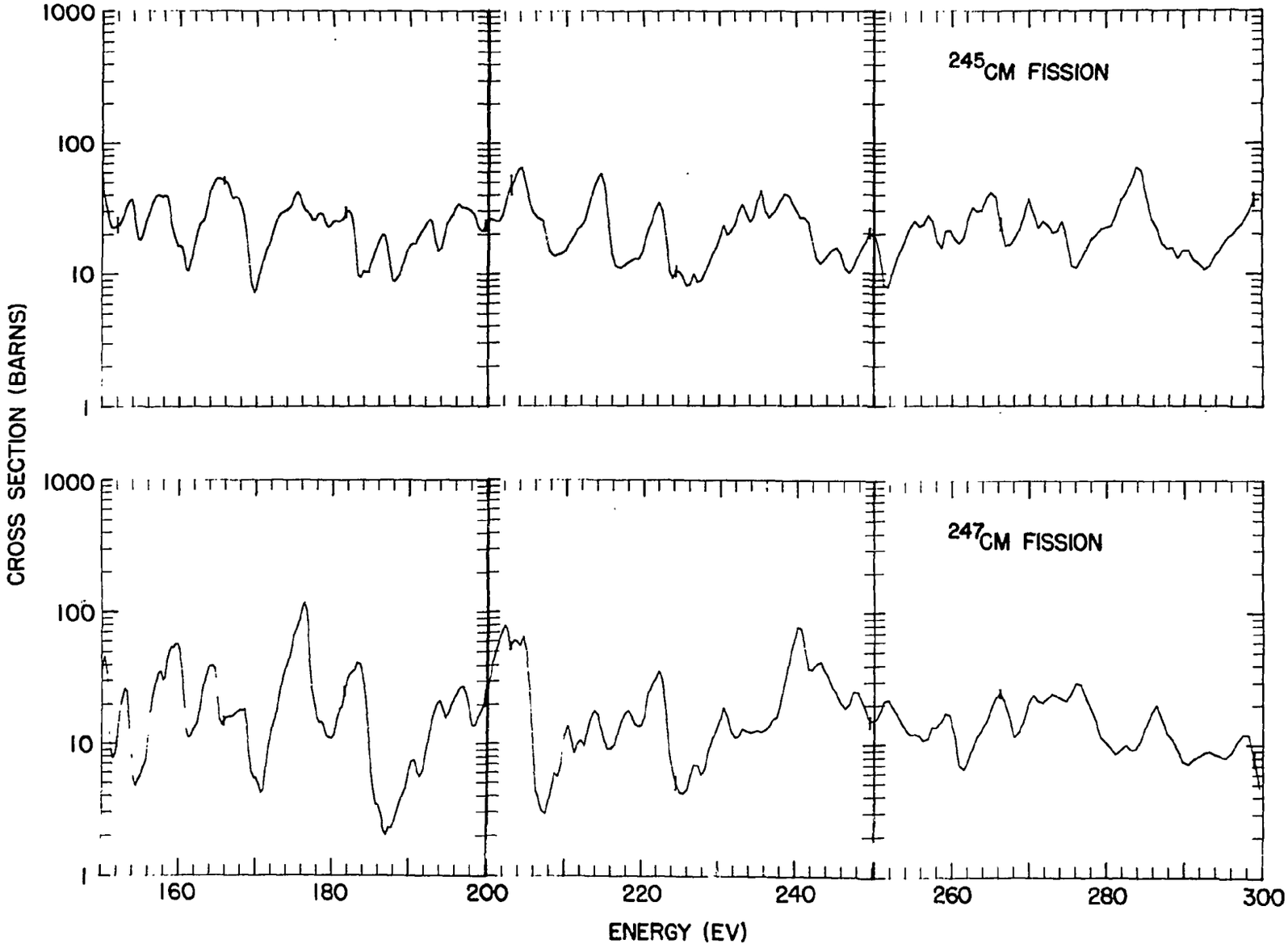


Fig. A-13. The fission cross sections of ^{245}Cm and ^{247}Cm between 150 and 300 eV, from the Physics-8 event.



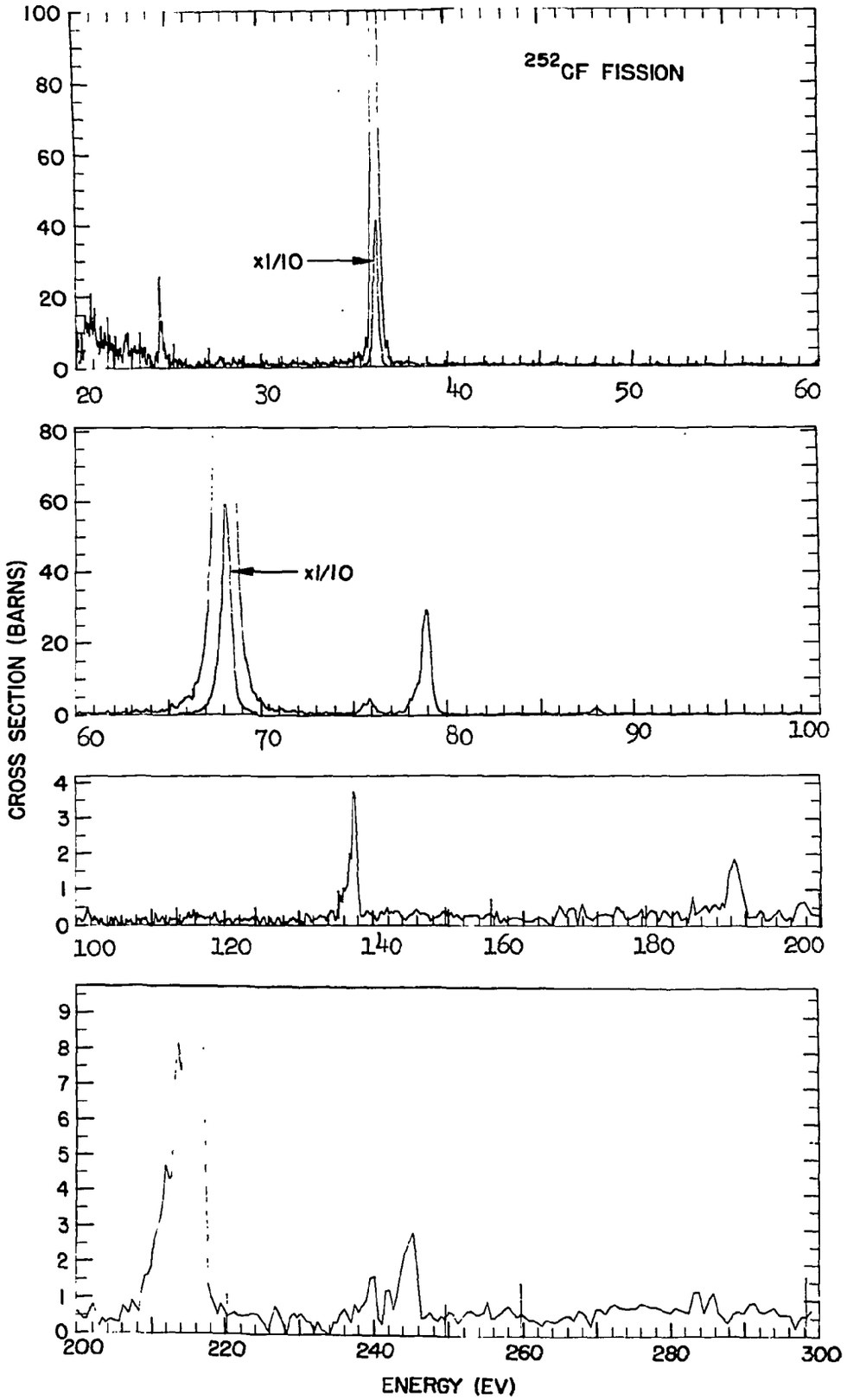


Fig. A-14. The fission cross section of ^{252}Cf, between 20 and 300 eV, from the Physics-8 event.

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TABLE A-I

Preliminary resonance parameters for even curium targets, for neutron energy between 20 and 300 eV. The neutron widths were normalized to data of Coté between 20 and 100 eV, under the assumption that Γ_γ = 37 mV.

E_o (eV)	$\frac{\pi}{2}\sigma_o\Gamma_\gamma$ (b-eV)	$\frac{\pi}{2}\sigma_o\Gamma_f$ (b-eV)	Γ_n (mV)	Γ_γ (mV)	Γ_f (mV)	Γ_n (Coté) (mV)
			^{244}Cm			
22.8	160	13.5	0.98	(37)	2.9	0.97
34.9	354	23.8	3.5	(37)	2.4	4.03
52.7	45	1.9	0.61	(37)	1.5	0.70
69.8	35	2.7	0.65	(37)	2.6	0.48
85.7	621	12.5	20.4	(37)	0.8	20.0
95.9	228	10.5	6.5	(37)	1.6	6.2
132.0	297	9.8	13.2	(37)	1.1	15.1
139.0	49	4.5	1.9	(37)	3.1	
149.0[a]	$\lesssim$ 9	0.2	$\lesssim$ 0.3	(37)	$\gtrsim$ 0.8	
171.0	46	1.6	2.1	(37)	1.2	
181.0	163	6.1	9.2	(37)	1.2	8.8
196.0	390	10.0	38.0	(37)	0.9	22.0
209.0	392	5.4	44.0	(37)	0.5	42.7
222.0	469	12.4	83.0	(37)	0.9	39.0
230.0	222	3.7	19.0	(37)	0.6	18.3
265.0	148	2.6	13.1	(37)	0.6	
273.0	181	2.7	18.0	(37)	0.5	43.0
			^{246}Cm			
84.3	666	22.2	22.3	(37)	1.1	
91.6	608	4.1	22.8	(37)	2.4	
158.0	246	10.3	13.2	(37)	1.5	
277.0		3.6				
287.0		4.2				
			^{248}Cm			
26.8	2325	4.4	25.8	(37)	0.06	
75.8	1260	132.0	68.7	(37)	3.6	
98.4	1290	15.1	187.0	(37)	0.4	
140.0		4.6				
186.0		3.9				
232.0		2.9				
237.0		6.4				

[a]Partly ^{246}Cm

TABLE A-II

Preliminary fission resonance parameters of (^{252}Cf + n)

E_o (eV)	$\frac{\pi}{2}\sigma_o\Gamma_f$ (b-eV)
24.72	5.4
36.32	138.0
51.41	0.23
68.2	450.0
79.0	20.1
88.0	1.2
138.0	4.5
188.0	3.9
216.0	81.0
243.0	11.5

6. Scattering, Capture, and Fission of ^{237}Np (M. M. Hoffman, W. L. Baird, G. B. Barber, G. J. Berzins, W. A. Biggers, J. H. Calligan III, M. R. Cates, R. E. Dorsey, and D. D. Phillips)

Most of the data from the Physics-8 event on the ^{237}Np partial cross sections have been read and will soon be reduced. The ^{237}Np scattering cross section is receiving most emphasis, and reduction of the raw readings to cross section will be completed in a few weeks. Good data on capture and fission were also obtained. Reduction of the capture and fission data will be done at a later time.

An experimental measurement was also made of the capture and scattering on ^{103}Rh. These data are only partially read, so the results from this measurement will not be available in the near future.

B. VAN DE GRAAFF NEUTRON STUDIES

1. Polarization of 22-MeV Neutrons Elastically Scattered from Liquid Tritium and Deuterium (R. K. Walter, EG&G; J. C. Hopkins, E. C. Kerr, J. T. Martin, A. Niiler, J. D. Seagrave, R. H. Sherman; D. R. Dixon, BYU)

The asymmetries from $T(\vec{n},\hat{n})T$ elastic scattering of 22.1-MeV incident neutrons have been measured for 11 laboratory angles between 40° and 118.5^o. The extrema are -60% at 85° (lab) and +98% at 110° (lab). Information about neutron polarization from n-T elastic scattering has heretofore been limited to one measurement at 1.1-MeV neutron energy[6] and to predictions

[6] J. D. Seagrave, L. Cranberg, and J. E. Simmons, Phys. Rev. 119, 1981 (1960).

from phase-shift calculations of cross-section data at 1.0, 2.0, 3.5, and 6.0 MeV.[7] A cryogenic system[8] built to provide a 23.5-cm^3 scattering sample of liquid tritium for the measurement of the n-T differential cross section has been used to study angular distribution of the scattered neutron asymmetry for incident neutrons of 22.1-MeV energy.

The Los Alamos vertical Van de Graaff accelerator and Mobley buncher were used to produce a pulsed beam of 6.0-MeV deuterons at the center of a tritium gas target. The 22.1-MeV neutrons produced in the $T(d,\vec{n})^4He$ reaction at 29.8° (lab) were (+40 ± 3)% polarized, based on the data of Perkins and Simmons[9] and on the separate measurements of the $T(d,\vec{n})^4He$ polarization made during the present experiment. The cylindrical scattering sample, containing approximately 1 mole of liquid tritium, was placed at 10.2 cm from the neutron source at 29.8° (lab), and neutrons were scattered into two detectors over 2.5-m flight paths.

The detectors were massively shielded with copper, polyethylene, and tungsten. Corrections for differences in detector efficiencies were based on measurements with the detectors interchanged. The data were corrected for various other artificial asymmetries. Pulses remaining after n-γ discrimination were routed to an on-line SDS-930 computer which was used for preliminary data reduction.

The results at an incident neutron energy of 22.1 MeV are shown in Fig. B-1 and tabulated in Table B-I. Tivol's $^3He(\vec{p},\hat{p})^3He$ polarization data at 21.3 MeV[10] are also sketched to facilitate comparison of the main features. The results in Table B-I have been corrected for multiple scattering. It can be seen by comparison with the figure, where multiple scattering effects are not included, that multiple scattering corrections were small.

In preparation for the tritium measurements, observations of n-D polarizations were made at the same energy. These results are shown in Fig. B-2 and tabulated in Table B-II. Since these data were taken

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[7] T. A. Tombrello, Phys. Rev. 143, 772 (1966).

[8] J. D. Seagrave has described the liquid-tritium system in Few Body Problems, Light Nuclei, and Nuclear Interactions, Proceedings of the Symposium held in Brela, Yugoslavia, June 26-July 5, 1967 (Gordon and Breach, New York, 1969) Vol. 2, p. 787; the experimental setup for the asymmetry measurements is described in The Proceedings of the Conference on the Three-Body Problem, Birmingham, England, 1969 (North-Holland, Amsterdam, 1970) p. 787.

[9] R. B. Perkins and J. E. Simmons, Phys. Rev. 124, 1153 (1961).

[10] W. F. Tivol, "Proton-^{3}He Polarization in the Range from 10 to 20 MeV," Ph.D. Thesis, University of California, Berkeley (April, 1968).

only to validate the method, the comparison with the results of Malanify et al.[11] is satisfactory. Details of this experiment will be found in the thesis by R. K. Walter.[12] A paper combining all LASL work on n-D and n-T cross section and polarization work is in preparation.

TABLE B-I

$T(\vec{n},\hat{n})T$ Polarizations $P_2(\theta_2)$ at 22.1 MeV. θ_2 is the scattering angle.

$\theta_2$lab (deg)	θ_2c.m. (deg)	$\cos\theta_2$ c.m.	e	$P_2(\theta_2)$	δP_2 absolute	$(\delta P_2/P_2)$ relative	$P_2(\theta_2)$
40	52.4	0.610	-0.095	-0.24	0.071	0.055	-0.24
55	70.9	0.327	-0.14	-0.36	0.074	0.050	-0.36
70	88.3	0.029	-0.19	-0.47	0.080	0.052	-0.47
80	99.2	-0.160	-0.22	-0.56	0.092	0.086	-0.57
85	104.5	-0.250	-0.24	-0.59	0.10	0.110	-0.60
90	109.5	-0.334	-0.20	-0.51	0.10	0.130	-0.52
95	114.5	-0.414	0.13	+0.33	0.09	0.210	+0.33
100	119.2	-0.468	0.24	+0.59	0.10	0.140	+0.68
105	123.8	-0.557	0.34	+0.86	0.13	0.110	+0.95
110¼	128.5	-0.623	0.36	+0.90	0.12	0.086	+0.98
118½	135.6	-0.714	0.31	+0.77	0.10	0.062	+0.82

[11] J. J. Malanify, J. E. Simmons, R. B. Perkins, and R. L. Walter, Phys. Rev. 146, 632 (1966).

[12] R. K. Walter, Ph.D. Thesis, Brigham Young University (1970); Los Alamos Scientific Laboratory Report LA-4334 (1969).

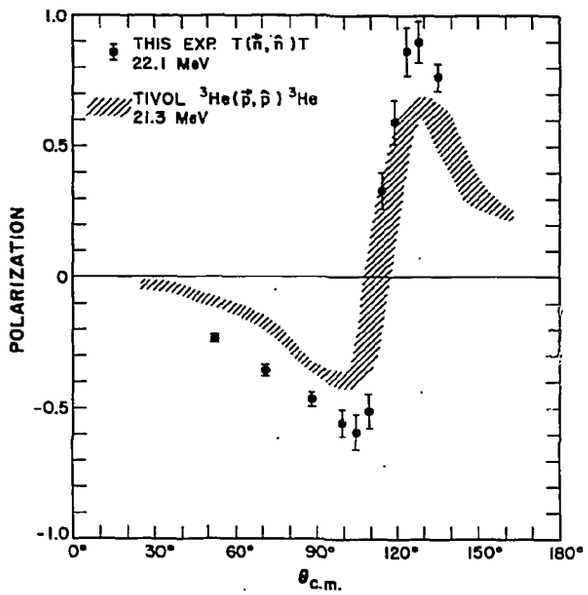

Fig. B-1. $T(\vec{n},\hat{n})$ polarizations at 22.1 MeV. Comparison is made with Ref. 10.

TABLE B-II

$D(\vec{n},\hat{n})D$ Polarizations $P_2(\theta_2)$ at 22.1 MeV.

E_n is the incident neutron energy. θ_2 is the scattering angle.

$\theta_2$lab (deg)	θ_2c.m. (deg)	$\cos\theta_2$ c.m.	e	$P_2(\theta_2)$	δP_2 absolute	$(\delta P_2/P_2)$ relative
40	58.8	0.518	-0.025	-0.063	0.066	0.17
50.5	73.2	0.288	-0.023	-0.057	0.070	0.35
73	101.6	-0.201	-0.078	-0.195	0.077	0.14
105	133.9	-0.694	+0.036	+0.091	0.094	0.74

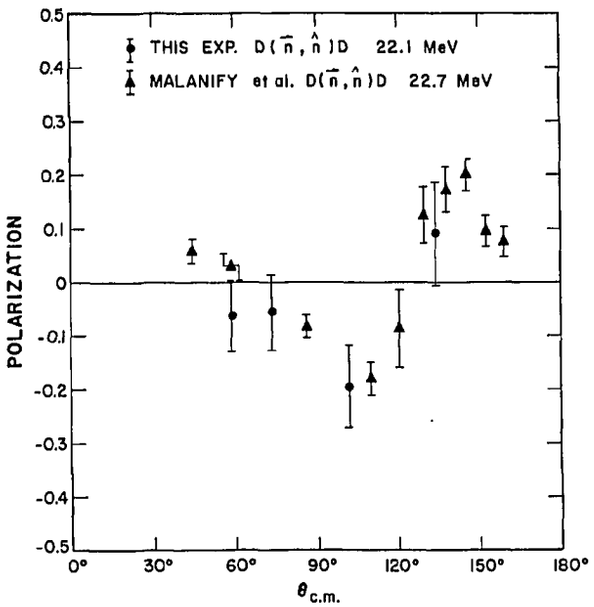

Fig. B-2. $D(\vec{n},\hat{n})$ polarizations at 22.1 MeV. Comparison is made with Ref. 11.

2. $^{12}C(n,n'\gamma)^{12}C$ (D. M. Drake)

Two more sets of data have been taken on the reaction $^{12}C(n,n'\gamma)^{12}C$. Angular distributions of the 4.44-MeV gamma ray have been taken at peaks and valleys of the resonances. All three runs appear to be internally consistent.

The efficiency of the gamma detector was measured using a PuBe source. In order to obtain a better number for how many gamma rays are emitted by this source, an experiment was done in which a carbon target was bombarded by 6.5-MeV protons. The strength of the PuBe source was measured by comparison to the number of gamma rays produced, and is within 1% of a previous and more difficult measurement made with neutrons.

The neutron flux for the $^{12}C(n,n'\gamma)^{12}C$ experiment was measured with a proton recoil telescope. A plot of "sample-out minus sample-in" telescope counts versus neutron energy should resemble the total neutron cross section. Such a plot of the data consistently shows an 80-100 keV shift from known resonances. This shift suggested recalibration of both the vertical and tandem accelerators, with the result of no change in the accepted calibration parameters for the tandem and only a small shift for the vertical. This problem is still unresolved.

3. Neutron-Alpha Particle Scattering (Niiler, Drosg, Hopkins, Martin, Seagrave, Kerr, and Sherman)

Work on the n-α elastic scattering angular distributions has continued at the newly completed time-of-flight facility in the Reaction Room of the tandem accelerator. Data for the neutron energy of 23.7 MeV have been collected. Further data up to $E_n \sim 31$ MeV are planned for this facility. Reduction and analysis of the 17.7- and 20.9-MeV data is continuing with the running of these data through the multiple scattering code MAGGIE2. An abstract on this work was submitted to the Washington, D. C., meeting of the APS.

4. Fast Fission Cross Section of ^{244}Cm (D. M. Barton and P. G. Koontz

Analysis of data and write-up is now in progress for the work done on measurement of the neutron-induced fission cross section of ^{244}Cm. Preliminary values given below are subject to further small corrections for radioactive decay, scattering, etc., as these factors are evaluated. The data at 1.0, 1.5, and 3.0 MeV reflect an improvement in the experiment which eliminated shifts in buncher parameters and considerably improved reproducibility in successive data sets.

Fabrication of targets for ^{245}Cm is still in progress at SRL and a similar measurement is planned for this curium isotope as soon as such targets become available.

E_n (MeV)	σ (barns)	approximate errors %
1.0	1.77	5
1.5	1.66	5
3.0	1.61	5
14.9	2.48	10

C. THERMAL NEUTRON CAPTURE GAMMA RAYS

1. Dy Isotopes (M. J. Bennett)

The relatively recent ^{160}Dy (n,γ) data are being incorporated into the analysis of the light odd-A Dy isotopes. If sufficient time is available on the capture gamma-ray facility, the ^{160}Dy and ^{158}Dy samples will be rerun with the new Ge(Li) detector and equipment in an attempt to see if any useful information can be obtained from the ^{158}Dy sample. It should at least be possible to obtain a more accurate neutron binding energy for ^{159}Dy.

2. Sm Isotopes (M. J. Bennett)

An abstract describing the ^{153}Sm research follows. The manuscript will be sent to Tallahassee for final changes and forwarded to Nuclear Physics.

Abstract: The nuclear levels of ^{153}Sm have been investigated by Ge(Li) and Si(Li) detector measurements of both high and low energy gamma-rays following thermal-neutron capture in ^{152}Sm, and by magnetic spectrograph measurements of the tritons from the $^{154}Sm(d,t)$ reaction. The observed states are classified within the Nilsson scheme as follows: the mixed $3/2^+[651\uparrow] + [402\downarrow]$ ground state band up to the $13/2^+$ member, the $3/2^-[521\uparrow]$ band to the $9/2^-$ member, the $3/2^-[532\downarrow]$ band to the $9/2^-$ member, the $11/2^-[505\uparrow]$ band head, the $3/2^+[402\downarrow] + [651\uparrow]$ configuration up to $7/2^+$ and the members up to $7/2^-$ of the highly mixed $1/2^-[521]$ band. Also, tentative assignments have been made of the $5/2^+$ and $7/2^+$ members of the $5/2^+[642\uparrow]$ configuration, the $1/2^+[660]$ band up to $5/2^+$, and some vibrational bands. The positive parity bands are observed to have their rotational energies severely distorted by strong Coriolis coupling. Strong $\Delta N = 2$ mixing is observed between the $3/2^+[651\uparrow]$ and $3/2^+[402\downarrow]$ orbitals. Comparisons are made with other 91 neutron nuclei and the calculations of Soloviev.

3. $^{16}O(n,\gamma)^{17}O$ (E. T. Jurney)

In the course of examining the (n,γ) spectrum from a target of BeO for possible impurities, four transitions from $^{16}O(n,\gamma)^{17}O$ were observed at approximately 870, 1080, 2185, and 3270 keV. We had observed these transitions several years ago in a NaI detector from a target of D_2O and reported a capture cross section for ^{16}O of 0.178 ± 0.025 mb (E. T. Jurney and H. T. Motz, Intl Conf. Nucl. Phys. with Reactor Neutrons, ANL 6797, 1963). In this earlier work the transition intensities were just above the sensitivity limits of the system, and, in fact, the 2185-keV transition could be seen only after background subtraction because it could not be resolved from the 2223-keV gamma ray following capture in ^1H present in the target. In the present measurements all four lines stand well above background and it should be possible to improve the accuracy of the O absorption cross section and of the four gamma-ray energies. An attempt will be made to confirm, and, if possible, to improve the accuracy of the accepted absorption cross section of Be.

4. $^{139}La(n,\gamma)^{140}La$. Higher Levels (E. T. Jurney)

The decay scheme for the lowest multiplet of states in ^{140}La arising from the mixed configuration $[\pi g_{7/2}\ \nu f_{7/2} + \pi d_{5/2}\ \nu f_{7/2}]$ has been studied. Immediately above these 14 states in energy lie 5 states intensely populated in the (d,p) reaction, followed by two weakly (d,p) populated states. The angular distributions and energies of these states suggest

that they might contain important components of the $\pi g_{7/2}\ \nu p_{3/2}$ and $\pi d_{5/2}\ \nu p_{3/2}$, with the states of spins 2, 3, and 4 strongly admixed.

The first 5 of these states are excited in the (n,γ) reaction by primary transitions strong enough to observe coincidences with gamma rays in the low-energy spectrum and thereby to determine unambiguously a significant portion of the decay of these levels. Extraction of spin and parity information through the observation of transitions to levels with known J^{π} is complicated, however, because it must be considered that E2 transitions can compete favorably with dipole transitions (to the degree that these higher states are not mixed the transitions would be pure E2; i.e., $\nu p_{3/2} \rightarrow \nu f_{7/2}$).

5. Nuclear Level Structure of ^{169}Er (M. E. Bunker, E. T. Jurney, and T. J. Mulligan)

The ^{169}Er paper has been extensively modified to include the more recent (n,γ) measurements and the results of additional Coriolis-coupling calculations. This paper was submitted to the Physical Review on February 18. The abstract follows:

Abstract: Levels in ^{169}Er have been studied through the reactions ^{168}Er(d,p)^{169}Er and ^{170}Er(d,t)^{169}Er, using 12-MeV deuterons, and via thermal-neutron capture in ^{168}Er. Over forty states below 1.5 MeV are populated in the charged-particle reactions. These data, coupled with the $\approx$ 150 capture gamma-rays observed, lead to a level scheme that includes the following spectroscopic assignments [rotational band-head energy in keV, followed by the Nilsson single-particle state believed to be dominant]: 0.0, $1/2^-$[521], with associated rotational band to spin $11/2^-$; 92.2, $5/2^-$[512], with band to $11/2^-$; 243.7, $7/2^+$[633], with band to $13/2^+$; 562.1, $1/2^-$[510], with band to $7/2^-$; 714.5, $3/2^-$[521], with band to $11/2^-$; 823, $7/2^-$[514], with band to $9/2^-$; 850, $5/2^-$[523], with band to $11/2^-$; and 1081.8, $3/2^-$[512], with band to $7/2^-$. In addition, a level at 860.2 keV is assigned as the head of a $K^{\pi} = 3/2^+$ band that is mainly the (K = 2) gamma-vibrational state associated with $7/2^+$[633]. The data suggest that the 562.1-, 714.5-, and 1081.8-keV bands also have significant vibrational admixtures. Several features of the level scheme, including certain gamma-ray branching ratios, are interpreted in terms of Coriolis mixing. The neutron separation energy for ^{169}Er is determined as 6003.1 ± 0.3 keV, and the Q-value for the ^{170}Er(d,t)^{169}Er reaction is found to be - 950 ± 30 keV.

D. FISSION ISOMER STUDIES (H. C. Britt, B. H. Erkkila, and W. E. Stein)

The study of the systematics of plutonium fission isomers has been completed and a paper describing these measurements has been accepted for publication in Phys. Letters.

A new series of experiments was started to study isomers formed by alpha particle bombardment of ^{237}Np, $^{239,240,242}Pu$, and ^{243}Am. The $^{237}Np(\alpha,2n)^{239m}Am$ reaction yielded an isomer with $T_{1/2} = 180^{+120}_{-60}$ nsec, isomer minus ground state threshold, $E_{II} = 3.0 \pm 0.2$ MeV and the peak isomer to prompt fission rate of $(8.5 \pm 1) \times 10^{-6}$. The half-life and threshold are in good agreement with values obtained by Lark et al.[13] from a (p,2n) reaction. The $^{239}Pu(\alpha,2n)^{241m}Cm$ reaction yielded an isomer with $T_{1/2} = 15.3 \pm 1$ nsec, $E_{II} = 2.6 \pm 0.2$ MeV and a peak isomer to prompt fission rate of $(2.3 \pm 0.2) \times 10^{-6}$. In this case the measured half-life agrees reasonably well with results obtained from a (d,2n) reaction by Polikanov and Sletten.[14]

Preliminary measurements on ^{243}Am show a weakly excited isomer with $T_{1/2} < 20$ nsec and an excitation function consistent with the $^{243}Am(\alpha,n)^{246m}Bk$ reaction. Failure to observe a strong isomer from the $^{243}Am(\alpha,2n)^{245m}Bk$ reaction suggests a limit $T_{1/2} < 5$ nsec for ^{245m}Bk.

Measurements at 25 MeV on ^{240}Pu and ^{242}Pu also indicate very weakly excited isomers with $T_{1/2} > 20$ nsec. These results are consistent with the production of ^{243m}Cm and ^{245m}Cm by (α,n) reactions. The results are consistent with a limit $T_{1/2} < 5$ nsec for fission isomers ^{242m}Cm and ^{244m}Cm which should be populated strongly by $(\alpha,2n)$ reactions.

E. RESEARCH IN SUPPORT OF NUCLEAR SAFEGUARDS

1. Delayed Neutron Yield from Fission as a Function of the Energy of the Neutron Causing Fission (M. S. Krick, A. E. Evans, C. F. Masters, M. M. Thorpe, and D. B. Smith)

Absolute delayed-neutron yields from fission of ^{235}U, ^{239}Pu, ^{233}U, and ^{242}Pu have been measured as a function of the energy of the neutron inducing fission in the range of neutron energies from thermal to 1.8 MeV.[15] In addition, the delayed-neutron yields of ^{239}Pu, ^{233}U, ^{238}U, and ^{232}Th were measured for 14.1-MeV and 3.1-MeV incident neutrons.[16] In these measurements, delayed neutrons were observed following bombardment of the fission samples with a modulated neutron beam. The number of fissions in the sample was monitored using two fission chambers which "sandwiched" the sample material.

Delayed neutrons were counted using a calibrated high-efficiency detector consisting of 13 ^{3}He proportional counters imbedded in polyethylene

[13] N. Lark, G. Sletten, J. Pedersen, and S. Bjørnholm, Nucl. Phys. A139, 481 (1969).

[14] S. M. Polikanov and G. Sletten, Preprint (1970).

[15] M. S. Krick and A. E. Evans, Bull. Am. Phys. Soc. 15, 87 (1970).

[16] C. F. Masters, M. M. Thorpe, and D. B. Smith, Nucl. Sci. Eng. 36, 202 (1969).

slabs.[17] Results obtained so far are shown in Table E-I, together with prior thermal- and fission-spectrum-neutron measurements[18] of delayed-neutron yields. It has been determined that the delayed neutron yield from fission is independent of incident neutron energy in the range from thermal to 3.1 MeV. There is, however, a decrease of approximately 40% in delayed-neutron yield when fission is induced by 14-MeV neutrons. Work is now underway to study the behavior of delayed-neutron yield in the incident-neutron energy range from 3.5 to 6.75 MeV, using $d(d,n)^3He$ neutrons from a Van de Graaff accelerator.

2. Abundances and Half-Lives of Delayed Neutron Groups from 14.9-MeV Fission (L. V. East, C. F. Masters, R. H. Augustson, and H. O. Menlove)

A program to measure delayed-neutron group abundances and half-lives from 14.9-MeV neutron-induced fission is in progress. To date, data have been obtained for ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, and ^{242}Pu using a $^3H(d,n)^4He$ neutron source. Results for ^{235}U, ^{238}U, and ^{242}Pu are shown in Table E-II. Results for the other isotopes are still being analyzed.

3. Delayed-Neutron Yield from the $^{17}O(n,p)^{17}N$ Reaction at 14.1 MeV H. O. Menlove, R. H. Augustson, and C. N. Henry[19])

Using the methods developed for the measurement of delayed neutron yields and half-lives from fission, the cross section for the production of delayed neutrons from the $^{17}O(n,p)^{17}N$ reaction at 14.1 MeV with subsequent beta decay to neutron-emitting states of ^{17}O was determined to be 21.5 ± 1.7 mb. The half-life for the decay of ^{17}N was measured and found to be 4.17 ± 0.02 sec, in agreement with prior determinations.

[17] L. V. East and R. B. Walton, Nucl. Instr. and Meth. 72, 161 (1969).

[18] G. R. Keepin, Physics of Nuclear Kinetics, P. 101, Addison-Wesley, 1965.

[19] H. O. Menlove, R. H. Augustson, and C. N. Henry, Nucl. Sci. Eng. 40, No. 1, 136 (1970).

TABLE E-I

ABSOLUTE DELAYED NEUTRON YIELDS

Element	Neutron Energy				
	Thermal[a]	Averaged 0.1-1.8 MeV	Fission[a] Spectrum	3.1 MeV	14.9 MeV
^{233}U	0.0066 ± 0.0003	0.0078 ± 0.0008	0.0070 ± 0.0004	0.0077 ± 0.0008	0.0043 ± 0.0004
^{235}U	0.0158 ± 0.0005	0.0171 ± 0.0017	0.0165 ± 0.0005	0.0180 ± 0.0018	0.0095 ± 0.0008
^{239}Pu	0.0061 ± 0.0003	0.0065 ± 0.0006	0.0063 ± 0.0003	0.0069 ± 0.0007	0.0043 ± 0.0004
^{242}Pu	- -	0.016 ± 0.005[b]	- -	- -	- -
^{238}U	- -	- -	0.0412 ± 0.0017	0.049 ± 0.005	0.0286 ± 0.0025
^{232}Th	- -	- -	0.0496 ± 0.0020	0.060 ± 0.006	0.031 ± 0.003

[a] Ref. 18

[b] 0.7 - 1.3 MeV

TABLE E-II

DELAYED NEUTRON ABUNDANCES AND HALF-LIVES IN 14.9-MeV FISSION

Group Index, i	Half-Life, T_i (sec)	Relative Abundance a_i/a
^{235}U (93% 235)		
1	50.6 ± 1.9	0.063 ± 0.006
2	19.59 ± 0.66	0.188 ± 0.003
3	4.95 ± 0.35	0.234 ± 0.024
4	1.95 ± 0.12	0.357 ± 0.021
5	0.41 ± 0.09	0.118 ± 0.027
6	0.16 ± 0.07	0.039 ± 0.033
^{238}U (99.7% 238)		
1	53.6 ± 5.1	0.023 ± 0.005
2	20.98 ± 0.81	0.148 ± 0.003
3	5.10 ± 0.51	0.162 ± 0.030
4	2.21 ± 0.15	0.369 ± 0.022
5	0.61 ± 0.07	0.183 ± 0.012
6	0.21 ± 0.02	0.115 ± 0.018
^{242}Pu (99.91% 242)		
1	53.7 ± 4.3	0.023 ± 0.005
2	21.6 ± 0.5	0.170 ± 0.003
3	5.3 ± 0.3	0.162 ± 0.020
4	2.1 ± 0.1	0.362 ± 0.010
5	0.71 ± 0.07	0.156 ± 0.010
6	0.24 ± 0.01	0.128 ± 0.010

F. CROSS-SECTION EVALUATION (P. G. Young and D. G. Foster, Jr.)

1. Hydrogen

The gamma-ray production cross section for the 2.22-MeV capture gamma ray has been added to the existing ENDF/B hydrogen evaluation. The cross section was taken from the evaluated (n,γ) data in file 3 of the present evaluation.

