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NUCLEAR PHYSICS RESEARCH IN THE USSR
COLLECTED ABSTRACTS

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Institute of Physics and Power Engineering

DETERMINATION OF THE PERCENTAGE COMPOSITION OF A MIXTURE OF ^{235}U AND ^{239}Pu BY DELAYED NEUTRON MEASUREMENTS

B.P. Maksyutenko, Yu.F. Balakshev, V.I. Bulanenko,
G.I. Zhdanova, A.A. Shimanskij

The authors investigated experimentally the dependence on ^{235}U concentration (η_a) of the ratio of the yield of a second group of delayed neutrons to that of a first group (y). They used a mixture of UO_2 and PuO_2 weighing 1 g. Fission was induced by thermal neutrons. The results are presented in Table 1.

Table 1

Ratio of the yields of groups of delayed neutrons

η_a	y
0	8,5I ± 0,I6
0,206	7,69 ± 0,08
0,4I6	7,307 ± 0,060
0,628	6,9I ± 0,I6
0,8I2	6,452 ± 0,092
I	6,209 ± 0,055

By treating the same experimental results in a different manner they obtained the ratio of the yields of delayed neutrons from the precursors ^{137}I and ^{87}Br. The results are presented in Table 2.

Table 2

Ratio of yields from ^{137}I and ^{87}Br

η_a	y
0	8,40 ± 0,27
0,206	7,0I ± 0,20
0,4I5	5,76 ± 0,I6
0,628	5,04 ± 0,I6
0,8I2	4,35 ± 0,0I
I	3,9I ± 0,I4

It was found that, on the basis of the relative yields, one could distinguish mixtures differing as regards the concentration of one of the fissionable substances by 3-5%.

The ratio of the yields of delayed neutrons from the precursor ^{87}Br for ^{239}Pu and ^{235}U was determined:

$$C = 0.397 \pm 0.$$

MECHANISM OF THE REACTION (n,nf) AND DELAYED NEUTRONS

B.P. Maksyutenko, Yu.F. Balakshev, G.I. Volkova

It is shown that the rapid change in the relative and total absolute yields of delayed neutrons in the energy region of neutrons which produce fission, where the reaction (n,nf) takes place, is caused by a change in the width of the distribution of the cumulative yields of fission fragment isotopes due to the combination of two Gaussian distributions from two fissionable nuclei.

From data on the relative yields of delayed neutrons in ^{238}U fission the authors calculated a change in total absolute yield with energy which is in good agreement with the results of direct measurements.

Table 1

Relative yields of delayed neutrons in ^{238}U fission

T, (s)	Relative yields					
	E_n (MeV)	3,9	4,2	4,5	4,8	5,I
55,6		I	I	I	I	I
24,7		6,65 ± 0,I9	6,50 ± 0,27	5,88	7,6I	6,34 ± 0,5I
I6,3		5,82 ± 0,I4	5,5I ± 0,08	5,9I	6,54	4,58 ± 0,78
6,I		2,64 ± 0,26	I,94 ± 0,08	I,82	3,43	7,4 ± 2,8
4,45		I0,88 ± 0,08	9,52 ± 0,I7	8,72	9,90	6,4 ± 2,4
2,5		26,9 ± 3,4	24,0 ± I,7	24,I	26,4	I4,00 ± 0,26
2,0		I5,7 ± I,4	I4,4 ± 2,9	I2,2	I8,4	I2,4 ± 4,6
I,5		4,25 ± 0,07	4,2 ± I,4	2,5	4,8	8,0 ± 6,0
I,0		0,592 ± 0,028	0,56 ± 0,25	0,I9	0,33	4,0 ± 2,3
0,5		0,2I6 ± 0,0I4	0,I8I ± 0,094	0,04	0,06	I,6 ± 0,6

Table 1 (continued)

T (s)	Relative yields						
	E_n(MeV)	5,25	5,5	5,9	6,0	6,2	6,4
55,6		I	I	I	I	I	I
24,7		7,09	7,6 ± I,0	7,I8	6,64	6,75 ± 0,04	6,92 ± 0,I4
I6,3		4,35	4,66 ± 0,35	3,83	4,25	3,8I ± 0,I4	3,69 ± 0,I5
6,I		3,27	5,4 ± 0,9	3,50	2,40	3,7 ± I,2	2,95 ± 0,23
4,45		7,39	5,5 ± 2,6	5,5I	7,56	6,9 ± I,7	7,6 ± I,5
2,5		I3,8	I3,6 ± I,3	I4,6	I4,5	II,9 ± 0,3	II,9 ± I,2
2,0		I0,I	I4,4 ± 0,8	I2,6	9,3	9,9 ± I,3	9,05 ± 0,45
I,5		5,4	8,3 ± I,I	6,2	4,4	5,7 ± 0,7	5,46 ± 0,63
I,0		2,5	I,8 ± 0,5	2,0	2,3	2,24 ± 0,47	2,59 ± 0,25
0,5		2,I	0,8 ± 0,6	I,9	2,9	I,8 ± 0,9	2,3 ± I,2

Table 1 (continued)

T (s)	Relative yields					
	E_n(MeV)	6,6	6,8	7,0	7,I	Mean error (%)
55,6		I	I	I	I	-
24,7		6,64	6,71	6,I2	6,87	5
I6,3		3,84	3,99	4,09	3,82	6
6,I		3,23	3,03	I,5I	I,38	I8
4,45		7,I9	6,60	7,82	7,83	20
2,5		I2,3	I4,3	I7,5	I7,6	8
2,0		9,0	II,I	6,2	7,7	I5
I,5		4,9	5,6	I,3	2,7	30
1,0		2,2	2,3	0,7	2,I	60
0,5		I,6	2,2	4,4	6,0	I00

Table 2

Width of the distribution of the cumulative yields of fission fragment bromine isotopes (σ_z) and total absolute yield of delayed neutrons (TAY)

E_n (MeV)	3,9	4,2	4,5	4,8	5,I	5,25	5,5	5,9
σ_z	I,0I	I,00	0,9I	0,88	0,99	I,I3	0,9I	I,I2
TAY	0,049	0,050	0,050	0,056	0,054	0,042	0,06I	0,054

Table 2 (continued)

E_n (MeV)	6,0	6,2	6,4	6,6	6,8	7,0	7,I
σ_z	I,29	I,30	I,52	I,33	I,I8	I,29	I,47
TAY	0,036	0,038	0,032	0,038	0,046	0,037	0,034

ACCURACY OF 21-GROUP EFFECTIVE CONSTANTS OF HYDROGEN IN CALCULATIONS OF THE SQUARE OF THE SLOWING-DOWN LENGTH IN DIFFERENT MEDIA

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(Article submitted to "Yadernye konstanty")

The authors have continued their investigation of the accuracy of the 21-group system of effective constants of hydrogen (intended for reactor calculations in the diffusion-transport approximation) in calculations of the square of the slowing-down length L_s^2 in different media. Calculations of L_s^2 were performed for various reactor material compositions (such as $Al-H_2O$, $Be-H_2O$ and $Zr-H_2O$), for uranyl nitrates and for a mechanical mixture of uranium with water. Use was made of two models describing slowing-down in hydrogen:

1. With model I an exact calculation of slowing-down in hydrogen was performed (in the P_I approximation; matrix description);
2. With model II the effective constants of hydrogen were used.

