2010 Symposium on Nuclear Data

November 25-26, 2010
C-CUBE, Chikushi Campus, Kyushu University

Abstract

Host： Nuclear Data Division, Atomic Energy Society of Japan
Co-host: Advanced Science Research Center, Japan Atomic Energy Agency
Support: Kyushu Branch of Atomic Energy Society of Japan

Program of 2010 Symposium on Nuclear Data

November 25, 26, C-CUBE, Chikushi Campus, Kyushu University
Host: Nuclear Data Division, Atomic Energy Society of Japan
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November 25 (Thursday)

13:40 - 13:45	1. Opening address	
13:45 - 15:15	2. Status of Evaluated Nuclear Data Library and Benchmark	Chair: N. Yamano (Fukui Univ.)
13:45 - 14:15	2.1 Personal Perspective of Strategy on Nuclear Data Activities at JAEA [25+5]	T.Fukahori (JAEA)
14:15 - 14:45	2.2 JENDL-4 benchmark for high temperature gas-cooled reactor, HTTR [25+5]	M. Goto (JAEA)
14:45 - 15:15	2.3 Isotope Concentration Prediction Besed on the Latest Nuclear Data Files, for the High Burn-up BWR fuel pellets. [25+5]	T. Ito (NFI)
15:15 - 15:40	Photo & Coffee Break	
15:40 - 17:30	3. Status of Nuclear Data Measurement Activities and Accelerator facility	Chair: M. Baba (Tohoku Univ.)
15:40 - 16:10	3.1 Measurements of Neutron-Capture Cross Sections at J-PARC/MLF/ANNRI (1) Measurements of Neutron-Capture Cross Sections of Minor Actinides using a high intensity pulsed neutron source [25+5]	A. Kimura (JAEA)
16:10 - 16:40	3.2 Measurements of Neutron-Capture Cross Sections at J-PARC/MLF/ANNRI (2) Measurements of Neutron-Capture Cross Sections of Long-Lived Fission Products using a high intensity pulsed neutron source [25+5]	J. Hori (Kyoto Univ.)
16:40 - 17:10	3.3 Research in Surrogate Method at JAEA [25+5]	S. Chiba (JAEA)
17:10 - 17:30	3.4 The present status of the IFMIF/EVEDA accelerator development [15+5]	S. Maebara (JAEA)

November 26 (Friday)

09:00 - 10:10	4. Tutorial	Chair: Y. Watanabe (Kyushu Univ.)
09:00 - 10:10	Evaluation of actinide nuclear data [60+10]	O. Iwamoto (JAEA)
10:20 - 12:00	5. Poster presentation	Chair: N. Shigyo (Kyushu Univ.)
12:00 - 13:00	Lunch	
13:00 - 14:45	6. Study of charged particle production from nucleon-induced reactions	Chair: I. Murata (Osaka Univ.)

13:00 - 13:30	6.1 Nuclear data and materials irradiation effects - Analysis of irradiation damage structures and multiscale modeling - [25+5]	T. Yoshiie (Kyoto Univ.)
13:30 - 13:55	6.2 Measurement of neutron-induced light-ion production at 175 MeV quasi mon-energetic neutrons [20+5]	R. Bevilacqua (Uppsala Univ., Sweden)
13:55 - 14:20	6.3 Experimental studies of light fragment production cross section for nucleon induced reaction at intermediate energies [20+5]	T. Sanami (KEK)
14:20 - 14:45	6.4 Intranuclear cascade model for cluster production reaction [20+5]	Y. Uozumi (Kyushu Univ.)
14:45 - 15:00	Coffee Break	
15:00 - 16:30	7. Latest Topics in International and Domestic Nuclear Data Activities	Chair: S. Chiba (JAEA)
15:00 - 15:30	7.1 Nuclear Data Activities in Korea [25+5]	Y.O. Lee (KAERI, Korea)
15:30 - 16:00	7.2 INRNE-BAS: Present Status and Future Prospects [25+5]	M.K. Gaidarov (INRNE, Bulgaria)
16:00 - 16:30	7.3 Use of γ-ray-generating reactions for diagnostics of energetic particles in burning plasma and relevant nuclear data [25+5]	Y. Nakao (Kyushu Univ.)
16:30 - 17:00	7.4 Studies on Reaction Mechanisms of Unstable Nuclei [25+5]	K. Ogata (Kyushu Univ.)
17:10 - 17:10	8. Poster Award and Closing Address	

November 27 (Saturday)

10:00 - 11:00	Technical Tour : FFAG accelerator facility, Center for Accelerator and Beam Applied Sciences, Ito Campus, Kyushu University