2. Nitrogen

A full-scale evaluation of the neutron cross sections for nitrogen is nearing completion. Particular emphasis has been placed upon establishing the total cross section as accurately as possible. Near $E_n = 8$ MeV, where a discrepancy has been noted[20] between the non-elastic cross section determined by summing the partials and that determined by subtracting the total from the elastic, we have assumed that the "missing" cross section lies in the elastic and (n,α) channels, with the greater contribution coming from the elastic. The evaluation includes $(n,x\gamma)$ cross sections and will be available in ENDF/B format.

3. Oxygen

A limited revision of the existing ENDF/B evaluation for oxygen has been performed, primarily to include gamma-ray production cross sections. The inelastic neutron cross sections were also revised (lowered) to agree with the $(n,n'\gamma)$ data that were added, and the total neutron cross section was increased somewhat at energies above 9 MeV to agree with recent time-of-flight measurements. The new data set is in ENDF/B format.

G. THEORETICAL STUDIES

1. Statistical Distribution of Kapur-Peierls Parameters for Fissile Nuclides (D. R. Harris)

A perturbation transformation has been developed[21,22] to clarify the interference transformation between the Wigner-Eisenbud and Kapur-Peierls cross section formalisms. The perturbation transformation is

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[20] J. K. Dickens and F. G. Perey, Nucl. Sci. Engrg. 36, 280 (1969).

[21] D. R. Harris, "Perturbation Transformation of Nuclear Cross-Section Parameters between Wigner-Eisenbud and Kapur-Peierls Formalisms: The PERTA Program," Los Alamos Scientific Laboratory Report LA-4327 (Jan. 1970).

[22] D. R. Harris, "Nuclear Reaction Cross Sections by Perturbation of the Inverse Level Matrix," Bull. Am. Phys. Soc. II, 14, 1215 (1969).

approximate but is relatively simple, and comparison of calculations from the PERTA[21] and POLLA[23] programs shows that it is adequate for cases of moderate multilevel interference such as that exhibited by the common fissile nuclides. An interesting and practical application is the inference of the statistical distribution of Kapur-Peierls parameters assuming Porter-Thomas and Wigner statistics for the Wigner-Eisenbud parameters. The perturbation theory indicates that a relevant variate is the product $y_n = x_1 \cdot x_2 \cdot \cdot \cdot x_n$ of n independent standardized normal variates, the distributions of which we have evaluated by Monte Carlo methods. In Fig. G-1 the total cross section interference parameter β_k introduced by the Adlers[24] is found to be distributed approximately as a normal product distribution y_n of order n approximately equal to 2-1/2 (as predicted by the perturbation transformation[21]) for 80 levels in ^{235}U.[24] Cramer[25] and others have found the reduced single level neutron width to approximate a Porter-Thomas variate; this corresponds to a y_2 distribution for the Adler parameter α_k. All interfering Kapur-Peierls parameters are correlated, but according to the perturbation transformation the ratio $\beta_k/\alpha_k^{1/2}$ is found to be approximately independent of α_k. A characteristic of the perturbation transformation is the approximate invariance of level energies and total level widths between the Wigner-Eisenbud and Kapur-Peierls formalisms. Thus, the Wigner level spacing distribution is applicable to Kapur-Peierls level sequences for these nuclides.

2. Nucleon-Nucleon Scattering (Hopkins; G. Breit, SUNY at Buffalo)

The LASL computer code that calculates the neutron-proton scattering observables was expanded to include 22 phase shifts, through $\ell = 5$, and 5 coupling parameters. It was also modified to include relativistic effects. In addition, the code now automatically interpolates phase shift tables using spline techniques. This code is called NPSCAT and is being used in a study of the n-p cross section as a nuclear standard.

The proton-proton scattering code PPSCAT was similarly modified to be used by Jett, Jarmie, and Detch in the analysis of their p-p scattering data.

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[23] G. de Saussure and R. B. Perez, "POLLA, a FORTRAN program to Convert R-Matrix-Type Multilevel Resonance Parameters for Fissile Nuclei into Equivalent Kapur-Peierls-Type Parameters," Oak Ridge National Laboratory Report ORNL-TM-2599 (June 1969).

[24] D. B. Adler and F. T. Adler, Proc. Conf. Breeding, Economics, and Safety in Large Fast Reactors, Argonne National Laboratory Report ANL-6792 (1963) p. 695.

[25] J. D. Cramer, "A Multilevel Analysis of the U^{235} Fission Cross Section," Nucl. Phys. A126, 471 (1969).

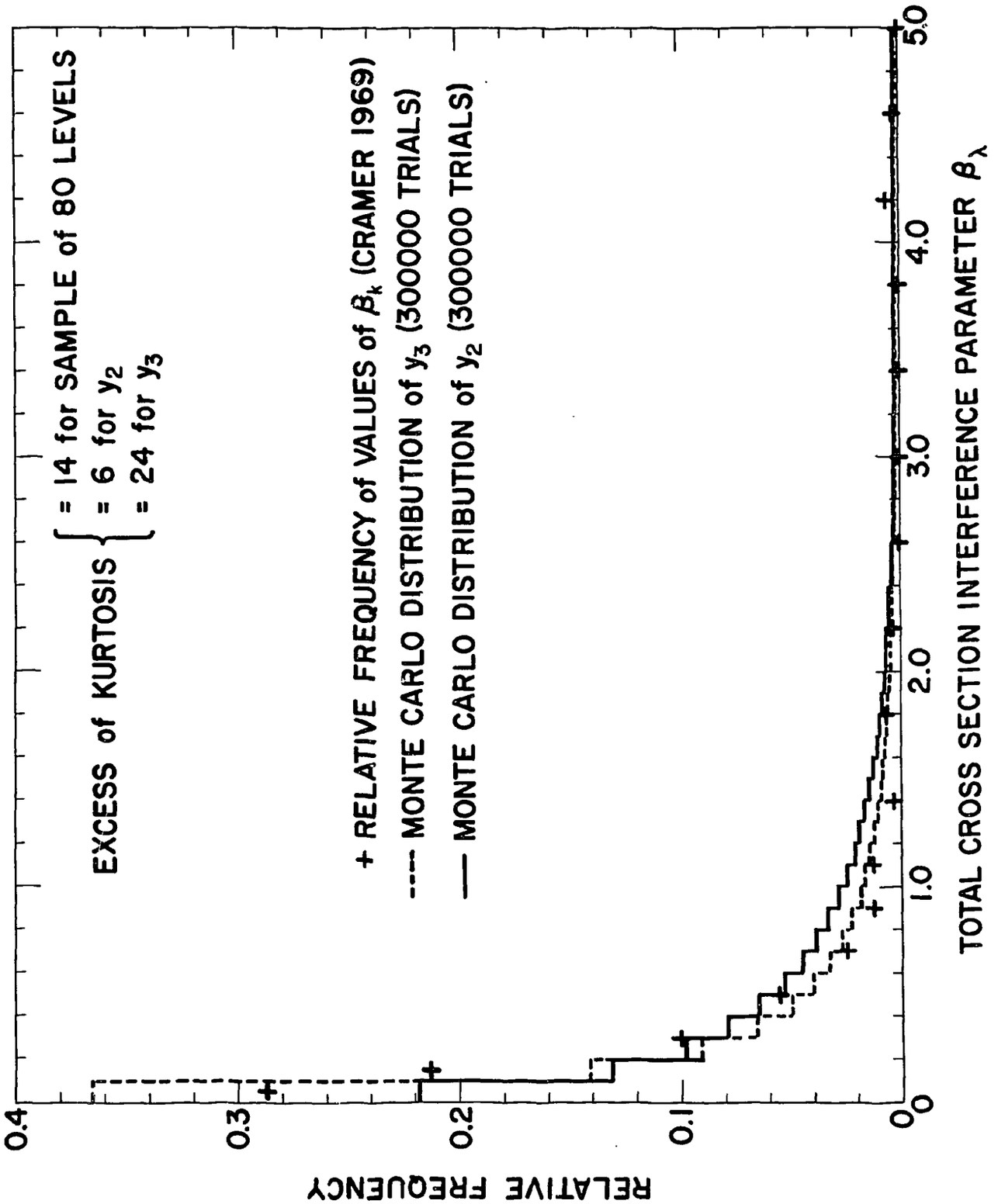

Fig. F1. Probability distribution of the Adler total cross section parameter β_k for ^{235}U, as determined by the analysis of J. D. Cramer.[25] Plotted also, as solid and dashed histograms, respectively, are the normal product distributions $y_2 = x_1 \cdot x_2$ and $y_3 = x_1 \cdot x_2 \cdot x_3$.

Both codes are being used in studies of the neutron polarization to be expected from the neutron source at the Nucleon Physics Laboratory of the LAMPF.

H. LIQUID FUEL HIGH INTENSITY NEUTRON SOURCES (L. D. P. King)

Work is proceeding on testing the properties of 3.1 M uranyl sulfate fuel (with additives) under the extreme pressure-temperature-time conditions found in a full-scale Liquid Excursion Pulsed Reactor (LEPR). Planned experiments make use of two methods for obtaining 10^6-10^7 calories/liter energy deposition in the fuel samples.

One method will heat the fuel by means of a 150 joule neodymium-doped laser focused on a 0.1 ml fuel sample. An expansion of a factor of 1000 is permitted for the fuel vapor. The nanosecond pulse width of the laser assures full energy deposition before fuel disassembly can occur.

The second heat source will be a large burst from the Livermore Super Kukla burst reactor. A 10-20 microliter fuel sample will be used with little or no free expansion. The long pulse width (1200 microsecond) requires fuel confinement during the pulse in order to assure full energy deposition without fuel disassembly and simultaneity in the temperature and pressure peaks. A capsule has been designed and tested with 0.8 g of explosive.

Static criticality tests of the basic reactor geometry for the Kinetic Intense Neutron Generator (KING) reactor have been completed. All components for the dynamic critical tests are on hand after considerable delay in the procurement of a suitable pump. Initial dynamic testing of the 0.4 M uranyl sulfate fuel (plus additives) are expected to begin in July.

NATIONAL BUREAU OF STANDARDS

A. NEUTRON PHYSICS

1. MeV Neutron Total Cross Sections (R. B. Schwartz, R. A. Schrack, and H. T. Heaton II)

We have recently completed measurements of the total neutron cross section of carbon in the energy range 0.5 to 15 MeV and of nitrogen in the energy range 0.5 to 25 MeV. The results are shown in Figures A-1 and A-2, respectively. In both cases, the resolution was approximately 0.1 nsec/m, and the absolute accuracy was estimated to be within 2%.

In general, where other data exist, our results are in good agreement. Particular mention should be made of the excellent agreement in the carbon cross section from 0.5 to 1.5 MeV between our results and the recent Argonne data of Meadows and Whalen. In this case, the differences in the two measurements are within 1/2% or less. The higher energy regions of our carbon data are in good agreement with the data of Yergin et al (RPI), Glasgow and Foster (Hanford), and Wisconsin, except for a discrepancy from 3 to 4 MeV. Our data, in excellent agreement with Glasgow and Foster, and Yergin et al., are some 5% to 7% higher than the Wisconsin results in this region.

Our nitrogen data, allowing for differences in resolution, are in excellent agreement with Glasgow and Foster and with the recent results of Carlson and Cerbone (GGA), except for a $\sim$ 3% discrepancy around 0.5 MeV. As a check on our internal consistency, we have just run a second nitrogen sample. (Both samples were liquid nitrogen: the first had an "n" of 0.9 atoms/barn; the second was 0.4 atoms/barn.) Preliminary analysis indicates good agreement between the two sets of data, so that we have no explanation for this discrepancy. As a further check on our internal consistency, we have also run a melamine sample over the energy range 5 to 18 MeV. The melamine results agree with the thick liquid nitrogen results to within 0.7%.

We have just completed measurements of the silicon total cross section. The data are not yet completely analyzed, but preliminary results show discrepancies with the low-energy results of Cabe et al. (Saclay). In particular, our data show a considerably higher peak cross section for the large resonance at 570 keV, and a sharp minimum in the cross section at about 650 keV.

We are continuing to analyze our data for evidence of intermediate structure, using self-correlation analysis as proposed by Pappalardo. While we have made significant refinements in the mathematical techniques, we have yet to find any cases of intermediate structure beyond those already pointed out by Elwyn and Monahan.

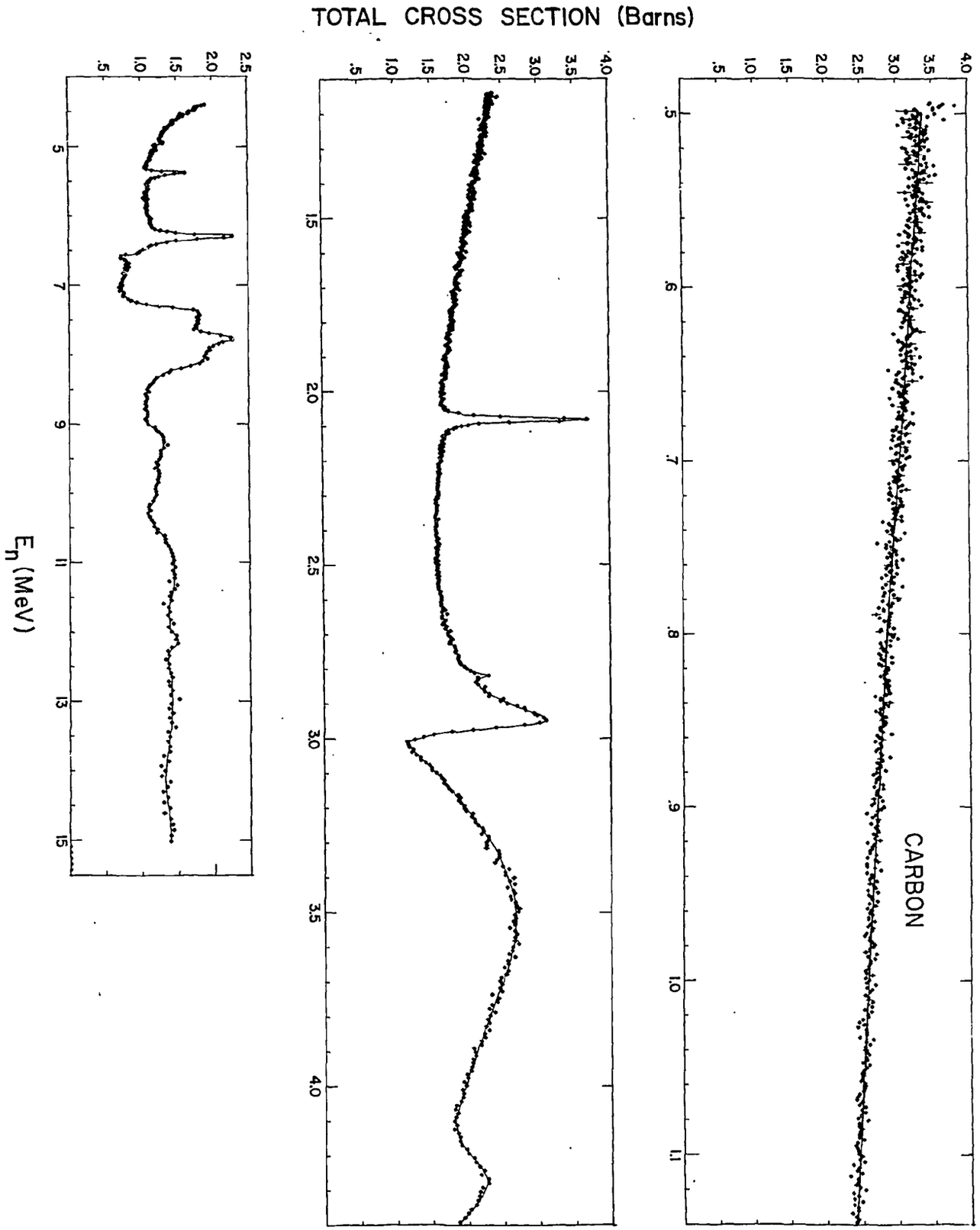

Fig. A-1

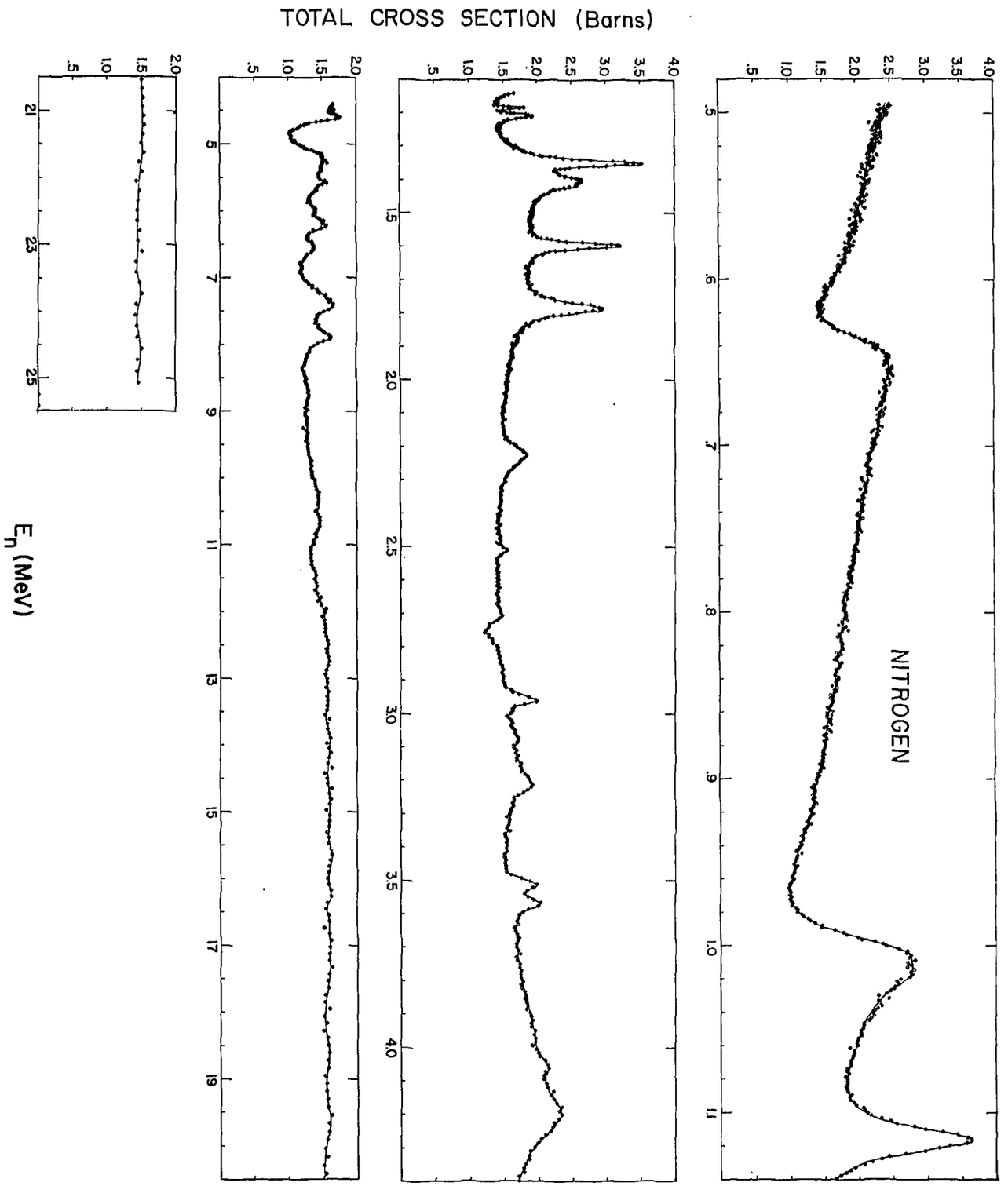

Fig. A-2

NUCLEAR EFFECTS LABORATORY, U.S. ARMY

A. SMALL-ANGLE ELASTIC SCATTERING OF NEUTRONS FROM CARBON, NITROGEN, AND OXYGEN (W. P. Bucher, C. E. Hollandsworth, R. R. Sankey)

(Work pertinent to Requests #31, #33, #39, #40, #44 WASH 1144 - Draft version)

A technique to measure the small-angle (2° to 15°) elastic scattering of fast neutrons has been devised. Scattering of 7.5 MeV neutrons from carbon has been observed at 3° and 10° in preliminary measurements. The assembly of dewars to contain liquid nitrogen and liquid oxygen scatterers is in progress. Measurements at several energies between 7.5 and 14 MeV are planned for the coming months.

B. NEUTRON ACTIVATION CROSS SECTIONS AT 14.1 MeV (J. K. Temperley, D. E. Barnes)

Fast-neutron activation cross sections for isotopes of ruthenium, palladium, and tin have been measured relative to the $^{56}Fe(n,p)^{56}Mn$ cross section. Powdered metallic samples of natural-isotopic-abundance Ru, Pd, and Sn were irradiated with (14.1 ± 0.5)-MeV neutrons. The activities produced were determined by observing the gamma radiation with a Ge(Li) detector. The cross sections measured are listed in the following table:

Reaction	σ(mb)
$^{96}Ru(n,2n)^{95}Ru$	600 ± 70
$^{96}Ru(n,p)^{96g}Tc$	160 ± 20
$^{96}Ru(n,d)^{95g}Tc$	200 ± 120
$^{96}Ru(n,d)^{95m}Tc$	76 ± 17
$^{98}Ru(n,2n)^{97}Ru$	970 ± 110
$^{99}Ru(n,p)^{99m}Tc+^{100}Ru(n,d)^{99m}Tc$	10 ± 2
$^{102}Ru(n,d)^{101}Tc+0.54\,^{101}Ru(n,p)^{101}Tc+0.59\,^{104}Ru(n,\alpha)^{101}Mo$	16 ± 2
$^{102}Ru(n,\alpha)^{99}Mo$	3.4 ± 0.4
$^{104}Ru(n,2n)^{1}$ [illegible] $+^{104}Ru(n,d)^{103}Tc$	1570 ± 180

$^{102}Pd(n,2n)^{101}Pd$	600 ± 70
$^{102}Pd(n,d)^{101m}Rh$	580 ± 160
$^{106}Pd(n,d)^{105m+g}Rh+0.81\,^{105}Pd(n,p)^{105m+g}Rh$ $+1.11\,^{108}Pd(n,\alpha)^{105}Ru$	28.0 ± 3.0
$^{110}Pd(n,2n)^{109m+g}Pd+^{110}Pd(n,d)^{109m+g}Rh$	950 ± 110
$^{112}Sn(n,2n)^{111}Sn$	900 ± 100
$^{112}Sn(n,d)^{111m+g}In$	190 ± 160
$^{114}Sn(n,2n)^{113m+g}Sn$	1090 ± 130
$^{116}Sn(n,p)^{116m}In+0.53\,^{117}Sn(n,d)^{116m}In$	9.5 ± 1.1
$^{118}Sn(n,2n)^{117m}Sn+0.32\,^{117}Sn(n,n')^{117m}Sn$	880 ± 100
$^{118}Sn(n,d)^{117m}In+0.32\,^{117}Sn(n,p)^{117m}In$	2.2 ± 0.4
$^{124}Sn(n,2n)^{123m}Sn+^{124}Sn(n,d)^{123}In$	540 ± 60

OAK RIDGE NATIONAL LABORATORY

1. Oak Ridge Electron Linear Accelerator (ORELA) (J. A. Harvey and F. C. Maienschein)

On August 25, 1969, the accelerator was accepted from Varian Associates having met essentially all specifications, and experiments were started immediately. Table 1 summarizes the accelerator operation up to April 1, 1970. With 3 accelerator operators, 5-days-per-week operation is possible with 8 hours of routine maintenance on Mondays. Occasionally a week shutdown is planned for major tests on the accelerator and improvements. We feel that the average operation of 71% of the scheduled time is very satisfactory for such an advanced high-current, high-beam-power electron linear accelerator. Three klystrons have operated over 2500 hours (with one failure at 3005 hours).

Suitable neutron-producing targets, collimators, beam stops, filter changers, and sample changers have been designed, fabricated, and installed. Experiments are now in progress on 4 flight paths, and collimators, etc., have been installed in 2 other flight tubes. As many as 5 experimenters have taken data or have been "debugging" experimental equipment at one time although the average is $\sim$ 2 experimenters. In addition to the specialized data collection equipment that is directly used by experimenters, the two ORELA computers have accumulated data into $\sim 2^{17}$ channels on the fixed head disks at rates of thousands per second.

A summary of the experiments in progress are being "debugged" and the experimenters are given in Table 2.

Other experimenters planning experiments are as follows:

H. Rosler, F. Plasil, H. W. Schmitt - high resolution, fission cross section measurements;
J. L. Fowler, C. E. Johnson - angular distributions of elastically scattered neutrons in the MeV energy region;
W. M. Good - total cross sections in the keV energy region;
R. W. Peelle and L. W. Weston, Neutron Physics Division - experiments on accurate fission cross section measurements.

Table 1. Utilization of the ORELA in Percent of a 120-Hour Week

ORELA Operation - 8-25-69 to 3-26-70

	8-25-69 to 9-30-69	10-1-69 to 10-31-69	11-1-69 to 11-30-69	12-1-69 to 12-31-69	1-2-70 to 1-31-70	2-2-70 to 2-28-70	3-2-70 to 3-26-70	TOTALS 8-25-69 to 3-26-70
Research Hours	272.2	216.4	243.5	315.0	273.9	292.5	167.0	1780.5
Scheduled Maintenance Hours	32.0	-	48.0	40.0	32.0	32.0	32.0	216.0
Unscheduled Maintenance Hours	14.8	307.6	14.5	24.3	28.9	114.9	218.4	723.4
Availability (%)	94.8	41.3	94.3	93.0	90.5	71.8	43.3	71.1

Table 2. Research Activities on ORELA

Flight Path No.	Flight Path Length (Meters)	Type of Experiment	Experimenters	Division
1	18,80 200 (under construction)	Transmissions of small samples of enriched and radioactive isotopes, ^{116}Sn, ^{243}Am. etc.	J. A. Harvey G. G. Slaughter	Physics
			R. W. Benjamin C. E. Ahlfeld	Savannah River
			F. B. Simpson O. D. Simpson	Idaho Nuclear Corp.
	10	Gamma-ray spectral measurements from resonance capture, ^{238}U, etc.	G. G. Slaughter J. A. Harvey	Physics
			R. E. Chrien O. A. Wasson	BNL
5	20	Measurement of η of ^{233}U near thermal energies	L. W. Weston	Neutron Phys.
6	40	Capture cross sections using a large scintillator tank, ^{238}U, α of fissile nuclides.	G. de Saussure R. Gwin R. Perez E. G. Silver L. W. Weston	Neutron Phys.
7	40	Capture cross sections of ^{10}B, ^{12}C, & ^{13}C and nuclides of interest to nucleosynthesis.	R. L. Macklin B. J. Allen	Physics
2	10 & 16	Fission measurements with aligned nuclei and transmission measurements with polarized neutrons (being installed).	J. W. T. Dabbs W. W. Walker* J. C. Clark**	Physics
9	30, 40	MeV neutron shielding studies (being installed)	E. A. Straker C. E. Burgart T. A. Love	Neutron Phys.

*University of Alabama (Sabbatical leave assignment with ORNL Physics Division 1969-1970).

**Oak Ridge Graduate Fellow under appointment with Oak Ridge Associated Universities.

2. Fast Neutron Capture Experiments Using the ORELA (R. L. Macklin and B. J. Allen*)

The Oak Ridge Electron Linear Accelerator (ORELA) has been designed and built primarily for accurate, high-resolution, neutron time-of-flight

The pulse height weighting technique has been applied to radiative neutron capture cross section measurements using the Oak Ridge Electron Linear Accelerator. The electron beam hits a water cooled tantalum target at the center of a disc of hydrogenous moderator. A copper and lead bar centered in the (40 meter) flight path blocks the fast neutrons and gamma rays coming directly from the tantalum while allowing the moderated neutrons to illuminate the sample. With a typical sample (0.5 mm thick Ta) the residual gamma flux in the beam induces a 500 keV pulse height in each (of two) detectors for 2.5 ns pulses and less than 14 MeV total for maximum intensity pulses. Using fast tunnel diode discriminators, the random background level is observed in an interval from 0.3 to 0.4 microseconds after each linac pulse.

The $^{10}B(n,\alpha\gamma)$ count rate at 40 meters corresponds to about 2900 n/cm^2-sec-per logarithmic energy interval (lnE) near 70 keV for full linac power. In addition to the ^{10}B sample flux measurement we use in the beam line a conventional $^{10}BF_3$ ion chamber with beryllium windows, a similar ^6LiF coated chamber with much better time resolution and, for the higher energies, a polythene proton recoil foil viewed by a surface barrier detector. The time dependent background from the accelerator as measured by the black resonance technique is less than 1% (below 105 keV).

Capture resonances in ^{13}C at 153 keV and ^{16}O at 442 keV have been observed. Two narrow resonances at $E_n = 96.6 \pm 0.5$ keV and $E_n = 111.4 \pm 0.5$ keV have been observed superimposed on the broad 105 keV s-wave resonance in sulfur in a transmission measurement using the $^{10}B(n,\alpha\gamma)$ reaction for neutron detection. Resonance structure is observed in the 0.5 - 2.8 microsecond range (1 - 30 MeV) for these targets at 40 meters, and is interpreted as evidence of inelastic scattering.

*On assignment from the Australian Atomic Energy Commission.

measurements. With 140 MeV electron pulses as short as two nanoseconds and peak currents up to 18 amperes it represents a significant advance in capability for this work. Among the dozen or so experiments in progress is a facility for measuring capture cross sections in the kilo-electron volt range. The sensitivity is adequate for 10^{-1} to 10^{-2} mole quantities of separated isotopes. In addition to the obvious interest to the AEC liquid metal fast breeder program this field can contribute significantly to our sketchy knowledge of p-wave and d-wave nuclear interactions and to quantitative understanding of the formation of the heavier chemical elements in nature.

Target and Moderator

Several model targets and moderators for neutron production were studied.[1,2] To handle the designed 50 kW electron beam, water cooled tantalum (rather than tungsten or uranium) was chosen on the basis of contemporary favorable experience with it at Rensselaer Polytechnic Institute. Intensity and resolution were studied for 1-10^5 eV neutrons as a function of moderator configuration and dimensions. A moderator slab beside the target or a pair on each side with B_4C decoupling layers did not appear advantageous compared to the halo design chosen. This last was a disc with the target centered in a hole at its center. A (radial) slot was cut for the electron beam. The recommended disc radius of 7.5 cm (H_2O) was calculated to give 90% of the infinite radius intensity, calculated for a point isotropic source of 1 MeV neutrons at the center of the target. Figure 1 indicates calculated quantities for several thicknesses of moderator. The total intensity appears to rise somewhat even beyond the 3.2 cm moderator thickness finally adopted and this is an advantage in some experiments at the lower energies. For high resolution work a figure of merit is more nearly the ratio of the intensity to the square of the time spread (or the equivalent flight path length uncertainty) introduced by the moderator. The figure of merit (dashed line - Figure 1) is seen to peak near 2.3 cm but not to fall off rapidly at a greater moderator thickness.

In addition to intensity, resolution and flux calculations for a flight path normal to the moderator face (i.e. perpendicular to the electron beam), the same quantities were tabulated for flight paths 15° and 30° from the normal. The flight path used in the present studies is at about 13° to the normal and gives a computed resolution due to the 3.2 cm thick moderator equivalent to a spread of 3.2 cm (FWHM) in flight

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[1] R. L. Macklin, G. de Saussure, R. C. Block, and later L. W. Weston served on the ORELA Target and Cell Planning Committee.

[2] J. R. Stockton, A. M. Craig, and G. J. Sullivan adapted the 05R Monte Carlo code to the model studies.

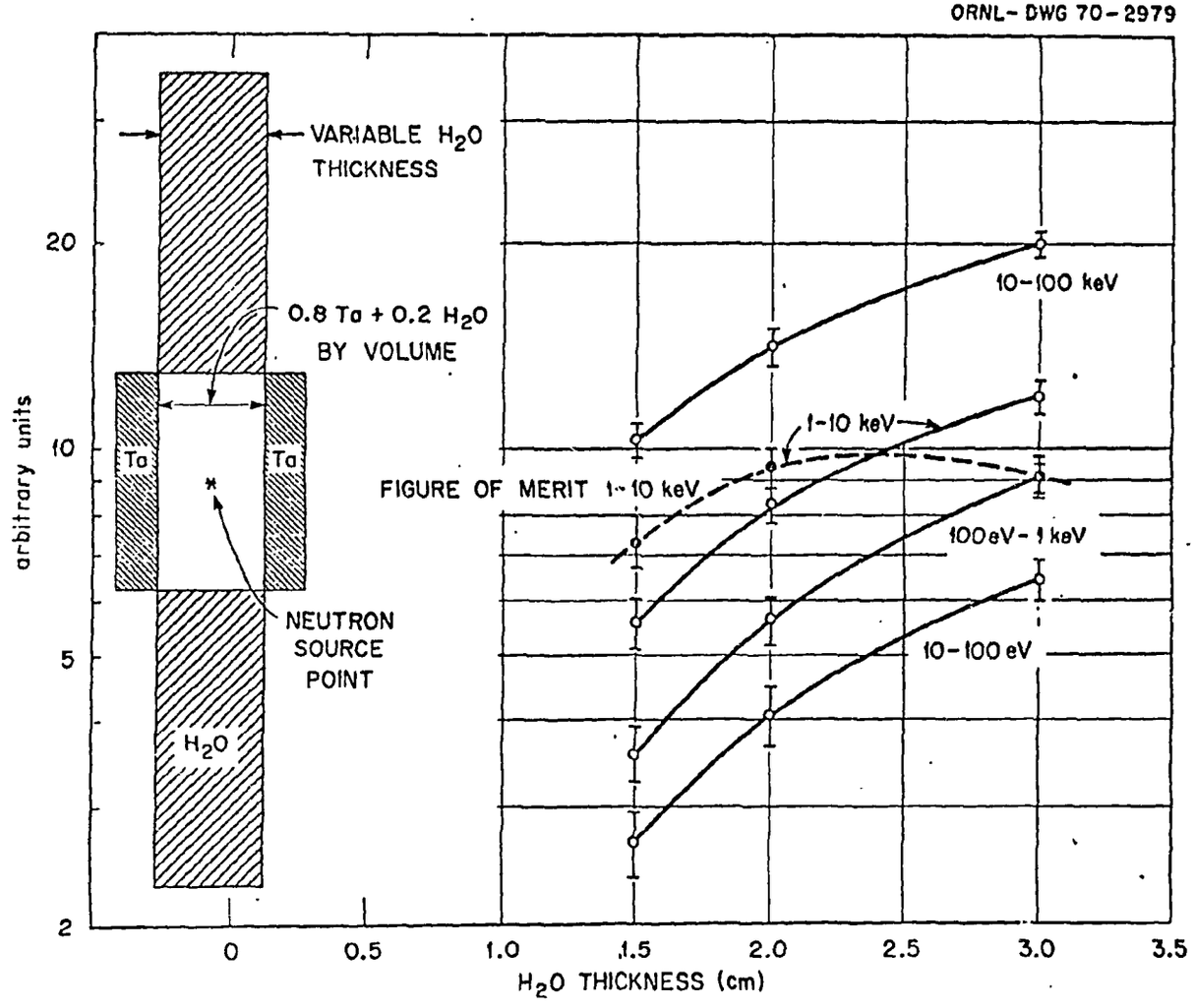

FIG. 1

Intensity vs Thickness; 7.5 cm Radius Moderator.

path. The intensity from the moderator is calculated to be 6% less than for the flight paths normal to the moderator. The energy spectrum below a few tens of keV is roughly of the form $E^{-0.82}$ (per eV), as also calculated by Michaudon[3] and found experimentally.[4] This corresponds to an average leakage probability per collision in the moderator of $\sim$ 8%.