The agreement between the results obtained with the two models is good (within ± 5%). The calculated values of L_s^2 are compared with experimental values. The divergences for media containing blocks of uranium and iron (up to 30%) are inherent in the two models to the same extent and require special study.

CONSIDERATION OF THE "BACK-BENDING" EFFECT IN THE PHENOMENOLOGICAL COLLECTIVE THEORY OF THE NUCLEUS

A.A. Seregin

Within the framework of the phenomenological collective theory of the nucleus, the author studies the dependence of the moment of inertia j on the square of the angular velocity. It is shown that the theory can explain the s-shaped dependence of j on ω^2 if the potential energy of collective motion v(ß) has two inflexions. The inflexion points in the potential energy are associated with anomalies in the low part of the energy spectrum of ^{184}Hg and ^{186}Hg nuclei. In this connection, highly accurate calculation of the potential energy of collective motion v(ß) is a matter of great interest.

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SUB-THRESHOLD CROSS-SECTION FOR ^{238}U FISSION BY NEUTRONS

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The authors measure the energy dependence of the cross-section for ^{238}U fission by monoenergetic neutrons with energies in the range 0.15-1.55 MeV. The neutron source is a solid tritium target bombarded by protons from an electrostatic accelerator.

Long counters are used as neutron beam monitors. The thickness of the ^{238}U layer exceeds the fission fragment path. The proportion of ^{235}U present $\lesssim 3 \times 10^{-5}$. Track detectors and glass-based detectors are used for detection of the fission fragments. Corrections are made for fission by scattered neutrons, the fission of impurity ^{235}U and photofission by gamma rays from the accelerator target. The results - normalized to 16 mbarn for E_n = 1000 keV[1] - are presented in the following table.

REFERENCE

[1] Neutron cross-sections, BNL-325, 2nd Ed., Suppl. No. 2, 1965.

Table

E_n (keV)	ΔE_n (keV)	σ_f (μbarn)	$\Delta\sigma_f$ (μbarn)	E_n (keV)	ΔE_n (keV)	σ_f (mbarn)	$\Delta\sigma_f$ (mbarn)
I60	25	30	20	753	39	2,80	0,31
240	26	60	30	758	35	2,90	0,21
3I0	30	I20	40	795	35	3,85	0,24
326	28	I02	25	810	39	4,70	0,50
350	25	I60	60	856	38	8,09	I,10
367	28	240	45	896	36	10,3	0,6
386	I2	260	II5	906	37	I4,0	I,6
400	27	320	57	940	36	I5,0	0,9
400	27	290	46	956	36	I5,6	I,7
402	I2	300	I05	962	35	I5,5	0,9
407	30	260	22	977	26	I8,9	I,I
420	I2	4I0	I20	980	38	I6,I	I,2
420	26	400	36	995	35	I6,2	I,4
432	I2	420	II5	IOI5	35	I5,5	0,9
440	29	390	27	I024	38	I8,0	I,4
454	II	260	I05	I050	35	20,4	I,3
473	25	280	75	II06	3I	26,I	I,5
477	27	340	60	II22	34	33,0	I,9
497	4I	300	44	II5I	30	34,5	2,0
502	4I	400	45	II72	34	42,8	2,5
537	35	600	30	I202	37	39,0	2,5
539	40	790	I00	I204	25	40,I	2,4
568	II	920	200	I230	34	43	2,4
598	28	I250	86	I253	30	46	3,0
604	II	I240	260	I276	33	5I,6	3,I
6I0	39	960	62	I305	30	58	3,5
6I5	40	II80	93	I327	33	70	4,3
628	II	I340	220	I356	30	88	5,0
650	40	I420	I20	I367	29	I00	5,8
653	36	II60	76	I367	29	94	5,4
659	I0	I260	220	I403	29	I45	8,7
66I	40	I240	I20	I453	29	230	I4
68I	38	I460	95	I479	2I	290	I8
686	I0	I740	260	I495	28	320	I9
7I6	36	2030	I50	I554	28	390	24
732	39	2500	220				

CROSS-SECTIONS FOR $(n,n'\gamma)$ REACTIONS IN Al AND Fe NUCLEI FOR $E_n = 0.8$–10 MeV

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(Article submitted to "Yadernaya fizika")

The authors present experimental values of cross-sections for the formation of individual gamma lines with $E_\gamma = 0.8$–3 MeV in the inelastic interaction of 0.8–10 MeV neutrons with ^{27}Al and ^{56}Fe nuclei.

The measurements were performed in a linear electron accelerator using the time-of-flight method and with a resolution of 1 ns/m. The gamma radiation was recorded by means of a NaI(Tl) crystal. The energy distribution of the neutrons and the neutron flux at the target were by means of a calibrated scintillation detector (a stilbene crystal; $\emptyset = 30$ mm, $h = 10$ mm). The results were obtained in two experiments.

In the first experiment, the authors used cylindrical samples and the gamma radiation was recorded at an angle of 90° to the direction of the neutron beam. In the second, they employed an annular geometry and the gamma radiation was recorded at an angle of 125°.

The results of the two experiments are presented in Tables 1–4. In their evaluation of the measurements, the authors made corrections for the angular distributions of the gamma rays, for multiple scattering and attenuation of the primary neutron flux in the sample, for the absorption of gamma rays in the sample and for contributions to the areas of the photopeaks from the corresponding annihilation "escape peaks". The angular distribution correction $\beta(\vartheta)$ is shown in Table 3.

The measurement errors and the total statistical errors are presented separately in Tables 1–4.