Poster Presentations of 2010 Symposium on Nuclear Data

10:20 - 12:00 November 26, C-CUBE, Chikushi Campus, Kyushu University

1	Thermal / epi-thermal neutron spectrometer with a 3Heposition sensitive proportional counter	M. Ito (Osaka Univ.)
2	Measurement of 151,153Eu Neutron Capture Cross-Sections using a pair of C6D6 Detectors	J.-H. Lee (Kyoto Univ.)
3	Resonance Parameter Measurements and Analysis of 155,156,157,158,160Gd From 10 eV to 1 keV at the RPI LINAC	Y.-R. Kang (KAERI)
4	Measurement of Deuteron Induced Thick Target Neutron Yields at 5 MeV and 9 MeV	K. Hirabayashi (Kyushu Univ.)
5	Systematic Measurement of Neutron and Gamma-ray Yields on Thick Targets Bombarded with 18 MeV Protons	M. Hagiwara (KEK)
6	Production of light charged particles from silicon bombarded by 175 MeV quasi mono-energetic neutrons	S. Hirayama (Kyushu Univ.)
7	Measurement of deuteron-production double differential cross sections by 290 MeV/u oxygen beams on C, Al and Cu targets at forward angles	K. Tahara (Kyushu Univ.)
8	Study of the BGO detector for the measurement of the double differential cross sections of cluster production reactions	A. Mzhavia (Kyushu Univ.)
9	Measurement of Neutron-Production Double-Differential Cross Sections for 290 MeV/u Oxygen Ion Incidence	D. Moriguchi (Kyushu Univ.)
10	Neutron and proton yields for reaction induced by 120 GeV proton on thick copper target	T. Kajimoto (Kyushu Univ.)
11	Comparison of Neutron Production from Heavy-ion Reaction using PHITS and FLUKA	C.-W. Lee (KAERI)
12	DPA calculations for heavy-ion and proton incident reactions using the PHITS code	Y. Iwamoto (JAEA)
13	Developments in INC model for extension for low energy region and cluster-induced reactions	M. Yoshioka (Kyushu Univ.)
14	A Study of Pre-equilibrium Reaction Induced by Neutron for Nickel	M.-H. Mun (KAERI)
15	Preliminary evaluations and covariances of neutron-induced reactions for 237Np and 240Pu above resonance region	H.-I. Kim (KAERI)
16	Effect of Newly-Measured Cross Sections of 157Gd on Burnup Characteristics of High Burnup BWR UO2 and MOX assemblies	Y. Ando (JNES)
17	Improvement of FP Decay Heat Calcutation by Introducing TAGS Data Ⅰ.Beta and Gamma Spectra	H. Tajima (Tokyo City Univ.)
18	Improvement of FP Decay Heat Calculation by Introducing TAGS Data II. Priority Proposal for Future	T. Arai (Tokyo City Univ.)
19	Activation analysis by the beam loss in the IFMIF/EVEDA accelerator	S. Maebara (JAEA)
20	Evaluation of gamma-ray and neutron energy in the IFMIF/EVEDA accelerator building	H. Takahashi (JAEA)
21	Sensitivity analysis for curium isotope concentrations of light water reactor mixed-oxide burned fuel	G. Chiba (JAEA)
22	Sensitivity analysis for higher order Legendre coefficients of elastic scattering matrices	G. Chiba (JAEA)
23	Detailed Evaluation Criticality Change of MOX Cores Based on Sensitivity Analysis	M. Kimura (Osaka Univ.)
24	Analysis of Sample Worth for Dy2O3, Ho2O3, Er2O3 and Tm2O3 Measured at KUCA by MVP with Recent Version of JENDL, ENDF and JEFF	K. Ieyama (Osaka Univ.)
25	Renewal of JENDL photonuclear data file 2004 (I) Elements of atomic number below 20	T. Murata (former NAIG)

Memo

2.1

Personal Perspective of Strategy on Nuclear Data Activities at JAEA

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The latest general purpose file of Japanese Evaluated Nuclear Data Library (JENDL) has been released as JENDL-4 in this year. The JENDL-4 was the one of the goals of the first period mid-term research plan for Japan Atomic Energy Agency (JAEA) and the main target of JENDL revision in this time was minor actinide (MA) and fission product (FP) nuclides. The second period of mid-term research plan has started since 2010FY. In the plan, the objective is "incident energy expansion of JENDL".

The above objective can be achieved by producing special purpose files as JENDL High Energy File (JENDL/HE), JENDL Photonuclear Data File (JENDL/PD), JENDL PKA/KERMA File (JENDL/PK), and so on. Those files are applicable for accelerator related applications such as an accelerator-driven nuclear waste transmutation system (ADS), International Fusion Material Irradiation Facility (IFMIF), radiation therapies, and accelerator-driven BNCT. For this purpose, the nuclear model code, CCONE which has been mainly used in the JENDL-4 evaluation, is planned to be improved by adding some models to expand the incident energy region.

On the other hand, we never forget that the main user of nuclear data is nuclear energy application, such as the fast reactor (FR), the next generation light water reactors (NGLWR), and the innovative reactors (ex. Gen-IV). Recently the importance is reported for the safety research of down-stream applications, which are related to the (spent) fuel transportation, reprocessing, waste management, etc. Nuclear forensics for nuclear non-proliferations is also new topics. For these applications, rather common nuclear data needs are for the burn-up calculations for inventory estimation as reactor physics, PKA and/or DPA calculation for material science with radiation damage, and activation library for clearances. Those nuclear data should be produced and merged into JENDL general purpose file as the next version or revision of JENDL-4.

Some items related to nuclear data activities not only in Japan and also in the world stand on the edge of precipice. They are human resources for nuclear data evaluation (especially for decay and nuclear structure data), the budget (especially for nuclear data measurements), and presence (appearing) to the stake-holders. Those should be considered as soon as possible so that nuclear data activity level is kept for next generations. The most urgent item is "*covariance business*" and this must be solved at least its direction of preparation.

2.2

JENDL-4 benchmark for high temperature gas-cooled reactor, HTTR

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In the past, benchmark calculations of criticality approach for the HTTR (Fig. 1), which is a Japanese HTGR, were performed by research institutes in several countries, and almost all of the calculations overestimated the excess reactivity. In Japan, the benchmark calculations performed by JAEA also resulted in overestimation. JAEA improved the calculations by revising the geometric model and replacing the nuclear data library with JENDL-3.3, which was the latest JENDL at that time. However, the overestimation remained and this problem has not been resolved until today. We performed calculations of the HTTR criticality approach with several nuclear data libraries, and found that slight difference in the capture cross section of carbon at thermal energy among the libraries causes significant difference in the keff values. The cross section value of carbon was not concerned in reactor neutronics calculation because of its small value of the order of 10^{-3} burn, and consequently the cross section value was not revised for a long time even in the major nuclear data libraries: JENDL, ENDF/B and JEFF. We thought that the cross section value should be revised based on the latest measurement data in order to improve the accuracy of the neutronics calculations of the HTTR. In April 2010, the latest JENDL (JENDL-4) was released by JAEA, and the capture cross section of carbon was revised. Consequently, JENDL-4 yielded 0.4-0.9%Δk smaller keff values than JENDL-3.3 in the calculation of the HTTR critical approach, and then the problem of the overestimation of the excess reactivity in the HTTR benchmark calculation was resolved.