The fraction of neutrons reaching thermal energies in the moderator is estimated to be 3×10^{-4} and 12% of these should be captured by hydrogen to give 2.2 MeV gamma rays. This thermal capture should show an exponential period of about 24 μsec in such a small high leakage system. Thus, for a flight path of 40 meters, the ratio of 2.2 MeV gamma flux to neutron flux should peak for neutrons of about 10 keV energy, at 5×10^{-4}.

Collimation and Beam Dependent Background

Copper was chosen for the collimator jaws for several reasons. The elastic scattering angular distributions are not too strongly forward peaked and the inelastic scattering is strong. The density is fairly high leading to neutron mean free paths near 4 cm even at many tens of MeV. With two stable isotopes, interference minima in the cross sections present little problem, the worst is at 7.2 keV where the mean free path rises to about 6.5 cm. The (γ,n) cross section is much smaller than for the high Z materials, yet the energy loss on scattering is much less than for the low Z materials. A total of 57 cm of copper was used for neutron attenuation outside the beam, backed up with 15 cm of lead for additional gamma ray attenuation.

The scatter and trap design is indicated in Figure 2 as it was used for Monte Carlo calculations.[2,5] The borated concrete regions are kept out of the direct beam after the first collimator and out of the line of sight from the target through the last collimator. Thus neutrons scattered by the copper can be moderated and absorbed in the borated concrete with little chance of detection. The Monte Carlo results indicate only 10^{-6} of the flux at 40 meters has lost > 0.01% of its energy or arrived > 0.05% late compared to the unscattered beam. Most neutrons suffering less than five collisions in the collimation system and then reaching the detector remain within these resolution limits. Indeed, 65% of all such scattered neutrons remain "good." The average

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[3] A. Michaudon, J. Nuclear Energy A/B 17, 165-186 (1963).

[4] G. de Saussure, private communication.

[5] R. L. Macklin, L. W. Weston, and G. de Saussure served on the ORELA Flight Path Committee.

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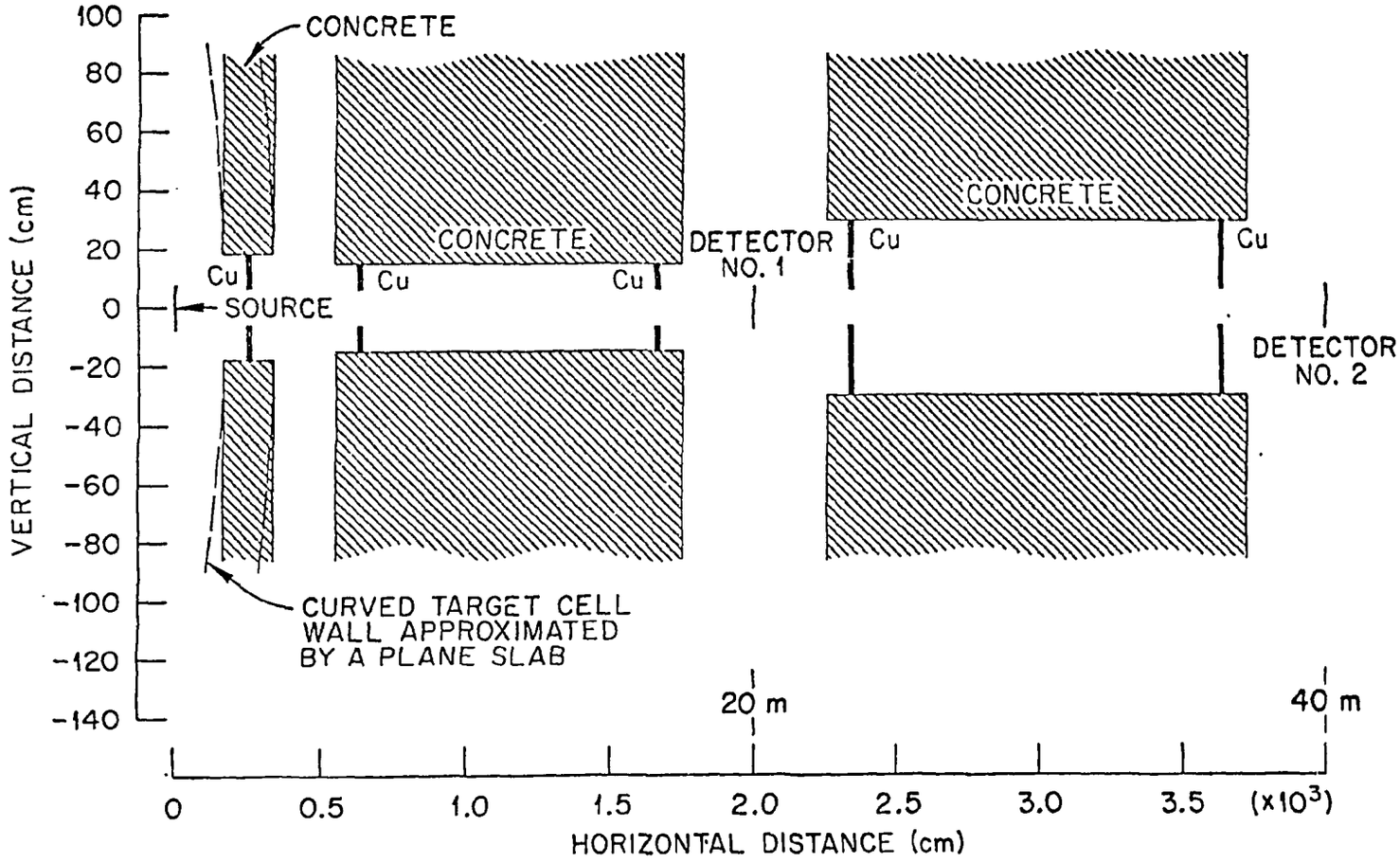

Test Collimator Calculation for ORELA.

FIG. 2

energy loss in the degraded tail ranged from 4% at 5 MeV to 10-20% at a few keV.

At energies up to 35 keV, overall neutron backgrounds measured with a $^{10}BF_3$ chamber and "black resonance" filters are less than 0.5%.[4] At 105 keV using a 5 cm sulfur filter and $^{10}B(n,\alpha\gamma)$ detector we find an upper limit of 1%. The steep rise of the $^{27}Al(n,n'\gamma)$ yield above 1013 keV (Figure 3) indicates a similar limit near 1 MeV.

Experimental Apparatus

Two fluorocarbon liquid scintillator[6] cells flank the collimated beam at 40 meters to detect neutron capture gamma rays from a separated isotope sample placed between them in the neutron beam. The technique of weighting each count according to its pulse height to obtain a statistical measure of the total gamma ray energy has been described previously.[7] To reduce the fast neutron flux and the gamma flash from the target a 57 cm copper plus 15 cm lead shadow bar is centered in the first collimator. This shadows the tantalum target region while allowing full illumination of the samples by the moderator. The residual gamma flash scattered into the detectors (whose linear outputs are summed) is less than typical neutron binding energies for high resolution conditions (electron pulses 2-5 ns, 15A. peak current).

The collimated beam passes through an ion chamber with beryllium windows for flux monitoring. A $^{10}BF_3$ chamber has been used successfully and a ^{6}LiF coated chamber is undergoing tests. A polythene foil inclined at 30° to the beam and viewed by a surface barrier detector has been constructed for proton recoil flux monitoring but is not yet in operation.

Results

Figure 4 shows a time of flight spectrum through a 2 cm sulfur filter. A 0.5 gm/cm^2 ^{10}B overlap filter was also used and the detector was a small ^{10}B powder sample. The transmission dips at 96.6 $\pm$ 0.5 keV and 111.4 $\pm$ 0.5 keV are attributed to p-wave resonances in ^{32}S within the width of the large 105 keV s-wave resonance. The resolution of the lower energy resonance is instrumental and about four times worse than that which can be expected for the shortest electron pulse widths. The

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[6] Nuclear Enterprises NE-226.

[7] R. L. Macklin and J. H. Gibbons, Phys. Rev. 159, 1007 (1967).

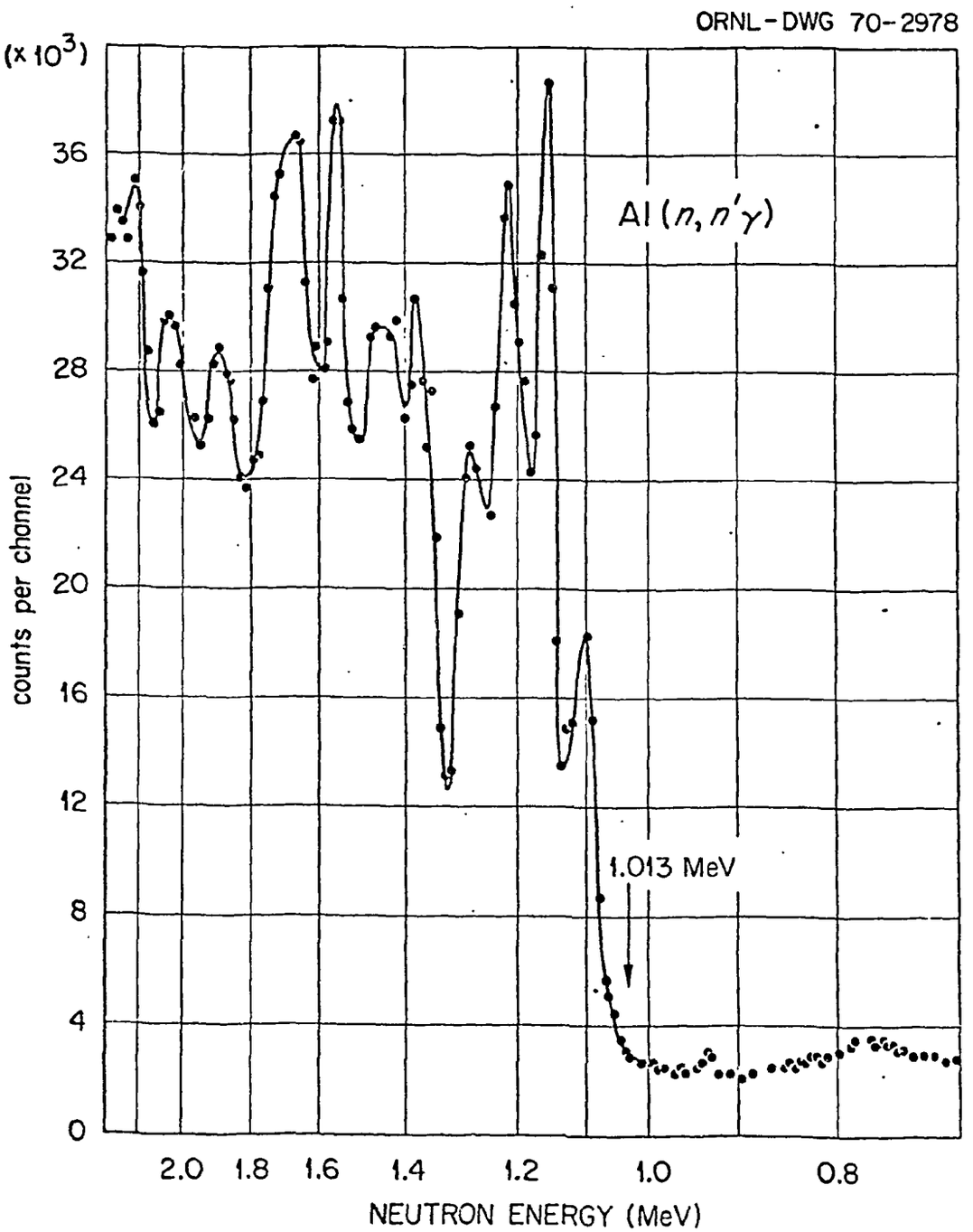

FIG. 3

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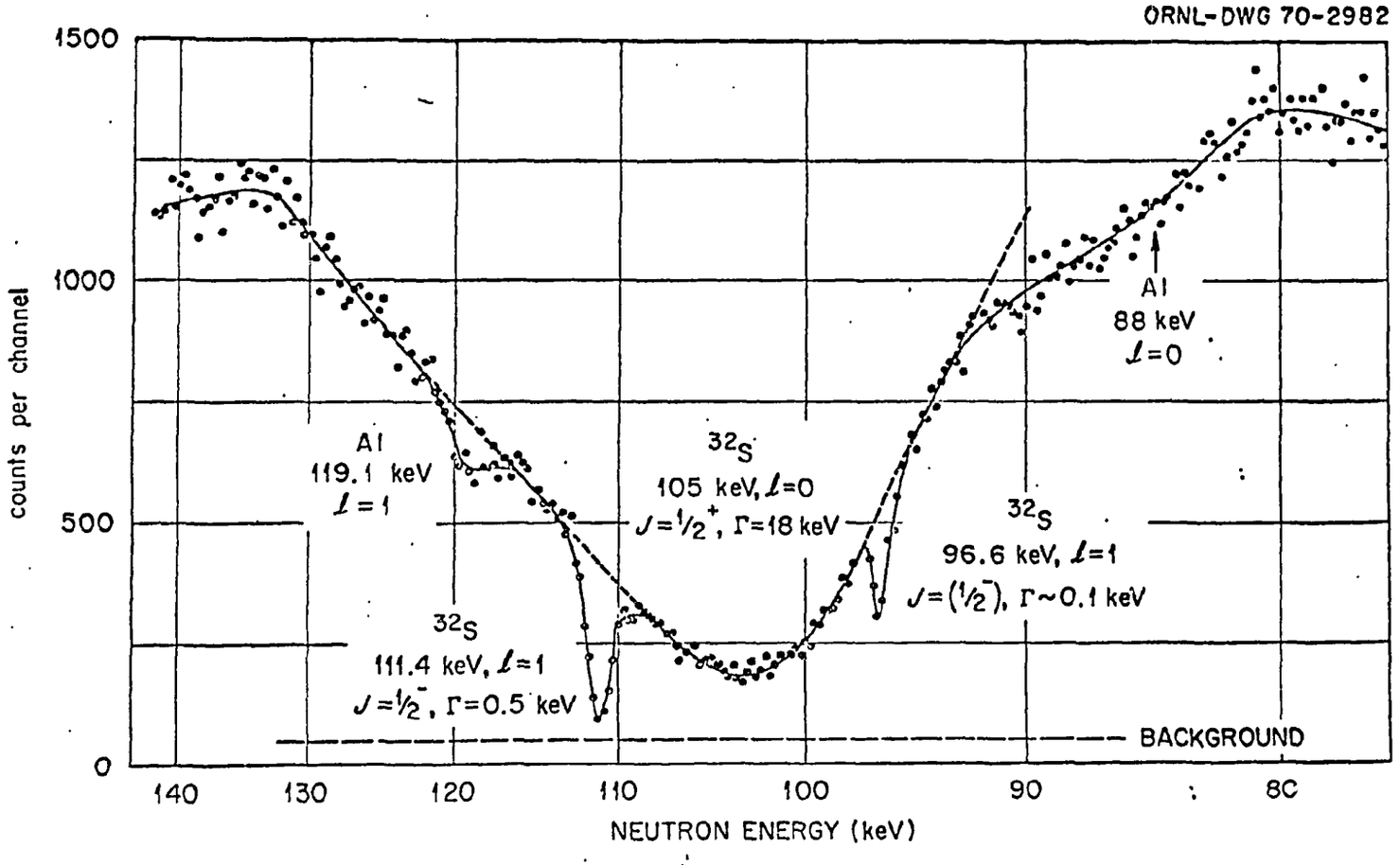

Transmission in Sulphur at 105 keV.

FIG. 4

total widths of the two resonances, interpreted as $J = 1/2^-$ states, are $\sim$ 0.1 and 0.5 lab keV respectively. The radiative widths have not been determined. An estimate of the flux at the 70 keV interference dip was made from the $^{10}B(n,\alpha\gamma)$ yield, extrapolating to 2900 n/cm^2 sec per logarithmic (lnE) energy interval for full linac power (50 kW). While the 530 keV resonance is not seen in the $^{10}B(n,\alpha\gamma)$ yield, a better flux shape measurement will be needed before a meaningful limit on the partial width can be determined.

Capture was observed at 153 keV in ^{13}C using a one gram sample enriched to 48% ^{13}C. The measured resonance total width was 4.5 keV, about half of that reported earlier.[8] Capture was also observed in the 442 keV resonance in ^{16}O using BeO as a sample. Radiative width results for these two resonances will not be reported until subsidiary experiments on effects of locally scattered neutrons are completed.

Conclusions

A capability for measuring neutron capture cross sections using less than 0.1 mole samples of separated isotopes has been demonstrated. Energy resolution better than 0.3% should be achievable below 1 MeV (< 80 ps/m) with time dependent backgrounds less than 1% of the beam intensity.

3. High Resolution Neutron Transmission Measurements on ^{116}Sn at ORELA (J. A. Harvey, G. G. Slaughter, and N. W. Hill)

This work will first appear in the 1969 Physics Division Annual Progress Report, ORNL-4513.

High-resolution neutron transmission measurements were made on ^{116}Sn at ORELA and data have been analyzed to give an s-wave strength function ($\bar{\Gamma}n^o/D \times 10^4$) of 0.26 $\pm$ 0.05.

4. The Total Cross Section of ^{234}U and the Parameters of its Sub-threshold Fission and Resonances (G. D. James* and G. G. Slaughter)

This work will first appear in the 1969 Physics Division Annual Progress Report, ORNL-4513 and as AERER-6039.

A measurement of the total cross section of ^{234}U is found to give a level spacing of 12.3 $\pm$ 1.5 eV and a neutron strength function of

[8] H. O. Cohn, J. K. Bair, and H. B. Willard, Phys. Rev. 122, 534 (1961).

*Atomic Energy Research Establishment, Harwell, England.

$(1.09 \pm 0.36)\cdot 10^{-4}$ determined from the neutron widths of 38 resonances below 687 eV. These fine structure resonances form the major part of a narrow intermediate structure resonance in the sub-threshold fission cross section of ^{234}U. Combined with the fission cross section data of James and Rae, the neutron widths enable the fission widths of the resonances to be determined. It is shown that the fission widths have a Lorentzian energy dependence superimposed on a Porter-Thomas distribution as predicted by Weigmann and Lynn and that the observed structure is most probably an example of weak coupling between states in the first and second fission potential barrier minima.

5. Gamma Transitions from keV Neutron Capture (B. J. Allen*)

This work will first appear in the 1969 Physics Division Annual Progress Report, ORNL-4513.

The study of gamma rays from neutron capture in the keV energy region provides information on the properties of individual resonances with keV spacing in light nuclei or nuclei near closed shells, and on the average behavior of resonances in heavy nuclei. The effects of p and d-wave capture can be investigated across the periodic table, as can the neutron capture mechanisms. A variety of techniques are applicable in this energy range and these, with the results obtained, are reviewed in the paper.

6. ORELA Data Acquisition System (N. A. Betz, R. W. Peelle, J. W. Reynolds, and G. G. Slaughter)

This work will first appear in the 1969 Physics Division Annual Progress Report, ORNL-4513.

The status of the ORELA Phase I (data acquisition) and Phase II (immediate analysis) programs is given.

Phase I, consisting of two small computers and associated fixed head disks, magnetic tape drives, teletypewriters, cathode ray tube displays, etc., and concomitant software is nearly complete. It is now possible to accumulate hundreds of thousands of channels of data on the disks at rates up to 5000/sec. The programming for multiple simultaneous experiments on each computer will be finished in May 1970. Phase II provides interactive displays and computers for rapid processing and analysis of data. A contract for the computers and associated equipment has been signed which calls for delivery in November 1970.

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*On assignment from the Australian Atomic Energy Commission.

7. Total Cross Section for ^{16}O for 3.685 to 4.340 MeV Neutrons (C. H. Johnson, J. L. Fowler, and R. M. Feezel)

Fowler, Johnson and Haas[9] previously reported the neutron total cross section of ^{16}O as measured with 2 to 3 keV resolution over most of the energy region from 1680 to 3671 keV. We have extended these measurements with 3 to 4 keV resolution for energies from 3685 to 4340 keV. The procedure was nearly identical to that used previously. We determined the total cross section by observing the transmission of a BeO sample relative to a matching Be sample. Neutrons were produced by the $^{7}Li(p,n)$ reaction in a thin target and detected in a stilbene crystal with associated electronics for pulse-shape discrimination against γ rays. The only significant change from our earlier procedure was that the lithium target was evaporated onto tungsten rather than onto a deposit of ^{58}Ni on platinum. We made corrections for background neutrons, in-scattering, and scattering of the second neutron group from the $^{7}Li(p,n)$ reaction. We found a sharp resonance at 3769 $\pm$ 3 keV in excellent agreement with the earlier value, 3770 $\pm$ 3 keV, observed[10] at this laboratory with neutrons from the T(p,n) reaction. For off-resonance energies these data generally agree well with the earlier work of Fossan et al.[11]; however, in the energy range from about 4.0 to 4.3 MeV our cross sections are systematically $\sim$ 0.2 barns higher than theirs.

8. Proton Strength Functions for Isotopes of Sn (C. H. Johnson, J. K. Bair, and C. M. Jones)

Earlier measurements[12] of strength functions for protons with energies less than 5.4 MeV indicated that the p-wave size resonance peaks near 5.4 MeV for ^{124}Sn and at progressively higher energies for the lighter isotopes of Sn. We have confirmed this expected behavior by measurements up to 7 MeV. Protons were accelerated by the "5.5-MV" Van de Graaff. We took care to evaporate targets of high uniformity and to weigh them carefully. We are in the process of recalibrating the graphite-ball detector with the NBS-II neutron standard. Thus we hope to obtain cross sections with an uncertainty of less than $\pm$ 2%. The preliminary results show that the strength function for protons has a maximum at 5.5 MeV for ^{124}Sn and at about 6.2 MeV for ^{117}Sn. We plan to extend this work to 9.5 MeV by use of the tandem accelerator.

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[9] J. L. Fowler, C. H. Johnson, and F. X. Haas, Proc. Int. Symp. Nucl. Structure, Contributions (Dubna, USSR, July 1968), p. 1, 1968.

[10] C. H. Johnson and J. L. Fowler, Phys. Rev. 162, 890 (1967).

[11] D. B. Fossan, R. L. Walter, W. E. Wilson, and H. H. Barschall, Phys. Rev. 123, 209 (1961).

[12] C. H. Johnson and R. L. Kernell, Phys. Rev. 23, 20 (1969).

9. Low-lying 3/2- and 5/2- Levels of $^{107,109}Ag$ (R. L. Robinson, F. K. McGowan, P. H. Stelson, and W. T. Milner)

Spins, B(E2)'s and B(M1)'s for transitions from five states in each of these nuclei were extracted from the yields and double and triple angular correlations of gamma rays following Coulomb excitation effected with 10-MeV α particles. Half-lives of the 787-keV state in ^{107}Ag and the 702- and 1324-keV states in ^{109}Ag obtained from Doppler broadening of the gamma-ray peaks resulting from ^{16}O ion induced Coulomb excitation are, respectively, 0.27 ± 0.08, 0.5 ± 0.2 and 0.31 ± 0.09 ps. The 3/2-, 787-keV and 5/2-, 950-keV states in ^{107}Ag and analogous states in ^{109}Ag have energies expected for coupling of the $p_{1/2}$ proton to the second 2, state of the even-mass core. Furthermore, the B(E2)'s for transitions from these states are consistent with those predicted if the low-lying states contain one and two phonon admixtures in the amounts deduced from inelastic proton scattering studies.[13] The spins of the ^{107}Ag 1464.7-keV state and the ^{109}Ag 1324.2-keV state are established as 3/2.

10. Improved Data Processing Facilities - Van de Graaff Laboratory (J. A. Biggerstaff, J. W. McConnell, F. G. Perey)

A used Control Data Corporation (CDC) 3200 computer has been installed in the Van de Graaff Laboratory, supplanting the CDC 160-A computer previously used. The system has 16K 24-bit words (an additional 16K memory is to be installed in late May, 1970), floating-point hardware, and three-1M word disk storage units; in addition, tape drives and a high speed line printer from the 160-A were retained for use in the new system. Our existing data terminal facility (from the 3 MV, 5 MV, and tandem accelerators) has been connected to the 3200, enabling multichannel analyzer memory dumps directly into the computer for immediate processing; the hardware also exists for event-by-event processing, but no software is yet available for this mode. When the expanded memory is available, it will be possible to have a resident "priority" program present at all times to service the data collection facilities and to "simultaneously" do off-line batch processing of data. Plans for an interactive graphics facility for the system are being formulated.

An interface between our existing PDP-7 computer and the disk storage controller of the CDC 3200 has been installed and is working beautifully. With this facility, either the CDC 3200 or the PDP-7 may

[13] J. L. C. Ford et al., Phys. Rev. 158, 1194 (1967) and Nucl. Phys. to be published.

read or write on any of the disk units whenever the other computer is not communicating with disk storage. This pseudo-satellite system, which allows the two computers to communicate with each other - each at its own pace, has been found to greatly simplify the software needed for inter-processor communication. In addition, the linking makes available to users of the CDC 3200 the graphics capabilities which already exist in the PDP-7.

RENSSELAER POLYTECHNIC INSTITUTE

A. CROSS SECTION MEASUREMENTS

1. Capture and Transmission Measurements on V, ^{60}Ni, ^{50}Cr, ^{52}Cr, ^{53}Cr and ^{54}Cr* (R. G. Stieglitz, R. W. Hockenbury and R. C. Block)

Capture and transmission measurements on V, ^{60}Ni, ^{50}Cr, ^{52}Cr, ^{53}Cr, and ^{54}Cr have been performed with overall instrumental resolutions of 0.6 and 1.3 nanoseconds per meter. The energy range 0.1 to 400 keV is covered in the transmission measurements while the capture measurements span 0.1 to 200 keV. These data have been analyzed for resonance energies and widths; resonance spins are determined for the s-wave resonances of ^{51}V and ^{53}Cr. Potential scattering radii, resonance integrals, and both s-wave and p-wave strength functions are also determined. These parameters will be presented in a later report. Examples of the data are shown in figures A-1 to A-4. The (capture yield)/(sample thickness) is equivalent to capture cross section except for experimental resolution broadening and thick-sample effects (multiple interactions and resonance self shielding). Average capture cross sections for the six nuclides and natural chromium with corrections applied for thick-sample effects appear in Figures A-5 and A-6.

The resonance structure observed in the capture measurements is significantly different from that observed in the transmission measurements. The capture measurements emphasize the narrow, probably p-wave resonances and the s-wave resonances appear only as wide, relatively flat "bumps" in the data. On the other hand, the transmission measurements predominantly show the wide s-wave resonances. Very few of the narrow resonances are seen in transmission. The trans-

* Pertinent to requests # 84, 87, 113, Wash.-1078.

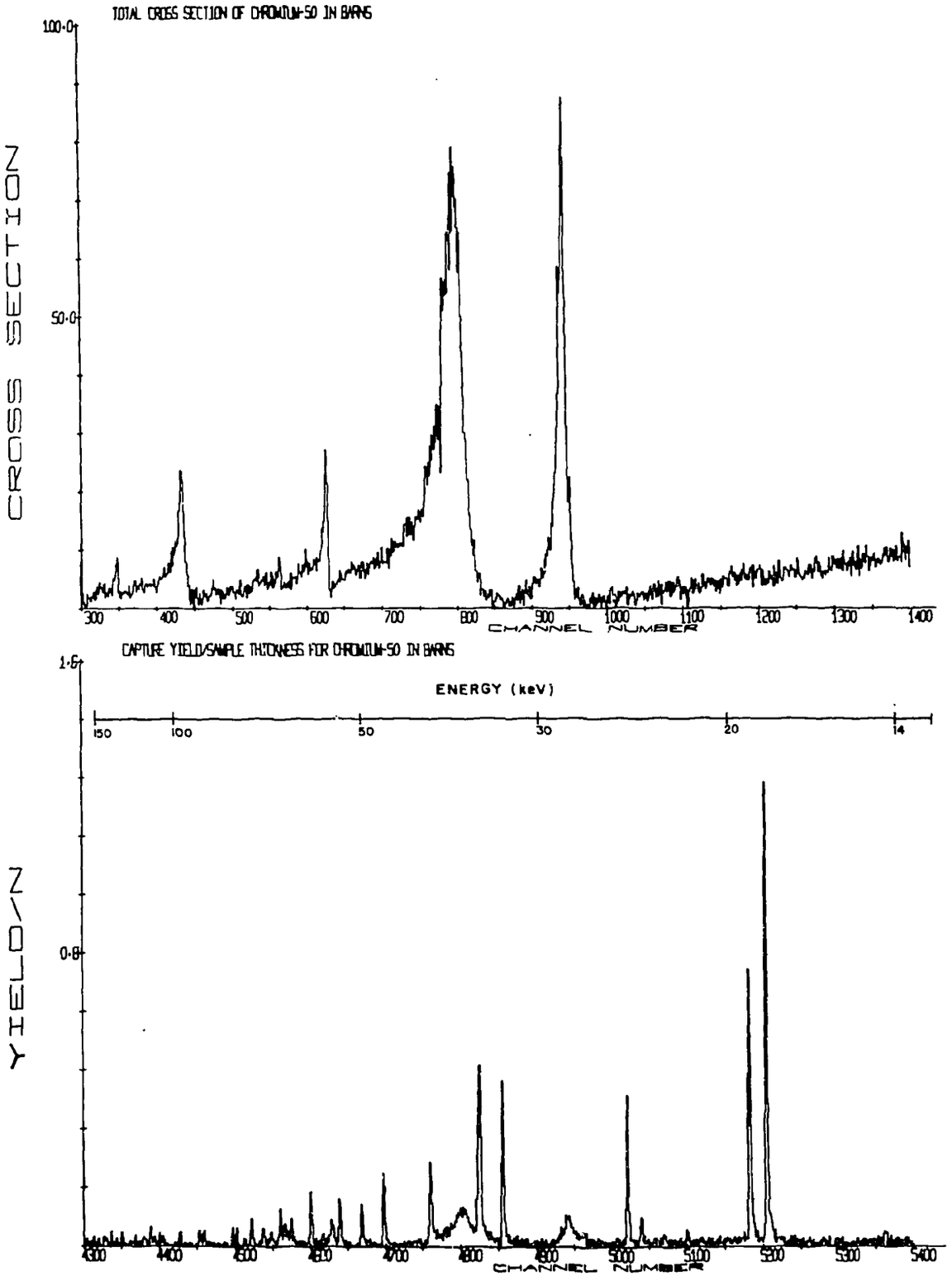

Figure
A-1
High Resolution ^{50}Cr Cross Sections

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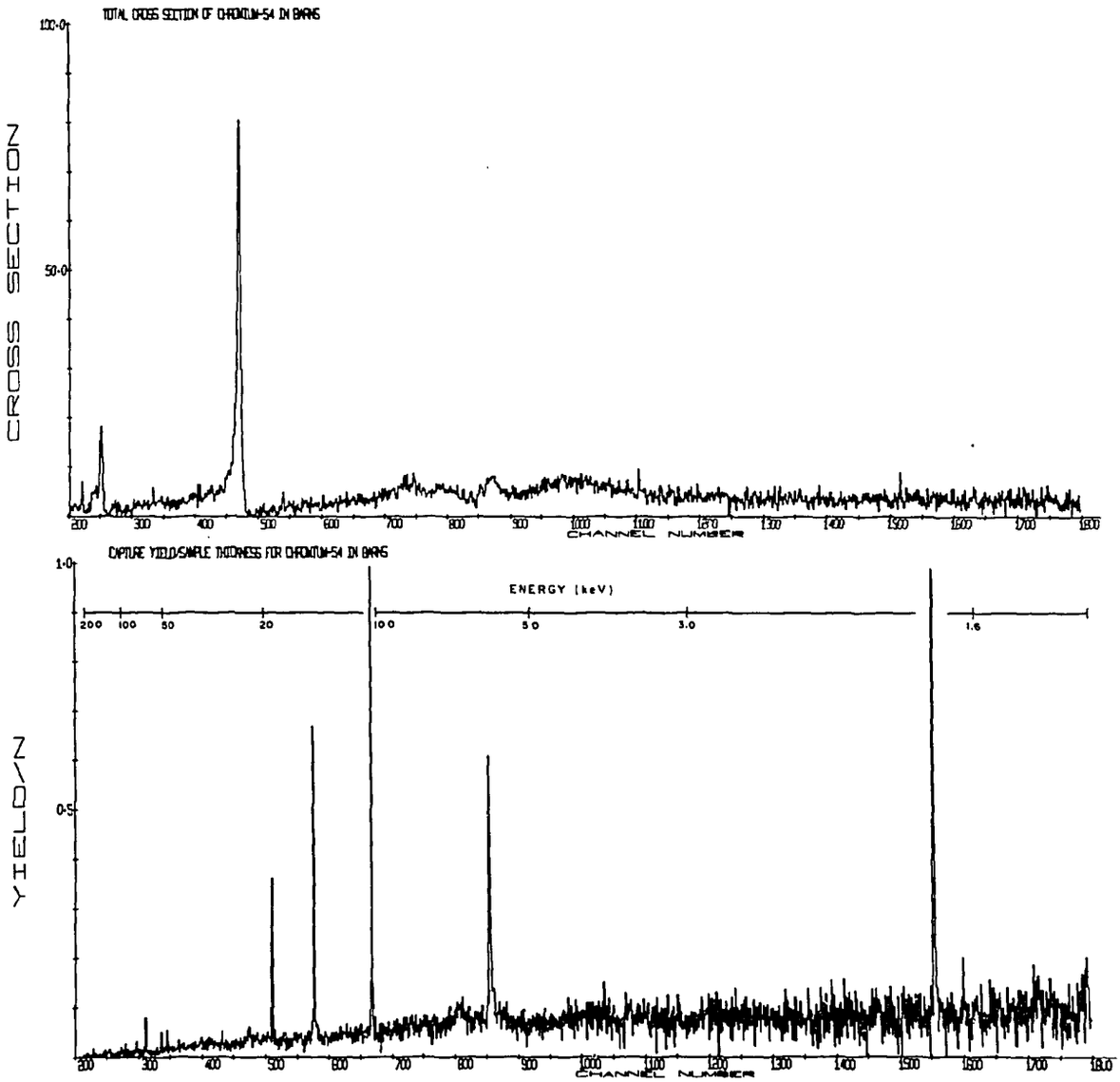

Figure
A-2
Medium Resolution ^{54}Cr Cross Sections.