Table 1

Cross-sections for the formation of gamma rays in the reaction Al(n,xγ) measured using a cylindrical sample: $\sigma = 4\pi d\sigma(90^\circ)$ mbarn

E_n (MeV)	E_γ, (keV)							
	844		I0I3		I7I9		22I0	
	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$
I,I9			76±5	2,8				
I,23			I44 ±8	3,8				
I,28			74±5	2,6				
I,33			I52±9	3,8				
I,39			I30±7	3,4				
I,44	53±4	2,2	92±5	2,8				
I,50	8I±5	2,4	52±3	2,0				
I,57	55±3	I,9	I49±8	3,5				
I,63	73±4	2,2	II5±7	3,0				
I,7I	I00±6	3,7	[illegible] ±7	3,I				
I,78	72±5	2,8	I9I±I0	3,9				
I,86	33±2	I,3	234±I3	4,3				
I,95	5I±3	I,8	2I4±II	4,0				
2,05	39±2	I,5	282±I5	4,7				
2,I5	27±2	I,I	276±I5	4,6				
2,26	39±2	I,5	263±I4	4,5				
2,38	58±3	I,8	223±I2	4,8			55±6	5,0
2,5I	45±3	I,5	2I2±II	4,0			36±4	3,4
2,65	3I±2	I,0	227±I2	4,2			II4±8	3,9
2,80	39±2	I,3	2I7±I2	4,4			I95±I3	5,6
2,96	75±5	3,0	I70±9	3,9	28 ± 3	2,3	I98±I3	5,8
3,I4	4I±3	I,7	2I7±I2	4,8	75 ± 5	2,9	247±I6	7,I
3,34	36±2	I,5	27I±I5	6,0	I2I ± 8	4,0	320±2I	9,3
3,55	48±3	2,0	274±I5	6,6	I52 ±I0	4,9	325±2I	8,9
3,79	47±3	2,I	I87±II	5,2	I58 ±I0	5,3	309±20	9,4
4,05	50±3	2,2	I89±II	5,5	I55 ±I0	5,4	308±2I	9,9
4,34	63±4	2,8	I89±II	5,9	I28 ±9	5,2	262±I8	9,3
4,66	58±4	2,8	I84±II	6,3	II7 ±8	5,2	304±2I	II,2
5,02	29±3	2,0	202±I3	7,3	II4 ±8	5,2	259±I9	II,0
5,42	3I±3	2,3	2I4±I4	8,5	I2I ±9	6,3	3I3±24	I4,6
5,87	22±2	2,I	I56±II	7,5	I55 ±II	7,0	246±I9	I2,9
6,38	36±4	4,0	224±I6	II,5	I03 ±9	7,3	296±24	I6,7
6,96	39±5	4,3	206±I7	I3,0	93±II	9,7	236±23	I8,[illegible]

Table 2

Cross-sections for the formation of gamma rays in the reaction Al(n;xγ) measured in an annular geometry: σ = 4πdσ(125°) mbarn

E_n (MeV)	E_n (keV)							
	844		I0I3		I7I9		2210	
	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$
I,I7	55±5	4,3	24±3	3,2				
I,2I	55±6	4,2	65±6	6,3				
I,24	48±5	3,9	67±7	6,8				
I,28	5I±5	4,I	80±7	5,6				
I,32	69±6	5,I	II4±8	6,4				
I,36	42±5	4,2	II6±8	5,7				
I,40	46±5	4,4	90±7	5,I				
I,45	85±7	5,9	57±4	2,8				
I,49	I00±7	4,9	69±5	3,6				
I,53	64±5	3,2	I0I±7	4,8				
I,60	66±5	3,2	I09±7	4,8				
I,65	76±7	4,0	I30±9	6,0				
I,7I	63±4	3,0	I44±9	5,3				
I,77	56±4	3,2	I67±II	6,8				
I,83	44±3	2,6	I99±I2	7,3				
I,89	49±4	2,6	I58±I0	5,4				
I,98	47±4	2,8	I78±II	5,6				
2,06	42±3	2,7	2II±I3	7,2				
2,I2	33±3	2,I	246±I5	7,7				
2,I9	49±4	2,9	22I±I3	7,3				
2,28	49±4	2,5	I90±I2	6,7				
2,38	4I±3	2,5	2I0±I3	7,I			34±6	5,3
2,47	44±4	2,7	I72±I0	5,4			47±6	4,9
2,6I	38±3	2,3	I96±I2	7,I			82±9	7,6
2,72	34±3	2,0	I92±I2	7,3			I45±I5	I2,3
2,85	56±4	3,2	203±I2	7,2	62±7	5,9	I38±I2	9,2
2,98	65±4	2,8	2I3±I4	8,8	26±3	2,6	224±I9	I3,7
3,II	33±3	2,0	22I±I4	8,5	9I±8	6,8	2I8±I8	I2,7
3,28	66±5	3,2	245±I5	9,0	I69±I2	8,3	247±20	I3,2
3,4I	43±3	2,2	245±I5	8,8	I24±I9	7,9	203±I7	II,5
3,59	64±4	3,I	22I±I3	7,2	I30±II	7,9	240±I7	I0,5
3,82	65±4	3,I	I67±I0	6,0	I2I±9	[illegible]	252±I8	II,2
4,02	68±4	3,8	I93±I2	7,4	II8±9	6,I	273±22	I5,5
4,2I	60±4	3,3	I94±I2	7,4	85±7	4,9	279±22	I4,7
4,4I	7I±5	3,7	I90±I2	7,3	I74±I3	9,0	249±20	I3,6
4,7I	53±4	3,I	I82±I2	7,3	II6±I0	7,4	267±20	I2,4
4,95	49±4	3,0	I90±I2	7,7	II9±I0	7,9	276±22	I4,8
5,25	39±3	2,3	I90±I2	7,I	II3±9	5,6	293±22	I4,3
5,67	48±4	2,9	I97±I3	7,8	I27±9	6,I	282±2I	I3,6
6,03	5I±4	3,5	I84±I3	9,0	I60±I3	9,7	272±24	I8,3
6,38	57±5	3,9	I98±I4	I0,2	II4±I0	8,2	309±26	I8,6
6,83	54±5	3,6	I83±I3	9,6	I35±I2	9,I	246±22	I6,2
7,34	49±5	3,8	207±I8	I5,0	92±I0	8,4	305±3I	I8,8
7,80	53±5	4,0	I93±I6	I2,4	I08±II	8,6	25I±26	2I,I
8,54	39±5	4,2	I56±I5	I2,4	II4±I5	I3,2	254±26	23,3
9,I2	37±6	5,3	I62±I7	I4,6	57±9	8,7	276±38	34,0
9,88			I50±I8	I6,5	74±II	9,7	223±29	25,3

Table 3

Cross-sections for the formation of gamma rays in the reaction $^{56}Fe(n,x\gamma)$ measured using a cylindrical sample: $\sigma = 4\pi d\sigma(90^\circ)\beta(\vartheta)$ mbarn