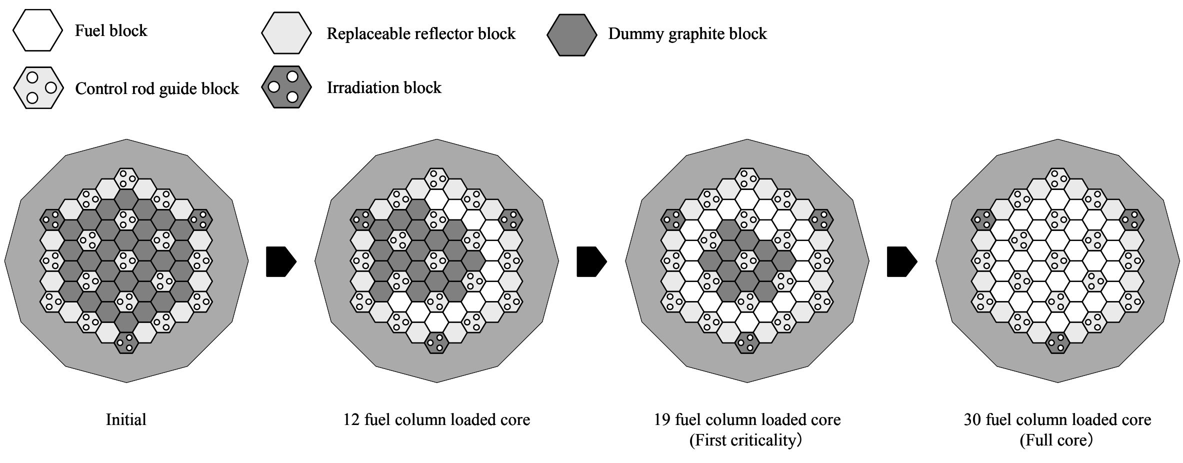

Figure 1 Procedure of the HTTR critical approach

2.3

Isotope Concentration Prediction Based on the Latest Nuclear Data Files for the High Burn-up BWR fuel pellets

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To understand the characteristics of evaluated nuclear data from view point of isotopic concentration prediction, burnup calculations for high burnup BWR MOX fuels were performed based on several nuclear data libraries. Calculation results were compared to measurements and each other calculations.

1. Introduction

JENDL/AC-2008 was released in 2008. In USA, ENDF/B-VII.0 was released in 2006 and preparation of ENDF/B-VII.1 is progressing. In Europe, JEFF-3.1.1 was released in 2009. JENDL-4.0 has been released in this spring, 2010, May. At present our calculation by using JENDL-4.0 is not finished yet.

In this study, isotopic prediction calculations for high burnup BWR MOX fuels with JENDL/AC-2008 are performed and compared to reference values. Isotopic prediction calculations with other recent evaluated nuclear data are also performed and calculation results are compared to each other.

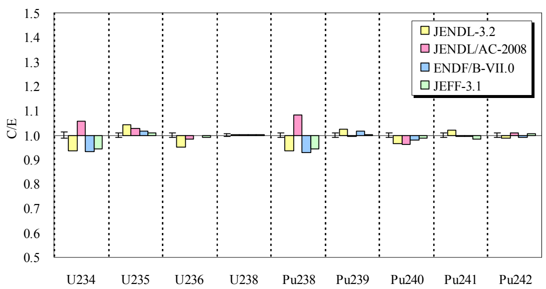
2. Analysis

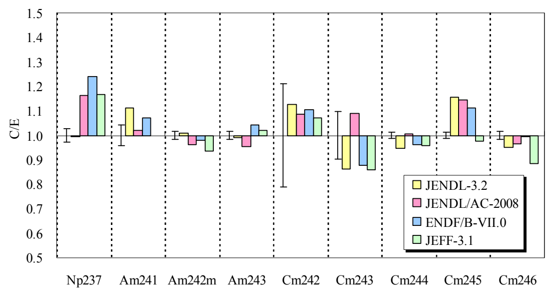
In this study, isotopic calculations with JENDL/AC-2008 are performed, and results are compared to the reference values. The reference value is the measurement results which had been evaluated by MALIBU program. MALIBU program is international PIE program for high burnup fuel which was irradiated in commercial reactors. Continuous energy Monte-Carlo code "MVP-BURN" is employed to reduce both of geometry approximation and effective cross section approximation. In calculation, fuel assembly geometry is simulated and irradiation data which are provided by MALIBU program are traced.

3. Results

For highest burnup BWR MOX sample of MALIBU, C/E values for heavy metals are shown below. Calculation results with all libraries are agreed to measurements within about 5% for most major actinides. On the other hand, difference between calculation and measurements are over 10% for some minor actinides.

For major actinides, the impact by difference of nuclear data is large about ^{234}U and ^{238}Pu. For minor actinides, the impact by difference of nuclear data is larger than for minor actinides and is large about ^{237}Np, ^{241}Am, ^{243}Cm, ^{244}Cm, ^{245}Cm.





