INDC(ENE)*013

INDC - 163

NEWSLETTER
N° 4

IAEA
NUCLEAR
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NEUTRON DATA COMPILATION CENTRE

EUROPEAN NUCLEAR ENERGY AGENCY

ABSTRACT

There is lot of interest these days in thorium fuel cycles. There was an international symposium on this subject in December 1962. Last year, a panel meeting was organised on 'Utilization of thorium in power Reactors' under the auspices of International Atomic Energy Agency. This year the '2nd International Thorium Cycle Symposium', organised by U.S.A.E.C. was held during May 2-6, in which about 46 papers were presented. A number of conclusions reached in these symposia would be discussed in this survey.

UTILIZATION OF THORIUM IN POWER REACTORS*

by

B.P. Rastogi

INTRODUCTION

1. It is easy to understand why work on nuclear fission reactors originated with uranium as the nuclear fuel. Nature provided only one readily fissionable isotope at this particular age of the earth - that is U-235 which constitutes only about 0.7% of naturally occuring uranium. It was recognised very early in the history of nuclear reactors that the long term importance of nuclear fuels for power production depends on our ability to use not only the original fissionable U-235 provided by nature but also at least an appreciable part of the much more abundant fertile materials U-238 and Th-232 which could be converted into fissionable isotopes.

2. Nature has provided abundant resources of uranium and thorium in the world. However, the abundance of thorium is many times more than that of uranium. With the help of breeders based on uranium cycle the energy content of uranium could be made about 100 times the energy content of fissile U-235. The addition of thorium breeders increases these energy resources many times. While discussing the natural resources of uranium and thorium one has to look into the question what is the quantity of these substances available and at what cost? Table 1 shows the resources of uranium in the U.S.A. and Canada(1) The first column of this table gives the price range and the second and third

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* Lecture given in the Trombay Colloquium held on September 13, 1966.

CCDN-NW/4

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PREFACE

The fourth CCDN Newsletter, and the last in 1966, sees the Centre trying to put its books straight; a worthwhile task certainly but perhaps it is the salutary effect of the attempt which is of more significance at the end of the first official three year period of the Centre's existence.

Once CINDA* was established in Europe, its publication became, if not a routine matter, at least a regular occurrence and it has developed into a tool acceptable to that section of the scientific community interested in neutron cross sections: even at the same time, of interest as a potential model for similar tools in other disciplines. However, the collection of references is but a small part of the task of a data centre. It is the logical beginning but the collection, classification and storage of the data themselves is the second and major task.

Data are collected in the SCISRS* system initiated by the Sigma Center at Brookhaven National Laboratory, and the CCDN in taking over the effort with regard to European data benefited greatly from the initial work carried out at BNL and of course in the beginning the Centre's files consisted for the most part of data inserted by the Sigma Center. Unfortunately, the original SCISRS system provided no index to the contents of the file; the CCDN soon found this a first priority requirement for its own use, and was simultaneously under heavy pressure from its customers in Europe to provide a short list of its wares. A simple solution involving the use of a tool, well known by then, was to earmark those CINDA references from which the data had been inserted in SCISRS. The result was a short CINDA file which appeared as the second CCDN Newsletter (CCDN-NW/2) in June 1966.

Connecting the two files, although apparently trivial, is nevertheless far from straightforward. This tedious job revealed many inconsistencies and in fact Newsletter no. 2 contains many errors and omissions. Thereafter the work was continued in a routine fashion but it became apparent in November that the connection could not be brought up to date for several months. As mentioned in the 2nd Newsletter, the use of two systems had the principal benefit that many faults in each were revealed by attempting to connect the two. In the meantime, the Sigma Center had coded a large quantity of data and the CCDN had produced internal working programmes for processing data on its own 360 rather than on 7094s. One of these programmes in essence produced reference files from the Master Data Tape (MDT) for internal Centre use: in particular to assist in the work of connecting CINDA and SCISRS.

It was logical at this point to publish the data index produced from the MDT rather than the incomplete list extracted from CINDA. This 4th Newsletter then is a reference index to the data held on the MDT at the CCDN at the end of December 1966. It will have its own internal faults as

* Symbolism is fully covered in the 1st Newsletter of the Centre

does the independently constructed CINDA publication and benefits which ensue from connecting the two systems must remain until a later date.

The data content of the MDT will not be identical to that held in the Sigma Center since data is waiting to be inserted into the files at both centres; in particular over the last year the Sigma Center has spent some considerable effort on correcting and up-dating the light elements up to Z = 20 but this tape of corrected data has not yet arrived at the CCDN. We should like to emphasize at this point that a major fraction of the data in these files has been inserted by the Sigma Center. The MDT which has resulted from the combined efforts of the CCDN and BNL, consists at the end of 1966 of some 8,000 entries corresponding to approximately 700,000 data points.