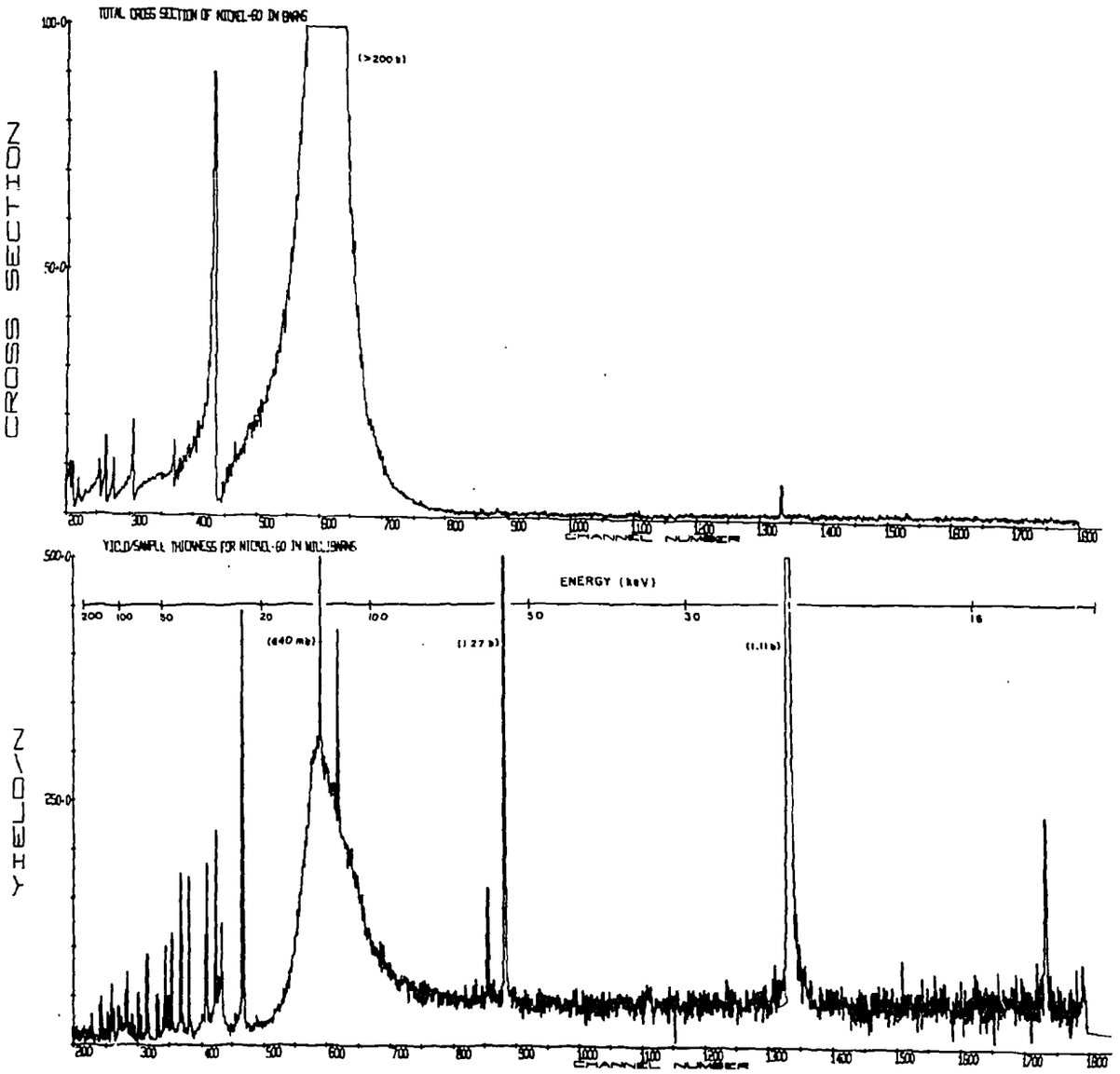

Figure
A-3

Medium Resolution ^{60}Ni Cross Sections.

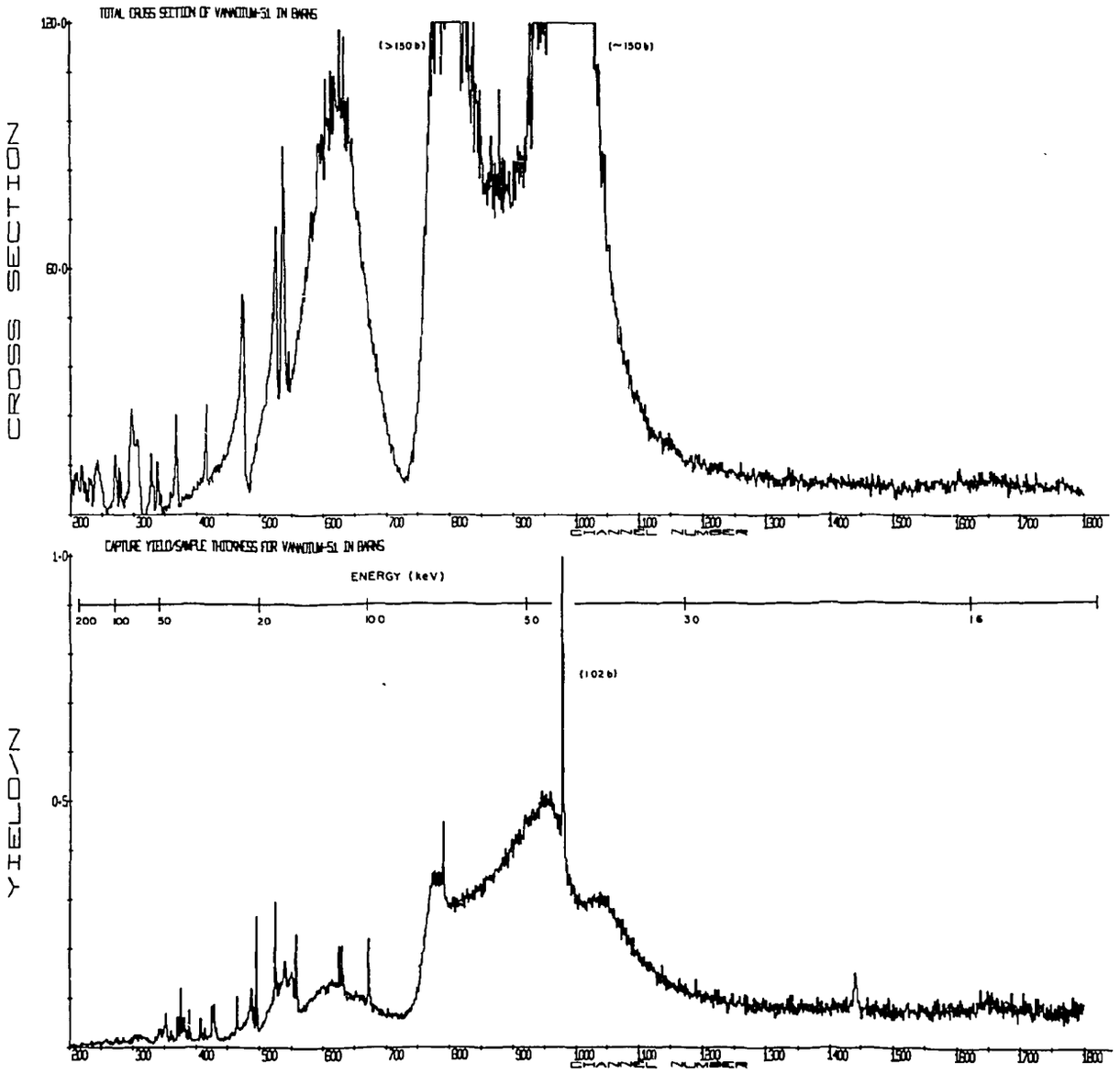

Figure
A-4

Medium Resolution Vanadium Cross Sections.

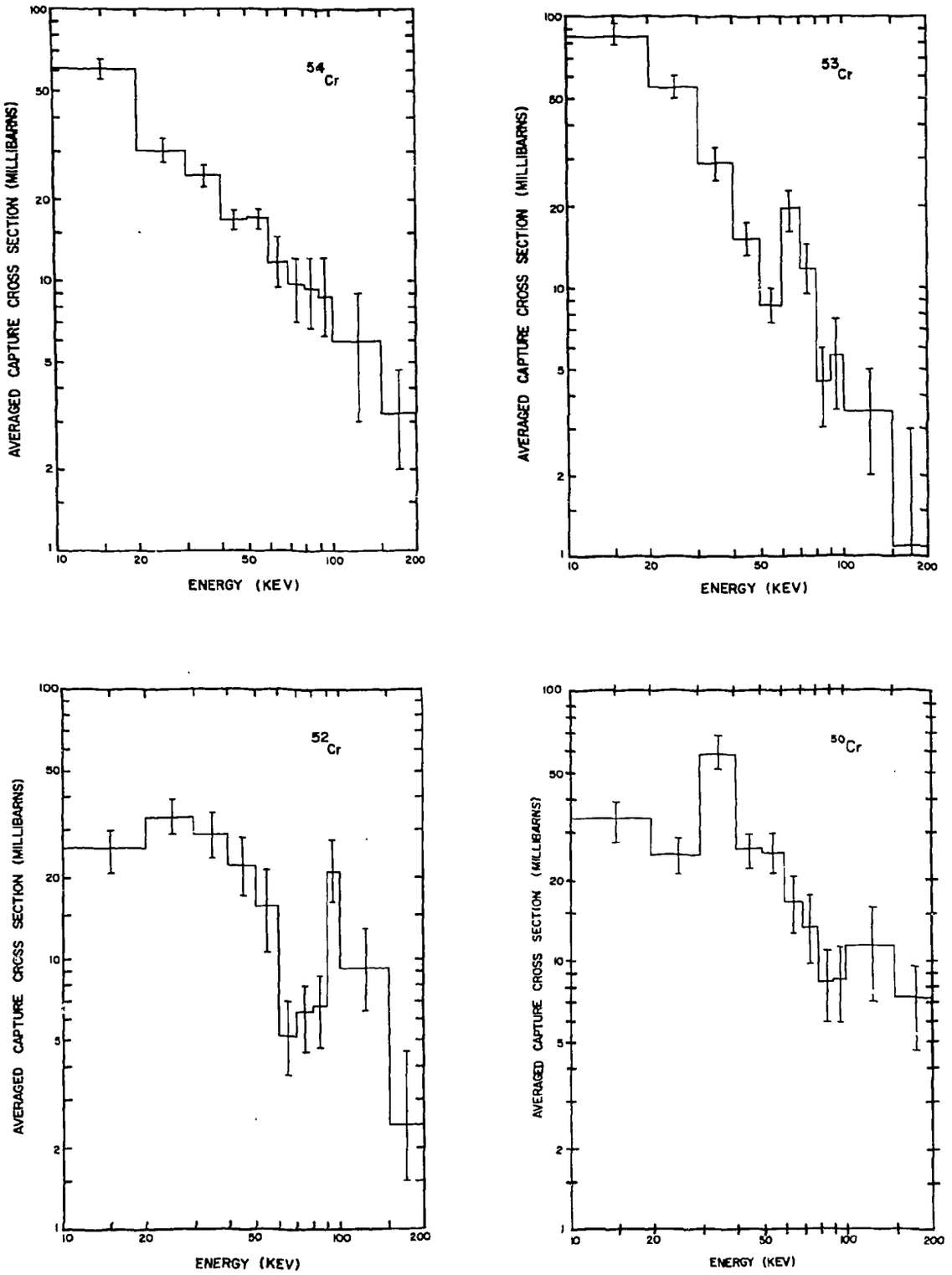

Figure
A-5

Averaged neutron capture cross sections for the chromium isotopes.

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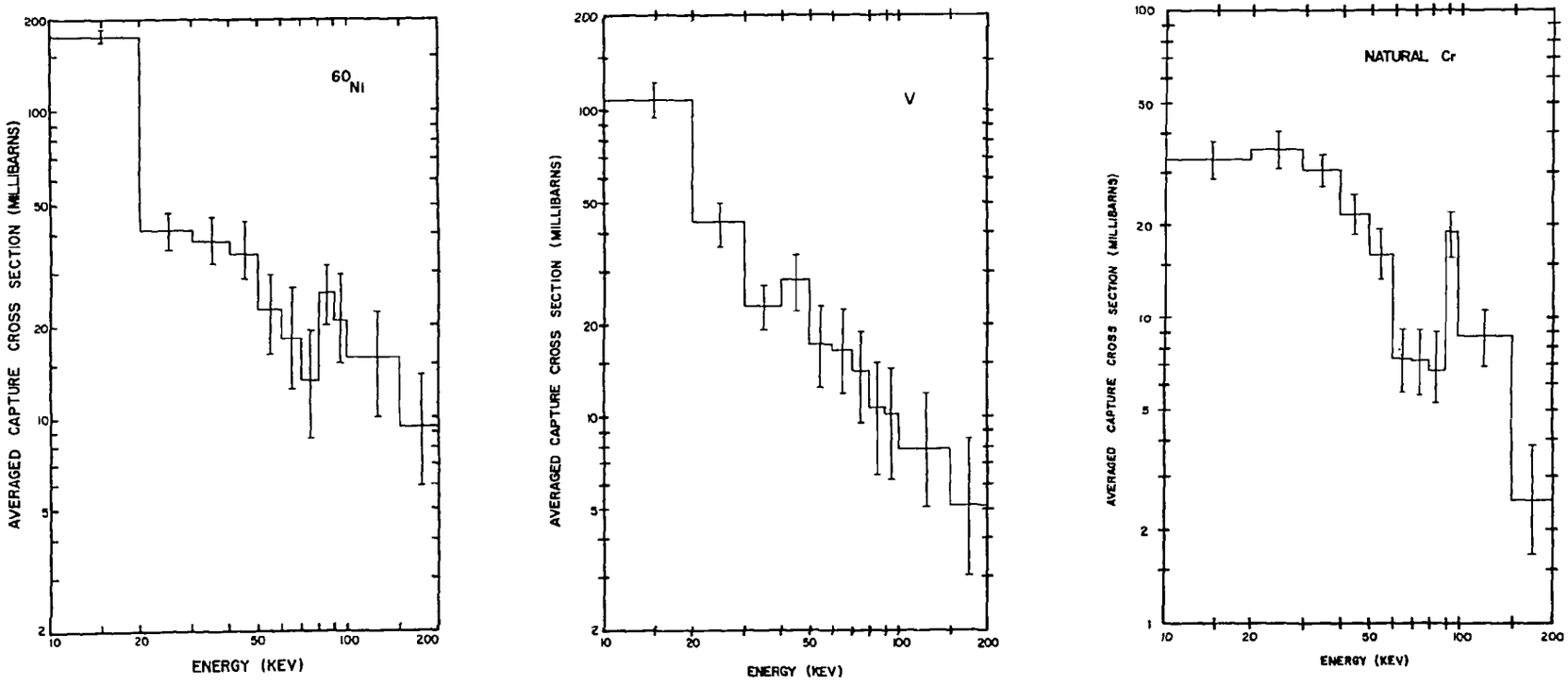

Figure A-6

Averaged neutron capture cross sections for ^{60}Ni, V, and Cr.

mission data are analyzed for resonance energies and total widths by an R-Matrix shape fitting computer code. Area analysis techniques are applied to the capture data to extract neutron widths for the narrow resonances and radiation widths for the wide s-wave resonances.

2. KeV Neutron Capture Measurements on ^{240}Pu*
(R. W. Hockenbury, J. D. Boice, W. R. Moyer and R. C. Block)

The ^{240}Pu absorption data have been reduced to average capture cross sections in the energy range from 4 to 60 keV. These data have been corrected for deadtime losses, background and a contribution due to subthreshold fission. The results are shown in Figure A-7. The locations of the subthreshold fission groups are indicated by arrows. The error bars shown include uncertainties due to background corrections and the relative neutron flux. There is also an uncertainty of $\pm 12\%$ in the absolute normalization. The capture cross section has a shape similar to that obtained by Harwell[1] but is 30% to 40% higher than the Harwell results. Analysis of the absorption data is in progress in order to reduce further the uncertainty in the capture cross section in the keV region.

As part of the above analysis, several resonance areas were determined from the absorption data. These results were compared to calculated resonance capture areas using previously reported resonance parameters[2,3] as input to our Monte Carlo code. Since several cases showed inconsistencies and since we wish to normalize the absorption

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* Work pertinent to requests # 357, 358, WASH-1078.

1 N. J. Pattenden, as quoted by Nucl. Sci. Eng. 40, 25 (1970).

2 W. Kolar and K. H. Bockhoff, J. Nucl. Energy, 22, 299 (1968).

3 H. Weigmann and H. Schmid, J. Nucl. Energy, 22, 307 (1968).

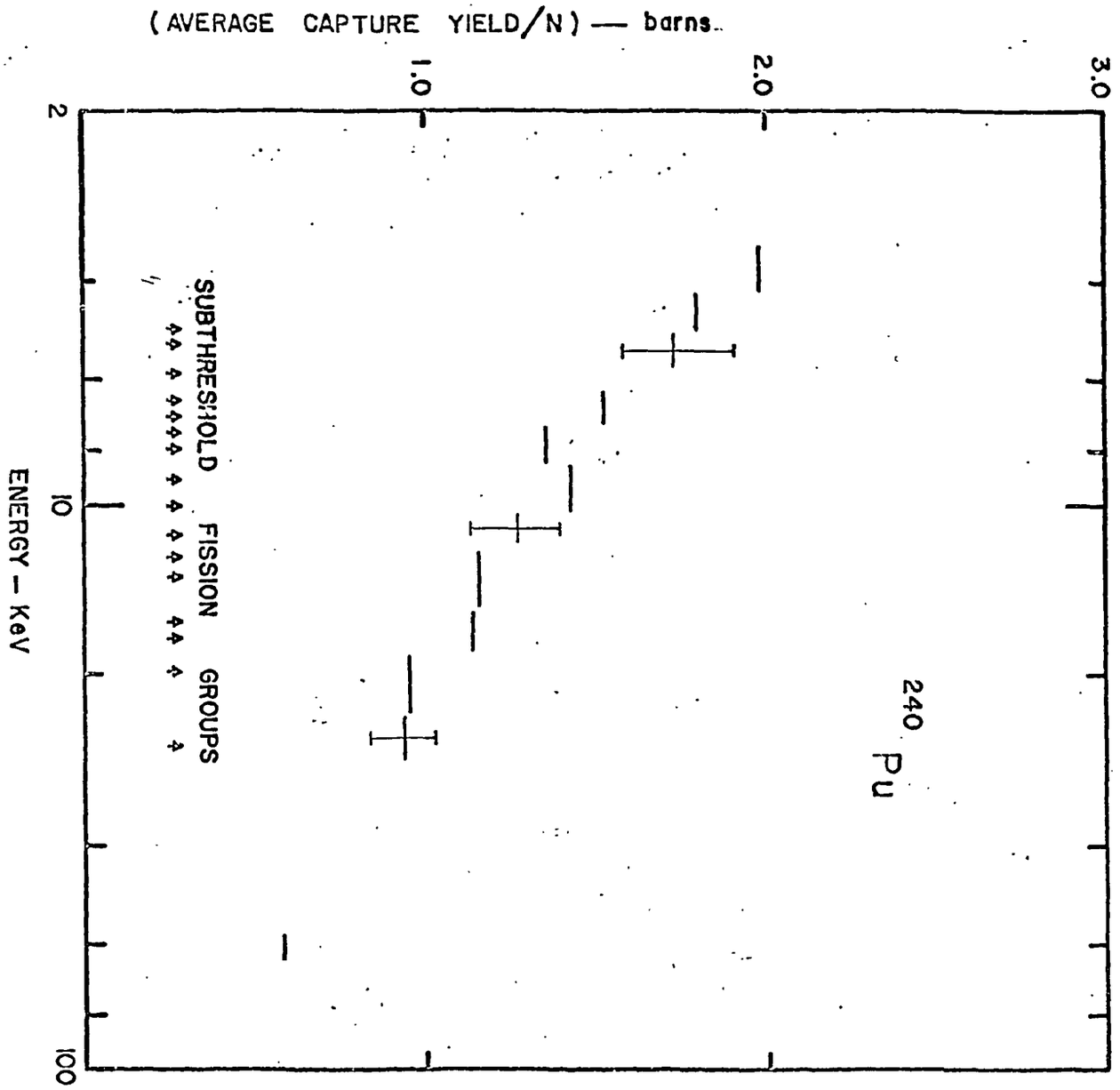

Figure
A-7

Averaged capture yield for ^{240}Pu from 4 to 60 keV. Locations of sub-threshold fission groups are shown by arrows.

data using low energy resonance parameters, transmission measurements were performed on the ^{240}Pu samples.[4]

3. Transmission Measurements on ^{240}Pu* (R. W. Hockenbury and R. C. Block)

Transmission measurements were made on two ^{240}Pu samples (.0013 atoms/barn total) over the neutron energy range from 25 eV to 30 keV using a ^{10}B-NaI detector at 28 meters. A computer-controlled sample changer and new automatic data processor[1] were used to cycle rapidly between "open" beam and sample "in" positions.

The new data have been reduced to absolute transmission up to about one keV neutron energy. Preliminary resonance analysis has been performed on five resonances below 300 eV. This transmission data will aid in the normalization of the ^{240}Pu keV capture cross section.[2] These transmission data will also assure a consistent set of capture and total cross sections in the low energy region and in the keV region.

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[4] R. W. Hockenbury and R. C. Block (This report).

* Work pertinent to requests # 357, 358, WASH-1078.

[1] R. G. Stieglitz and W. R. Moyer, RPI Annual Tech. Report, Oct. 1, 1968 - Sept. 30, 1969.

[2] R. W. Hockenbury, J. D. Boice, W. R. Moyer and R. C. Block (This report).

4. A Measurement of the Radiation Width of the 2.85 KeV Resonance and of the Thermal Capture Cross Section in Sodium* (N. Yamamuro,** R. W. Hockenbury, R. H. Wolfe and R. C. Block)

The following is an abstract of a Technical Note accepted for publication in Nuclear Science and Engineering.

Abstract

Neutron radiative capture measurements upon samples of sodium have been carried out at the Rensselaer Polytechnic Institute's 100 MeV electron linear accelerator. The radiation width of the 2.85 keV resonance was determined to be (0.47 ± 0.045) eV. The capture cross section in the 0.025 to 0.200 eV energy range had a $1/v$ energy dependence (to an accuracy of ±2%), and a capture cross section of (0.50 ± 0.03) barn was obtained at 0.0253 eV. The measured radiation width of the 2.85 keV resonance is approximately 50% greater than the radiation width that is inferred from the thermal capture cross section.

* Work pertinent to request # 59, WASH 1078.

** Visiting Professor from Tokyo Institute of Technology.

5. Spin Determination of Resonances in ^{165}Ho (n, γ) from Low Level Occupation Probability Ratios (J. R. Tatarczuk and W. P. Poenitz*)

The following is an abstract of a paper that has been accepted for publication in Nuclear Physics.

Abstract

The dependence of the low-level occupation probabilities on the compound state spin has been used to assign spin values to fourteen resonances in the reaction ^{165}Ho (n, γ) ^{166}Ho in the neutron energy range from 18 eV to 86 eV. The low-level occupation probabilities were determined from the intensities of γ-rays de-exciting these levels. These intensities have been measured in a time-of-flight experiment at the RPI Linac using a Ge(Li) detector. The spins assigned in the present experiment agree for the seven resonances where spin values have been recommended in BNL-325.

6. Thick-Sample Neutron Transmission Measurements of the 229-eV Resonance in ^{65}Cu (N. Yamamuro* and R. C. Block)

The following is an abstract of a paper that has been prepared for publication.

Abstract

Thick-sample neutron transmission measurements were carried out upon copper to determine the orbital angular momentum of the 229-eV resonance in ^{65}Cu. Characteristic s-wave resonance-potential interference was observed in the transmission data, and together with reported capture spectra results, leads to a J^{π} of 2^- for this resonance. A neutron width of (15.0 $\pm$ 1.5) meV is obtained from this measurement.

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* Argonne National Laboratory, Argonne, Illinois.

* Visiting professor from the Tokyo Institute of Technology.

7. Neutron Transmission and Self-Indication Measurements Upon Tantalum at Room Temperature* (T. Y. Byoun, R. A. Cress and R. C. Block)

Neutron transmission and self-indication measurements have been carried out upon tantalum at room temperature from several eV to about 100 keV. The ^{10}B-NaI detector at 27 meters and the 1.25-meter-diameter liquid scintillator detector at 25 meters were used respectively for the transmission and self-indication measurements. Tantalum thicknesses of 0.0056, 0.0281, 0.05614, and 0.0786 atom/barn were used for the transmission measurements; for the self-indication measurements a 0.0028 atom/barn tantalum sample was placed inside the scintillation detector and the same four samples were used in transmission. The data have been reduced to transmission and self-indication ratios.

This is the first stage in the series of average transmission and self-indication experiments on Ta as a function of sample thickness and temperature to study the self-shielding temperature dependence and the effects of neutron resonances in the unresolved resonance region.

8. 250-Meter Time-of-Flight Facility (J. Clement, C. Goulding, P. Stoler and P. Yergin)

The 250-meter time-of-flight facility is almost complete and is in initial stages of operation. The detector consists of seven separate liquid scintillator proton-recoil neutron detectors. Each of the seven modules presents a 15"x15" square face to the neutrons and is viewed from behind by four XP1040 photomultiplier tubes.

The experiments planned for the facility include MeV total neutron cross section measurements of ^{1}H, ^{2}H, ^{3}He, ^{22}Na, as well as materials normally existing in gaseous form, and separated isotopes. Some data have been obtained on ^{1}H and ^{12}C.

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*Sponsored by NASA

B. THEORY AND ANALYSIS

1. Temperature Dependent Self-Indication-Ratio Studies (T. E. Shea, S. N. Purohit,* T. Y. Byoun and R. C. Block)

As part of a continuing study of the temperature dependence of self-indication-ratio experiments,[1] the Monte Carlo multiple scattering code[2] is being modified to give the effects of multiple scattering in the capture sample. Two versions of this new code SIR/Ø5R are being prepared. The first version will treat sequences of isolated s- or p-wave resonances, as is done with the SELFIND[1] code. The second version will treat resonances in the unresolved range, generating ladders of resonances from distributions obtained from resolved resonance analysis.

2. Quasi-Resonance Formalism: ^{235}U Fission Cross Section (T. E. Shea, S. N. Purohit,* and R. C. Block)

Analytical expressions to evaluate the effects of distant levels in the triplet approximation scheme have been obtained. The expressions are derived on the basis of ignoring off-diagonal elements in the inverse level matrix, $A^{-1}_{\lambda\nu}$. Grouping terms by resonances, this approximation gives Quasi-Resonance parameters of the form

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* Rensselaer Adjunct Research Professor, Brookhaven National Laboratory.

1 T. E. Shea, S. N. Purohit and R. C. Block, RPI Report NES-260 (1969).

2 J. G. Sullivan, G. G. Warner, R. C. Block and R. W. Hockenbury, RPI-328-155 (1969).

$$\mathrm{Symm}_i = \frac{\Gamma_{ni}^{o}}{\Gamma_i} \sum_{c_f}^{N_f} \Gamma_{cf}^{i} + \sum_{j \neq i} \frac{(\Gamma_i + \Gamma_j)}{\Gamma_i} T_{ij} \tag{1}$$

and

$$\mathrm{Asymm}_i = \sum_{j \neq i} \frac{(E_i - E_j)}{\Gamma_i} T_{ij} \tag{2}$$

where

$$T_{ij} = R_i R_j / \left\{ (E_i - E_j)^2 + \tfrac{1}{4} (\Gamma_i + \Gamma_j)^2 \right\} \tag{3}$$

and

$$R_i = \sum_{c_f}^{N_f} \sqrt{\Gamma_{ni}^{o} \Gamma_{cf}^{i}} \tag{4}$$

These parameters reproduce the ^{235}U fission cross section quite accurately in regions where multi-level interference is not too severe. The cross section is calculated with the formula

$$\sigma_{nf}(E,T) = 2\pi \lambda^2 \sqrt{E} \sum_J g_J \sum_\lambda \left\{ \mathrm{Symm}_\lambda \psi + \mathrm{Asymm}_\lambda \chi \right\} \tag{5}$$

with the symbols having standard definitions. In regions of severe interference, the terms giving contributions from other levels to the Symm parameter (Eq. 1) are a sensitive test of the degree of interference between resonances i and j. A version of the Triplet code is being prepared which selects resonances experiencing severe interference phenomena. These resonances are then treated in the Triplet approximation, giving a final set of Q. R. parameters for cross section calculation. Preliminary results show significant improvement in the shape of the cross section in comparison with an R-matrix calculation. Future efforts will be concentrated on systematizing parameter selection.

3. An Interactive Transmission Shape-Fitting Code for the IBM 1130 (R. G. Stieglitz and R. C. Block)

The program RMATX has been developed to aid the analysis of the transmission data for vanadium, ^{60}Ni, ^{50}Cr, ^{52}Cr, ^{53}Cr and ^{54}Cr. It employs single channel (i.e. pure scattering) R-Matrix theory to fit the shape of the experimentally observed transmission. The output of the code is the superposition of the calculated transmission curve onto the experimental transmission data points. It is displayed on the Tektronix Type 611 storage display oscilloscope which is interfaced to the IBM 1130 computer. After a visual inspection of the "fit" any parameter in the code may be altered and the theoretical curve recalculated. The changes are entered through the keyboard of the 1130. The typical time involved in the R-Matrix calculations and the display is about four minutes. This scheme allows the rapid and accurate analysis of large amounts of transmission data.

C. "INTEGRAL" CHECKS OF CROSS-SECTION DATA

1. Fast Reactor Physics Studies (E. R. Gaerttner, M. W. Golay, N. N. Kaushal and B. K. Malaviya)

Time-of-flight studies of position-dependent fast neutron spectra in a large aluminum assembly are continuing. The experimental results are being compared with theoretical spectra calculated by the S_n code DTF-IV using a 49-group set generated from cross sections in the ENDF/B compilation. The analyses of earlier measurements on iron and depleted uranium have revealed inadequacies in cross section data as well as deficiencies in the codes employed in analysis.

Work is in the final stages on the design and construction of a large cuboidal assembly of sodium, appropriate to "integral" measurements of the above type.

BONNER NUCLEAR LABORATORIES, RICE UNIVERSITY

A. NEUTRON PHYSICS

1. Preparation of a Monoenergetic Neutron Beam (A. Hochberg, D. Rendić, and G. C. Phillips)

Neutron time-of-flight and the associated particle method are used in the $^{2}H(d,n)^{3}He$ reaction to get a monoenergetic beam of neutrons with energies of 8-14 MeV. Time-of-flight technique is used for ^{3}He identification. A preliminary working system was tested, and efforts are being made to increase the count rate.

2. Fast Neutron Spectroscopy (D. Rendic, G.S.Mutchler, W. Sweeney, J. Sandler, and G. C. Phillips)

Using the fast neutron time-of-flight facilities including a thin walled, low total mass scattering chamber, the measurement of $^{11}B(d,n)$ reaction at a bombarding energy of 11.8 MeV has been completed. Angular distributions for five levels in ^{12}C (9.5, 4.44, 9.64, 12.71, and 15.11 MeV) from 12° to 145° in center of mass have been extracted from the data in multiparameter format using the pulse shape gamma ray discrimination. Angular distributions, exhibiting mostly stripping patterns, have been preliminarily analyzed in terms of zero-range local DWBA, using the code DWUCK. Spectroscopic factors extracted are in good agreement with theoretical predictions. Detailed DWBA analyses using the same code for previously measured $^{12}C(d,n)$ and $^{13}C(d,n)$ angular distributions are presently being undertaken. Some preliminary preparations to measure $^{9}B(d,n)$ at the same energy have been done.

B. FEW NUCLEON PROBLEMS AND MANY-PARTICLE BREAK UP STUDIES

1. The p-p Final State Interactions in the D(p,pn)p Reaction (Ivanovich, von Witsch, Hungerford, Sandler, and Phillips)

The three-nucleon system has been studied *via* the D(p,pn)p reaction in a kinematically complete experiment at six incident proton energies between 8 and 13 MeV. Coincidences were recorded between protons, observed by a solid state detector at 25° Lab angle, and neutrons, the neutron detector being positioned on the recoil axis for a diproton system with zero relative energy. Strong manifestations of the p-p final state interaction were observed. Consistent

fits to the data using Phillips, Griffy, and Biedenharn[1] theory have been obtained at all energies.

2. Low Relative Energy n-p Final State Interaction in the D(d,dp)n Reaction (von Witsch, Ivanovich, Rendić, Sandler, and Phillips)

The reaction D(d,dp)n has been studied in a complete experiment at bombarding energies of 11, 12, and 13 MeV. The two charged particles were detected in coincidence at pairs of angles corresponding to the recoil axes of the reaction D(d,d)d* where d* is a p-n system near zero relative energy. Time-of-flight and ΔE-E information were used for background subtraction and particle identification, respectively. Each of these spectra is dominated by a strong but broad peak at low relative energies in the p-n system which might be attributed to the isospin-forbidden formation of the "singlet deuteron." However, first attempts to fit the spectra using the theories of Watson-Migdal or Phillips, Griffy and Biedenharn have not been successful.

3. Singlet Deuteron and Proximity Scattering Contributions to the $^{12}C(d,pn)^{12}C$ Reaction (Sandler, Otte, Hungerford, Mutchler, Rendić, von Witsch, and Phillips)

Proximity scattering has recently been reported[2,3] in the kinematically complete $^{12}C(d,pn)^{12}C$ reaction, and lifetimes of the sequential decay processes involved have thereby been deduced. This reaction has been re-investigated at various geometries suitable for both singlet deuteron and proximity scattering reaction mechanisms. The importance of the isospin forbidden singlet deuteron production in this reaction has been demonstrated in disagreement with previous conclusions.

4. Singlet Deuteron Contributions from the $^{13}C(p,pn)^{12}C$ Reaction (Otte, Sandler, von Witsch, Rendic, and Phillips)

p-n coincidences resulting from 12.5 MeV protons

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[1] G. C. Phillips, T. A. Griffy, and L. C. Biedenharn, Nuclear Phys. 21, 327 (1960)

[2] J. Lang, Muller, Wolfi, Bosch, and Marmier, Nuclear Phys. 88, 576 (1966)

[3] W. Bohne, Hilscher, Hofmeyer, Morgenstaum, and Scheer, Nuclear Phys. A106, 442 (1968)

bombarding ^{13}C were measured using associated particle time-of-flight and pulse shape discrimination techniques. Both proton and neutron detectors were at the same angle to ensure the possibility of detecting events down to zero relative energy in the final state p-n system. Preliminary analysis indicates that relative to other final state interactions the contribution to the yield from the p-n interaction is small. These data are being compared to similar published data taken at 17 MeV where it was reported[1] that the p-n singlet interaction contributes strongly.

5. Investigation of Coulomb Rescattering Process (Rendić, Hungerford, Sandler, Sweeney, and Phillips)

In order to investigate rescattering in 3-body final state processes between two charged particles the reactions $p+^{16}O \rightarrow \alpha + \gamma + ^{12}C$ and $d+^{14}N \rightarrow t+p+^{12}C$ have been investigated. According to the very low cross section we could not see the needed resonance in ^{13}N system (3.51 - 3.55 MeV) so we switched to the $p+^{11}B \rightarrow 3\alpha$ equipment at 10.9 MeV. Some preliminary spectra on 20° - 40° have been obtained. It was found that the cross sections of forming 16.63 and 16.93 MeV resonances in ^{8}Be are also small, but inasmuch as they appeared on the locus, experiments need more statistics to get some conclusions about rescattering.

6. A Large Solid Angle Reaction - Chamber and Detector (D. Rendić and G. C. Phillips)

Building of a chamber that will allow mounting two of the large hexagonal multiwire counters is almost finished. We expect that the chamber will be operable in approximately two months.

7. Neutron-Proton Coincidence Measurements in the Reaction $^{9}Be(p,pn)^{8}Be$ (Wilson, Sandler, Otte, and Phillips)

This work has been completed and is being prepared for publication.

8. Investigation of the Reactions $^{9}Be(p;p,\alpha)^{4}HeN$ and $^{9}Be(p;p,N)^{8}Be$ (Hungerford, Ivanovich, Sandler, and Phillips)

Interpretation and collection of data of the neutron and alpha decay of the 2.43 MeV level of ^{9}Be is in progress.