4. Conclusion

The characteristics of the latest evaluated nuclear data were measured from view point of isotopic concentration prediction. For major heavy metal isotopes, their performances are excellent. For minor heavy metal isotopes, their performances are good, but some remarkable differences are observed. An analysis of performance of JENDL-4.0 including fission products prediction is a next work.

3.1

Measurements of Neutron-Capture Cross Sections at J-PARC/MLF/ANNRI (1)

Measurements of Neutron-Capture Cross Sections of
Minor Actinides using a high intensity pulsed neutron source

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Accurate data of neutron-capture cross sections of minor actinides (MAs) and long-lived fission products (LLFPs) are important in the detailed engineering designs and safety evaluations of innovative nuclear reactor systems. However, accurate measurements of these cross sections are very difficult due to high radioactivity of these samples. To overcome these difficulties, Accurate Neutron-Nucleus Reaction measurement Instrument (ANNRI) and a large Ge-detectors array named “4π Ge spectrometer” has been developed. ANNRI is located on the Beam Line No. 04 of the MLF in the J-PARC. The “4π Ge spectrometer” is the main detector of ANNRI and composed of two cluster-Ge detectors and eight coaxial-shaped Ge detectors. The energy-integrated neutron intensities at the sample position are 4.5×10^6 n/s/cm^2 in the neutron energy range of 1.5-25 meV, and 6.6×10^5 n/s/cm^2 in 0.9-1.1 keV.[1]

As an example of experimental results of MAs, obtained preliminary neutron- capture cross section of ^{244}Cm is shown in Fig. 1. A target in a ^{244}Cm sample was 0.6-mg curium oxide and its activity was 1.8GBq. The measurement time for the ^{244}Cm sample was about 33 hours. The results of the 7.67-eV and 16.77-eV resonance peaks are the first experimental results in the world. Also, obtained cross section of ^{246}Cm will be shown in this presentation.

These results show that neutron-capture cross section can be obtained using a small amount of a high radioactive sample in ANNRI.

Present study is the result of "Study on nuclear data by using a high intensity pulsed neutron source for advanced nuclear system" entrusted to Hokkaido University by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

[1] Y. Kiyanagi, et al. Abstract book of ND2010, 2010, p.95

[2] M. S. Moore and G. A. Keyworth, *Physical Review C*, 3, 1656 (1971)

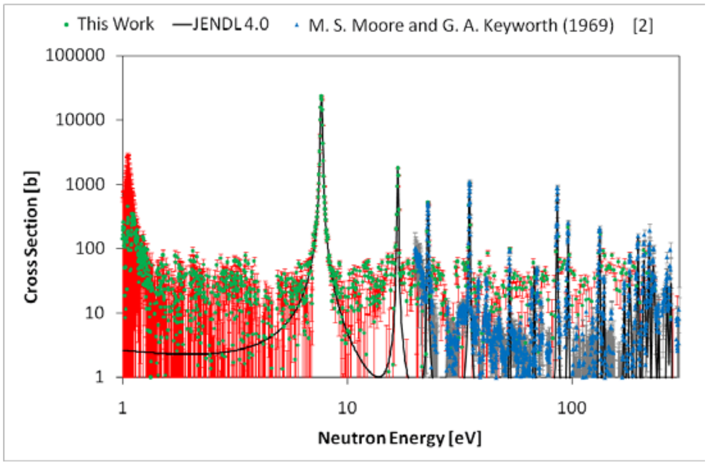

Fig. 1 Deduced capture cross sections of ^{244}Cm, one measured by Moore[2] and JENDL 4.0.

3.2

Measurements of Neutron-Capture Cross Sections at J-PARC/MLF/ANNRI (2)

Measurements of Neutron-Capture Cross Sections of Long-Lived Fission Products using a high intensity pulsed neutron source

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The neutron-capture cross sections of long-lived fission products (LLFPs) are of great importance for the research of the nuclear transmutation of radioactive waste. However, the current status of experimental data is not sufficient both in quality and in quantity. This is because it is not easy to prepare enough amount of sample with a high purity.

To overcome the difficulty, we have started a series of experimental studies for LLFPs using a new apparatus called "Accurate Neutron-Nucleus Reaction measurement Instrument (ANNRI)" which was installed at the Beam Line No. 04 of the Materials and Life science experimental Facility (MLF) in the Japan Proton Accelerator Research Complex (J-PARC). Neutron capture γ rays from a sample were measured with a 4π Ge spectrometer using a time-of-flight (TOF) method. The background due to impurities contained in the sample could be removed by extracting the discrete γ-ray components of the objective ground-state transitions from the observed events using Ge detectors with a high energy resolution.

The metal or oxide powder of ^{99}Tc, ^{93}Zr and ^{107}Pd were encapsulated in aluminum disk-shaped containers of 30 or 9 mm in diameter. For ^{93}Zr and ^{107}Pd which contains large amount of impurities, the isotopic purities were determined with a Thermal Ionization Mass Spectrometer (TIMS) as 19 % and 15 %, respectively.

In this talk, we will report preliminary results of the neutron-capture cross sections for ^{99}Tc, ^{93}Zr and ^{107}Pd.

Present study includes the result of "Study on nuclear data by using a high intensity pulsed neutron source for advanced nuclear system" entrusted to Hokkaido University by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

3.3

Research in Surrogate Reaction Technique at JAEA

S.Chiba
Japan Atomic Energy Agency

With the advance of nuclear science and technology, neutron cross sections of unstable nuclei, including minor actinides (MAs) and long-lived fission products (LLFPs), are becoming more and more necessitated. Neutron cross sections of radioactive nuclei also play important roles in reactor dosimetry and astrophysical nucleosynthesis. In spite of the importance, however, measurement of neutron cross sections is extremely difficult for these nuclei since preparation of sample is difficult or practically impossible.