DATA REQUESTS

Data, to which the references in this index refer, may be requested by scientists in participating member countries. Retrieval is made on the Master Data Tape in a variety of different classifications. The results are available in the form of listings, magnetic tapes, or punched cards, as preferred.

Requests should be specified in terms of Z, A, quantity and energy limits. The information sent to the requestor will not necessarily match the references contained in the index since more material is continually added into the files and the energy limits specified are less exact than those of the data files. At this moment, it is not possible to answer data requests specified by reference.

The Centres would greatly appreciate being informed of errors which are detected in this list and these of course should be identified by page and line number; references are numbered from 1 to 50 in the extreme left-hand margin of each page.

Data requests from Canada and the United States should be directed to:

Sigma Center,
Building 197,
Brookhaven National Laboratory,
Upton, Long Island,
N.Y. 11973, USA

Data requests from other participating OECD countries should be directed to:

ENEA Neutron Data Compilation Centre,
B.P. 9,
91 - Gif-sur-Yvette,
France

INTRODUCTION

HOW TO READ THIS INDEX

Space permitting, information in the index is expressed in normal English in order that the reader may avoid too frequent reference to dictionaries. The abbreviations used are listed in a fold-out sheet at the end of the Newsletter and in the introduction discussion is limited to quantities the meaning of which is not clear from the form used in the index. The columns in the listing are considered in turn.

NUCLIDE (Table 1)

Where no atomic number is given, the experiment refers to the natural isotopic composition of the element. Chemical compounds are listed under the element chiefly responsible for the neutron cross section, with an "atomic number" based on the other elements included. The same convention is used for elements with an unusual isotopic composition.

QUANTITY (Table 2)

The categories into which cross sections and other quantities are divided are those of the original SCISRS system*. Using a few abbreviations, most cross section types can be defined without ambiguity in the space available on a printed listing. The abbreviations are explained in the fold-out sheet at the end of the Newsletter, and the less obvious cross section types are defined in Table 2. The broad categories of data held in the file are:

Cross sections such as σ (n,2n), σ (total), σ (n,f).

Resonance parameters for states of the compound nucleus (target nucleus plus a neutron)

Energies of gamma rays observed in neutron-induced reactions, or differential cross sections for radiation of a given energy

Fission parameters such as ν, α, and η

Differential cross sections in millibarns per steradian (mb/sr). Only quantities which are functions of the angle of measurement are classified as differential (chiefly angular distributions, including the case where the distribution of reaction products is anisotropic and the cross section is measured at a single angle). For example, the inelastic scattering cross section to different levels of the target nucleus is listed under

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* BNL 883 with revisions, "Sigma Center Information Storage and Retrieval System"

Sig (tot inelastic) if integrated over all angles

The data listed refer to reactions where the incoming particles are neutrons, and are almost exclusively experimental.

Emin Emax

The lowest and highest neutron energies in the experiment are expressed in eV.

The entry 32 4 should be read 32×10^4 eV = 320 keV
25-3 should be read 25×10^{-3} eV = 0.025 eV

REFERENCE

For journals, the standard CINDA journal abbreviation* is followed by the volume and page number. References for reports usually contain only the report designation and a number.

DATE

The date given is the date of publication, or the date when a private communication was received.

LAB (Table 3)

The laboratory at which the work was done is listed using standard CINDA laboratory abbreviations*. A few additions to the list and obsolete forms are listed in Table 3.

S STATUS

A blank signifies that the data are the most recent available for the measurement. Numbers entered in the status column are to be interpreted as follows:

1. Results as received, but not selected as the author's best data;
2. Result withdrawn or superseded;
3. Result based on theoretical calculations;
4. Result as published: needs renormalisation;
6. Recommended value.

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* See the tables in CINDA '66 (EANDC 60'U', NYO-72-107, CCDN-CI/11) or the October 1966 supplement (EANDC 66'U', CCDN-CI/13, TID-23357)

STD (Table 4)

The reference standard used in the cross section measurement is listed either by one of the abbreviations explained in Table 4, or merely by the symbol for an element or isotope. In the Master Data Tape a comment card accompanying the data gives more details of the value taken for normalisation and, where only the element or isotope symbol is given, of the cross section.

METHOD (Table 5)

Most method indications will be clear when the abbreviations are expanded using the fold-out sheet at the end of the Newsletter. Others are explained in Table 5.

DATA PTS

This column gives the number of data points in the Master Data File for each index entry. In certain cases this number will be incorrect. Problems associated with deletion of incorrect data blocks and with compression of the data files to produce this index have not yet been clarified and lead by their very nature to duplication of reference entries in the index. Removal of double entries did not of course involve correction of the number of data points.