[1] B. L. Cohen, May, O'Keefe, and Fink, Phys. Rev. 179, 962 (1969)

Preliminary analysis shows a broad double peak in the decay particle spectra which cannot be described by either a simple sequential decay through ^{8}Be or ^{5}He. This experiment supplies additional information to that of $^{9}Be(p,pn)^{8}Be$ reported above. This work is being continued.

C. NUCLEAR SPECTROSCOPY AND NUCLEAR REACTION STUDIES

1. The Spin and Lifetime of the 6.75 MeV State in ^{40}Ca (C. H. Sinex, R. S. Cox, and C. M. Class)

The 6.75 MeV state in Ca was populated by inelastic proton scattering. This level decays 100% via a 3.0 MeV gamma ray to the 3^- state at 3.74 MeV which then decays 100% to the ground state. The lifetime was measured by Doppler shift attenuation. The recoil axis was defined by detecting inelastic protons in an annular counter placed at 180° and the coincident gamma rays were observed at 30° and 120° in a 25 cm^3 Ge(Li) counter. The shift in the 3.0 MeV gamma ray was determined with respect to the unshifted 3.7 MeV gamma ray from the long-lived 3^- state. The Ge(Li) counter was then replaced by a 5" x 5" NaI(Tℓ) crystal and the double correlation functions, $p'-\gamma_{3.0\ MeV}$ and $p'-\gamma_{3.7\ MeV}$, were measured (Litherland-Ferguson "method II" geometry). Finally, a second 5"x 5" NaI(Tℓ) crystal was added to this geometry (at 90° in the plane) and two triple correlation functions, $p'-\gamma(\theta)3.0\ MeV - \gamma(90^o)3.7\ MeV$ and $p'-\gamma(90^o)3.0\ MeV - \gamma(\theta)3.7\ MeV$, were measured. Analyses of these data yield a lifetime $< 2 \times 10^{-13}$ sec for the state and a definite spin assignment of 2.

2. Radiative Capture of Protons by ^{40}Ca (Clark, Greenwood, Dougherty, and Class)

The radiative capture of protons by ^{40}Ca has been studied in the energy range $5 \leq E_p \leq 9$ MeV by measuring the activity associated with the ground state positron decay of ^{41}Sc [$E(\beta^+)_{max}$=5.5 MeV, τ 1/2 = 0.6 sec]. Because all excited states of ^{41}Sc are particle unstable, only capture events leading directly to the ground state are detected. Extension of the measurements beyond 9 MeV is hampered by the intrusion of strong ^{37}K activity produced by the competing $^{40}Ca(p,\alpha)$ reaction. Throughout the energy range studied, strong resonances are superimposed on a continuum, whose cross section increases from a vlue of 2 μb at 5 MeV to 25 μb at 9 MeV. Both the magnitude and energy dependence of the continuum is well described by the extended Lane-Lynn direct capture theory. The energy-averaged resonance yield generally agree with those predicted by compound statistical theory except for two broad anomalies centered at 6.5 and 8 MeV.

3. The Scattering of Protons by ^{40}Ca (J.S. Duval, Jr., T. M. Jurgensen, and C. M. Class)

A large body of data is now available on the elastic scattering of protons by ^{40}Ca in the energy range up to 20 MeV. These data, contributed by several laboratories including our own, consist of high resolution excitation functions, a continuous set of angular distributions measured with 50 keV resolution in the interval 8 - 12.5 MeV, angular distributions measured with 300 keV resolution at 13 energies in the interval 9 - 21 MeV, and proton polarizations measured at 10.5, 14.5, and 21 MeV. The detailed energy dependence of the total reaction cross section is also known from 12-21 MeV and at 10 isolated energies from 12 - 21 MeV. Hauser-Feshbach estimates of compound nucleus contributions to the elastic cross sections in the important region below the (p,n) threshold (15.5 MeV) have been calculated.

4. An Optical Model Analysis of Proton Scattering by ^{40}Ca (T.M. Jurgensen, J.S.Duval, and C. M. Class)

Data describing the elastic scattering of protons by ^{40}Ca have been analyzed over the energy range of 4 - 22 MeV using the optical model. The data analyzed consisted of differential cross sections, polarizations, and total reaction cross sections as summarized in C.3. A standard 10 parameter model yielded satisfactory fits to the data at lower energies ($\chi^2 \sim 5$) but a volume imaginary term became necessary above 14 MeV. Searches were made at each energy for optimum geometrical parameters which were then averaged to give a constant and reasonably conventional geometry over the entire energy range. It became necessary, however, to alter the geometry of the imaginary and spin-orbit wells above the (p,n) threshold (15.5 MeV). Searches on the potential strengths yielded: for the real well depth, a dependence on energy given by U = 56.35 - 0.40 E MeV, for the imaginary well depth, values not simply parameterized and for the spin-orbit well, a value approximately constant at 5 MeV.

5. Study of the $^{40}Ca(d,n)^{41}Sc^*(p)^{40}Ca$ Reaction (L. R. Greenwood, Cox, Sandler, and Class)

Angular distributions of the neutrons leading to the 1.714 MeV, $J^{\pi} = 3/2^-$ level of ^{41}Sc (Q = - 2.858 MeV) have been measured at ten energies in the range $3.2 \leq E_d \leq 6$ MeV with time-of-flight apparatus. Characteristic $\ell = 1$-type stripping patterns are observed at each energy. Angular distributions of the protons from the break up of the 1.714 MeV level have also

been measured in this energy range with a magnetic spectrometer. These distributions are of the form $W(\theta) = 1 + a_2(E) P_2(\cos\theta)$ where the magnitude of a_2 decreases smoothly from a value near 1 at 3 MeV to about 0.35 at 4 MeV, remaining about constant at this value to 6 MeV. Results of calculations using plane wave stripping theory do not describe the behavior of the data of either set of measurements. Failure to do so cannot be ascribed to compound nucleus formation which makes only a minor contribution to the cross section. An attempt is now being made to account for the observed behavior by DWBA calculations. To furnish the deuteron optical well parameters needed for these calculations, deuteron elastic scattering has also been studied.

6. Proton Spin-Flip in (p,p') Reactions on Chromium Isotopes (W. E. Sweeney, Jr. and J. L. Ellis)

The proton spin-flip probability in the excitation of the first 2^+ states in the even chromium isotopes is being studied at 12 MeV incident proton energy using the (p,p'γ) coincidence technique.[1] The gamma rays emitted perpendicular to the proton scattering plane were detected by a 12.7 cm x 12.7 cm NaI crystal enclosed in a lead shield and collimator. Fast timing was accomplished using timing single channel analyzers and a time-to-amplitude converter. Gamma ray, particle, and time spectra were simultaneously recorded using the Rice on-line computer. Preliminary measurements have been made comparing the spin-flip probability for the reactions $^{50}Cr(p,p')^{50}Cr^*$(0.79 MeV) and $^{12}C(p,p')^{12}C^*$(4.44 MeV). At E_p = 12 MeV the spin-flip probability ratio, S.F.(^{50}Cr)/S.F.(^{12}C) is about 25% and 70% at laboratory proton scattering angles of 120° and 150°, respectively. Measurements on ^{52}Cr are planned.

D. POLARIZATION STUDIES

1. ^{3}He-^{3}He Elastic Scattering Using a Polarized ^{3}He Below 12 MeV (Wilber Boykin and S. D. Baker)

In view of the results at high energies an investigation of ^{3}He-^{3}He polarization asymmetries with improved statistics has been employed. A target of optically pumped ^{3}He gas, and the $^3He^{++}$ beam from the 6 MV Van de Graaff accelerator is being employed. In addition to elastic scatter-

[1] F. H. Schmidt et al., Nuclear Phys. 52, 353 (1964)

ing it has been possible to observe the protons from the $^3He(^3He,p)^5Li_{g.s.}$ with the present apparatus. At 30^o_{LAB} there is no evidence for any target polarization effects in either reaction.

2. Scattering of 7.5 to 17.9 MeV ^4He by Polarized ^3He
(D. Hardy, Baker, Spiger, and Tombrello)

Left-right asymmetries from an optically pumped ^3He target at 33^o_{LAB} have been measured using ^3He and ^4He beams over the range 7.5 - 17.9 MeV which were supplied by the Caltech tandem. For ^4He-^3He elastic scattering two c.m. angles were observable. The forward angle $79^o_{c.m.}$ provided a verification of the high polarization > 90% which persists over a large energy interval as predicted from the plane shifts of Spiger and Tombrello. This region appears to be optimal from the standpoint of constructing a ^4He polarimeter for medium energy ^3He scattering experiments. The back angle ($114^o_{c.m.}$) polarization does not display the structure predicted from the plane shifts. The large discrepancies are probably accounted for by the sensitivity of the polarization to inelasticity in both resonance and non-resonant phase shifts. This has been reported in Physics Letters (1970). A more detailed account is in preparation for publication.

3. Scattering of Low Energy ^4He by Polarized ^3He
(W. Boykin, S. D. Baker, and D. Hardy)

This work, at 30^o_{LAB}, augments the data of Hardy (D.M. Hardy, M.A., thesis, Rice University (unpublished). It is hoped that the simplicity of the phase shift parameterization of the data in this energy region will allow a completely unambiguous determination of the p-wave splitting.

4. Scattering of 6 to 12 MeV Deuterons by Polarized ^3He
(D. Hardy, R. J. Spiger, and S. D. Baker)

Further asymmetry data at 68.6^o_{cm}, 96.0^o_{cm}, and 121.0^o_{cm} confirm the earlier evidence that in d + ^3He elastic scattering the ^3He polarization and the deuteron vector polarizations[1] $\langle iT_{11} \rangle$ have almost identical angular distributions in the energy range 6 to 12 MeV.

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[1] G. R. Plattner and L. G. Keller, Phys. Letters 24B, 301 (1969)

E. NUCLEAR THEORY

1. Nuclear Cluster Model Trial Functions (J.E. Beam Karl Wildermuth)

Work is continuing on an investigation of nuclear cluster-model wave functions. It is expected that judicious choice of trial functions should appreciably simplify the wave function antisymmetrization, thus reducing total computer time needed. A summary of work on a one-dimensional model problem is in preparation.

2. A Faddeev Model of the Reaction $^{11}B(p,\alpha)2\alpha$ (C. Alex McMahan and Ian M. Duck)

We use an exactly soluble model of the decay of a 2^+ particle into three identical strongly interaction 0^+ particles to investigate the reaction $^{11}B(p,\alpha)2\alpha$ at proton energy of 2.65 MeV with the parent particle the 18.37 MeV state of ^{12}C. The strong interactions are described by equations of the Faddeev type with separable two-body interactions for the ground and first excited states of ^8Be. An *ad hoc* Coulomb correction is added through the inclusion of a Coulomb phase shift. We find it necessary to use a mixed ^{12}C configuration to reproduce the observed[1] interference effects. The decay mechanism is predominantly sequential two-body decay through the ground and first excited states of ^8Be.

F. INSTRUMENTATION

1. 1800 Computer System Hardware and Software (J. Buchanan, H. Jones, and M. Jones)

Final tests of the 8-parameter, multi-experiment system using BONER are currently underway. A demonstration of the system to LAMPF engineers occurred on 12 May 1970.

2. Position Sensitive Counters and Electronics (Phillips, Buchanan, Persson, and Windish)

Two- and three-coordinate Multi-wire Proportional

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[1] J. D. Bronson, W. D. Simpson, W. R. Jackson, and G. C. Phillips, Nuclear Phys. 68, 241 (1965)

Counters have been built and used in experiments (see below). A paper describing the system is in preparation. Abstracts were presented to the Washington APS meeting.

2a. Charged Particle Spectrometry and Measurements Using Multi-wire Proportional Counters

Multi-wire proportional counter systems have been constructed for applications to low, intermediate, and high energy nuclear physics problems. These systems have many advantages over other available techniques and allow simultaneous particle-ray tracing and dE/dx measurements with high count rates and fast coincidence timing. Three configurations of counters have been constructed: 1) a focal plane counter for use with a Browne-Buechner magnetic spectrograph; 2) two large solid angle detectors attached to a reaction chamber for use in studies of low-energy multi-particle nuclear break up; and 3) arrays of detectors and magnets that provide precise ray tracing of individual particles and thus allow the determination of intermediate or high energy particle momenta to a relative error of about 10^{-3}.

2b. The Design, Construction, and Operating Characteristics of Multi-wire Proportional Counters

Highly reliable, large area, multi-wire proportional counters have been designed, which can be semi-mass produced using standard machine shop techniques. The counters, originally designed for localization of low ionizing events such as high energy protons, pions, etc., operate with a 99^{+}% efficiency over an operating plateau greater than 1 KV wide, without sparking. The design features a modular approach, where anode wires and cathode foils are separately mounted on 1/4" fiberglas (G-10) boards. The boards, which "O" ring seal to one another, may be assembled as a single or multi-coordinate sandwich as desired. A system of six single coordinate and two multi-coordinate counters has been in operation for three months. They have 50 mil wire spacing and an active area greater than 100 in^2. The counters operate with a simple gas flow system which proportions argon and an inexpensive quench gas without the need for temperature controlled bubblers. Various geometrical forms and configurations have been investigated.

2c. Electronics for Multi-Wire Proportional Counters

Design and construction of electronics for determination of position in multi-wire proportional counters has been investigated. The electronic system is divided into

three subsystems: 1) amplifier cards and bin; 2) readout control; and 3) computer interface. Each amplifier card contains 16 amplifiers, 16 variable threshold discriminators, and 16 storage registers. Sensitivity can be adjusted to give a logic level output for a 1-20 millivolt input pulse. A bin will house 13 amplifier cards and thus accommodate up to 208 counter wires with necessary drivers to operate up to 100 feet from the control station. Readout control is housed in a 2-width NIM module. It provides counter coincidence control, intermediate storage registers with gated output, and control signals for serial-to-parallel conversion in 54 microseconds. The computer interface provides on-off control and timing signals for up to 20 such 208-wire counters. Included is provision for scintillation counter coincidence and time-of-flight derived real-accidental tagging. Output is to an IBM 360-44 computer but is readily modifiable for other similar computers.

3. Multiwire Proportional Counter Camera for a Browne-Buechner Magnetic Spectrograph (R. Plasek, Persson, Buchanan, and Phillips)

A camera of 1000 proportional wires and a backing scintillation counter is being designed for the Bonner Nuclear Laboratories Brown-Buechner magnetic spectrograph. The position sensitive multiwire counter, coupled to the 1800 computer system will give $B\rho$ of the particles and the dE/dx is given by the linear signal. When used with a pulsed-bunched beam to measure time-of-flight to the scintillation detector the system will be capable of giving magnetic spectra versus Z and m. Construction of the system is proceeding.

4. A Large-Solid Angle Reaction-Chamber and Detector (D. Rendic and G. C. Phillips)

Design is completed on a chamber that will allow mounting two of the large hexagonal multiwire counters. Each will subtend about 1/2 steradian. Construction of the system is proceeding.

5. New Terminal for the 6 MV Accelerator (J.R.Risser)

Bids have been received, reviewed, and a recommendation to Oak Ridge Operations office has been transmitted.

G. INTERMEDIATE ENERGY PHYSICS

1. Multiple Scattering of 600 MeV Protons (Hungerford, Mutchler, Phillips (Rice University); Allred, Lee, and Mayes (University of Houston))

Usual multiple scattering theory assumes the Coulomb amplitude to completely dominate the scattering at small angles.[1] Recent work[2] has indicated, however, that the small angle multiple scattering of medium energy protons is significantly effected by the interference between the nuclear and Coulomb amplitudes. Because of the importance of small angle multiple scattering in many investigations, and especially in the design of the LAMPF, we have begun a series of measurements on the small angle scattering of 600 MeV protons from C, Al, Cu, and Pb. The measurements were made with the multi-wire proportional counters developed at Rice University. The measured rms angles have been compared with the calculated rms angles due to the Coulomb interaction. Results show significant deviations for all targets.

2. Multiple Scattering of 365 MeV/C π^- (Mutchler, Hungerford, and Phillips (Rice); Allred, Lee, and Mayes (U. of H.))

Recent work[2] has indicated that the small angle multiple scattering of medium energy protons is significantly effected by the interference between the nuclear and Coulomb amplitudes. We have measured the small angle scattering of 365 MeV/C pions from C, Al, Cu, and Pb in an attempt to observe this effect for pions. The measurements were made with the thin multi-wire proportional counters developed at Rice for nuclear structure studies with medium energy pions. An angular resolution of 0.1° was achieved. The measured rms angles have been compared with the calculated widths due to the Coulomb interaction alone.[1] Results show significant deviations for all targets.

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[1] W. T. Scott, Rev. Mod. Phys. 35, 231 (1963)

[2] T. A. Griffy and I. L. Morgan, Am. Phys. Soc. Bull. 14, 1223 (1969)

TEXAS NUCLEAR

A. NEUTRON PHYSICS

1. Gamma-Ray Production in Nitrogen and Oxygen (W. E. Tucker, D. O. Nellis, P. S. Buchanan, and J. A. Stout)

(Work pertinent to requests #43, #47 WASH 1144)

Gamma rays produced by the interaction of 14.8 MeV neutrons with nitrogen and oxygen are currently being measured at several angles to the incident beam direction using a large Ge(Li) detector. Large volume scattering samples of liquid nitrogen and water are being used to compensate for the low intrinsic efficiency of the Ge(Li) detector. Figure 1 shows a spectrum obtained for oxygen at 55°. No background has been subtracted from the spectrum and some of the peaks shown, such as the two silicon peaks, originate in background objects. Doppler broadening of the 7.12, 6.92 and 4.43 MeV peaks as seen in the figure, has been observed by other experimenters at Lund, ORNL, and GGA. The distortion of the 3.69 MeV peak from ^{13}C, observed by both the Lund and ORNL group and ascribed to Doppler broadening by the latter group , appears rather to indicate the presence of a doublet. Improved statistics and measurements at several angles should indicate which assumption is correct.

2. Elastic and Inelastic Neutron Scattering From Nitrogen (G. H. Williams, P. S. Buchanan, T. C. Martin, W. E. Tucker, and D. O. Nellis)

(Work pertinent to requests #39, #40, #41 WASH 1144)

Measurements of elastic and inelastic scattering of neutrons from nitrogen have been obtained using a 5 inch diameter NE213 scintillator and photomultiplier electronics incorporating n-γ discrimination. The Los Alamos tandem facility was used to provide the 9 and 11 MeV incident neutrons employed in this study. The scattering sample consisted of liquid nitrogen contained in a Los Alamos-designed cryostat.

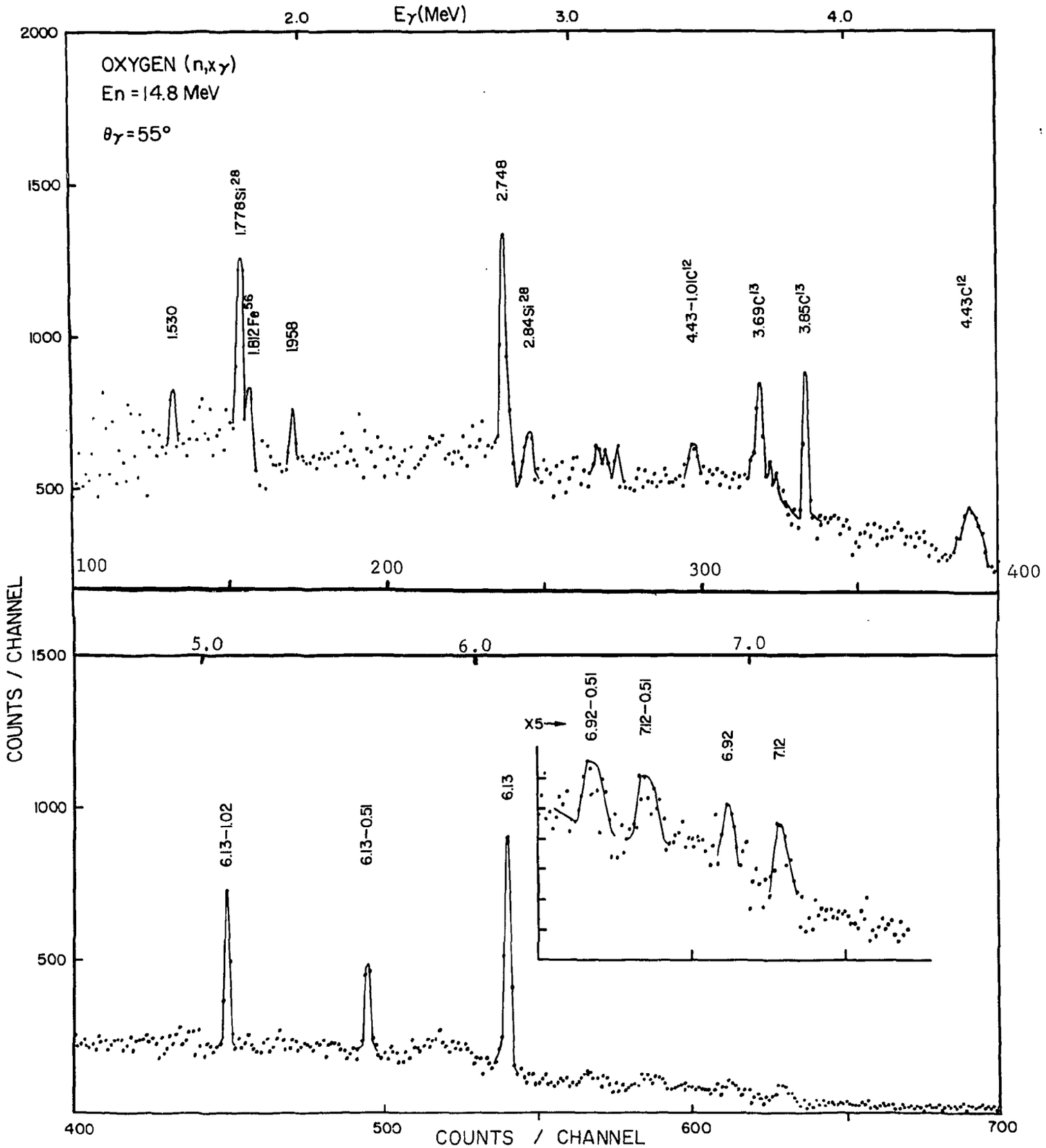

Figure A-1

DATA NOT FOR QUOTATION

Measurements were made at 10° intervals over the angular range 30° to 120°. The data are currently being analyzed.

3. Elastic and Inelastic Neutron Scattering From Aluminum and Iron (P. S. Buchanan, T. C. Martin, W. E. Tucker, D. O. Nellis, and G. H. Williams)

(Work pertinent to requests #61, #62, #99, #100, #101, #102 WASH 1144)

Measurements of elastic and inelastic scattering of 11 MeV neutrons from Al and Fe have begun at Los Alamos using the detection system described in the section above. Measurements are to be made over the angular range described above, using both 9 and 11 MeV incident neutrons.

4. Tungsten (D. O. Nellis, P. S. Buchanan, T. C. Martin, W. E. Tucker, and J. A. Stout)

(Work pertinent to requests #321, #322 WASH 1144)

Measurements of the gamma-ray production in natural tungsten by incident 300 keV to 1 MeV neutrons is continuing. The work should be completed in the next two months and a publication will be prepared.

5. Fissionable Isotopes (D. O. Nellis, G. H. Williams, W. E. Tucker, T. C. Martin, and J. A. Stout)

(Work pertinent to reports #413, #414, #415 WASH 1144)

Additional measurements of the neutron produced gamma-ray yields from ^{238}U and ^{239}Pu have been taken. Further measurements in the fluorescent and low energy region are planned as well as additional measurements in the intermediate energy region to overlap the previous measurements. Results will be submitted to a technical journal for publication.

6. Yttrium-89 (P. S. Buchanan)

A high-resolution study of the ^{89}Y nucleus by means of the $^{89}Y(n,n'\gamma)^{89}Y$ reaction has been completed. The 33cc Ge(Li) detector has been used to obtain 55° differential cross section data at 0.25 MeV intervals in the range from 3.5 to 5.0 MeV incident neutron energy, and angular distributions at E_n = 4.00 and E_n = 4.75 MeV. The level energies and decay modes of ^{89}Y below 4.3 MeV were deduced from these data. The experimental distributions and excitation functions were compared with the Satchler theory corrected for width fluctuation effects. On the basis of these comparisons, definite spin and parity assignments have been made to a number of levels in ^{89}Y. In particular, the levels of the triplet at 3.1 MeV have been assigned definite spins on the basis of the experimental angular distribution shapes of the ground state decays from these levels.

A summary of the level energies, spins and parities, and decay modes deduced from the present study of ^{89}Y is provided in Table 1. The spins and parities in parentheses should be considered as doubtful assignments. Work is almost complete on preparation of this study for publication.

7. Niobium-93 (G. H. Williams)

The study of the reaction $^{93}Nb(n,n'\gamma)^{93}Nb$ is now complete and in preparation for publication. Production cross sections $\sigma_\gamma(55°)$ have been obtained for neutron bombarding energies in the regions $0.70 \leq E_n \leq 2.00$ MeV and $3.00 \leq E_n \leq 5.50$ MeV, with angular distributions taken at 1.10 and 1.60 MeV. The experimental data shows good agreement with theoretical calculations using Rosen coefficients.

TABLE 1

Configuration of the ^{89}Y Nucleus

Initial State Energy (MeV)	J^{π}	Final State Energy (MeV)	J^{π}	E_{γ} (MeV)	Trans. Prob. (%)
4.307	$(5/2^+)$	2.220	$(5/2^+,7/2^+)$	2.087	100
4.229		0.908	$9/2^+$	3.321	100
4.185		1.507	$3/2^-$	2.678	100
4.169	$(3/2^-,5/2^-)$	0	$1/2^-$	4.169	100
4.103		1.507	$3/2^-$	2.596	100
4.027	$(1/2)$	1.507	$3/2^-$	2.520	(50)
		0	$1/2^-$	4.027	(50)
3.990	$3/2$	0	$1/2^-$	3.990	100
3.864		1.745	$5/2^-$	2.119	(50)
		1.507	$3/2^-$	2.357	(50)
3.852		1.745	$5/2^-$	2.107	(60)
		1.507	$3/2^-$	2.345	(40)
3.748	$(5/2^+)$	1.745	$5/2^-$	2.003	40
		0.908	$9/2^+$	2.840	60
3.716		0.908	$9/2^+$	2.808	100
3.625	$(9/2^+)$	0.908	$9/2^+$	2.717	100
3.559	$(9/2^+)$	1.507	$3/2^-$	2.052	70
		0.908	$9/2^+$	2.651	30
3.511	$(1/2^-,3/2^+)$	0	$3/2^-$	3.511	100
3.502	$(1/2^-)$	1.507	$1/2^-$	1.995	100
3.450	$7/2^{(+)}$	0.908	$9/2^+$	2.542	100
3.411	$9/2$	0.908	$9/2^+$	2.503	100
3.138	$5/2^{(-)}$	0	$1/2^-$	3.138	100
3.106	$5/2^{(-)}$	0	$1/2^-$	3.106	100
3.067	$3/2$	0	$1/2^-$	3.067	100
2.881	$3/2^-$	0	$1/2^-$	2.881	100
2.871	$(7/2^+,9/2^+)$	0.908	$9/2^+$	1.963	100
2.622	$9/2^+$	0.908	$9/2^+$	1.714	100
2.568	$11/2^+$	0.908	$9/2^+$	1.660	100
2.529	$7/2^+$	0.908	$9/2^+$	1.621	100
2.220	$(5/2^+,7/2^+)$	1.507	$3/2^-$	0.713	30
		0.908	$9/2^+$	1.312	70
1.745	$5/2^-$	0	$1/2^-$	1.745	100
1.507	$3/2^-$	0	$1/2^-$	1.507	100
0.908	$9/2^+$	0	$1/2^-$	0.908	100
0	$1/2^-$				

TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

A. NEUTRON PHYSICS AND FISSION

1. Resonance Cross Section Measurements with Continuous Beam (R. L. Walter, W. F. E. Pineo, J. Malan, E. G. Bilpuch, H. W. Newson)

Preliminary experiments are underway to investigate the applicability of this method to high resolution measurements at bombarding energies above one MeV.

2. Average Total Neutron Cross Sections (W. F. E. Pineo, E. G. Bilpuch, H. W. Newson)

The following is the abstract of the Ph.D. Dissertation of W. F. E. Pineo:

"Average neutron total cross sections were measured for samples of potassium chloride, scandium, zinc, arsenic, selenium, rubidium bromide, cesium iodide, cerium, neodymium, samarium, gadolinium, terbium, dysprosium, holmium, mercury, and the separated isotopes ^{144}Nd, ^{146}Nd, ^{148}Nd, ^{149}Sm, and ^{152}Sm. These measurements were made with an improved geometry designed to minimize the inscattered and extraneous neutron background.

Cross sections averaged over the energy ranges of 100-650 keV and 350-650 keV were compared with optical model calculations made using both spherical and deformed potentials.

The agreement between the spherical optical model calculations and the averaged cross section data is only fair below A= 140, where the nuclei are not statically deformed, and fail completely above A= 140 where the nuclei are known to exhibit large static deformations. The agreement between the deformed optical model calculations and the averaged cross sections is somewhat better but discrepancies are still apparent near A= 100 and above A= 140. The effect of the simplified coupling schemes and of the known limits of error in the quadrupole deformation para-

meters which were used in the calculations are discussed at length.

S-, p-, and d-wave strength functions, the s-wave scattering length, and the p-wave phase shift ratio were extracted from the average neutron total cross sections data using the Duke low resolution method. These parameters are compared with optical model calculations made using deformed potentials. The measurements of the s-wave strength functions add to the overwhelming evidence that the 4s giant resonance is split, and the measurements of the s-wave scattering length R' add considerably to the details of its [rapid] variation in the 4s giant resonance region."

The computer code JUPITOR I is now running at the Triangle University Computation Center on the IBM 306/75. Preliminary results indicate agreement with experimental average cross sections within the uncertainties of the deformation parameters compiled by Stelson and Grodzins[1] and Perey's optical model parameters.[2] A paper was presented at the Washington APS meeting.

3. Average Total Neutron Cross Sections and Strength Functions (W. F. E. Pineo, M. Divadeenam,* E. G. Bilpuch, H. W. Newson)

Papers on this topic based on the theses of M. Divadeenam and W. F. E. Pineo are in preparation. These papers should mark the end of this program since little can be added to the understanding of the optical model

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[1] P. H. Stelson and L. Grodzins, Nuclear Data Tables, 1, 21 (1965).

[2] F. Perey and B. Buck, Nuclear Physics 32, 352 (1962).

by this technique until much more is known about deformation parameters than is included in reference 1, below. As a byproduct of these measurements, we were able to compare the level densities of the isotones of N = 50 (see next section). We conclude that the effect of the subshells at Z = 38 and Z = 40 is within experimental uncertainty and much less than expected by Newton. A paper was presented at the Washington APS meeting.

4. A Multi-Level Analysis of ^{92}Mo + n Resonances (5-60 keV) (M. Divadeenam, E. G. Bilpuch, H. W. Newson)

Preliminary results of this analysis follow. Any lower energy resonances were too weak for interpretation. In our previous report the J^{π} assignments were not stated clearly and a revised table is shown below:

E_0(keV)	J^{π}	ℓ_n	$g\Gamma_n$(keV)	Γ_n(keV)
8.5		1	.0113	---
11.3	$\frac{1}{2}^+$	0	.022	0.022
13.5	$\frac{1}{2}^+$	0	.057	0.057
16.3	$\frac{1}{2}^+$	0	.072	0.072
18.8		1	.0251	---
20.8	$\frac{1}{2}^+$	0	.05	0.05
23.4	$\frac{1}{2}^+$	0	.035	0.035
25.6	$\frac{1}{2}^+$	0	.090	0.090
28.4		1	.040	---
29.4	$\frac{1}{2}^+$	0	.047	0.047
30.8	$\frac{1}{2}^+$	0	.07	0.07
32.1		1	.022	---
34.3		1	.045	---
36.2		1	.10	---
37.8		1	.03	---
39.8	$\frac{1}{2}^+$	0	.065	0.065
45.9		1	.03	---
48.5	$\frac{1}{2}^+$	0	.02	0.02
49.7	$\frac{1}{2}^+$	0	.05	0.05

E_o(keV)	J^π	ℓ_n	$g\Gamma_n$(keV)	Γ_n(keV)
52.8	$\frac{1}{2}^+$	0	.014	0.014
53.6		1	.05	---
54.4	$\frac{1}{2}^+$	0	.055	0.055
58.1		1	.02	---

It is evident that the energy spread ($\leq$1 keV) is not much less than the average spacing between resonances. The above results must be considered tentative--good only until higher resolution measurements on the separated isotope are available.

5. Theoretical Calculation of the Low-Lying Negative Parity Levels in ^{51}Ti (M. Divadeenam, W. P. Beres)

A paper on this work has been submitted for publication.

6. Shell Model Calculation of the Neutron Resonances and Intermediate Structure (F. T. Seibel, M. Divadeenam,* W. P. Beres,** H. W. Newson)

Properties of 2p-1h bound and continuum states of nuclei near doubly closed shells have been calculated in an attempt to study doorway states. The calculations are being compared with experimental data. A paper is nearly ready on Sr^{89}, Zr^{91} and Ca^{49}. Later papers will discuss evidence for (or sometimes against) intermediate structure in the neutron resonances of P, S, Mg, Ca, Ni, Sr, Mo, Tl, Pb and Bi.

7. Charged Particle Fission (F. O. Purser, J. R. Boyce, Jr., T. D. Hayward, E. G. Bilpuch, H. W. Newson, H. W. Schmitt***)

The high resolution pulsed beam of the Cyclo-Graaff is particularly well suited for charged particle time of flight studies. At present, experiments measuring the fission characteristics of nuclei are of particular interest. Recent studies of the fission problem have inspired considerable interest in accurate measurements of the fission cross sections, angular anisotropy, fission fragment mass distributions, and total fission energy balance. The short pulse (~0.5 ns), easy energy adjustment, and other superior Cyclo-Graaff beam characteristics

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for protons up to 30 MeV will facilitate measurement of the energy dependence of these properties. A cooperative program with ORNL is under discussion.

8. Scattering of 8 MeV Polarized Neutrons from ^{4}He (Th. Stammbach, J. Taylor, G. Spalek, R. L. Walter)

Final determinations of the phase shifts at 8 MeV have been made and the values have been found to overlap with the ones from the optical model analysis of Satchler et al.[1] The results of the 8 MeV polarization experiment and the phase shift analysis are discussed in a paper submitted to Phys. Rev.

9. Level Analysis of Nucleon-^{4}He Scattering (Th. Stammbach, R. L. Walter)

In view of the polarization data reported in section A-8, a new level analysis of n-^{4}He and p-^{4}He data was initiated in an attempt to provide sets of phase shifts which have a consistent energy dependence for both neutrons and protons. The method seems to represent the data quite well and a report describing the fits will be available soon.

10. Polarization in n-d at 7.8 MeV (J. Taylor, G. Spalek, Th. Stammbach, R. A. Hardekopf, R. L. Walter)

This work appeared in Phys. Rev. 1C, 803 (1970).

11. The ^{9}Be(α,n) Reaction as a Source of Polarized Neutrons (Th. Stammbach, J. Taylor, G. Spalek, R. L. Walter)

This work should appear in Nuclear Instruments and Methods.

12. Polarization in (^{3}He,n) Reactions on ^{9}Be, ^{11}B and ^{13}C (R. S. Thomason, L. A. Schaller, Th. Stammbach, J. Taylor, R. L. Walter, R. M. Drisko ((Univ. of Pittsburgh))

More calculations have been made since the preliminary report at the Quebec Symposium on Nuclear Reaction Mechanisms and Polarization Phenomena (to be published by the Univ. of Laval Press). No satisfactory fits to both the

[1] G. R. Satchler, L. W. Owen, A. J. Elwyn, G. Morgan, and R. L. Walter, Nuclear Physics A112, 1 (1968).

cross-section and polarization data have been achieved for the ^{9}Be or the ^{11}B reactions. A more complete report is being prepared.