Recently, a new method, called the surrogate method, has come to be used actively to determine neutron cross sections of unstable nuclei. This is a method which uses (multi) nucleon transfer reactions (both stripping and pick-up) or inelastic scattering on available target nuclei and produce the same compound nuclei as those of the desired neutron-induced reactions, and measure the decay branching ratios leading to capture and/or fission channel. Identification of the produced compound nuclei and their excitation energies can be done by detection of the ejectile species and their energies.

At a first glance, it seems to be a simple and effective method to simulate the neutron-induced reactions. However, even if we produce the same compound nuclei at the same excitation energy as produced in the desired neutron-induced reactions, the spin-parity distributions are plausibly different between them. Since we are interested in low-energy neutron cross sections relevant to reactor applications and astrophysics, the produced compound nuclei decay statistically, and the branching ratio is strongly influenced by the spin and parity of the decaying nuclei. Therefore, difference of the spin-parity distributions between the surrogate and neutron-induced reactions must be properly taken into account in converting the branching ratio determined by the surrogate method to the one for neutron-induced reactions. Up to now, however, it has not been able to deduce the spin-parity distribution in the surrogate reactions, since they are normally multi-nucleon transfer reactions, the reaction mechanisms of which are not understood well.

In this talk, we will describe the status of development of the surrogate reaction technique at JAEA including both the theoretical and experimental approaches. Some of preliminary results will be also shown.

3.4

The present status of the IFMIF/EVEDA accelerator development

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International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based neutron irradiation facility to develop materials for a demonstration fusion reactor next to ITER [1]. For providing materials to make a decision of IFMIF construction, Engineering Validation and Engineering Design Activities (EVEDA) under the Broader Approach agreement have been started. The IFMIF/EVEDA prototype accelerator consists of Injector (output energy;100keV), a 175MHz RFQ linac (0.1-5.0MeV), a matching section, the first section of Superconducting RF linac (5.0-9.0MeV), a high energy beam transport line and a beam dump(9MeV-125mA CW) in Fig1, and the acceleration tests by employing the deuteron beam of 125mA are planning in Rokkasho, Aomori, Japan.

In this symposium, the present status of the IFMIF/EVEDA accelerator development and the schedule planning of Engineering Validation will be presented in details.

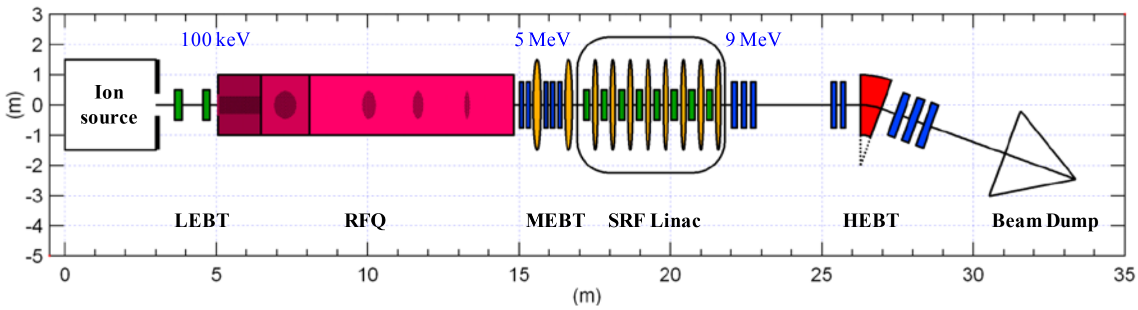

Fig.1 A schematic drawing of the prototype accelerator

[1] IFMIF-CDA Team (Ed.) M. Martone, "IFMIF Conceptual Design Activity Final Report", *ENEA Frascati Report*, RT/ERG/FUS/96/17 (1996).

6.1

Nuclear data and materials irradiation effects
- Analysis of irradiation damage structures and multiscale modeling -

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Material degradation by irradiation damage with high energy particles is one of the most important factors in determining the lifetime of nuclear systems. Displacement per atom (DPA) is commonly used as a damage parameter to estimate the effect of high energy particle irradiation on materials. DPA is, however, not sufficient to reflect for the effect of high energy recoils such as cascade formation. Authors have proposed the primary knock-on atom (PKA) energy spectrum analysis [1,2]. A large PKA forms several subcascades. In each subcascade, a vacancy rich area is surrounded by an interstitial rich area. In the case of FCC metals, stacking fault tetrahedra are formed directly from subcascades. Authors analyzed the cascade and subcascade formation in FCC metals such as Au, Ag, Cu and Ni using the formation of stacking fault tetrahedra by D-T fusion neutron irradiation. The experimentally observed distribution of cascade zone size and the number of subcascades were fitted to the calculated PKA energy spectrum, and the energy subdivided into each subcascade was obtained to be as high as several tens of keV/subcascade. A method to calculate the subcascade formation energy has been developed and experimental values agreed well with the calculated results [3].

Above mentioned results indicate that the number of subcascades is an important parameter to determine the defect structural evolution, since nuclei of defect clusters and freely migrating defects are formed in each subcascade. Although most of nuclei of defect clusters are annihilated by the absorption of freely migrating defects with increasing irradiation dose, the number of clusters is, however, proportional to that of subcascades.

In this paper, some examples of PKA energy spectrum analysis are demonstrated. Then a multiscale modeling of irradiation effect in high energy proton irradiated Ni is shown as an application of the analysis,.