E_n (MeV)	E_γ (keV)														
	847			I239			I3I0			2II3 + 2272			2522 + 2600		
	σ	$\Delta\sigma_{st}$	β(θ)	σ	$\Delta\sigma_{st}$	β(θ)	σ	$\Delta\sigma_{st}$	β(θ)	σ	$\Delta\sigma_{st}$	β(θ)	σ	$\Delta\sigma_{st}$	β(θ)
0,93	I59±I0	6	I,224												
0,96	2I3±I3	8	I,2I7												
0,99	3I6±20	I2	I,2I2												
I,02	385±24	I5	I,206												
I,06	338±21	I3	I,200												
I,08	507±32	20	I,I96												
I,I4	45I±28	I8	I,I86												
I,I8	4I5±26	I6	I,I80												
I,22	376±24	I5	I,I74												
I,27	4I9±26	I6	I,I68												
I,32	404±25	I6	I,I63												
I,37	470±30	I8	I,I56												
I,43	625±39	24	I,I49												
I,49	59I±37	23	I,I43												
I,55	693±40	2I	I,I37												
I,62	7I8±4I	22	I,I30												
I,69	785±45	24	I,I25												
I,77	69I±39	2I	I,II9												
I,85	649±37	I9	I,II4												
I,9I	750±43	22	I,I08												
2,03	832±47	25	I,I03												
2,I3	974±56	29	I,097												
2,24	I026±6I	33	I,094												
2,36	I0I5±60	33	I,090												
2,48	958±57	3I	I,085												
2,63	I029±6I	33	I,080	25±4	3	I,I46									
2,77	I098±65	36	I,076	30±3	3	I,I40									
2,93	I03I±6I	34	I,073	39±3	2	I,I36									
3,II	I05I±62	34	I,070	52±4	3	I,I32	89±I2	II	I,097	20±4	4	I,I45			
3,30	II76±69	39	I,068	53±4	3	I,I26	I4I±I7	I5	I,085						
3,51	II70±69	39	I,067	73±6	4	I,I22	I7I±2I	I9	I,075	73±8	6	I,I30			
3,75	I244±76	45	I,066	II4±8	5	I,II5	239±29	26	I,062	I59±I3	9	I,I23	23±4	4	I
4,00	I224±75	44	I,065	I42±II	8	I,II0	204±25	23	I,052	I35±I3	II	I,II5	73±9	8	I
4,29	II94±73	43	I,065	II4±9	7	I,I02	237±30	26	I,045	I62±I6	I3	I,I05	II7±I3	II	I
4,60	II30±69	40	I,065	II6±I0	8	I,095	20I±25	23	I,04I	I66±I6	I3	I,097			
4,95	III9±68	38	I,065	I[illegible]±I3	I0	I,090	I6I±2I	I8	I,038	I24±I2	I0	I,085	84±9	8	I
5,34	II59±7I	42	I,064	I45±I3	I0	I,032	I39±23	22	I,032	I42±I4	II	I,073	I06±9	8	I
5,79	II27±I0I	85	I,063				I50±25	24	I,026	I06±II	I0	I,060	I06±9	8	I
6,29	I247±II2	94	I,063	262±24	20	I,075	90±I5	I4	I,020	I02±I0	9	I,050	II0±9	7	I
6,85	I270±II4	95	I,062	294±29	25	I,075	I48±25	24	I,0I5	82±I0	9	I,040	I25±I2	II	I
7,49	I200±II7	98	I,060	305±36	32	I,075	I28±23	2I	I,0I0	I29±I9	I8	I,025	I24±I2	II	I

Table 4

Cross-sections for the formation of gamma rays in the reaction $^{56}Fe(n,x\gamma)$ measured in an annular geometry:
$\sigma = 4\pi d\sigma(125°)$ mbarn

E_n (MeV)	E_γ (keV)										
	847		I239		I8I0		2II3 + 2272		2523+2600		
	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	
I,47	664±37	I7,6									
I,50	672±37	I7,8									
I,54	72I±40	I9,I									
I,57	750±42	I9,9									
I,6I	794±44	2I,0									
I,65	752±42	I9,9									
I,69	768±42	20,2									
I,73	77I±43	20,4									
I,77	685±38	I7,3									
I,8I	594±33	I5,0									
I,86	658±36	I6,6									
I,90	674±37	I7,0									
I,95	688±38	I7,4									
2,00	725±40	I8,3									
2,06	804±44	20,3									
2,II	868±48	2I,9									
2,I7	964±54	25,2									
2,23	935±52	24,6									
2,29	983±55	25,9	I6±2	2,0							
2,35	926±52	24,5	26±4	3,3							
2,42	902±50	23,9	25±3	3,I							
2,49	887±49	23,6	I5±2	I,8							
2,56	I026±57	27,4	II ± I,4	I,3							
2,64	II39±66	34,2	44 ± 5	4,8							
2,72	I0I2±59	3I,4	64 ± 7	6,4							
2,80	II58±68	37,0	54 ± 6	5,2							
2,89	999±59	32,2	40 ± 4	3,8	23±3	2,8					
2,97	I067±63	34,7	6I ± 7	5,8	78±II	9,5					
3.07	I074±63	35,0	78 ± 8	6,8	I27±I7	I5,5					
3,I7	I057±62	34,7	70 ± 7	5,5	I20±I6	I4,6	30±4	3,7			
3,28	I042±62	34,4	II3 ± I0	8,6	I52±20	I8,0	32±4	3,9			
3,39	II00±65	36,3	79 ± 7	5,9			78±II	9,5			
3,50	II9I±7I	40,5	73 ± 6	5,I	203±25	22,3	I23±I7	I5,0			
3,63	I05I±62	33,7	I37 ± II	7,7	2I6±24	2I,I	57±7	6,3			
3,75	II72±69	37,I	I03 ± 8	5,8	224±I9	2I,I	I00±II	9,9			
3,89	I206±7I	38,8	I6I ± I2	9,I			I7I±I9	I6,6			
4,03	II28±66	36,4	I20 ± 9	6,8	209±23	I9,7	I89±2I	I8,4	63±II	I0	I
4,I8	II34±67	40,9	II9 ± 8	5,8	287±33	I9,4	I76±20	I7,I	96±I5	I4	I
4,34	II60±69	4I,9	I79 ± I3	8,8			I85±27	25,0	I07±I5	I4	I
4,5I	II52±69	4I,6	204 ± I5	I0,I	220 ±25	22,4	I60±23	2I,6	56±II	I0	I
4,69	II56±69	47,7	I62 ± I2	8,I	I56 ±I8	I6,0.	I43±2I	I9,3	II4±I5	I4	I
4,88	II08±66	40.0	22I ± I6	II,3	207 ±24	2I,3	I23±I8	II,3	II0±I5	I4	I

Table 4 (continued)