13. Polarization of Neutrons from the $^{6}Li(d,n)$ and $^{7}Li(d,n)$ Reactions (R. S. Thomason, G. Spalek, R. L. Walter)

The DWBA calculations for the $^{6}Li(d,n_0)$ and $^{6}Li(d,n_1)$ reactions have been terminated even though the fits to the cross-section and polarization data were only moderately successful. A publication is being prepared which shows the calculations using the available optical model parameters. Sensitivities to parameter variations are also given. For $^{7}Li(d,n_0)$ and $^{7}Li(d,n_1)$, little success was achieved in describing the data. This may be attributed to the high Q-values for these reactions. These results will also be included in the above publication.

14. Polarization in the ^{40}Ca, ^{28}Si, and ^{24}Mg (d,n) Reactions (J. Taylor, Th. Stammbach, G. Spalek, R. A. Hardekopf, R. L. Walter)

All of the polarization data for the neutrons from the g.s. (d,n) reactions on ^{40}Ca, ^{28}Si, and ^{24}Mg havebeen analyzed. The DWBA calculations are incomplete and are still being investigated. The $^{40}Ca(d,n)$ data weregiven at the Quebec Symposium on Nuclear Reaction Mechanisms and Polarization Phenomena along with early DWBA results.

15. A DWBA Study of the Polarization of Neutrons from (d,n) Reactions in the 1p Shell (M. M. Meier, R. L. Walter, R. Seyler ((Ohio State University)), T. R. Donoghue ((OSU)), R. M. Drisko ((Univ. of Pittsburg))

A paper on (d,n) reactions in the 1p shell has been prepared and will be submitted shortly. It gives a thorough report on DWBA sensitivities to various optical model families and to other parameter modifications. The calculations center on the $^{14}N(d,n)$ reaction (at 3.5 MeV) as this was representative of the polarization observed in other (d,n) reactions and as $^{14}N(d,d)$ data were available. Results are also shown for a variety of Q-values to help explain data obtained on other 1p-shell nuclei as reported in Sections A-13, A-15 and A-16.

16. Polarization of (d,n) Reactions on 1p-Shell Nuclei from 3 to 4 MeV (M. M. Meier, R. S. Thomason, G. Spalek, J. Taylor, R. A. Hardekopf, Th. Stammbach, R. L. Walter)

Analysis of the $^{9}Be(d,n)$ polarization data for the first five neutron groups was reported at the Washington APS meeting. DWBA

results were also given. To limit the parameter space, $^{9}Be(d,d)$ data was obtained at 3.0, 3.5, 4.0 and 5.0 MeV and optical model searches were conducted. Some reasonable fits were obtained to the g.s. and 3rd excited state reaction cross-section and polarization data. The other states have mixed j-transfer or are quite weak. More DWBA calculations have been done for the other targets studied, i.e., ^{6}Li, ^{7}Li, ^{10}B, ^{11}B, ^{12}C, ^{13}C, ^{14}N and ^{15}N but probably much more remains.

17. The j-dependence in the $^{11}B(d,n_0)$ and $^{11}B(d,n_1)$ Polarizations from 3 to 12 MeV (J. Taylor, G. Spalek, Th. Stammbach, R. A. Hardekopf, R. L. Walter)

Measurements of the polarization in the $^{11}B(d,n_0)$ and $^{11}B(d,n_1)$ reactions were conducted for about nine angles at about 8, 10 and 12 MeV. The j-dependence is observed by noting the difference between the n_0-polarization ($p_{3/2}$ transfer) and the n_1 polarization (mostly $p_{\frac{1}{2}}$ transfer). The n_1 polarization observed at 10 and 12 MeV looked quite similar to that seen for other $p_{\frac{1}{2}}$ transfers at 3-4 MeV. This is in contrast to the polarization of opposite sign seen in this reaction previously in the 3-4 MeV region. A report on this work was given at the Washington APS meeting. Reaction cross sections at 8, 10, and 12 MeV were also measured for use in DWBA comparisons.

18. Angular Distributions of Neutrons Scattered from ^{4}He from 0.2 to 7.0 MeV (G. L. Morgan and R. L. Walter)

Cross-section data have been unfolded from He recoil spectra reported previously in Phys. Rev. 168, 114 (1968) in order to make the data suitable for use in current phenomenological investigations of the nucleon-helium interaction. A report was submitted to Phys. Rev. (Comments and Addendum Section).

B. CHARGED PARTICLE REACTIONS

1. Fine Structure of Isobaric Analog States in Medium-Weight Nuclei (D. P. Lindstrom, J. D. Moses, N. H. Prochnow, J. C. Browne, W. M. Wilson, W. C. Peters, G. E. Mitchell, H. W. Newson, E. G. Bilpuch)

a. The Chromium Isotopes

Investigations of the resonance structure of some Mn isotopes through elastic proton scattering on the even Cr isotopes have been completed.

The following excitation functions have been measured:

$^{50}Cr(p,p)$	from 1.80 MeV to 3.30 MeV at 160°, 135°, 120°, and 90°.
$^{50}Cr(p,p_1)$	from 2.31 MeV to 3.30 MeV at 160°, 135°, 120°, and 90°.
$^{52}Cr(p,p)$	from 2.00 MeV to 3.23 MeV at 160°, 135°, 120°, and 90°.
$^{54}Cr(p,p)$	from 1.81 MeV to 2.90 MeV at 160°, 135°, 120°, and 90°.
$^{54}Cr(p,n)$	total cross section from threshold (~2.20 MeV) to 2.90 MeV.

Spin and parity assignments, elastic and reaction partial widths, and resonance energies have been extracted from the data for most resonances observed in the elastic channel. Work on the interpretation of these resonance parameters is in progress.

b. The Iron Isotopes

Analysis of elastic proton scattering data on ^{54}Fe, ^{56}Fe, and ^{58}Fe has been completed. These data extend from 1.8 to 3.3 MeV in $^{54}Fe(p,p)$, 2.0 to 3.1 MeV in $^{56}Fe(p,p)$ and 2.0 to 2.65 MeV in $^{58}Fe(p,p)$. Energy resolution was found to be 300-400 eV. Six analog states were identified: the 6th, 9th, and 11th excited states of ^{55}Fe, the 7th excited state of ^{57}Fe, and the ground state and first excited state of ^{59}Fe. Spectroscopic factors and Coulomb displacement energies were extracted for these analogs. Proton strength functions were extracted from the off-analog data. These results will be included in a Ph.D. dissertation by one of the above authors (Lindstrom).

c. The Nickel Isotopes

Proton elastic scattering measurements on ^{58}Ni from 1.8 to 3.2 MeV have been completed and analyzed. This completes the elastic scattering measurements on the even-even isotopes of nickel. The results of this study have been submitted for publication in Nuclear Physics in a paper titled "Fine Structure of Analogue States in ^{59}Cu, ^{61}Cu, ^{63}Cu and ^{65}Cu".

d. The Ti Isotopes

The fine structure of the isobaric analog of the first excited state of ^{51}Ti has been observed in the $^{50}Ti(p,p)^{50}Ti$ reaction using the TUNL 3 MV Van de Graaff accelerator and high resolution analyzer-homogenizer system. A total energy resolution of 325-350 eV was obtained. The spins, parities, and widths of 50 resonances were obtained by fits to the data for an energy range of 2.46 MeV to 2.60 MeV over the analog region. These data are shown in the

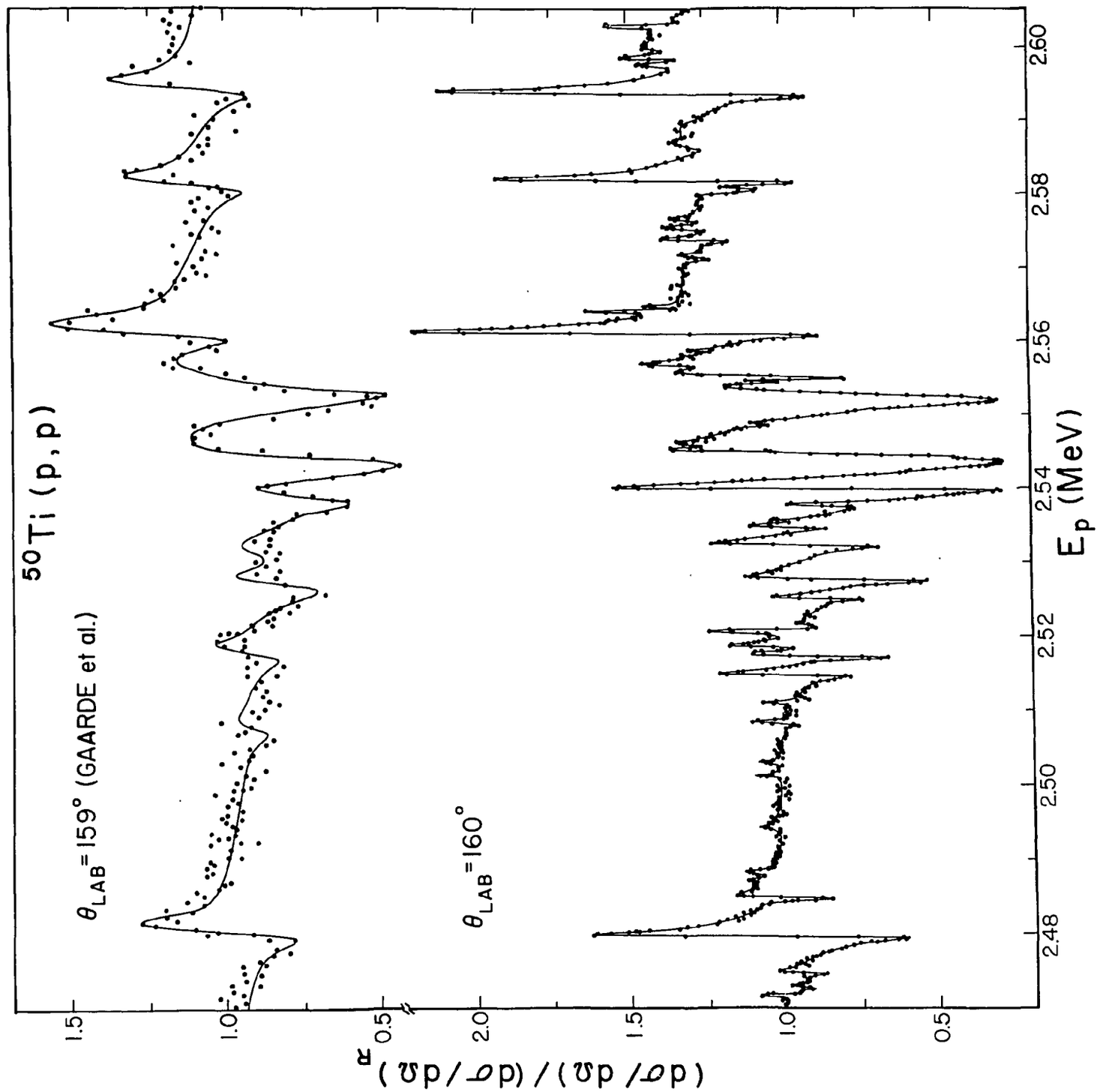

Fig. B-1

DATA NOT FOR QUOTATION

lower curve of Fig. B -1. The upper curve is that of Gaarde et al.[1] which is shown for comparison. The line shown in the upper curve is a fit to the data and the line shown in the lower curve is simply to aid the eye. In addition, a coulomb energy difference and spectroscopic factor has been obtained for this analog. Preliminary data have also been taken on the analog of the ground state of ^{51}Ti. Further experiments are currently in progress to examine several other analog states through the reactions $^{46}Ti(p,p)^{46}Ti$ and $^{48}Ti(p,p)^{48}Ti$. The work on Ti^{50} will be presented at the 1970 Washington APS meeting.

2. $Mg^{24}(He^3,\alpha\gamma)Mg^{23}$ Angular Correlation Measurements (L. C. Haun,* N. R. Roberson, D. R. Tiliey, R. V. Poore)

This work has been published in Nuclear Physics, A-140, 333 (1970).

3. $^{29}Si(\alpha,p\gamma)^{32}P$ and $^{31}P(\alpha,p\gamma)^{34}S$ Angular Correlation Measurements (C. E. Moss**, R. V. Poore, N. R. Roberson, D. R. Tilley)

A paper entitled "Spins of Levels in ^{32}P and ^{34}S" has been accepted for publication in Nuclear Physics.

4. $^{32}S(P,\alpha\gamma)^{29}P$ Angular Correlation Measurements (G. P. Lamaze, C. R. Gould, C. E. Moss, R. V. Poore, N. R. Roberson, D. R. Tilley)

The Method II Angular Correlation technique of Litherland and Ferguson has been applied to the $^{32}S(p,\alpha\gamma)^{29}P$ reaction in order to study the low-lying levels of ^{29}P. Spins of $3/2^+$ and $5/2^+$ were determined for the first and second excited state respectively in agreement with previous work. A new spin assignment of $J^\pi = 3/2^+$ was made for the third excited state at 2.40 MeV. Branching ratios of (93±3)% and (7±3)% were measured for the decay of the second excited state to the ground and first excited states respectively. Branching ratios of (87±4)%, (11±4)%, and (2±2)% were measured for the decay of the third excited state to the ground, first, and second excited states respectively. The decay of the first excited state to ground was found to have an $E2/M_1$ mixing ratio of .122 ± .06. The decay of the second excited state to ground was found to be pure E2. The decay of the third excited state to ground was found to have an E2/M1 mixing ratio of -.158 ± .05 or 2.6 ± .4. These results are being prepared for publication.

[1] C. Gaarde, K. Kemp and T. Nielsen, Nuclear Physics, A118, 641 (1968).

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** Now at the University of Colorado, Boulder, Colorado.

5. (He^3,α) Reaction Studies in the S-d Shell (J. E. McQueen, J. M. Joyce, E. J. Ludwig, F. Everling, D. W. Miller)

a. Studies Using S-d Shell Target Nuclei at 7 and 8 MeV

The analysis of the data corresponding to targets of ^{24}Mg, ^{26}Mg, ^{28}Si, ^{30}Si and ^{32}S has been completed and represents the thesis work of J. E. McQueen. A paper will appear in Nuclear Physics entitled "The $^{30}Si(^3He,\alpha)^{29}Si$ Reaction at 8 and 7 MeV". Another paper has been submitted to Nuclear Physics entitled "The (^3He,α) Reaction with Nuclei in the S-d Shell".

b. $^{28}Si(^3He,\alpha)^{27}Si$ Reaction at 21 MeV

The purpose of this experiment was to study the high-lying states of ^{27}Si which should be preferentially excited by the large positive Q-value (^3He,α) reaction as compared to other neutron pick-up reactions. Two detector telescopes were used with on-line computer mass separation techniques to separate the elastically scattered ^3He particles from the α-particles. Mass separation was complete and overall resolution of the α-peaks was 30 keV. Angular distributions have been taken in 5° steps to 60° at this time and preliminary analysis shows agreement with the previous assignment of ℓ-values. Analysis of the high-lying states is still underway.

6. ^3He Scattering and Polarization Studies (W. S. McEver, E. J. Ludwig, T. B. Clegg, J. M. Joyce, R. L. Walter)

a. Elastic Scattering Cross Sections

Cross section data taken with targets of ^9Be, ^{12}C and ^{16}O have been analyzed with optical-model computer code JIB3. The extracted parameters have then been used to calculate polarization angular distributions. The elastic scattering angular distributions can be well fit out to angles of $\approx$100° with reasonable parameter sets. The data corresponding to scattering from ^{12}C at 18, 20 and 21 MeV have been analyzed with parameters employing real well depths of 130, 145, 177 and 205 MeV. Elastic scattering excitation data for ^{12}C have been taken in 100 keV steps from 17 MeV to 24 MeV at 4 backward angles. These data along with data taken at lower energies have been analyzed with computer code ANSPEC to see if resonances exist which affect the polarization measured at forward angles. The effect of these resonances has been found to alter the expected polarizations by only a few per cent.

b. Polarization Angular Distributions

The polarization of 18 MeV ^{3}He particles scattered from ^{9}Be, ^{12}C and ^{18}O has been measured in 2.5° steps at forward angles ($20° \leq \theta_{LAB} \leq 45°$). A polarization angular distribution for ^{12}C(^{3}He,^{3}He) scattering has also been taken at 20 MeV to check the variation of the measured polarization with bombarding energy. The polarization angular distributions for scattering from ^{12}C appear identical at the two energies. Polarizations as large as 60% were measured near $\theta_{LAB} = 60°$ for ^{12}C scattering while large polarizations (~50%) were measured for the scattering from ^{9}Be at a laboratory angle of 45°.

The optical model parameters which fit the elastic scattering cross section data also were used to produce reasonable comparisons to the polarization distributions. A spin-orbit potential of 4 to 5 MeV was necessary to produce good comparisons to the magnitudes of the measured polarizations.

A description of the polarization analysis system has been accepted for publication in Physics Letters and the data have been presented at APS meetings in Boulder and Washington.

7. Gamma Decay of Isobaric Analog Resonances (S. M. Shafroth, J. M. Joyce, G. J. F. Legge,* H. Ejiri,** T. Hain, W. McEver, E. J. Ludwig)

a. The ^{90}Zr(p,γ)^{91}Nb Reaction

The $d_{5/2}$ ground-state analog resonances at 4.735 MeV are being studied. Data havebeen acquired with the 80-cc as well as with the 20-cc Ge(Li) detectors.

b. The ^{51}V(p,γ)^{52}Cr Reaction

A measurement on some analog resonances has been made with the 80-cc Ge(Li) detector as a check on the previous data which weretaken with the 20-cc detector. The results appear to be consistent, but some additional efficiency calibrations may be necessary.

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* Visiting scientist from the University of Melbourne, Melbourne, Australia.

** Visiting scientist from the University of Washington, Seattle, Washington.

8. Gamma-Ray Studies Using the 80 cc Ge(Li) Detector (S. M. Shafroth, J. Montgomary, A. Seila, T. Hain, J. M. Joyce, G. J. F. Legge)

A study of the 0.991 MeV resonance in the $^{27}Al(p,\gamma)$ reaction has confirmed the recent Cal. Tech. results[1] concerning the width of this resonance if the low energy 1.78 MeV gamma ray yield is observed, and if it is correct that 96% of the decays of this resonance go through this level. However, the 10.76 MeV γ-ray efficiency is still in doubt and is being further investigated.

9. Yields of K X-rays for Ca, T, and Ni from E_p = 2 - 28 MeV (G. A. Bissinger, J. M. Joyce, W. McEver, E. J. Ludwig, S. M. Shafroth)

This work has now been published in the Physical Review.

A study of fluorescence yields for Ca, Ti and Ni is underway since the main source of error in the K-hole production cross sections was due to uncertainties in these fluorescence yields.

10. Energies of Some ^{25}Al Levels from the $^{24}Mg(p,\gamma)^{25}Al$ Reaction (F. Everling, G. L. Morgan, D. W. Miller, L. W. Seagondollar, P. W. Tillman, Jr.)

This work has been submitted for publication in Can. J. Phys.

11. Levels in ^{25}Al from the $^{24}Mg(^3He,d)^{25}Al$ Reaction (F. Everling, G. L. Morgan, D. W. Miller, P. W. Tillman, Jr.)

An angular distribution of the deuterons was obtained. The work is in progress.

12. Gamma Decay of the 2.138 MeV Resonance in the $^{20}Ne(p,\gamma)^{21}Na$ Reaction (G. L. Morgan and F. Everling)

This work was discontinued due to the weakness of the γ-transitions in ^{21}Na.

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[1] P. B. Lyons, J. W. Toevs, and D. G. Sargood, Nucl. Phys. A130, 1 (1969).

13. Chopped Beam Experiments (S. M. Shafroth, A. A. Jaffe, G. A. Bissinger, T. Dzubay, F. Everling, D. W. Miller, P. W. Tillman)

A beam chopper useful in the range from 0.1 - 1.00 sec. has been built and installed in the 38° line. It is used in conjunction with Ge(Li) detectors and the on-line computer to study beta or gamma activities arising from (p,n), (p,2n) or (He^3,2n) reactions. The $^{27}Al(He^3,2n)^{28}P$ reaction has been studied from threshold (12.59 MeV) to 24 MeV and the yield of 28p is approximately proportional to $(E_T - E_{th})^3$. The half-life of ^{28}P was determined to be 285 ± 7 ms. Positron activities from ^{27}Al and $^{46}Ti(p,2n)$ were searched for up to 27 MeV using the Cyclo-Graaff but none was found. The $^{78}Kr(p,n)^{78}Rb$ reaction has been studied in the region near the threshold. A known 6 min. activity due to ^{78}Rb has been found as well as a new 9 min. activity. The first experimentally determined mass excess value for ^{78}Rb results from this threshold measurement. The result is -66.725 MeV. A search for ^{77}Rb via the (p,2n) reaction is planned next with the use of the Cyclo-Graaff since the threshold is expected at around 20 MeV. Two papers were contributed to the Washington APS meeting.

14. Studies of (d,t) and (d,^{3}He) Reactions (T. G. Dzubay, R. V. Poore)

Preliminary studies of (d,t) and (d,^{3}He) reactions have been completed on targets of ^{27}Al, ^{31}P, and ^{32}S. Cross sections for members of isobaric multiplets will be compared with the simple relation:

$$\frac{\sigma\,(d,{}^3He)}{\sigma\,(d,t)} = \frac{K_T}{K_t}\,(2Ti + 1)$$

where Ti is the isospin of the target, and K_x represents the momentum of an outgoing particle. Slight corrections to the above due to differences in Q-values and bound state radial wave functions will be studied in terms of DWBA calculations.

15. ^{14}N(d,t) and (d,^{3}He) Angular Distributions at 16 MeV (G. A. Bissinger, T. B. Clegg, T. G. Dzubay, E. J. Ludwig)

Angular distributions of tritons and ^3He particles from the $^{14}N(d,{}^3He)$ and (d,t) reactions have been measured for the lowest 4 states of ^{13}C and ^{13}N, respectively. The angular distributions corresponding to mirror states in these nuclei are very similar in shape and absolute cross section. It is planned to measure the left-right asymmetry of the reaction products with vector and tensor polarized deuterons incident on the target. Other targets which will be used in similar investigations include ^{10}B, ^{12}C, ^{16}O and ^{20}Ne.

16. Studies of α and ^{7}Li Induced Reactions on ^{14}C (R. A. Hilko, G. E. Mitchell, G. L. Morgan, N. R. Roberson, D. R. Tilley)

The study of the $^{14}C(\alpha,\alpha)^{14}C$ and $^{14}C(\alpha,n)^{17}O$ reactions has been essentially completed. The abstract of a paper accepted for publication in Nuclear Physics follows:

"The reaction $^{14}C(\alpha,\alpha)^{14}C$ has been studied over the bombarding energy range 3.5 to 16.5 MeV. Yield curves at eight angles were measured over the entire energy range; angular distributions were measured on resonances in the energy region below 8 MeV. Measurement was made of the relative yield from the reaction $^{14}C(\alpha,n)^{17}O$ from 4.9 to 8.5 MeV. Seventeen new levels have been observed and spin and parity assignments made for a majority of these. Evidence for the existence of rotational bands in ^{18}O is discussed."

Measurements have also been made on the $^{14}C(^{7}Li,t)^{18}O$. Triton angular distributions were measured at a bombarding energy of 20.4 MeV. Twenty triton groups were observed. The data are consistent with a ground state rotational band in ^{18}O (0^+, 0 MeV; 2^+, 1.98 MeV; 4^+, 7.10 MeV, 6^+, 11.69 MeV). Part of this work was reported at the Boulder, Colorado meeting of APS.

17. The $^{54}Fe(p,t)^{52}Fe$ Reaction (R. Nelson, N. R. Roberson, C. R. Gould)

Data for the $Fe^{54}(p,t)Fe^{52}$ reaction have been obtained with the 30.0 MeV proton beam from the TUNL Cyclo-Graaff. The scattered particles were detected in two ΔE - E detector telescopes. The ΔE and $E + \Delta E$ signals were routed into the on-line computer in the two parameter mode, a mass parameter calculated, and energy spectra for four mass windows stored. Preliminary analysis of data indicates levels at 0.0(0^+), 0.85(2^+), 2.42, 2.78, 3.59, 4.40(3^-), 4.87, 5.13, 5.37, 5.84, 6.04, 6.46 and 8.57 MeV. Angular distributions for levels at 0.0, .85 and 4.40 MeV have been fit using Bayman's two nucleon transfer code. The level at 8.57 MeV is the T = 2 state reported by Garvey. The Q-value for this level was calculated relative to the $C^{12}(p,t)$ Q-value. Carbon was present in the target as a backing for the Fe^{54}.

18. Mean Lifetimes of Levels in ^{33}S (C. E. Ragan III, C. E. Moss, C. R. Gould, R. V. Poore, N. R. Roberson, D. R. Tilley, G. E. Mitchell)

Using the Doppler shift attenuation methods, mean lifetimes of levels were measured in ^{33}S. A paper has been published on this work--Phys. Rev. 188,

1806 (1969). The results were T(0.842 MeV level) = 1.65 ± 0.34 psec, T(1.968) = 150 ± 20 fsec, T(2.313) = 158 ± 24 fsec, T(2.869) < 17 fsec, T(2.937) > 4 psec, T(2.970) = 69 ± 12 fsec, T(3.221) < 55 fsec.

The lifetime of the 2.937 MeV level has been measured by the recoil distance method utilizing the $^{30}Si(\alpha,n)^{33}S$ reaction. The lifetime was found to be 40.5 ± 2.0 psec. A paper has been submitted to the Physical Review on this measurement. These results were reported at the Washington meeting of the APS.

19. Mean Lifetimes of Low-Lying Levels of ^{34}S (C. E. Ragan III, R. V. Poore, N. R. Roberson, G. E. Mitchell, D. R. Tilley)

The lifetimes of levels in ^{34}S were measured using the $^{31}P(\alpha,p)^{34}S$ reaction and the DSAM method. The following lifetimes were found: T(2.13 MeV level) = 400 ± 32 fsec, T(3.30) = 175 ± 25 fsec, T(3.92) > 1.39 psec, T(4.07) < 24 fsec, T(4.11) = 110 ± 10 fsec, T(4.62) = 135 ± 17 fsec, T(4.69) = 131 ± 13 fsec, T(4.88) = (57 ± 22 fsec), T(4.89) = (52 ± 14) fsec. A paper has been accepted for publication in Physical Review on these measurements. These results were reported at the APS meeting in Boulder, Colorado.

20. Lifetime Measurements in ^{57}Ni (C. R. Gould, E. C. Hagen, R. V. Poore, N. R. Roberson, G. L. Morgan, G. E. Mitchell, D. R. Tilley)

The lifetimes of the low lying levels in ^{57}Ni have been investigated using the Doppler shift attenuation method in the reaction $^{54}Fe(\alpha,n)^{57}Ni$. The first two excited states are the $f_{5/2}$ and $p_{1/2}$ single particle levels and a measurement of their lifetime provides detailed information about the quality of the shell closure at ^{56}Ni. The γ-rays were observed in coincidence with neutrons at 0° to reduce background from competing reactions. Preliminary analysis of shifts gives mean lifetimes of 4^{+4}_{-2} ps, 130^{+35}_{-30} fs and 56^{+15}_{-10} fs for the states at 0.769, 1.112 and 2.576 MeV respectively. The results for the first two states are in qualitative agreement with calculations including up to two particle-two hole admixtures in the ^{56}Ni core. The enhancement for the $f_{7/2}$ two particle-one hole state at 2.576 MeV is also close to the value for the decay of the first excited state in ^{58}Ni, indicating possible collective admixtures. The results were reported at the APS meeting in Washington.

21. Lifetimes in ^{37}Ar Using Doppler Shift Techniques (C. E. Ragan III, N. R. Roberson, G. E. Mitchell, D. R. Tilley)

The $^{34}S(\alpha,n)^{37}Ar$ reaction has been used to populate the low lying levels of ^{37}Ar. Preliminary runs at 8.1, 8.75, and 9.2 MeV populated levels up to the fifth excited state. The first excited state at 1.41 MeV exhibited a Doppler shift when observed at 0°. The second excited state at 1.61 MeV exhibited no Doppler shift which is consistent with the known lifetime[1] of 5.17 ± .70 nsec. The other states were only weakly populated and future runs with thicker targets are planned.

C. GENERAL

1. Nuclear Binding Energy Systematics Including Excited States (F. Everling)

This work has been accepted for publication in Nuclear Physics. It was also presented at the APS Boulder meeting under the title "Systematics of Coulomb-Energy Differences of Excited Mirror Nuclei with $T_z = \pm\frac{1}{2}$"; the abstract is included in Appendix XVIII.

2. IBM Systems 360 Programming (C. R. Gould, J. M. Joyce, R. O. Nelson, C. E. Ragan)

The programs JIB3 (F. G. Perey), DWUCK (P. D. Kunz), EAGLE-HAUSER-FESHBACH (M. M. Meier), SNOOPY (P. Schwandt), JUPITOR-2 (T. Tamura), and ORGLS mentioned in the last report continue to be used in the analysis of many experiments.

A new version of DWUCK has been obtained from Dr. P. D. Kunz of the University of Colorado and is being modified to run on the TUCC IBM computer system. This new version includes options for two-particle transfer reaction cross section calculations and microscopic interaction calculations.

A two-particle transfer DWBA code (B. Bayman) is now running on the Systems 360.

Particle γ-ray angular correlation data are presently being analyzed by the computer code M2 (D. J. Church). This code fits data directly to theoretical correlation functions and can treat up to six γ-rays and two population pa-

[1] D. R. Goosman and R. W. Kavanagh, Phys. Letters 24B, 507 (1967).

rameters simultaneously to yield values for the spins and mixing ratios involved in the transitions.

The results of Doppler shift attenuation measurements are being analyzed with the program FTAU (C. E. Ragan) which calculates the expected Doppler shift as a function of the lifetime. The program uses the slowing-down formalism given by Blangrand[1] and evaluates all integrals numerically instead of with an analytic approximation to the stopping process. Finite target thicknesses are taken into account by dividing the target into ten layers and averaging over these layers.

3. Journals - Midstream Evaluation Conference (K. Way, S. M. Shafroth, J. Y. Park, H. W. Newson)

Seven papers growing out of the conference are being presented at the Washington meeting of the American Physical Society, April 27 - 30.

4. Large-Capacity Foil Stripper for The Tandem Accelerator (T. B. Clegg, G. L. Morgan, T. G. Dzubay, G. Spalek)

A foil stripper with capacity to hold 72 carbon foils is being designed for the tandem accelerator terminal. The foils will be supported on a chain and will be driven remotely from the accelerator control room. The foil mechanism can be either advanced or reversed and remote indication will be kept of which foil is in the beam.

In addition, the usual gas stripper tube will be used but its support structure is being redesigned to allow the stripper tube to be biassed at ± 10 keV with respect to the tandem terminal. A power supply to provide this bias voltage to help reduce terminal ripple on the accelerator will be built at some future date.

5. Table of Weighted Averages (F. Everling, J. Taylor, P. W. Tillman, Jr.)

The print-out was further improved and shortened. The table is being prepared for publication.

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[1] A. E. Blangrand, Nucl. Phys. 88, 501 (1966).

D. REPORTS OF PROJECT COMMITTEES

1. On-Line Data Acquisition And Analysis (R. V. Poore, S. E. Edwards, N. R. Roberson, J. M. Joyce, J. Boyce, R. Nelson, W. S. McEver)

The new DDP-224 computer purchased by the University of North Carolina at Chapel Hill on a grant from the National Science Foundation has been interfaced to a magnetic tape unit and a 20 cm by 25 cm display scope with light pen. The display scope has proved very useful for optical model calculations of angular distribution for one and two particle transfer reactions where the fits are displayed along with the data. When more funds become available construction of a small data acquisition interface is planned.

A digital octal display unit has been added to one of the output channels on the time sharing computer. This provides a digital display of the contents of any requested memory location; greatly facilitating debugging of programs.

Two 50 MH_Z, 8192 channel analog to digital connectors have been interfaced to the time sharing computer.

A computer method for identification of protons, deuterons, tritons, ^{3}He particles and α particles using solid-state detector telescopes has been placed in operation. Mass separation is accomplished by use of the Goulding formula or by comparison to a range-energy table, depending on the energy range. This work was reported at the APS meeting in Washington.

2. Scattering Chambers (E. J. Ludwig, T. B. Clegg, W. S. McEver, J. M. Joyce, N. R. Roberson)

A second 24" scattering chamber is to be constructed at the Duke and University of North Carolina machine shops. This chamber will be used for high resolution experiments with multiple cooled detectors.

3. Lamb-Shift Polarized Ion Source (T. B. Clegg, G. A. Bissinger)

The hardware for the Lamb-shift polarized ion source is now completed and assembled. During the last six months solenoids for the "spin filter" have been tested successfully. The first of two spin rotation solenoids has been fabricated and tested at magnetic fields large enough to rotate the spin quantization axis of an 80 keV polarized deuteron beam through 90°. A deionized water system to cool the diffusion pumps on the high voltage frame of the ion source

has been assembled. It provides 10 gpm of water with conductivity low enough so that leakage currents are less than 250 μA at 80 kV. An oil cooling system has been constructed to cool the various solenoids. Initial attempts to cool these solenoids with the deionized water failed because of increased conductivity when the iron cases of the solenoids began to rust. After initial tests showed problems of high voltage breakdown in the three-gap acceleration lens system, the lens support structure was redesigned and has now been successfully tested to voltages required to accelerate the polarized beam to 80 keV. A remote switching system has been constructed which will allow the orientation of the spin-quantization axis to be selected by signals from the computer being used to accumulate the polarization data. For polarized deuteron beams a choice of a beam with $m_z = +1$ or $m_z = 0$ is also provided remotely.

Initial tests of the beam from the ion source are underway. As of May 1st, 1970, beam currents of 30 μA of positive hydrogen ions at 500 eV had been obtained through the 2" diameter argon charge exchange canal. A 1×10^{-9} ampere beam of H^- ions which was about 50% polarized had been obtained after acceleration and momentum analysis. A paper was presented at the APS meeting in Washington.

4. Tandem Accelerator

Difficulty with flashing in the accelerator tube or discharge down the column or charging belt has caused limitations on the maximum terminal voltage at which experiments may be conducted. As one raised the voltage, the instability was first noticed by large vertical excursions of the beam on the high energy scanner and considerable terminal ripple and terminal γ-radiation. At higher energies, a considerable fraction of the up-charge could not be accounted for. Two tank openings with minor modifications did not help the situation. At the end of April, the maximum operating voltage with a stable beam was 3 MV. A new charging belt was installed with the hope that this might cure the problem. This new belt is now being conditioned. The He-ion source has been running successfully since it was installed last year, but some difficulty is being experienced understanding the Varian corona control circuit.

5. Beam Transport System (F. O. Purser, T. D. Hayward, J. R. Boyce, Jr. H. W. Newson)

The high resolution analyzing magnets and the beam transport system have been installed. Testing of the vacuum system and electrical components has been completed. System operating characteristics are being measured and preliminary results are favorable. Final tests of system resolving power when

operated in the high resolution mode and system transmission for near achromatic operation are scheduled following installation of a replacement charging belt in the FN tandem.

A scattering chamber for preliminary studies of proton induced fission cross sections is being installed to utilize one of the target legs of this system and installation of a second scattering chamber for reaction studies is planned for the near future.

6. Injector Cyclotron (F. O. Purser, T. D. Hayward, N. R. Roberson, J. R. Boyce, Jr., M. T. Smith, H. W. Newson)

The cyclotron and beam transport components connecting it with the tandem have been repositioned recently in the vertical plane to correct a misalignment of approximately $\frac{1}{2}$" brought about by settling of the concrete floor of the cyclotron vault. Operation has been considerably improved by this realignment.