References

[1]M. Kiritani, T. Yoshiie, S. Kojima and Y. Satoh, Rad. Eff and Defect. Solid., 113, 1990, 75.
[2]T. Yoshiie, X. Xu, Q. Xu, S. Yanagita and Y. Satoh, Reactor Dosimetry: Radiation Metrology and Assessment, ASTM STP 398 (2001) 625-632.
[3]Y. Satoh, T. Yoshiie and M. Kiritani, J. Nucl. Mater., 155-157 (1988) 1098.

6.2

Measurement of neutron-induced light-ion production at 175 MeV quasi-monoenergetic neutrons

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[e]*LPC, ENSICAEN, Université de Caen, 14050 CAEN Cedex, France*
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Abstract

We have measured double differential cross sections for emission of light charged particles in the interaction of 175 MeV quasi-monoenergetic neutrons with iron and bismuth using the Medley setup, a spectrometer system installed at the The Svedberg Laboratory (Uppsala, Sweden). Medley offers well defined particle identification with low-energy thresholds, over a wide dynamic range. Energy spectra were measured at eight laboratory angles. The time-of-flight was used to reduce the contribution from the low energy tail in the accepted incident neutron spectrum. The experimental data presented in this work will provide benchmark points for state-of-the-art theoretical models, helping to produce reliable evaluated data, to verify new phenomenological optical model potentials, to ensure a good link between low and high energy processes. We compared experimental double differential cross sections with exciton model calculations and Kalbach systematics using the TALYS code; these successfully describe the production of protons, while fail to reproduce the emission of composite particles, generally overestimating it. We show that the Kalbach phenomenological model needs to be revised for energies above 90 MeV. We have also compared our data with quantum molecular dynamics (QMD) calculations complemented by the surface coalescence model (SCM); we observed that the SCM improves the predictive power of QMD. I will present and discuss these results.

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6.3

Experimental studies of light fragment production cross section for nucleon induced reaction at intermediate energies

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Applied Physics Laboratory, High Energy Accelerator Research Organization

Masashi TAKADA

National Institute of Radiological Sciences

Atsushi TAMII

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Mamoru BABA

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In recent years, an application of intermediate energy beam has been expanding to various fields together with the advance of accelerator technology. For designing phase of new applications, double differential cross section (DDX) data are required to evaluate particle transportation, energy deposition and products in a matter. The cross section of neutron scattering and light charged particle (Hydrogen and Helium isotopes) production, which is primary concern due to large cross section, have been studied experimentally and theoretically until now. The production of light fragment (heavier than Helium) had been less concern or neglect due to relatively low production rate, however it plays important role on irradiation effects depending on linear energy transfer of single particle. As a result, there are no systematic DDX data covering wide energy range, emission angle and target nuclei. Therefore, we construct a new fragment detector, Bragg Curve Counter (BCC), for DDX data taking in this energy range. The BCC is gridded ionization chamber filled with P10 gas. The BCC can identify Z number of incident ions from its Bragg peak height without transmission type detector that is useless due to large stopping power of fragment. To cover desired energy region for fragments from intermediate energy reactions, the acceptable energy range of the BCC is improved using two newly developed techniques, offline analysis of punch through fragment and range measurement with cathode signal. Beam experiments were carried out two Cyclotron facilities, at National Institute of Radiological Sciences (NIRS) for 40-80 MeV and at Research Center for Nuclear Physics(RCNP), Osaka University for 140-300 MeV protons on five thin foil targets, C, N, O, Al, Ti and Cu. The targets were set at the center of a scattering chamber that mounts four BCCs on 30, 60, 90 and 120 degree arms. Lithium, Beryllium, Boron and Carbon were identified with measuring their energies. The obtained DDXs of these fragments were compared with the results of particle transport codes that can treat fragment production with typical reaction models for intermediate energy range. Since the models were focused on neutron and light charged particle emission, systematic discrepancies were found depending on target nuclei, incident energy and angular distribution, which would be useful to refine models, nuclear reaction data tables and energy deposition calculation.

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6.4

Intranuclear cascade model for cluster production reaction

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The intranuclear cascade (INC) model is investigated to explain cluster productions in intermediate-energy nucleon-nucleus reactions. Although a great deal of efforts has been made toward unraveling the cluster formation mechanism, its dynamical and quantitative aspect is still controversial. The emission of a cluster is governed mainly by the knock-out and the indirect-pickup (or coalescence) processes. To describe these two, the nucleon correlation is introduced into the initial and the final state within the INC model. Resultant double differential cross sections are demonstrated to be in good agreements with experimental.