Table 1 - Chemical Compounds and Isotopic Mixtures

H^{101}	H_2O liquid
H^{202}	D_2O liquid
H^{206}	C_2H_6O
H^{606}	C_6H_6
Si^{808}	SiO_2 (quartz)
Zr^{924}	50% Zr^{92} with 50% Zr^{94}
Pb^{406}	Radiogenic lead, chiefly Pb^{206}

Table 2 – Cross Sections and Other Quantities

2g * G(n)	2g Γ_n in meV, where g is the statistical weight
2g * G(n)s-wave * Abun	2g Γ_n^o x unknown isotopic abundance, in meV
2g * G^2(n)/G(total)	2g Γ_n^2/Γ for the resonance, in eV
Defined in comment	Quantities outside the SCISRS definitions are specified in the comment (not printed in this index)
Diff(el + some inel)	Differential cross section in mb/sr for elastic scattering, with some unresolved inelastic scattering
Diff Sig(np + nnp)|p	Differential proton emission cross section in mb/sr
Fit(cos) to (n,n') Fit(cos)Chargd Part	Fitting coefficients for expansion of the angular distribution for (inelastic scattering) (charged particles) as a power series in $\cos\theta$
Fit(Leg)Elastic Sct Fit(Leg)Chargd Part	Legendre coefficients for expansion of the (elastic scattering) (charged particle) angular distribution
Fission yield (%)	The percentage yield of different fission products (listed with the data)
G(A) at Resonance	The alpha width Γ_α in meV
G(f) at Resonance	The fission width Γ_f in meV
G(G) at Resonance	The gamma width Γ_γ in meV
G(n) for l = 0	The reduced neutron width in meV for s-wave scattering, Γ_n^o
G^2(total) * SigZero	$\Gamma^2\sigma_o$ in eV^2-barns
(n,f) |n-frag corr	The angular correlation in fission between prompt neutrons and fragments

(np + nnp) |p emissn	Proton emission cross section in barns
Nu, unspecified	Neutrons per fission, where the reference does not specify whether the neutrons are prompt or delayed
Sigma(abs) * (E)$^{.5}$	σ(absorbtion) x $E_n^{\frac{1}{2}}$
Sig(el + some inel)	Total elastic scattering cross section, with some unresolved inelastic scattering
Sig(n,A) |comp nuc	The compound nucleus component of the (n,α) cross section, in barns
SigZero at Res	σ_o, the peak total cross section in barns
SigZero * G(G)	$\Gamma_\gamma \sigma_o$ in eV-barns

Table 3 - Laboratories

This list contains only abbreviations not included in the foreword to CINDA '66 supplement 1

GES = GEF = General Electric Space Lab

HAV = HRV = Harvard

MNT = UMT = University of Montana

MUS = MUA = Muslim University, Aligarh

STD = AE = Aktiebolaget Atomenergi, Studsvik

STK = Aktiebolaget Atomenergi, Stockholm

STR = Nuclear Research Centre, Strasbourg

VAL = GEV = General Electric, Vallecitos

Table 4 - Reference Standard

Al+Cu	$Al^{27}(n,\alpha) + Cu^{63}(n,2n) + Cu^{65}(n,2n)$
Total	Normalised to the total cross section of the target isotope
React	Normalised to the total reaction cross section
Cun2n	$Cu^{63}(n,2n)$
Cf^{252}	Cf^{252} spontaneous fission rate
Absol	Absolute determination; no standard
Aln,p	$Al^{27}(n,p)$
$U^{235}f$	$U^{235}(n,f)$ (Oralloy)
CfAbs	Normalised to absolute measurements
Th/nf	$Th^{232}(n,f)$
$U^{238}f$	$U^{238}(n,f)$
H (nn)	Elastic scattering on hydrogen
SigTH	Normalised to the same thermal cross section of the same nuclide
ib ZA	Normalised to another reaction of the same isotope
ib Z	Normalised to another isotope of the same element
ibSig	Normalised at some energy (not thermal) to the same cross section of the same nuclide
Diff	Differential cross section normalised at one angle
None	Cross section given in arbitrary units

Table 5 - Method

4 Pi * Sig90°	4π x cross section at (90° ± 10°)
Accelerator	Monoenergetic neutrons from (p,n), (d,n) or other reactions used
Back-to-Back	Back-to-back fission counter
Breit-Wigner	Calculated from parameters by single-level formula
Diff Sig Int	Integrated differential cross section
Polarizn-l/r	Left-right comparison for polarisation
Field Rotatn	Magnetic field rotation for polarisation
Mirror Refl	Total reflection from mirrors
Slowing-Down	Slowing-down-time spectrometer
Extrapolatn	Extrapolation from other energies