All necessary electronic components to implement dee voltage stabilization through use of a feedback signal (derived from the external beam) have been manufactured and tested. Tests of beam resolution and stability with this arrangement in operation will be made shortly.

A replacement distributive resistor (for the harmonic bump coils of the extraction system) has been manufactured and tested. The new resistor incorporates the capability of tuning the azimuthal location of the harmonic field bump during extraction; this installation should lead to greatly improved extraction and therefore improved beam intensity for high resolution external beams.

A second set of harmonic coils has been designed for installation near the radius of the first $\nu_r = 1$ resonance of the cyclotron field. These coils will be used to modify the amplitude of the radial betatron oscillations to enhance single turn extraction when operating in the high resolution configuration ($\Delta E < 30$ keV). All materials for their construction are on hand.

Design of a pulse suppression system for the cyclotron to improve its characteristics for time of flight studies has been completed. This system will provide for selection of pulses which will allow use of flight times up to 640 ns with a pulse length of less than 0.5 ns. Initial use of the time of flight capability is intended for fission fragment identification studies.

Deuteron operation of the injector cyclotron has become an appre-

ciable fraction of total Cyclo-Graaff operating time. Performance of the cyclotron with deuterons has proved exceptionally stable with extracted beam currents of 2-5 μA.

The principal development effort continues to be directed toward further improvement of the ratio of extracted beam intensity to the energy spread in the extracted beam.

E. RADIOACTIVITY

1. Radioactivity Studies With The 80-cc Ge(Li) Detector (T. Hain, J. G. F. Legge, J. Montgomery, S. M. Shafroth)

The $^{38}A(p,n)^{38}K$ Reaction was used to produce very pure sources of 7.71 min. ^{38}K. Two new gamma rays have been found. One has an energy of 3.934 ± 0.002 MeV with an intensity of 0.3% of the 2.170 MeV gamma and the other one has an energy of 1.764 ± 0.003 MeV. This work is being prepared for publication. It was reported at the SESAPS meeting in Gainesville.

F. THEORY

1. Elastic Scattering of ^{3}He-Particles by ^{9}Be and ^{11}B between 4.0 and 18.0 MeV (J. Y. Park, J. L. Duggan ((ORAU)), P. D. Miller ((ORNL)), M. M. Duncan ((University of Georgia)), R. L. Dangle ((University of Georgia))

   This work has been published in Nuclear Physics A134, 277 (1969).

2. Microscopic Analysis of the ^{3}He Inelastic Scattering from ^{90}Zr (J. Y. Park)

This work has been published in New Physics, Supplement to vol. 9, No. 1, 43 (1969).

3. A Feynman-diagram study of Knock-out Nuclear Reactions (S. D. Danielopoulos, J. Y. Park)

A formalism has been developed, based primarily on Feynman diagrams, which constructs reaction amplitudes from the amplitudes of intermediate

elementary processes. We have located the knock-out mechanism within the framework of an S-matrix description of direct nuclear reactions. We have also established the relationship between the distorted wave Born approximation and the S-matrix theory of knock-out reactions and examined the simplifying assumptions which led to the former from the latter. We have concluded that in comparison with such processes as stripping, pick-up, heavy particle stripping, which are represented by pole-diagrams, knock-out is a higher order process. In certain cases, the higher order triangle diagrams have singularities located closer to the physical region, than the poles of competing process. This indicates the predominance of the knock-out mechanism. Although the formalism is general and applicable to all reactions, detailed knowledge of the vertex functions is required for each case. A talk on this work will be presented at the Washington APS meeting.

4. Shell-Model Analysis of the $^{90}Zr(^{3}He,^{3}He')$ Reaction Including Core Polarization Effects (J. Y. Park, G. R. Satchler ((ORNL))).

Inelastic scattering of 25.0 and 43.7 MeV ^{3}He particles is studied using the shell model form factors and including the effects of core polarization. Both the Yukawa and Gaussian interactions were examined. A report on this work has been presented at the Boulder APS Nuclear Physics Division Meeting.

5. ^{3}He Elastic Scattering from ^{10}B and ^{14}C in the Range of 4 to 18 MeV (J. Y. Park, S. D. Danielopoulos, J. L. Duggan ((ORAU)), P. C. Miller ((ORNL)), M. M. Duncan ((Univ. of Georgia)), R. L. Dangle ((Univ. of Georgia)), J. Lin ((Tennessee Tech. Univ.))).

A systematic optical-model analysis of the ^{3}He elastic scattering data from ^{10}B at 4, 8, 10, 12, 15, and 18 MeV and from ^{14}C at 10, 12, 15, and 18 MeV has been carried out including the spin-orbit interaction various ambiguities are found and examined. The variation of the optical potential parameters with energy and mass are investigated. Average energy dependent potentials were obtained for each nucleus in the energy range studied. This work has been accepted for publication in Nuclear Physics (1970).

6. Core Polarization Effects in the Triton Inelastic Scattering from ^{40}Zr (J. Y. Park)

A microscopic analysis of the triton inelastic scattering from ^{90}Zr at 20 MeV has been carried out. A special emphasis has been to examine the core polarization effects, especially in the light of new measured values for the re-

duced electromagnetic transition rates. A "realistic" nucleon-nucleon Gauss folded interaction has been used. Just as in the case of (p,p') the transitions are found to be dominated by core polarization. A report on this work has been presented at the Chicago APS meeting.

7. Analysis of (^{3}He,α) Reactions in Terms of The Knock-out Theory (S. D. Danielopoulos, J. Y. Park)

This work is inactive at present and will be resumed later when more computer time becomes available.

8. A Systematic Study of The ^{3}He Optical Model Potential in Light Nuclei (J. Y. Park, P. D. Miller ((ORNL)), J. L. Duggan ((ORAU)))

This work is inactive at present and will be resumed within a few months.

9. The Deuteron Scattering by ^{4}He (B. H. Choi, W. J. Thompson, J. Y. Park)

^{4}He(d,d)^{4}He elastic scattering cross section and vector polarization data for the incident energy range 3 to 25 MeV has been analyzed in terms of the optical-model. Good fits were obtained using the volume absorption and spin-orbit potential of Thomas form. A report of the work was presented at the 1970 Washington APS meeting.

YALE UNIVERSITY

A. NEUTRON TIME-OF-FLIGHT STUDIES

1. Photoneutron Reactions (F.W.K. Firk, C.-P. Wu, G.W. Cole, R. Nath, and B.L. Berman (on leave from Lawrence Radiation Laboratory, Livermore))

The 90° differential cross section for the reaction $^{4}He(\gamma,n_{0})^{3}He$ is being measured relative to the known deuterium cross section at energies between 22 and 35 MeV. A new cryostat for the liquid He target has been built and successfully operated. This measurement is necessary in view of present discrepancies between the observed cross sections for the total $^{4}He(\gamma,n)$ and $^{4}He(\gamma,p)$ reactions which imply appreciable isospin mixing in the dipole states of ^{4}He.

The 90° differential cross section for the reaction $^{26}Mg(\gamma,n)^{25}Mg$ is being measured at different bremsstrahlung end-point energies up to 27 MeV in order to search for neutron transitions from possible $T_{>}$ components of the dipole states.

2. Polarization Studies (G.W. Cole, R. Nath, C.-P. Wu, F.W.K. Firk, and B.L. Berman (on leave from Lawrence Radiation Laboratory, Livermore))

The differential polarization of photoneutrons from the reaction $^{16}O(\gamma,n)^{15}O$ has been measured at reaction angles of 45° and 90° using the $^{4}He(n,n)^{4}He$ reaction as an analyser. Neutron scattering angles were $\pm 130^{\circ}$. The neutron energies were determined using a nanosecond time-of-flight system with a resolution of 0.4 ns. m^{-1}. A detailed calculation of the analysing power of the He has been carried out using the phase shifts of Hoop and Barschall and a computer code kindly supplied by Professor Sample (University of Alberta). This calculation takes into account the effects of multiple neutron scattering in the liquid He target (3" dia.) and effects of the finite geometry of the two neutron detectors at $\pm 130^{\circ}$. The observed differential polarizations from the $^{16}O(\gamma,n)$ reaction at 45° and 90° are shown in Figs. A-1 and A-2. For

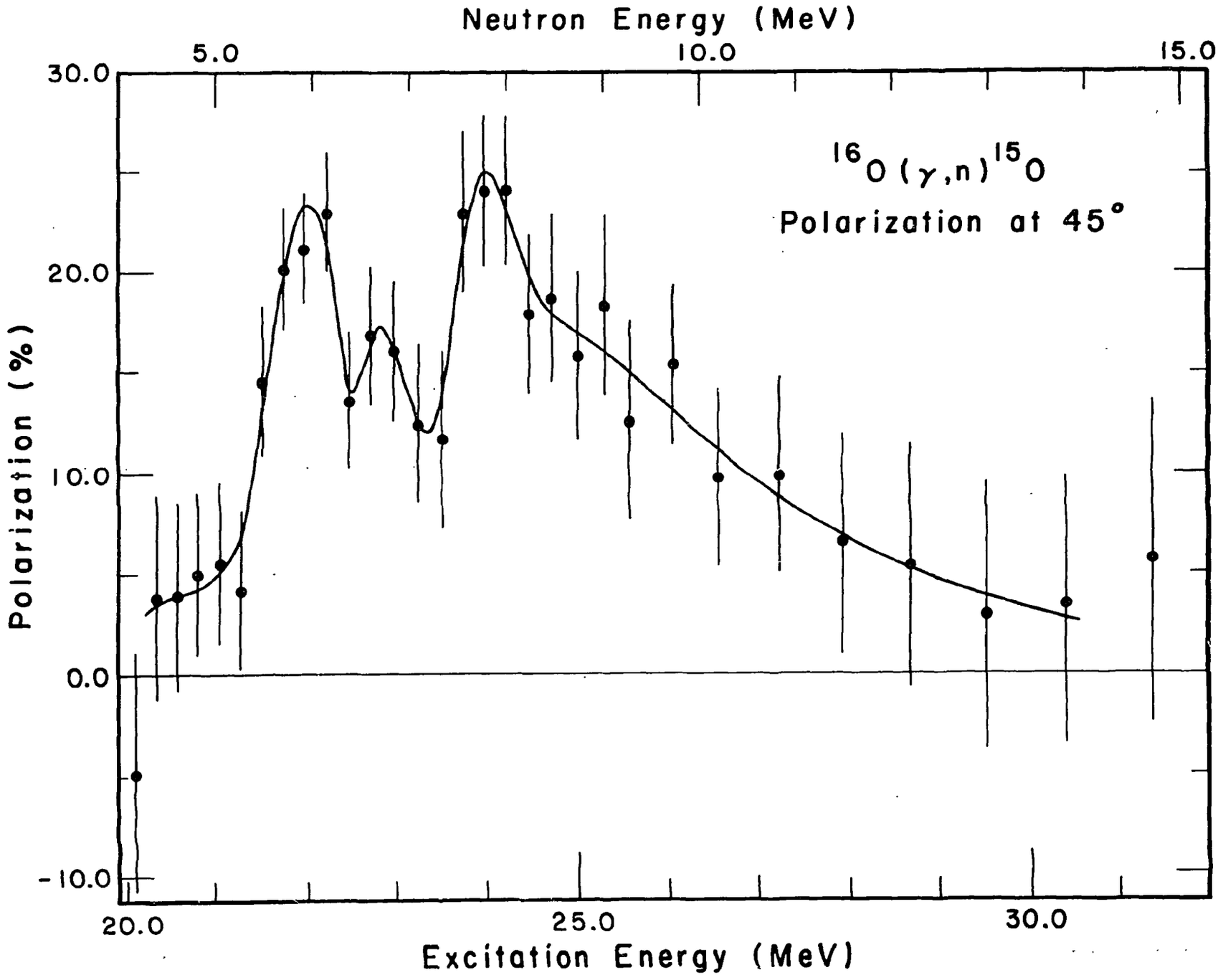

Fig. A-1

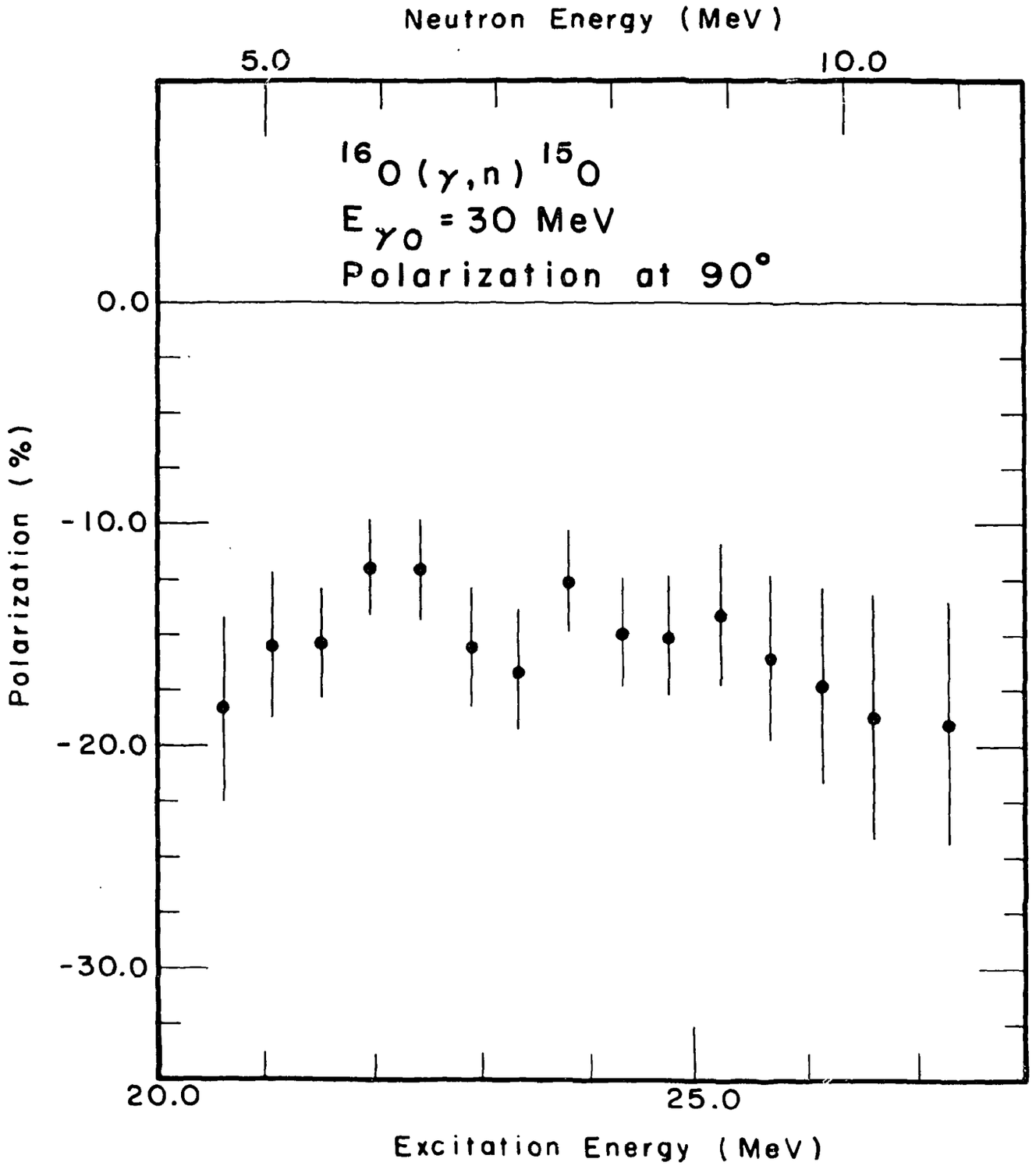

Fig. A-2

DATA NOT FOR QUOTATION

the first time, the energy dependence of the polarization at 45° has been measured with sufficient resolution to observe a resonant behavior which follows that of the known differential cross section. When analysed in conjunction with the angular distribution data obtained by Baglin and Thompson, these new results yield estimates of the s- to d-wave amplitudes in the dipole states of ^{16}O: such information is of importance in testing nuclear structure theories of these states which have been put forward in recent years. The polarization observed at 90° is indicative of E2 contributions in this reaction at energies above 20 MeV. Unfortunately, a unique solution to this problem must await new and, as yet, untried experiments in which the azimuthal distribution of photoparticles are studied following the absorption of polarized photons.

Preliminary measurements of the 90° differential polarization of photoneutrons from the reaction $D(\gamma,n)p$ have been made using the liquid He polarimeter and the associated time-of-flight system. Measurements are made using targets of CD_2, CH_2 and C and the polarization from deuterium is then deduced by taking appropriate differences. These measurements are, of course, of fundamental importance in testing the basic theories of nucleon-nucleon forces. Preliminary results already indicate significant departures (in both magnitude and energy dependence) from the theories of Partovi and of Lomon and Feshbach at energies between 10 and 40 MeV.

B. OTHER PHOTONUCLEAR REACTION STUDIES

1. Angular Distribution of Photoprotons from ^{14}N (J.E.E. Baglin, R.W. Carr, C.P. Wu)

This study was undertaken with the objective of comparing the giant resonance properties of ^{14}N with those of ^{16}O. The case of ^{16}O has been exhaustively studied[1] and a similarity might be expected since in each case the same $(p_{3/2} \rightarrow d_{5/2,3/2})$ single particle excitation is responsible for most of the E1 absorption.

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1. J. Baglin, M.N. Thompson, Nuc. Phys. 138, 73 (1969).

Earlier trial results have now been superceded by a series of measurements with good statistics taken at the Los Alamos EPA. Proton spectra were recorded simultaneously at seven angles between 20° and 160° using Si(Li) detectors. The nitrogen gas target was irradiated with bremsstrahlung whose end point was stepped in 2 MeV intervals from 25.6 MeV down. This will enable us to determine angular distributions for the ground state protons uniquely in 100 keV bins over the whole ^{14}N giant resonance.

Absolute differential cross sections were determined with reference to the known $^{2}H(\gamma,p)$ cross section.

Analysis is proceeding.

2. <u>The $^{14}N(\gamma,{}^{n}_{p}\gamma')$ and $^{16}O(\gamma,{}^{n}_{p}\gamma')$ Processes</u>* (J.E.E. Baglin, E.J. Bentz, R.W. Carr)

The angular distributions have been observed for gamma rays arising from prompt decay of residual states after photodisintegration of ^{14}N and ^{16}O. These distributions are specifically influenced by the admixture of higher multipoles in the E1 giant resonance excitation. We expect to use these results along with proton angular distribution data to isolate those higher order contributions from the simple E1 process.

Since these distributions must be symmetric about 90°, measurements were made in the backward quadrant only. A 40 cc coaxial-drift Ge(Li) detector was moved to positions at 90°, 110°, 130° and 150° to the bremsstrahlung beam and the runs were normalized with reference to both a P2 ionization chamber and a 30 cc Ge(Li) detector fixed at 90°.

To reveal the energy dependence of each distribution the sequence was repeated at 1 MeV intervals of bremsstrahlung tip energy from 19.5 MeV to 26.5 MeV.

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*Work done in collaboration with D.B. McConnell and B. Thomas of the University of Toronto, supported by N.R.C. of Canada contract.

A spectrum from oxygen is shown in Fig. B-1. The raw spectra from a series of angular measurements appear in Figs. B-2 and B-3. (Note the non-linear energy scale in these pictures). Worthy of mention are the excellent statistics on all these spectra, made possible by the use of the Los Alamos EPA (the data shown represent less 40 hours of beam time). The high data acquisition rate and large detector have enabled us to see the 15.11 MeV ^{12}C line from $^{16}O(\gamma,\alpha\gamma')$ which appears at the top of each individual spectrum.

Peak area determinations are presently being carried out to assign strengths to all spectral lines prior to fitting angular distributions and deducing cross section shapes.

C. ELECTRON SCATTERING

1. Inelastic Electron Scattering from ^{39}K (R.J. Peterson, H. Theissen and W.J. Alston)

This work has been completed and is published in Nuclear Physics A143, 337 (1970).

2. Inelastic Electron Scattering from ^{56}Fe (R.J. Peterson, H. Theissen and W.J. Alston)

This study was prompted by the desire to investigate the state dependence of inelastic electron scattering of known E2 multipolarity. Six states of known 2^+ spin in ^{56}Fe were studied. The angular distributions do exhibit a variety of shapes, and these imply a range of transition radii (from 4.30 fm to 6.45 fm). The values of B(E2) extracted from electron scattering data depend very strongly on the DWBA prediction for the shape, and the fact that our results for B(E2) agree with recent Doppler shift measurements points out the correctness of our analyses of the shapes of the angular distributions. This work has been submitted for publication.

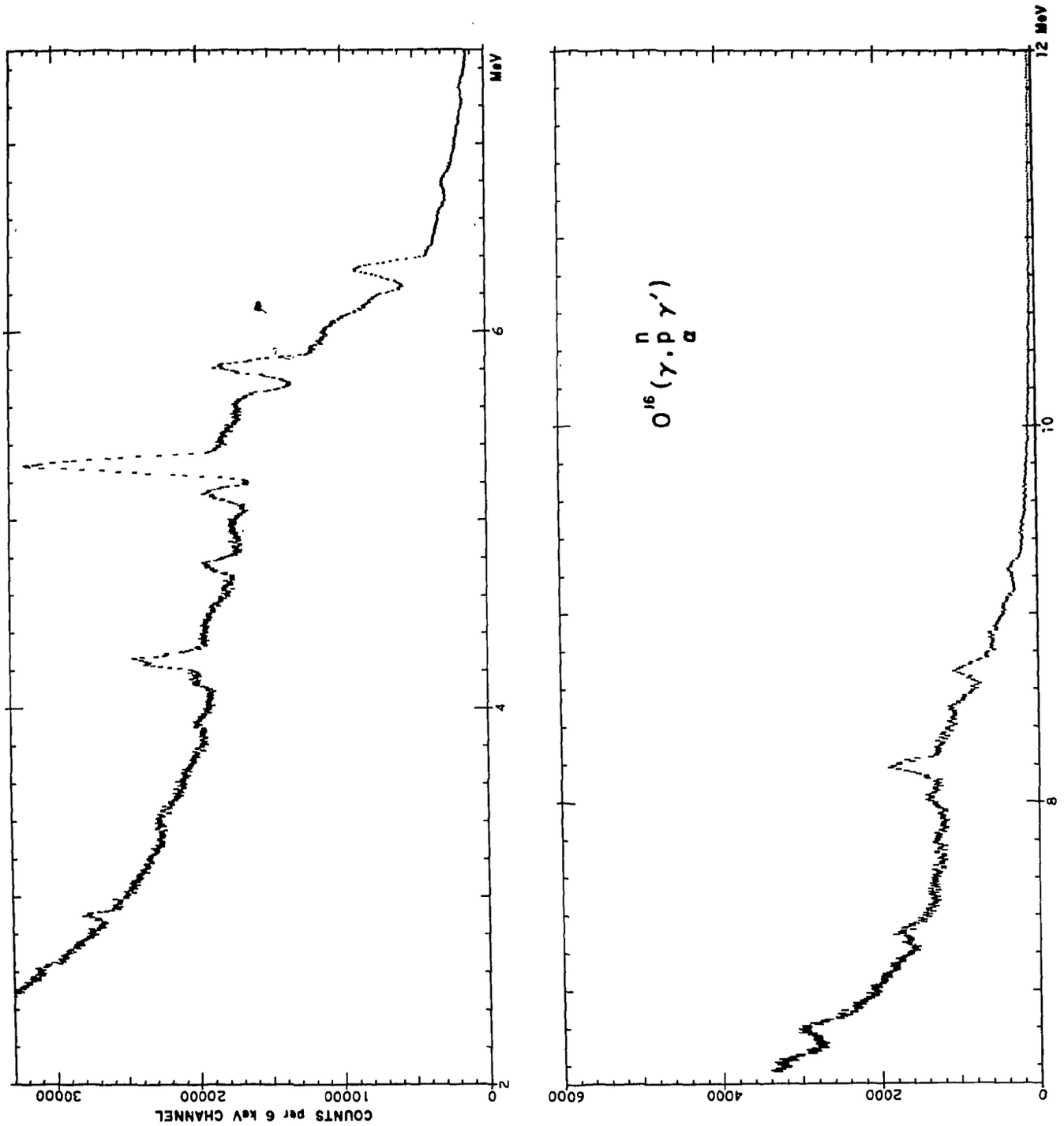

Fig.B-1

DATA NOT FOR QUOTATION

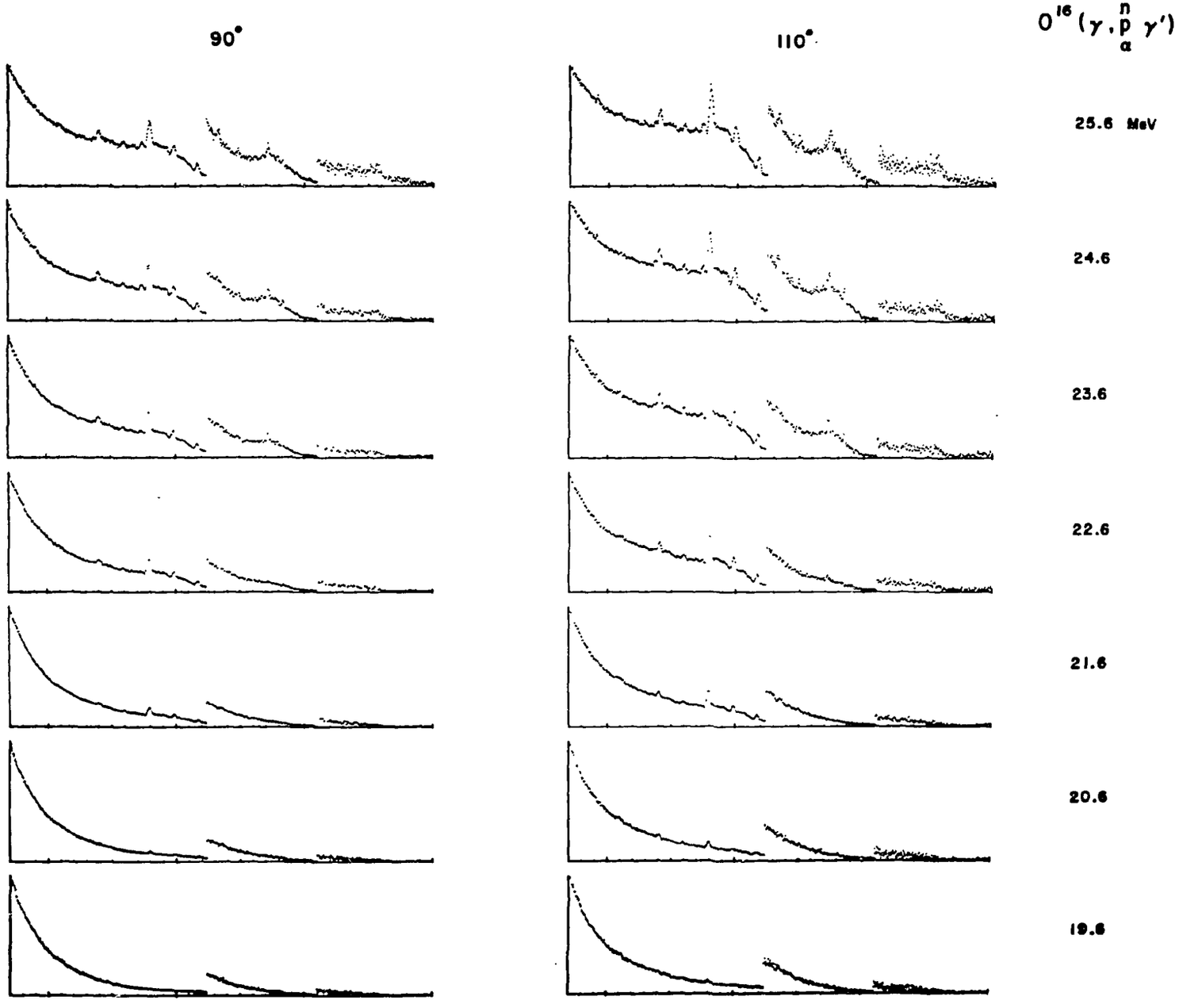

Fig.B-2

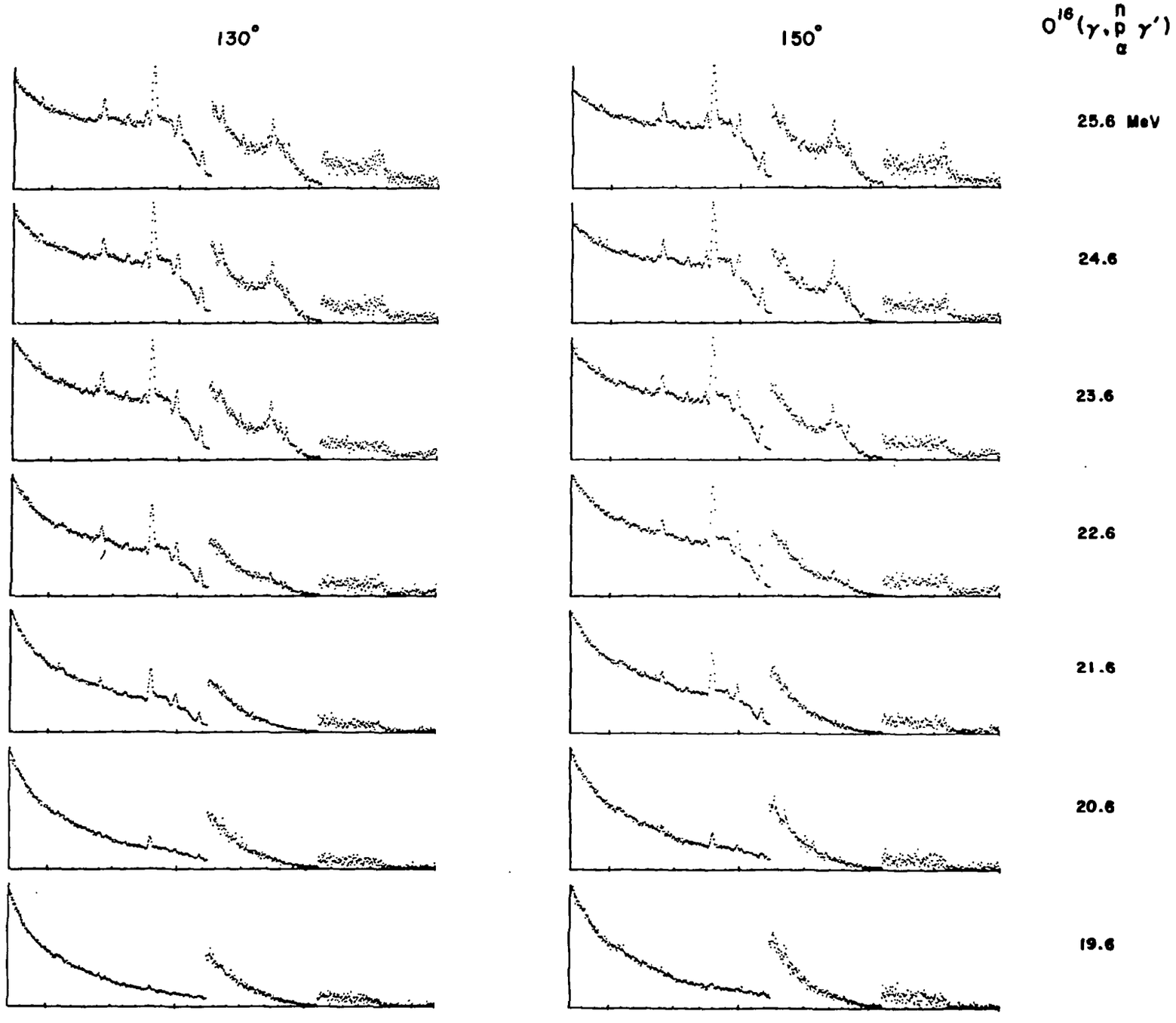

Fig.B-3

D. THEORETICAL DEVELOPMENTS

1. Work on model-independent analysis of electron scattering was completed early in the present fiscal year and the results have been published (T.H. Schucan).

2. Microscopic Calculations of Elastic and Inelastic Electron Scattering (R.J. Peterson and J.R. Caldwell)

The radial wave functions for the valence $f_{7/2}$ protons in ^{51}V and ^{52}Cr have been computed for protons bound in the proper Woods-Saxon well, and versatile techniques for folding in the finite charge distribution of the proton have been developed. The elastic electron scattering from ^{51}V and ^{52}Cr is computed by hypothesizing an inert ^{48}Ca core (with its well known charge distribution) and these valence $f_{7/2}$ protons. Our predictions for the scattering of 60 MeV electrons from ^{51}V are in excellent accord with the data, but the results for 150 MeV electrons on ^{52}Cr are not in agreement with the data. We might expect that the higher energy results are more sensitive. A variety of further predictions are available and await data.

The same wave functions may be used to generate the E2 inelastic electron scattering cross sections. The DWBA code DUELS is being modified to read the externally computed transition charge densities.

Microscopic transition charge densities for the 3^- state of ^{40}Ca are also available, and shortly will be used to compute the corresponding electron scattering cross sections.

3. Microscopic Analyses of Electron Scattering (R.J. Peterson)

A handbook of methods for computing inelastic electron scattering from a shell model description of the target has been prepared, and will be circulated as an internal report.

4. Analysis of High Energy Photonucleon Emission from ^{16}O and ^{12}C (M.G. Mustafa and F.B. Malik*)

A continuing study has been made of the angular distribution of the high energy (10-30 MeV) photoprotons from the reactions $^{16}O(\gamma,p_o)^{15}N$ and $^{12}C(\gamma,p_o)^{11}B$ in a direct reaction model. Electric dipole, electric quadrupole and magnetic dipole interactions are included in the calculation.** The ground state wave function is taken to be of the shell model type, and the final continuum wave function is calculated from an appropriate Wood-Saxon potential. Non-electric dipole amplitude is found to be less than ten percent of the dipole amplitude, and the calculated angular distribution is seen to agree well with the experimental observations. A study of the giant resonance phenomena in the intermediate-coupling model is now in progress. Preliminary calculation indicates a lowering of the dipole strength in the giant resonance region.

E. MAJOR INSTRUMENTATION

1. New 20" Magnetic Spectrometer for Electron Scattering (L. Cardman, J. Legg and C.K. Bockelman)

The spectrometer magnet has been installed and positioned. The vacuum systems, beam transport equipment, and Faraday collector are complete. Fast electronics for the 25 channel detector hodoscope array has been built and tested. Data acquisition and analysis programs have been written and checked. Completion of the remaining major item, the detector array, is expected before the end of the month. Calibration procedures will be carried out early in June, after which the spectrometer system should be fully operational.

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*Present Address--Department of Physics, University of Indiana.

**The pure dipole case has been studied and results have been published in the Physical Review.

APPENDIX

Recent Publications

Argonne publications which have appeared since the last report to NCSAC:

1. The Reduction of Time-of-Flight Errors in Pulsed Neutron Measurements, J. W. Meadows, Nucl. Instr. Methods 75, 163 (1969).

2. Studies of Fast Neuton Cross Sections Through Integral Experiments, J. M. Kallfells, W. P. Poenitz, B. R. Sehgal and B. A. Zolotar, Trans. Am. Nucl. Soc. 12, 187 (1969).

3. The Ratio σ_γ (U238) σ_f (U235) in the Neutron Energy Range 30—900 keV, W. P. Poenitz, Trans. Am. Nucl. Soc. 12, 279 (1969), Nucl. Sci. Eng. Submitted-letter.

4. Multi-level Parameters for the Pu-239 Cross Section from 40 to 100 eV, P. Lambropoulos, Nucl. Sci. Eng. Submitted-letter.

5. Fast Neutrons Incident on Vanadium, A. B. Smith, J. F. Whalen and K. Takeuchi, Phys. Rev. to be published, see also: ANL-7564 (May 1969).