7.1

Nuclear Data Activities in Korea

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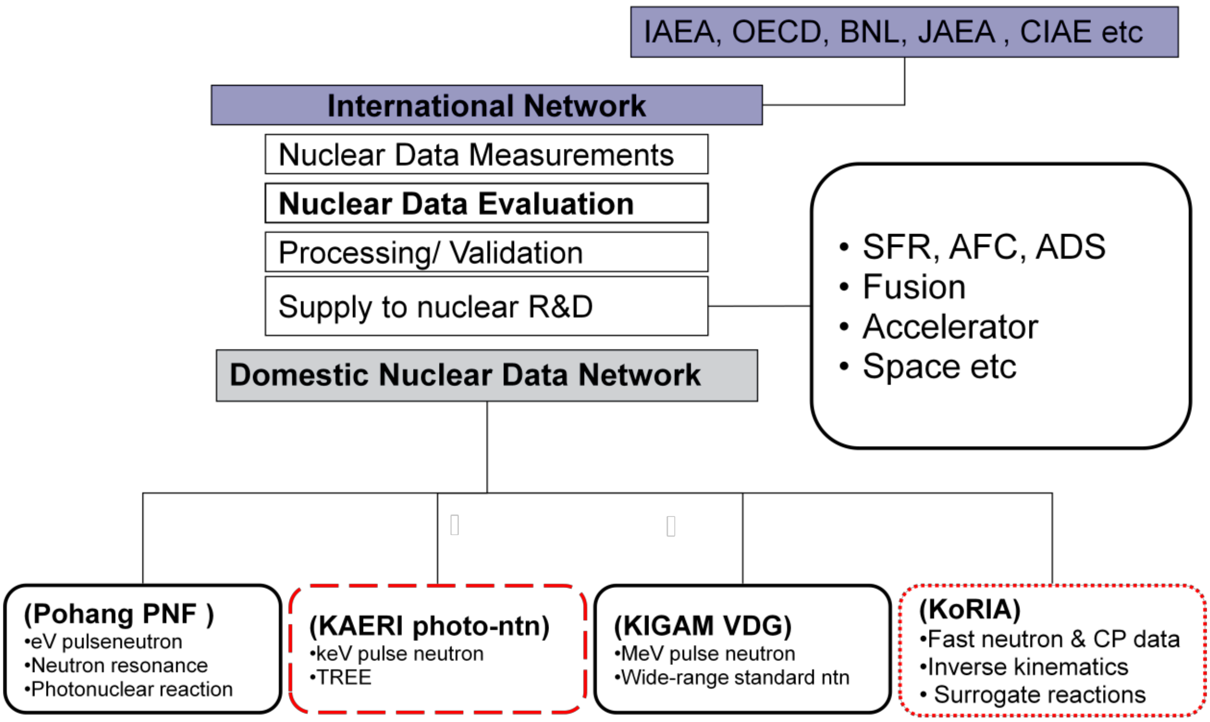
Mission of Nuclear Data Evaluation Laboratory (NDEL) of Korea Atomic Energy Research (KAERI) includes disseminating outcomes of international network as well as promoting domestic nuclear data activities. Nuclear data needs in Korea are mainly from following major nuclear R&D programs:

- SFR (Sodium-cooled fast reactor) project requires high quality neutron data including uncertainties for actinides, MA and structural materials for fast energy region.
- AFC (Advanced Fuel Cycle) project needs cross sections and covariance for MA as well as fission products for full energy region of neutron.
- Korea, as one of ITER members, requires reliable nuclear data of major ITER components (first wall, tritium breeding module, etc) for their neutronics calculations and analyses.
- Korea Rare Isotope Accelerator (KoRIA) project which has started this year needs more reliable nuclear data of spallation and fragmentation reactions for energies up to a few hundred MeV of charged particles and heavy ions.

KAERI/NDEL is performing nuclear data evaluation, multi-group library processing, and validation which are required by the above mentioned R&D program in Korea. For measurement of nuclear reaction data, KAERI/NDEL is coordinating measurements of Pohang Neutron Facility (PNF) of Pohang Accelerator Laboratory (PAL), Van de Graff laboratory of Korea Institute of Geosciences and Mineral Resources (KIGAM), and MC-50 Cyclotron at Korea Institute of Radiological and Medical Sciences (KIRAMS).



7.2

INRNE-BAS: Recent State and Future Prospects

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In this presentation a review of the Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences (BAS) will be done. The main accent is to show the mission and the vision of the Institute, its structure and the general scientific activities. First, a short historical introduction will be made. A special attention will be paid to the international contacts of INRNE (with world-wide organizations, institutions and universities) which are very important for the successful Institute staff's work. As it was concluded by the 2009 Science Review Committee for INRNE from the side of the European Science Foundation (ESF) and the All European Academies (ALLEA), "INRNE is currently well placed in the national and international context, having gained considerable experience in international collaborations". As a part of the international collaboration, the INRNE participation in the Sixth and Seventh Framework Programs of European Commission (EC) is given. Particularly, the Institute's participation in SPIRAL2 project in GANIL (France) being one of the EC infrastructure projects with a priority will be considered. The two basic experimental facilities of INRNE, namely the Nuclear Scientific and Experimental Centre with Research Reactor and the Basic Environmental Observatory "Moussala" are presented. A specific view on the present state of the Nuclear Theory Laboratory of the INRNE, one of the laboratories in the field of theoretical nuclear and particle physics in Bulgaria, will be done. The publication activity for the last few years, knowledge dissemination and innovation transfer are shown together with the educational activity performed by the scientists of the Institute. Finally, the future plans in developing of INRNE are indicated. For more details, please use the Institute web-site: http://www.inrne.bas.bg/

7.3

Use of γ-ray-generating reactions for diagnostics of energetic particles in burning plasma and relevant nuclear data

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Fusion plasmas at burning stage will contain great variety of energetic particles: products of nuclear fusion and satellite reactions, injected beam ions, ions accelerated by electromagnetic waves, and knock-on particles scattered by these particles. These particles are indispensable constituents for plasma burning, as they heat bulk electron and ion fluids so that high temperature is sustained and fusion reactions continue for a sufficiently long time. On the other hand, high pressure of the energetic particles can trigger many wave-particle interactions and fast particle-driven instabilities. Furthermore, after slowing-down, fusion-born α-particles become impurities and negatively dilute the bulk fluids, so this helium ash should be removed effectively. It is not surprising that diagnosing properties of energetic particles confined in burning plasma is one of the most important issues in nuclear fusion research. Since measurements inside plasma are hardly possible, it is appropriate using indirect methods operating with neutral particles or photons freely escaping from burning zone. Gamma-ray spectroscopy is recognized to be a promising tool for such purposes.[1]

Previously we examined rates of various γ-ray-generating reactions in fusion plasmas, and found that some of them are essentially enhanced by supra-thermal channels induced by energetic knock-on ions.[2] The respective γ-ray fluxes carry signature of the knock-on ions and may effectively be used for plasma diagnostics. This especially concerns the threshold ^{6}Li (t, p_1) ^{8}Li* reaction emitting 0.981-MeV γ-quanta and governed by fast tritons. Thus we proposed use of this γ-line for diagnosing knock-on tritons and α-particles confined in burning DT plasmas.[3]

In this presentation I will talk about the outline of the energetic particle diagnostics based on the γ-ray measurement, and show that key parameters of the knock-on triton population (T_{eff}, n_{eff}), as well as the confinement property of α-particles can be obtained by comparing experimental data on the 0.981-MeV γ-ray yield and emission spectrum with the theoretical slowing-down calculations.