$E_{n'}$ (MeV)	E_n (keV)										
	847		I239		I8I0		2II3+2272		2523+2600		
	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	σ	$\Delta\sigma_{st}$	
5,09	II68±69	42,2	I44±II	7,5	I76±2I	I8,I	II2±I6	I5,I	I20±I4	I3	I
5,30	I278±76	46,I	2I2±I6	II,2	I98±23	20,6	76±II	7,8	II7±I5	I4	I
5,53	II02±65	39,8	I62±I2	8,7	I53±I8	I6,0	97±I6	4,2	I28±I6	I5	I
5,77	I256±75	45,5	232±I7	I2,8	I44±I6	9,2	87±I4	I3,0	I42±I8	I7	I
6,03	II39±80	58,6	28I±2I	I5,3	I40±I7	8,4	II6±I9	I8,I	I67±2I	I9	I
6,3I	II96±84	6I,6	280±2I	I5,8	I2I±I6	II,6	I02±I7	I5,9			
6,6I	II36±80	58,6	327±26	I9,I	94±I6	8,4	III±I9	I7,4	I54±22	2I	I
6,93	I426±I0I	73,9	306±25	I8,6	I40±I9	II,4			I75±23	2I	I
7,27	II20±80	56,2	34I±28	2I,7	II9±I6	8,0	II5±I9	I8,3	I43±I9	I8	I
7,64	II37±8I	59,5	354±30	23,7	II0±I5	I3,3	I07±I8	I7,2	I24±I8	I7	I
8,04	II50±82	60,4	299±26	2I,I	I25±I7	I2,7	80±I4	I2,9			
8,47	II49±I00	82,9	264±26	22,2			I02±20	I8,7	I58±23	22	I
8,93	I080±95	78,2	337±35	29,8	II0±I9	I8,I					
9,44	I008±89	73,3	227±24	2I,2	I23±22	20,5	88±I7	I6,4			
9,99	948±83	69,3			II4±20	I9,5	88±I7	I6,7			

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CROSS-SECTIONS FOR ^{227}Ac FISSION BY NEUTRONS

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The purpose of the work was to determine cross-sections for ^{227}Ac fission by fast neutrons, an investigation being carried out for the first time. Impurities were removed from the Ac preparation by partition chromatography. The Ac target weighed 1.2 μg. The neutron flux passing through the Ac target was determined by counting the fission events in ^{238}U and ^{232}Th targets positioned right up against it. The fission fragments were recorded by means of fission track detectors (see in this connection Ref. [1]). The authors measured cross-sections for ^{227}Ac fission by neutrons with energies E_n = 0.9–18.6 MeV. The ^{228}Ac fission barrier was found to be 7.1 ± 0.2 MeV. On the basis of the results (Table 1), the authors calculated the effective fissionabilities $W_{f\ eff.}$ of the compound ^{228}Ac nucleus at excitation energies of 7.0–23.6 MeV. They agree with the $W_{f\ eff.}$ values for ^{228}Ac obtained on the basis of the reaction ^{226}Ra(d,f) [2] and differ appreciably from those obtained on the basis of the reaction ^{226}Ra(^{3}He,pf) [3]. At the same time, the ^{228}Ac fission barrier determined by the authors and those reported in Ref. [3] (B_f = 7.2 MeV) virtually coincide.

Table 1

E_n(MeV)	0,9	2,I	2,9	5,0	6,9	7,9
σ_f(mbarn)	I,3±0,6	I6±2	32±3	3I±3	37±3	53±5
E_n (MeV)	9,5	I4,0	I4,9	I6,4	I7,6	I8,6
σ_f(mbarn)	60±6	I24±I2	I26±I3	I26±20	I5I±20	I40±20

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TIME CHARACTERISTICS OF THE EMISSION OF LOW-ENERGY NEUTRONS IN SPONTANEOUS FISSION

M.V. Blinov, V.A. Vitenko, I.T. Krisyuk

Following the appearance in the literature of information about the low-energy neutrons emitted in ^{252}Cf fission 10^{-8}–10^{-7} s after the fission event, the authors have investigated this question further.

The method employed by them consisted in measuring neutron time-of-flight spectra for various path lengths. The fission fragments were recorded by means of a scintillation counter and the neutrons by means of a ^{6}LiI(Te) crystal with a photomultiplier. The measurements were performed under conditions of high time resolution (1.2 ns) and low scattered neutron background. Under these conditions, they observed that there was agreement among the spectra for the various path lengths.

These findings do not confirm the existence of a fission neutron "retarding" effect at neutron energies below 500 keV.

SILVER CHLORIDE TRACK DETECTORS

N.P. Kocherov, N.R. Novikova,
N.A. Perfilov

The authors describe the preparation of silver chloride track detectors on a trial basis. The silver chloride crystals were grown using glass, quartz and mica sheets. To achieve increased sensitivity, the crystals were alloyed with cadmium. The results of tests carried out with the detectors are presented. Their detection properties are similar to those of detectors prepared by E. Schopper in the Federal Republic of Germany. The sensitivity of the detectors is about 4 MeV with respect to protons. The latent image produced by the charged particles is stabilized through exposure to yellow light at the same time as to the particles. The charged particle tracks are visualized by exposing the detectors to light with a wavelength of 410 nm.

The authors discuss the uses in which silver chloride detectors would offer advantages compared with other known track detectors.

ALPHA-SPECTROMETRIC ANALYSIS OF MATERIALS OF ESPECIALLY LOW ACTIVITY

M.I. Yakunin

The author presents the results of work on devising apparatus and improving a method for the alpha-spectrometric analysis of materials of especially low activity.

For materials with a specific activity of 10^{-13}–10^{-9} Ci/g (i.e. in the range which includes the typical activity values of most naturally occurring substances), the author recommends a spectrometer based on an ionization chamber designed for use with sources having an area of up to 4000–5000 cm^2. For special purposes, however, where it is necessary to determine partial specific activities close to 10^{-14} Ci/g, if such cases are not unique (i.e. if a series of such cases can occur) it is better to use a special spectrometric chamber which is designed for sources with an area of the order of 15 000 cm^2 and enables one to obtain an energy resolution of 45 keV.

For the preparation of large-area spectrometric sources from the materials under investigation the author recommends two methods which possess the merit of universality and complement each other: cathode sputtering with the help of a special system and a "dry" method also developed especially for the purpose in question.

With the apparatus devised by the authors, in conjunction with the amplifying, analytical and auxiliary apparatus which is usually employed, it is possible to carry out <u>direct</u> determinations of the concentration of natural and artificial alpha-active nuclides in any dry samples - i.e. without the usual preliminary chemical separation of the elements of interest. The apparatus should be useful in solving a number of applied and theoretical problems.