6. Fast Neutron Cross Section of Hf, Gd, Sm., G. L. Sherwood, A. B. Smith, J. F. Whalen, Nucl. Sci. Eng., 39, 67 (1969).

7. Averaging Methods in Nuclear Reaction Theory, P. A. Moldauer, Phys. Rev. Letters 23, 708 (1969).

8. Analog Fine Structure and Asymmetry, P. A. Moldauer, Nuclear Isospin, edited by John D. Anderson et al. (Academic Press, N. Y., pp. 415-419 1969).

9. Neutron Spectra for Fast Reactor Irradiation Effects, D. Okrent, J. M. Kallfelz, W. B. Lowenstein, A. D. Rossin, A. B. Smith and B. A. Zolotar, Trans. Am. Nucl. Soc. 12, 2 (1969).

10. Fast Neutron Total and Scattering Cross Section of Bismuth, A. B. Smith, J. F. Whalen, E. Barnard, J. A. M. de Villiers and D. Reitmann, Nucl. Sci. Eng. to be published, ANL-7636 (1970).

11. Spin Determination of Resonances in $Ho^{165}(n, \gamma)$ from Low-Level Occupation Probability Ratios, W. P. Poenitz and J. R. Tatarczuk, Nucl. Phys. Submitted-letter, Bull. Am. Phys. Soc. submitted.

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14. The Fission Cross Section Ratio of ^{239}Pu and ^{235}U in the Neutron Energy Range 150-1400 keV, W. P. Poenitz, Trans. Am. Nucl. Soc. 12, 2, 742 (1969).

15. Measurement of the Cross Section Ratios of $^{235}U(n, f)$, $^{238}U(n, \gamma)$ and $^{239}Pu(n, f)$ in the Energy Range 130-1400 keV, W. P. Poenitz, Nucl. Sci. Eng., to be published.

16. MATDIAG, A Program for Computing Multilevel S-matrix Resonance Parameters, P. A. Moldauer, R. N. Hwang and B. S. Garbow, ANL-7590 (1969).

17. R-Matrix Shell Model Calculations of Scattering and Reaction Cross Sections, K. Takeuchi and P. A. Moldauer, Phys. Rev. Letters-submitted.

18. The Thermal Neutron Absorption Cross Sections of ^{6}Li and ^{10}B, J. W. Meadows and J. F. Whalen, Nucl. Sci. Eng., to be published.

19. Fragment Angular Distributions from Neutron Induced Fission of ^{242}Pu, K. Otozai, J. W. Meadows, A. N. Behkami and J. R. Huizenga, Nucl. Phys.-submitted.

20. Functionals for Flux Synthesis with Discontinuous Trial Functions, P. Lambropulos and V. Luco, ANL-7627.

21. Polarization in Neutron-Deuteron Elastic Scattering at 1.2 MeV[g], D. L. Smith and T. G. Miller, Nucl. Phys.-accepted for publication.

22. Analysis of Response Data for Several Organic Scintillators[g], R. L. Craun and D. L. Smith, Nucl. Inst. Methods-accepted for publication.

23. Focusing Properties of Electric and Magnetic Quadrupole Lenses[g], D. L. Smith, Nucl. Instr. Meth. - accepted for publication.

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35. Single-Particle Analog-State Anomalies in the Scattering of Protons from Au^{197}, Pt^{196}, and W^{184}, J. P. Schiffer, P. Kienle, and G. C. Morrison, Nuclear Isospin, Proc. 2nd. Conf., Pacific Grove, Calif., March 13-15, 1969, ed. J. D. Anderson, S. D. Bloom, J. Cerny, and W. W. True. Academic Press, Inc., New York, 1969, pp. 679-684; also Bull. Am. Phys. Soc. 14, 964 (1969). Abstract

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41. The Ground State of Homogeneous Nuclear Matter and the Foundation of the Nuclear Shell Model, Fritz Coester, Lectures in Theoretical Physics. Quantum Fluids and Nuclear Matter, Vol. 11-B, Ed. K. T. Mahanthappa and W. E. Brittin. Gordon and Breach, New York, 1969, pp. 157-186.

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20. Level Scheme of Hf^{180}, D. L. Bushnell, R. K. Smither and D. J. Buss, Bull. Am. Phys. Soc. 15, 524 (1970).

21. Particle-Hole Multiplets and (d, α) Reactions in the A ≈ 90 Region, J. R. Comfort, J. V. Maher, G. C. Morrison, and H. T. Fortune, Bull. Am. Phys. Soc. 15, 574 (1970).

22. Mean Level Width and Its Ratio to Mean Level Spacing in Highly Excited Compound Nuclei, K. A. Eberhard, and A. Richter, Bull. Am. Phys. Soc. 15, 570 (1970).

23. Energy Levels in Cl^{34} from $S^{33}(He^3, d)Cl^{34}$, J. R. Erskine, D. J. Crozier, J. P. Schiffer, and W. P. Alford, Bull. Am. Phys. Soc. 15, 484 (1970).

24. Nuclear Structure of ^{20}F: The $^{19}F(d, p)$ Reaction, H. T. Fortune, R. C. Bearse, G. C. Morrison, J. L. Yntema, and H. Wildenthal, Bull. Am. Phys. Soc. 15, 483 (1970).

25. Some Calculated Angular Distributions for Channeled Ions, D. S. Gemmell, Bull. Am. Phys. Soc. 15, 657 (1970).

26. Polarization and Differential Cross Section for Neutrons Scattered from ^{10}B, S. L. Hausladen, R. O. Lane, J. E. Monahan, A. J. Elwyn, F. P. Mooring, and A. Langsdorf, Jr., Bull. Am. Phys. Soc. 15, 567 (1970).

27. Proton Scattering on ^{96}Zr through Isobaric Analog Resonances, R. R. Jones, C. F. Moore, P. Dyer, N. Williams, and G. C. Morrison, Bull. Am. Phys. Soc. 15, 626 (1970).

28. The $Mg^{24,26}(p,\alpha)Na^{21,23}$ Reactions at 35 MeV, E. Kashy, W. Pickles, G. C. Morrison, and R. C. Bearse, Bull. Am. Phys. Soc. 15, 544 (1970).

29. $Sr^{86}(He^3,d)Y^{87}$ Reaction at 20 MeV, J. V. Maher, J. R. Comfort, and G. C. Morrison, Bull. Am. Phys. Soc. 15, 551 (1970).

30. Angular Distribution of Radiation from Proton Capture by Chlorine Isotopes, L. Meyer-Schutzmeister, D. S. Gemmell, N. G. Puttaswamy, H. T. Fortune, J. V. Maher, E. L. Sprenkel-Segel, R. C. Bearse, and R. E. Segel, Bull. Am. Phys. Soc. 15, 566 (1970).

31. The $^{48}Ca(He^3,t)^{48}Sc$ Reaction at 23 MeV, A. Richter, J. R. Comfort, and J. P. Schiffer, Bull. Am. Phys. Soc. 15, 594 (1970).

32. $Zr^{96}(He^3,t)Nb^{96}$ Reaction at 21 MeV, G. C. Morrison, J. R. Comfort, J. V. Maher, and J. P. Schiffer, Bull. Am. Phys. Soc. 15, 574 (1970).

33. Polarization and Differential Cross Sections for Scattering of Neutrons from ^{11}B, C. E. Nelson, R. O. Lane, J. L. Adams, J. E. Monahan, A. J. Elwyn, F. P. Mooring, and A. Langsdorf, Jr., Bull. Am. Phys. Soc. 15, 567 (1970).

34. Mean Lives of the Second and Third Excited States in ^{40}K, R. E. Segel, N. G. Puttaswamy, N. Williams, G. H. Wedberg, and G. B. Beard, Bull. Am. Phys. Soc. 15, 600 (1970).

35. Excited 0^+ States in the (p,t) Reaction on Pt, W, and U. Isotopes, J. P. Schiffer, J. V. Maher, J. R. Erskine, A. M. Friedman, and R. H. Siemssen, Bull. Am. Phys. Soc. 15, 528 (1970).

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38. Positive-Parity States of ^{190}Os from Average-Resonance-Capture in $^{189}Os(n, \gamma)^{190}Os$, G.E. Thomas and L. M. Bollinger, Bull. Am. Phys. Soc. 15, 549 (1970).

39. Study of Mn^{55}, Mn^{56}, and Fe^{57} with the Coriolis-Coupling Model, P. Wasielewski, J. R. Comfort, F. B. Malik, and W. Scholz, Bull. Am. Phys. Soc. 15, 478 (1970).

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BROOKHAVEN NATIONAL LABORATORY

Recent Publications

1) R. E. Chrien, O. A. Wasson, S. Dritsa, S. Bokharee and J. B. Garg, High Energy γ Rays Following Neutron Capture in ^{239}Pu and ^{235}U, to be presented at Proceedings Second Int'l Conf. on Nuclear Data for Reactors, Helsinki, Finland, 15-19 June 1970.

2) K. Rimawi, J. B. Garg, R. E. Chrien, and R. G. Graves, Resonance Neutron Capture in Rh^{103}. Phys. Rev. (submitted).

3) O. A. Wasson and R. E. Chrien, Resonant Neutron Capture in ^{175}Lu, Phys. Rev. (submitted).

4) M. R. Bhat, R. E. Chrien, D. I. Garber, and O. A. Wasson, Gamma Rays from Thermal and Resonance Capture in Sb^{121} and Sb^{123}, Phys. Rev. (submitted).

5) M. Beer, Doorway States and the Reaction Mechanism of Primary Neutron Capture γ-rays, Bull. Am. Phys. Soc. 15, 548 (1970).

6) S. F. Mughabghab, R. E. Chrien, and O. A. Wasson, Spin Assignments of Neutron Resonances of Dy^{163} Using the (n,γ) Reaction, Bull. Am. Phys. Soc. 15, 549 (1970).

7) R. G. Graves, C. Olmer, and R. E. Chrien, Resonant and Thermal Neutron Capture Gamma Rays from Cesium, Bull. Am. Phys. Soc. 15, 548 (1970).

8) R. E. Chrien, Gamma-Ray Spectra Following Capture of Epithermal Neutrons, Invited Talk presented at the American Nuclear Society Meeting on Nuclear Data for Shielding at San Francisco on November 30-December 4, 1969.

9) S. F. Mughabghab, R. E. Chrien, O. A. Wasson, D. I. Garber, and M. R. Bhat, Investigation of P-wave Neutron Capture in Mo-92, Bull. Am. Phys. Soc. 15, 86 (1970).

10) S. F. Mughabghab and R. E. Chrien, Study of Radiation Widths and Neutron Strength Functions of Dy Isotopes. Phys. Rev. (submitted).

11) Resonance Neutron Capture Gamma Rays from $^{175}Lu(n,\gamma)^{176}Lu$. O. A. Wasson and R. E. Chrien. Bull. Am. Phys. Soc. 15, 87 (1970).

12) R. E. Chrien, M. R. Bhat, and O. A. Wasson, Gamma Rays Following Neutron Capture in Fe-56. Phys. Rev. C Third Series Vol. 1, 973 (1970).

13) R. E. Chrien, S. Bokharee, J. B. Garg, and O. A. Wasson, Gamma Rays Following Resonant Neutron Capture in Pu-239 and U-235. Bull. Am. Phys. Soc. 15, 87 (1970).

14) M. R. Bhat, R. E. Chrien, D. I. Garber, and O. A. Wasson, Spin Assignment of S-Wave Neutron Resonances from Low Energy Capture γ-Rays. Bull. Am. Phys. Soc. 14, 1236 (1969)

15) K. Rimawi, R. E. Chrien, J. B. Garg, M. R. Bhat, D. I. Garber, and O. A. Wasson, Role of Doorway States in Neutron Capture in ^{93}Nb Resonance. Phys. Rev. Letters 23, 1041 (1969).

16) O. A. Wasson, Nonstatistical Effects in Neutron Radiative Capture. Invited Talk presented at Washington APS Meeting April 30, 1970.

17) S. F. Mughabghab and R. E. Chrien, Study of the Radiation Widths of Dy Isotopes. Bull. Am. Phys. Soc. 14, 1236 (1969).

18) R. E. Chrien, Epithermal Neutron Capture γ-Rays, IAEA Study Group Meeting on Research Reactor Utilization, LaCasaccia, Rome, Italy, February 2-6 1970.

19) W. R. Kane and G. Scharff-Goldhaber, Evidence for the Missing 2^- State in ^{110}Ag. Phys. Rev. (submitted).

20) M. A. J. Mariscotti, W. Gelletly and W. R. Kane, States of ^{208}Pb Excited in the (n,γ) Reaction. Bull. Am. Phys. Soc. Series II Vol. 14, 1236 (1970).

21) W. Gelletly, J. A. Maragues, M. A. J. Mariscotti and W. R. Kane, Level Structure of ^{141}Ce from the ^{140}Ce(n,γ)^{141}Ce Reaction. Phys. Rev. C, Third Series, Vol. 1, 1052 (1970).

22) K. H. Beckurts and G. Brunhart, Magnetic Moments of Compound States in ^{168}Er, Phys. Rev. C1, 726 (1970).

23) S. S. Malik, G. Brunhart, F. J. Shore, and V. L. Sailor, Factors in the Precision of Slow Neutron Capture Cross Sections Using a Simple Moxon-Rae Detector. Nuclear Instruments & Methods (submitted).

24) G. Brunhart, H. Postma, D. C. Rorer, V. L. Sailor and L. Vanneste, Spin Assignment of Dy^{161} and Dy^{163} Neutron Resonances by Nuclear Polarization. Bull. Am. Phys. Soc. 15, 569 (1970).

25) H. Postma, L. Vanneste, and V. L. Sailor, Spin Dependence of the Neutron Capture Cross Section and the Internal Magnetic Field at Vanadium Nuclei. Phys. Rev. (to be submitted).

CASE WESTERN RESERVE UNIVERSITY

The following papers were presented at the annual meeting of the A.P.S. in Chicago, Illinois, January 26-29, 1970:

Normalization of Neutron Scattering Cross Sections Using Organic Scintillators, P. P. Boschung, J. T. Lindow, and E. F. Shrader, Bull. Am. Phys. Soc. II, 15, 85 (1970).

Fast Neutron Scattering Cross Sections of $^{54,56}Fe$, $^{58,60}Ni$, and Natural Carbon, J. T. Lindow, P. P. Boschung, and E. F. Shrader, Bull. Am. Phys. Soc. II, 15, 86 (1970).

The following paper was presented at the spring meeting of the A.P.S. in Washington, D. C., April 27-30, 1970.

An Investigation of the ^{13}C + d System, P. Liebenauer, E. A. Silverstein, K. G. Kibler, and K. F. Koral, Bull. Am. Phys. Soc. II, 15, 521 (1970).

The following papers have been accepted for publication in Nuclear Instruments and Methods:

An Improved Computer Program for Reduction of Multichannel Analyzer Data, P. R. Bevington and K. G. Kibler.

Absolute Normalization of Neutron Scattering Cross Section Data Using Organic Scintillators as Scatterers, J. T. Lindow, P. Boschung, and E. F. Shrader.

The following paper has been submitted for publication in Physics Letters B:

Gamma Ray - Neutron Branching Ratio in the Triton - Deuteron Reaction, A. Kosiara, P. Boschung, and H. B. Willard.

GULF GENERAL ATOMIC CORPORATION

RECENT PUBLICATIONS

1. The ^{236}U Neutron Capture Cross Section, A. D. Carlson, S. J. Friesenhahn, W. M. Lopez and M. P. Fricke, Nucl. Phys. A141, 577 (1970).

2. Delayed Neutrons from Low Energy Photofission, L. A. Kull, R. L. Bramblett, T. Gozani and D. E. Rundquist, Nucl. Sci. Eng. 39, 163 (1970).

3. $^{3}He(n,p)T$ Cross Section from 0.3 to 1.16 MeV, D. G. Costello, S. J. Friesenhahn and W. M. Lopez, Nucl. Sci. Eng. 39, 409 (1970).

4. Neutron Resonance Parameters and Radiative Capture Cross Section of Gd from 3 eV to 750 keV, S. J. Friesenhahn, M. P. Fricke, D. G. Costello, W. M. Lopez and A. D. Carlson, to be published in Nucl. Phys.

5. High Resolution Measurements of the Total Neutron Cross Sections of Nitrogen and Iron, A. D. Carlson and R. J. Cerbone, to be published in Nucl. Sci. Eng.

6. The $^{141}Pr(\gamma,n)$ Cross Section from Threshold to 24 MeV, R. E. Sund, V. V. Verbinski, Hans Weber and L. A. Kull, to be published in Phys. Rev.

7. Crystal-Binding Effects on Doppler Broadening of Neutron Absorption Resonances, G. M. Borgonovi, D. H. Houston, J. U. Koppel and E. L. Slaggie, to be published in Phys. Rev.

Contributions Presented or to be Presented at Meetings

1. Gamma Rays Following Thermal and Resonance Neutron Capture in ^{238}U, Joseph John, V. J. Orphan and C. G. Hoot, Bull. Am. Phys. Soc. 14, 1237 (1969).

2. Measurements of Nuclear Data for Shielding Using a LINAC, V. J. Orphan, Trans. Am. Nucl. Soc. 12, 922 (1969).

3. Resonance Parameters and Average Capture Cross Sections of Gadolinium, S. J. Friesenhahn, D. G. Costello, W. M. Lopez, M. P. Fricke and A. D. Carlson, Trans. Am. Nucl. Soc. 12, 754 (1969).

4. Measurements of Cross Sections for the Radiative Capture of 1-keV to 1-MeV Neutrons by Mo, Rh, Gd, Ta, W, Re, Au and ^{238}U, M. P. Fricke, W. M. Lopez, S. J. Friesenhahn, A. D. Carlson and D. G. Costello, to be presented at the International Conference on Nuclear Data for Reactors, Helsinki, Finland, June 15-19, 1970.

5. Calculations of Cross Sections for the Radiative Capture of Fast Neutrons, M. P. Fricke, W. M. Lopez, S. J. Friesenhahn, A. D. Carlson and D. G. Costello, to be presented at the International Conference on Nuclear Data for Reactors, Helsinki, Finland, June 15-19, 1970.

LOS ALAMOS SCIENTIFIC LABORATORY

Recent journal articles which may be of interest:

D. R. Smith W. U. Geer	Critical Mass of a Water-Reflected Plutonium Sphere	Nucl. Appl. 7, 405 (1969).
L. V. East R. B. Walton	Polyethylene Moderated Helium-3 Neutron Detectors	Nucl. Instr. Methods 72, 161 (1969).
G. G. Ohlsen J. L. McKibben R. R. Stevens, Jr. G. P. Lawrence	Depolarization and Emittance Degradation Effects Associated with Charge Transfer in a Magnetic Field	Nucl. Instr. Methods 73, 45 (1969).
R. R. Fullwood	Wide-Band Pulse Multiplier	Nucl. Instr. Methods 73, 231 (1969).
D. M. Drake	Inelastic Neutron Scattering and Gamma Production from Fast-Neutron Bombardment of U-235	Nucl. Phys. A133, 108 (1969).
D. C. Hoffman F. O. Lawrence W. R. Daniels	Decay of Pu-243	Nucl. Phys. A131, 551 (1969).
J. D. Knight O. E. Johnson A. B. Tucker J. E. Solecki	Levels of Y-91 from the Decay of Sr-91	Nucl. Phys. A130, 433 (1969).
J. R. Nix G. E. Walker	Discussion of the Secondary-Minimum Hypothesis for Spontaneously Fissioning Isomers	Nucl. Phys. A132, 60 (1969).
L. R. Veeser D. D. Armstrong P. W. Keaton, Jr.	Polarization of Tritons Scattered from Hydrogen	Nucl. Phys. A140, 177 (1969).
J. C. Vigil R. J. LaBauve J. L. Meem, Jr.	Analysis of a Radially Loaded Thermal Reactor	Nucl. Sci. Eng. 39, 215 (1970).
J. R. Nix	Predicted Properties of the Fission of Super-Heavy Nuclei	Phys. Letters 30B, 1 (1969).

R. K. Walter J. C. Hopkins E. C. Kerr J. T. Martin A. Niiler J. D. Seagrave R. H. Sherman D. R. Dixon	Polarization of 22-MeV Neutrons Elastically Scattered from Liquid Tritium	Phys. Letters B30, 626 (1969).
A. C. Berick A. E. Evans J. A. Meissner	Delayed Gamma Rays from Thermal Neutron Fission of U-235 and Pu-239	Phys. Rev. 187, 1506 (1969).
G. J. Berzins M. E. Bunker J. W. Starner	Energy Levels of Ru-100	Phys. Rev. 187, 1618 (1969).
H. C. Britt J. D. Cramer	(t,p) Q-Values for Thorium, Uranium, and Plutonium Isotopes	Phys. Rev. 185, 1553 (1969).
K. W. Ford J. G. Wills	Muonic Atoms and the Radial Shape of the Nuclear Charge Distribution	Phys. Rev. 185, 1429 (1969).
M. Minor R. K. Sheline E. B. Shera E. T. Jurney	Energy Levels of Lu-176	Phys. Rev. 187, 1516 (1969).
R. C. Mjolsness H. M. Ruppel	Evaluation of Electron-Atom Bremsstrahlung from Elastic Scattering	Phys. Rev. 186, 63 (1969).
M. E. Schillaci R. R. Silbar	Failure of Soft-Pion Techniques for the Reaction Proton plus Proton Yields Deuterium Plus Pion at Threshold	Phys. Rev. 185, 1830 (1969).
E. R. Flynn J. G. Beery	Evidence for Particle-Quasihole States in Sn-124	Phys. Rev. Letters 24, 143 (1970).
G. J. Igo P. D. Barnes E. R. Flynn	Mixing of Two Particle-Two Hole States in Pb-208	Phys. Rev. Letters 24, 470 (1970).
N. Jarmie R. E. Brown R. L. Hutson J. L. Detch	Accurate Proton-Proton Differential Cross Sections Near 10 MeV	Phys. Rev. Letters 24, 240 (1970).

L. Rosen	Los Alamos Meson Factory	Sci. J. 5A, 39 (1969).

Papers recently submitted for presentation at meetings included the following:

American Nuclear Society Meeting, San Francisco, California, Nov. 30-Dec. 4, 1969: Trans. ANS 12:

D. R. Harris, Jr. J. A. Mitchell	Anisotropy of Neutron Migration in Lattices of Fuel Rods in Light Water
D. R. Harris, Jr. J. I. Sackett	Kinetic and Power Characteristics of Bare Pulsed Neutron Multipliers
S. A. Dupree H. A. Sandmeier G. E. Hansen W. W. Engle	Time Dependent Neutron Escape from Nuclear Explosions
L. L. Carter	Coupled Sampling with the Monte Carlo Method in Time-Dependent Neutron Transport Calculations
H. O. Menlove R. H. Augustson C. N. Henry	Cross Section for the Delayed-Neutron Yield from the $^{17}O(n,p)^{17}N$ Reaction at 14.1 MeV

ANS Symposium on Engineering with Nuclear Explosives, Las Vegas, Nevada, Jan. 14-16, 1970:

G. A. Cowan B. C. Diven	Present Status of Scientific Applications of Nuclear Explosions
B. C. Diven	Use of Nuclear Explosives in Measurement of Nuclear Properties of Fissile Materials
M. M. Hoffman	Elastic Neutron Interaction Measurements with a Moderated Bomb Source Spectrum

American Physical Society Meeting, Boulder, Colorado, Oct. 30-Nov. 1, 1969: Bull. Am. Phys. Soc. Ser. 2, V. 14 (1969):

E. R. Flynn	Triton Scattering and Reactions
H. A. Thiessen	Pion Production in Proton Nucleus Interaction at 740 MeV
O. Hansen	Pairing Vibrations and Isospin

A. Hemmendinger	Physics with Intense Neutron Sources
J. D. Cramer J. R. Nix	Exact Calculation of the Penetrability Through Two-Peaked Fission Barriers
S. C. Burnett H. C. Britt B. H. Erkkila W. E. Stein	Plutonium Fission Isomers
H. C. Britt J. D. Cramer	Direct Reaction Fission of Odd-A Uranium and Plutonium Isotopes
D. R. Harris, Jr.	Nuclear Reaction Cross Sections by Perturbation of the Inverse Level Matrix
G. J. Igo P. D. Barnes E. R. Flynn	$^{206}Pb(t,p)^{208}Pb$ and $^{210}Pb(p,t)^{208}Pb$ Reactions at 20 MeV
G. G. Ohlsen G. P. Lawrence J. L. McKibben D. D. Armstrong P. W. Keaton	Polarization Calibration of the LASL Lamb-Shift Source
N. Jarmie R. E. Brown R. L. Hutson J. L. Detch, Jr.	Proton-Proton Scattering at 10 MeV
J. E. Simmons W. B. Broste G. P. Lawrence J. L. McKibben G. G. Ohlsen	Neutron Polarization in the Triton $(d,n)^4He$ Reaction with an 11.4 Polarized Deuteron Beam
E. M. Bernstein G. G. Seaman J. M. Palms	Coulomb Excitation of Eu-151 with Oxygen Ions

American Physical Society Meeting, Chicago, Illinois, 26-29 January 1970: Bull. Am. Phys. Soc. Ser. 2, Vol.15 (1970):

J. L. Detch, Jr. R. L. Hutson N. Jarmie	Accurate Cross-Sections for $^3H(p,p)^3H$, $^3H(p,d)^2H$, and $^3H(p,^3He)n$

J. B. Cross N. C. Blais	Molecular Beam Kinetics: The Differential Cross Section of the Reaction Cl + Br_2
J. D. Johnson J. E. Brolley	Elastic Scattering of Protons and Electrons from Helium Atoms in the Glauber Approximation
M. S. Krick A. E. Evans	Delayed Neutron Yield from ^{235}U as a Function of the Neutron Energy Inducing Fission

American Physical Society Meeting, Washington, D. C., 27-30 April 1970:
Bull. Am. Phys. Soc. Ser. 2, V. 15:

J. H. Jett R. L. Hutson J. L. Detch, Jr. N. Jarmie	Accurate Proton-Proton Scattering Cross Sections at 13.6 MeV
D. M. Drake S. L. Whetstone I. Halpern	Spectra of High Energy Photons from Proton Bombardment of ^{64}Zn
M. M. Minor R. K. Sheline E. T. Jurney	Investigation of ^{178}Hf Levels
[illegible] [illegible] [illegible] D. C. Hoffman	Decay of the ^{178}Lu Isomers and the New Isotope ^{178}Yb
W. Ogle S. Wahlborn R. Piepenbring S. Fredriksson	Single-Particle Levels of Deformed Nuclei in the Region $150 < A < 190$
A. Niiler M. Drosg J. C. Hopkins R. K. Walter J. T. Martin	Neutron-Alpha Particle Elastic Scattering Near 20 MeV
O. Hansen R. F. Casten E. R. Flynn T. J. Mulligan P. Kienle R. K. Sheline	^{106}Ru, A New Deformed Nucleus

E. R. Flynn O. Hansen T. Mulligan	One and Three Quasiparticle States in ^{121}Sn
R. H. Stokes G. E. Walker	Nuclear and Coulomb Pairing Energies in Light Nuclei
G. E. Walker R. H. Stokes	Theoretical Interpretation of Nuclear and Coulomb Pairing Energy Systematics in Light Nuclei
K. D. Ware J. W. Mather P. J. Bottoms J. P. Carpenter A. H. Williams	High Voltage Plasma Focus Development
P. J. Bottoms J. W. Mather J. P. Carpenter K. D. Ware A. H. Williams	Line Radiation Contributions in Plasma Focus
W. E. Stein H. C. Britt S. C. Burnett B. H. Erkkila	Spontaneous Fission Isomers of Plutonium

The following have appeared as Los Alamos reports:

C. C. Cremer R. E. Hunter J-J. H. Berlijn D. R. Worlton	Comparison of Calculations with Integral Experiments for Plutonium and Uranium Critical Assemblies. LA-3529
W. K. Brown P. A. Seeger M. G. Silbert	Neutron Flux Determination in Time-of-Flight Cross-Section Measurements Using Underground Nuclear Explosions. LA-4095
C. R. Emigh	Thick Target Bremsstrahlung Theory. LA-4097-MS
R. G. Fluharty	Proposal for a Pulsed-Neutron Facility. LA-4138-MS
D. D. Armstrong J. G. Beery P. W. Keaton, Jr. L. R. Veeser	Cross-Section Measurements for the $^{9}Be+d$ and $^{12}C+t$ Interactions. LA-4177
R. R. Fullwood J. E. Gallegos	$\sqrt{N}$ Fanout and the Avalanche Pulser. LA-4182-MS

G. E. Hansen H. C. Paxton	Reevaluated Critical Specifications of Some Los Alamos Fast-Neutron Systems. LA-4208
J. Furnish	Data of Nuclear Reactor Physics, 1967 - 1968: A Bibliography. LA-4225-MS
	Nuclear Safeguards Research and Development Program Status Report, April-June 1969. LA-4227-MS
D. R. Waymire N. Jarmie	Annotated Bibliography of Possible False Asymmetries and Their Corrections in Experimental Measurements of Polarization Asymmetries. LA-4235
Editors: R. L. Henkel H. T. Motz R. H. Stokes R. F. Taschek	Proposed Heavy Ion Facility at the Los Alamos Scientific Laboratory. LA-4238
	Medium-Energy Physics Program Quarterly Status Report for the Period Ending July 31, 1969. LA-4241-MS
K. B. Mitchell	Fluorescence Efficiencies and Collisional Deactivation Rates for N_2 and N_2^+ Bands, Excited from Deposition of Soft X-Rays. LA-4248
H. L. Anderson	Vacuum Polarization in Muonic Atoms. LA-4255-MS
B. M. Moore	Short-Lived Delayed Gamma-Ray Emission from Fast Fission of Plutonium. LA-4257
T. P. Seitz H. J. Lang R. L. Henkel	Door Alarm and Interlock System at the Los Alamos Tandem Accelerator Facility. LA-4262
R. L. Leydig R. B. Perkins	Phototube Gain Stabilization Using Gallium Phosphide Light Emitting Diodes. LA-4263-MS
J. D. Johnson L. E. Porter J. E. Brolley	Target-to-Detector Transport Code for Low-Energy P-P Vacuum Polarization and Bremsstrahlung Experiments. LA-4274
H. D. Arlowe A. P. Furnish	Magnetic Recording of Neutron Cross-Section Data from an Underground Nuclear Explosive Source. LA-4277
	Quarterly Status Report on the Advanced Plutonium Fuels Program April 1 to June 30, 1969 and Third Annual Report, FY 1969. LA-4284-MS

J. D. Cramer D. W. Bergen	Neutron Induced Fission Cross Sections for ^{235}U from the Persimmon Event. LA-4285
	Advanced Plutonium Fuels Program. Quarterly Status Report, July 1 to September 30, 1969. LA-4307-MS
	Medium-Energy Physics Program Quarterly Status Report for the Period Ending October 31, 1969. LA-4310-MS
J. P. Balagna S. B. Helmick	Atlas of Gamma-Ray Spectra. LA-4312
J. L. Dunn R. F. Holland	Fluorescence Efficiencies of Nitrogen Excited by 1- to 5-MeV Positive Ions. LA-4314
	Nuclear Safeguards Research and Development Program Status Report July - September 1969. LA-4315-MS
	Nuclear Safeguards Research and Development Program Status Reports January 1967 - June 1969. LA-4320-MS
D. R. Smith	Application of S_n Calculations to the Evaluation of a Shipping Container for Small Quantities of Fissile Radioactive Material. LA-4325
D. R. Harris	Perturbation Transformation of Nuclear Cross-Section Parameters between Wigner-Eisenbud and Kapur-Peierls Formalisms: The PERTA Program. LA-4327
G. P. Ford D. C. Hoffman E. Rost	Calculation of Single-Particle Levels in a Deformed Diffuse Well. LA-4329
R. K. Walter	Polarization Measurements of 16.5-MeV and 22.1-MeV Neutrons Elastically Scattered from Liquid Tritium and Liquid Deuterium. LA-4334
J. M. Davidson N. Jarmie A. Niethammer	RELKIN, Two-Body Relativistic Kinematics Code. LA-4349-MS
G. R. Keepin	Nuclear Safeguards Research and Development, Program Status Report, October-December 1969. LA-4368-MS
W. K. Brown D. M. Drake	Fission Cross Sections of ^{237}Np from Pommard. LA-4372
P. W. Keaton, Jr.	Time Reversal in Polarization Phenomena of Nuclear Interactions. LA-4373-MS

P. W. Keaton, Jr. E. M. Aufdembrink L. R. Veeser	Model for the Optical Potential of Composite Particles. LA-4379-MS
	Quarterly Status Report on the Medium-Energy Physics Program for the Period Ending January 31, 1970. LA-4384-MS
J. Furnish	Effects of Neutron Radiation (or Radiation Damage) on Niobium and Niobium Alloys: A Bibliography. LA-4387-MS

The following may also be of interest:

G. A. Cowan B. P. Bayhurst R. J. Prestwood J. S. Gilmore G. W. Knobeloch	Symmetry of Neutron-Induced ^{235}U Fission at Individual Resonances. III. presented at ANS Symposium on Engineering with Nuclear Explosives, Las Vegas, Nevada, Jan. 14-16, 1970; also accepted for publication by The Physical Review.
J. C. Hopkins	Nuclear Physics Studies with Fast Neutrons: A Survey. LA-DC-11039. Presented at Split, Yugoslavia, September 1969. To be published by Gordon and Breach.
R. K. Walter J. C. Hopkins E. C. Kerr J. T. Martin A. Niiler J. D. Seagrave R. H. Sherman D. R. Dixon	Polarization of 22-MeV Neutrons Elastically Scattered from Liquid Tritium. APS Boulder Meeting, Oct. 30-Nov. 1, 1969. Bull. Am. Phys. Soc. 14, 1230 (1969).

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Listed below are papers published or submitted for publication during the period since the last NCSAC Meeting.

Rapid Data Acquisition Into More than 10^5 Channels at ORELA, N. A. Betz, J. W. Reynolds, and G. G. Slaughter, pp. 218-224 in Proc. Conf. on Computer Systems in Experimental Physics (Skytop, Pennsylvania, March 1969), Conf. 690301, Columbia University, 1969.

ORELA Data Acquisition into Greater than 10^5 Channels Through a Priority Multiplexer Operating on a Direct Memory Access and a Program Controlled Device Interface, J. W. Reynolds, N. A. Betz, and D. A. McCully, paper presented at the IEEE 1969 Nuclear Science Symposium, San Francisco, Calif., October 1969; IEEE Transactions on Nucl. Sci., NS-17, No. 1 (Feb. 1, 1970).

Neutron Capture Cross Sections and Nucleosynthesis, B. J. Allen, J. H. Gibbons, and R. L. Macklin, submitted to Advances in Nuclear Physics.

The $^{12}C(\alpha,\gamma)^{16}O$ Capture Cross Section Below 3.2 MeV, R. J. Jaszczak, J. H. Gibbons, and R. L. Macklin, submitted to Phys. Rev.

Statistical Properties of the Resonance Parameters of the Fissile Isotopes, G. de Saussure and R. B. Perez, Trans. Am. Nucl. Soc. Vol. 12, No. 2, p. 753 (1969).

Measurement of Neutron Fission and Absorption Cross Sections of ^{239}Pu, R. Gwin, L. W. Weston, G. de Saussure, R. W. Ingle, J. H. Todd, F. E. Gillespie, R. W. Hockenbury, and R. C. Block, presented at American Nuclear Society Annual Meeting, June 15-19, 1969, Seattle, Washington; ORNL-TM-2598 (Oct. 7, 1969); distributed to EANDC members for information purposes; and to be published in Nucl. Sci. Eng. (May, 1970).

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The $^{14}N(n,x\gamma)$ for $5.8 \leq E_n \leq 8.6$ MeV, J. K. Dickens and F. G. Perey, Nucl. Sci. Eng. 36, 280 (1969).

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