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All-Union Scientific Research Institute for
Physico-Technical and Radiotechnical
Measurements (VNIIFTRI)

COMPARISON OF RESULTS OBTAINED IN REGENERATING A TEST NEUTRON SPECTRUM BY ACTIVATION METHODS

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(Article submitted to "Metrologiya
nejtronnogo izluchenija na reaktorakh
i uskoritelyakh"; proceedings of 2nd
VNIIFTRI-ATOMINFORM conference,
Moscow, 1974)

The authors present the results of the second stage of a comparison (compilation?), initiated some time previously, of neutron activation measurements (cf. article by G.A. Borisov et al. in "Yadernye konstanty", issue 7, Atomizdat, Moscow, 1971, p. 459). The second stage consisted in comparing the results obtained in regenerating a test neutron spectrum. As their test spectrum the authors took a differential neutron flux density spectrum [neutrons/(cm^2.s.MeV)] for the neutron energy range 0.1-8 MeV obtained by combining a fission neutron spectrum and a cosine curve with a period of 4 MeV and an amplitude of 0.17.

Eight organizations took part in the comparisons; they were given activation integrals calculated on the basis of the activation cross-sections and reactions employed by them. For regenerating the test neutron spectrum they used six different methods and from six to 16 activation reactions. The greatest differences between the regenerated spectra and the test spectrum lay in the range 10-80% (in one case there was a difference greater than a factor of two). Only one of the participating organizations attempted to estimate the error associated with the regenerated spectrum.

In view of the significant discrepancies between the various results it is recommended that systematic comparisons of test spectra be made so as to discover the causes of the discrepancies.

SECOND ALL-UNION CONFERENCE ON NEUTRON METROLOGY IN REACTORS AND ACCELERATORS

R.D. Vasil'ev

(Article submitted to "Atomnaya ehnergiya")

The Second All-Union Conference on Neutron Metrology in Reactors and Accelerators, convened by the State Committee on Standards of the USSR Council of Ministers and the USSR State Committee on the Utilization of Atomic Energy and organized by the All-Union Scientific Research Institute for Physico-Technical and Radiotechnical Measurements, took place in Moscow from 14 to 17 November 1974.

The purpose of the conference was to review metrological work done during the three years since the first conference. Before the conference, participants received a set of 80 papers in two volumes: "Neutron Metrology in Reactors and Accelerators. Proceedings of the Second All-Union Conference".

The following subjects were covered:

- Problems of neutron metrology in reactors and accelerators (plenary session, two papers);
- Means of measuring the characteristics of neutron fields and standard samples; calibration and certification (section 1, 43 papers);
- Measurements of the characteristics of neutron fields in reactors and accelerators (section 2, 23 papers);
- Comparisons (compilations?) in reactors (section 3, 6 papers);
- Nuclear data for neutron measurements and metrological aspects of the study of such data (section 4, 6 papers);
- Determination of errors and planning of experiments (section 5, 7 papers).

It was recommended that the Third All-Union Conference on Neutron Metrology in Reactors and Accelerators be held in 1977 and that its organization again be entrusted to the All-Union Scientific Research Institute for Physico-Technical and Radiotechnical Measurements.

CREATION OF A STANDARD SOURCE (FIELD) OF NEUTRONS IN THE MR REACTOR OF THE I.V. KURCHATOV INSTITUTE OF ATOMIC ENERGY (IEA)

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P.P. Babulevich (IAE)
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A.I. Inikhov, V.I. Petrov (SNIP)

(Article submitted to "Atomnaya ehnergiya")

For the first time an attempt has been made to create a standard source (field) of neutrons on the basis of a nuclear reactor. The standard source was created in the MR reactor of the I.V. Kurchatov Institute of Atomic Energy for the calibration of self-powered detectors on the basis of the neutron flux density [neutrons/(cm^2.s)]. The standard source in question is some thoroughly investigated part of the neutron field inside or around the reactor, together with the means for monitoring, adapted for metrological work and certified by the competent metrological authorities as a standard measure of neutron flux density.

The certified characteristics of the standard source (field) are: the thermal neutron flux density at the moment of calibration of the self-powered detectors in relation to the current of the reactor field monitor; a correction factor taking into account the influence of the cadmium screen on the detector readings. The paper describes the methods used for determining these quantities and the means of measurement; it is shown how these means of measurement were certified and how they are related to the special State standard for a unit of neutron flux density in the custody of the VNIIFTRI. The random and systematic errors associated with the certification of the standard source are considered in detail. The total certification error was 3.6% in the 95% confidence interval.

It is shown that, using this standard source, self-powered detector calibration with an error of 5-6% can be achieved.

Institute of Nuclear Energy

MONTE CARLO CALCULATIONS OF A REACTOR CELL IN THE RESOLVED-RESONANCE REGION

V.A. Naumov, S.G. Rogozin, T.I. Ehl'perin,
A.G. Kozhinov

The authors describe a physical algorithm for calculating a heterogeneous reactor cell by the Monte Carlo method on the basis of which a FORTRAN program has been written. The group approximation is not employed for the cross-sections in the cell problem. The neutron transverse cross-sections are calculated for the energy with which the neutron appeared in the neutron history.

The neutron cross-sections of ^{233}U, ^{238}U and ^{239}Pu nuclei are calculated on the basis of the Breit-Wigner formalism with allowance for interference between potential and resonance scattering. The Doppler effect is taken into account. The parameters of the separated resonances are taken from the ENDF/B and REDAK evaluated data files and from the results of the latest experiments carried out at Oak Ridge National Laboratory. The smooth cross-sections of non-fissionable nuclei are given in 40 energy groups.

The cell is in the form of a three-dimensional regular hexahedral prism or a cylinder with concentric cylinders inside. Calculations are performed for a hexagonal uranium-water lattice (pitch 1.441 cm) with a block of metallic uranium (enriched to 1.03% in ^{235}U) of 0.983 cm diameter. For the energy region 0.5-1000 eV and with the ^{238}U resonance parameters from ENDF/B III, a value of 8.47 barn is obtained for the effective resonance integral in the lattice for ^{238}U and a value of 0.7100 ± 0002 is obtained for the probability of avoiding absorption.

ABSTRACTS RELATING TO COMPUTER PROGRAMS

PROGRAMS FOR SOLVING EXTREME-VALUE PROBLEMS

Yu.G. Bobkov, L.T. Pyatnitskaya

Methods to solve non-linear programming problems of the type

$$\varphi(\vec{x}) \rightarrow MIN \text{ for } g_i(\vec{x}) \leq 0 \quad i = 1, \dots m$$

have been formulated for the ALGOL TA-IM translator on the M-222A computer. The problems are solved by the penalty function method - i.e. conditional minimization of the function $\varphi(\vec{x})$ is replaced by a succession of unconditional minimizations of the function $F(N,K,\vec{x})$:

$$F(N,K,\vec{x}) = \varphi(\vec{x}) + (N)^K \sum_{i=1}^{m} \{MIN[g_i(\vec{x}), 0]\}^2$$

For the unconditional minimization of $F(N,K,\vec{x})$, programs are written for numerical search for the extremum by means of the iterations

$$x_{\ell+1} = \vec{\alpha}_\ell + \beta_\ell \Delta\vec{x}_\ell$$

The quantity β_ℓ is determined at each step on the basis of the condition MIN $F(N,K,\vec{x}_{\ell+1})$, by means of a quadratic approximation or with the help of the "golden section".

The following methods are developed for determining the direction of $\Delta\vec{x}_\ell$:

1. A simplex method, using the value only of a function;
2. A Fletcher-Reeves conjugate gradient method, using the gradients $\nabla F(N,K,\vec{x}_{\ell-1})$ and $\nabla F(N,K,\vec{x}_\ell)$;
3. A Newton method, using a matrix of second derivatives.

In order to use the programs it is sufficient to write procedures for calculating the function $F(N,K,\vec{x})$, the gradient $\nabla F(N,K,\vec{x})$ and the matrix of second derivatives (depending on the type of method).

If the problem is solved without constraints, the corresponding procedures are written for $\varphi(\vec{x})$.

SIMPLEX METHOD OF SEARCHING FOR EXTREMA

V.I. Popov, E.M. Saprykin

The authors describe a program which solves the problem of finding the extremum of a function which depends on an arbitrary number of parameters by a simplex method. From the initial point (start of the search) in space, where the parameter values are the co-ordinates, one constructs a simplex - i.e. an assembly of equally spaced points exceeding the number of parameters by unity. During the search process, the simplex point at which the function is at a maximum (if the minimum is being sought) is determined, after which this point undergoes reflection relative to all the remaining points.

The program is written in ALGOL-60 and designed as an autonomously translated procedure for the TA-IM translator, whereby the number of parameters and the form of the function - which are not given - can be chosen arbitrarily.

COMPLEX OF PROGRAMS FOR ESTABLISHING A MACHINE FILE OF EXPERIMENTAL NEUTRON DATA IN THE EXCHANGE FORMAT

V.V. Surgutanov, V.N. Manokhin

At the Nuclear Data Centre, Obninsk, a complex of programs for establishing on magnetic tape a machine file of experimental neutron data written in the Exchange Format (EXFOR)[1] has been developed and put on an M-222 computer. The programs are written in ALGOL for the TA-IM translator[2] using the operator FORMAT[3].

The complex consists of programs for the following processes:

- Recording on magnetic tape of incoming material (compilation of experimental results) and conversion to EXFOR;
- Editing of the EXFOR test;
- Editing of codes serving as criteria for the introduction of changes in the contents;

- Assembly of edited EXFOR texts;
- Assembly of exchange tapes;
- Extraction of service print-outs;
- Determination of the position of data on the magnetic tape;
- Extraction on magnetic tape of incoming material from library files;
- Preparation of a catalogue of the contents of the magnetic tapes.

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PROGRAM FOR DATA SEARCH AND EXTRACTION FROM THE KEDAK MACHINE LIBRARY OF EVALUATED NUCLEAR DATA

V.N. Manokhin, E.N. Korol', V.V. Surgutanov

At the Nuclear Data Centre, a program has been written and set up for data search and extraction from the KEDAK machine library of evaluated nuclear data, the format of which is described in Ref. [1]. The program is written in ALGOL using a TA-IM translator with complementary equipment[2] and carries out searches on the magnetic tape and the retrieval of files, blocks of data and cross-sections in a given energy range.

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PROGRAM FOR VERIFYING THE EXCHANGE FORMAT

V.V. Surgutanov

At the Nuclear Data Centre, a program for verifying observance of the formalism in compilations based on EXFOR[1] has been developed and set up on an M-222 computer:

1. Sequence rules for recording system identifiers;
2. Composition and completeness of keywords in bibliographic sections;
3. Contents of indicators and counters;
4. Numerical identification of recordings;
5. Rules for the arrangement and composition of mnemonic search codes;
6. Rules for the recording and composition of numerical table headings;
7. Rules for recording numerical data in tables.

The program is written in FORTRAN[2, 3].

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PROGRAM FOR CALCULATING COULOMB FUNCTIONS

A.B. Pashchenko

When solving the problem of the scattering of charged particles by atomic nuclei it is necessary to know the wave functions describing their behaviour in the Coulomb field of a nucleus. Accordingly, a program for calculating Coulomb functions has been written and put on an M-222 computer at the Nuclear Data Centre.

The program enables one to calculate the regular and irregular Coulomb wave functions $F_\ell(\rho)$ and $G_\ell(\rho)$, their first derivatives and the Coulomb phase shifts σ_ℓ. The functions $F_\ell(\rho)$ and $G_\ell(\rho)$ are solutions of Schrödinger's radial wave equation for the scattering of charged particles in the Coulomb field of a nucleus. The algorithm of the program is described in detail in Ref. [1].

The program is written in ALGOL for a TA-IM translator and is in the form of a procedure.

The program operates in the value range $\rho \geq \gamma$ (where $\rho = kr$ is the distance from the centre of the nucleus in $1/k$ units and $\gamma = \mu Z_1 Z_2 \ell^2/k\hbar^2$ is the Coulomb parameter), which means that it can be used virtually without limitations in calculating cross-sections for the interaction of charged particles with nuclei within the framework of the optical model.

The results of calculations have been compared with values [2] presented in tabular form to five significant figures. As a rule, differences do not appear before the fifth significant figure.

The program running time on M-220 computers for one point (ρ,γ) is $\sim$ 10 s for $\ell = 15$.

REFERENCES

[1] HODGSON, P.E., Optical model of elastic scattering, London-Oxford, 1963.

[2] LUK'YANOV, A.V., TEPLOV, I.B., AKIMOV, M.K., Tables of Coulomb wave functions - Whittaker functions (in Russian), Computer Centre of the USSR Academy of Sciences, 1961.

PROGRAMS FOR INFORMATION SEARCH AND EXTRACTION FROM A LIBRARY OF EVALUATED NUCLEAR DATA IN THE UKNDL FORMAT

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Programs for information search and extraction from a machine library of evaluated nuclear data in the UKNDL format have been written and put into use at the Nuclear Data Centre. The "Katalog" program analyses the contents of a file recorded on magnetic tape and gives the information necessary for the automatic preparation of initial data for a program for extracting numerical arrays.

The extraction program, which combines several autonomous procedures, forms the numerical data from the file into prescribed arrays which are continuous with respect to argument and records them on magnetic tape for further processing by computer. The programs are written in ALGOL for a TA-IM translator [1] using the FORMAT operator [2].

REFERENCES

[1] LYASHENKO, V.F., Programming a digital computer with a system of instructions of the M-20 type (in Russian), Sovetskoe radio, 1973.

[2] PAN'KOV, V.M., FORMAT operator in ALGOL (in Russian), preprint FEI-395, 1973.

COMPLEX OF PROGRAMS FOR PREPARING EXPERIMENTAL NUCLEAR DATA FOR EVALUATION

V.V. Vozyakov, N.E. Kuznetsov

A complex of programs for performing a number of operations associated with the preparation of nuclear data for evaluation has been put on computer at the Nuclear Data Centre.

The need for such preparation arises in connection with the variety of different ways in which nuclear physics quantities are represented in libraries of experimental data and with the peculiarities of using large arrays in M-222 computers. The data preparation consists in conversion of the arrays on the basis of length of recording in zone, in putting the measurement results of different authors into a comparable form as regards dimensions, in averaging over some function, in the graphic representation of the arrays, etc. The programs are written in ALGOL for a TA-IM translator. Each of the programs is in the form of an autonomously translatable procedure.

REFERENCES

[1] LYASHENKO, V.F., Programming a digital computer with a system of instructions of the M-20 type (in Russian), Sovetskoe radio, 1973.

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ALGRAF: A COMPLEX OF PROGRAMS FOR REPRESENTING INFORMATION ON A GRAPH RECORDER

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L.N. Usachev

A complex of programs for the automatic construction of graphs - ALGRAF - has been written as mathematical software for the Nuclear Data Centre's M-222 computer on the basis of a TA-IM translator from ALGOL-60 with the complementary equipment described in Refs [1, 2].

The purpose of developing ALGRAF was to create a convenient apparatus for the graphic representation of nuclear data from machine libraries in a computer memory. A characteristic feature of this problem is determined by the need to represent in a drawing an array of points without preliminary retrieval in numerical form for analysis of its boundaries and selection of a scale. The proposed complex of programs is characterized by a well-thought-out system of procedures for choosing the scale, tracing the axes with their subscripts and representing the experimental points with their associated errors. The totality of accesses to these programs constitute a fairly simple and expressive language for graphic representation.

ALGRAF is a multilevel system consisting at present of ten standard programs in the IS-2 system and autonomously translated procedures. All the procedures are recorded in the library of programs and procedures on magnetic tape.

The zero level consists of programs for the start and finish of the drawing and programs for tracing a straight line which forms instructions for the graph recorder and effects the recording of the instructions on magnetic tape.

The first level of the complex includes programs for writing the text and constructing the symbol (for a discrepancy of curves on the graph).

The third level consists of: a program for depicting numbers from the machine representation; a program for analysing a data array of an argument or function; a program for choosing the scale of the graph. It also includes a co-ordinate axis subscript program and a program for constructing experimental points.

For high operational efficiency, some of the most frequently used procedures are written in the IPM autocode and during operation are placed in another stack of the magnetic store so as to economize with the memory in the magnetic store of the user.

REFERENCES

[1] PAN'KOV, V.M., FORMAT operator in ALGOL (in Russian), preprint FEI-395, 1973.

[2] PAN'KOV, V.M., Development of M-222 computer program software (in Russian), preprint FEI-475, 1974.

THE KOP PROGRAM

A.B. Pashchenko

In order to calculate cross-sections for nuclear reactions with charged particle emission - (n,p), (n,α), etc. - it is necessary to know the penetration coefficients for protons, alpha particles, etc. For this purpose, the KOP program has been written and put on an M-222 computer at the Nuclear Data Centre.

The program enables one to calculate, within the framework of the optical model, the real and imaginary components of the scattering matrix $S_{\ell, j}$, the penetration coefficients $T_{\ell j}$, the total cross-section σ_{tot}, the cross-section for compound nucleus formation σ_c, and the integral and differential cross-sections for potential scattering $\sigma_{e\ell}$ and $d\sigma_{e\ell}/dQ$.

A spherical complex potential with 13 parameters [1] is used in the program:

$$U(r) = V(r) + iW(r);$$

$$V(r) = -V_R \cdot f(r, R_R, Q_R) \qquad \text{- central real}$$

$$+ V_{\delta O} \cdot \hat{\sigma}\, \hat{\ell} \cdot \lambda_\pi^2 \cdot (1/r)(d/d_r)\, [f(r, R_{so}, Q_{so})] \qquad \text{- spin orbital}$$

$$(Z_1 Z_2, \ell^2/2R_c)\, [3 - (r^2/R_c^2)] \text{ for } r \leq R_c$$

$$+ Z_1 Z_2 \ell^2/2 \qquad \text{- Coulomb for } r \geq R_c$$

$$W(r) = -W_v \cdot f(r_1 R_I', a_I') \qquad \text{- imaginary volume}$$

$$+ W_{\delta F} \cdot 4a_I(^d/dr)\, [f(r_1 R_I, a_I) \qquad \text{- imaginary surface}$$

where $f(r,R,a) = [1 + \exp((r - R)/a)]^{-1}$

$$R = rA^{1/3}$$

$\hat{\sigma}\,\hat{\ell}$ = scalar product of the operators of the intrinsic and orbital angular momenta

= ℓ for $j = \ell + \frac{1}{2}$

= $-(\ell + 1)$ for $j = \ell - \frac{1}{2} > 0$

j, ℓ = quantum numbers of the total and orbital angular momenta for an incident particle

λ_π^2 = Compton wavelength of π-meson

Z_1 and Z_2 are the charges on the target and the incident particle

A = mass number of the target.

Integration of Schrödinger's equation within the nucleus as far as the matching radius is effected by the Milne-Stermer method with pitch $\Delta\varrho = \Delta(kr) = 0.1$, where $k = \sqrt{2\mu E}$ is the wave number of the incident particle.

The Coulomb functions were calculated by means of a "Coulomb functions" procedure, a description of which is included in the present publication.

The matching radius is chosen as

$$R_M = R_R = 12a_R \quad \text{if } R_M \geq \gamma + 1$$

and

$$R_M = \gamma + 1 \quad \text{if } R_M < \gamma + 1,$$

where

$$\gamma = \frac{\mu Z_1 Z_2 \ell^2}{k\hbar^2} \quad \text{is the Coulomb parameter.}$$

In a particular case, for $Z_1 = 0$ the program enables one to solve the scattering problem for neutrons. The results agree fully with those of calculations based on the ROPT program [2].

The program is written in ALGOL for a TA-IM translator and is in the form of a procedure. The program running time for M-220 machines is 1 min.

REFERENCES

[1] BECCHETTI Jr., F.D., GREENLESS, G.W., Phys. Rev. 182, issue 4 (1969) 1190.

[2] BYCHKOV, V.M., POPOV, V.I., The ROPT program (in Russian), Yadernaya fizika (1973) issue 15, p. 5.