References:

1. V.G. Kiptily, *et al.*, "Gamma-ray diagnostics of energetic ions in JET", *Nucl. Fusion* **45** (2002) 999; V.G. Kiptily, *et al.*, "First γ-ray measurements of fusion–particles in JET trace tritium experiments", *Phys. Rev. Lett.* **93** (2004) 115001; V.G. Kiptily, *et al.*, "Gamma-ray imaging of D and alpha ions accelerated by ion cyclotron heating in JET plasmas", *Nucl. Fusion* **45** (2005) L21.
2. M. Nakamura, Y. Nakao, V.T. Voronchev, H. Matsuura, O. Mitarai, " Kinetic analysis of γ-ray-generating reactions for fuel ion and energetic particle diagnostics of DT fusion plasma", *J. Phys. Soc. J.* **75** (2006) 024801; M. Nakamura, Y. Nakao, V.T. Voronchev, "On the enhancement nuclear reaction rates in high-temperature plasma", *Phys. Lett. A* **359** (2006) 663.
3. M. Nakamura, Y. Nakao, V.T. Voronchev, "Use of the ^{6}Li+T nuclear reaction for diagnostics of energetic particles in burning plasmas" *Nucl. Inst. Meth. Phys. Res. A* **580** (2007) 1052; Y. Nakao, M. Nakamura, V.T. Voronchev, "Use of the γ-rays from the ^{6}Li (t, p_1) ^{8}Li* reaction for studying knock-on tritons in the core of fusion plasmas", *Fusion Sci. Technol.* **52** (2007) 1045.

7.4

Studies on reaction mechanisms of unstable nuclei

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Recent studies on reaction mechanisms of unstable nuclei by means of the continuum-discretized coupled-channels method (CDCC) are reviewed. The topics covered are:

i. four-body breakup processes for ^{6}He induced reaction,

ii. microscopic description of projectile breakup processes,

iii. description of inclusive breakup processes.

Some applications of CDCC to nuclear data studies will also be reported.

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P- 1

Thermal / epi-thermal neutron spectrometer with a ^{3}He position sensitive proportional counter.

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At present, measurement of energy spectrum for thermal and epi-thermal neutrons becomes crucial to apply to the medical, as well as physical applications. In the present paper, we described the preliminary result of ongoing development of a new thermal and epi-thermal neutron spectrometer using the detection depth information measured by a ^{3}He position sensitive proportional counter.

1.Introduction Spectrum measurement of thermal and epi-thermal neutrons is becoming crucial recently considering possible applications such as boron neutron capture therapy (BNCT). The author's group thus started development of a new spectrometer which aimed at measuring thermal and epithermal neutron spectra precisely. We have developed a 2.53cm in diameter and 50cm long ^{3}He position sensitive proportional counter. The ^{3}He gas pressure is 0.5 MPa. The neutron spectrum can be derived by unfolding the detection position (depth) distribution with the response function of the detector. This time, we measured thermal neutrons which are produced by moderating fast neutrons emitted from an AmBe source using a graphite column.

2.Experiments The experiment was carried out at OKTAVIAN facility of Osaka University, Japan. We designed a graphite thermal column with an AmBe source by MCNP5 calculations. The detector was positioned outside the column so that neutrons can insert uniformly from the side surface of the detector. Two signals from both ends of the detector were amplified and measured by two MCAs to obtain a two dimensional contour for one output and the sum of the two by the coincidence counting technique.

3.Results and discussion A measured two dimensional spectrum of signals from the ^{3}He position sensitive proportional counter is shown in Fig.1. In Fig.1, the horizontal axis shows the sum of the two signals and the vertical axis shows one of the two signals. It was confirmed that the detection position information could successfully be extracted. In the next step, the incident direction of neutrons is changed to be parallel to the detector axis in order to measure the detection depth distribution. The distribution could be converted into the neutron spectrum by an appropriate unfolding process.

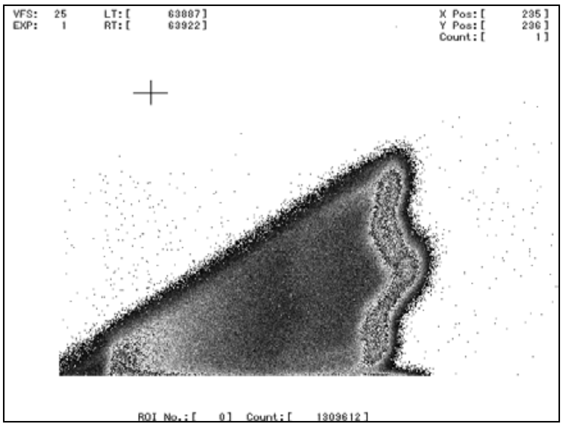

Fig.1 Two dimensional spectrum of thermal neutrons with the ^{3}He position sensitive proportional counter

P- 2

Measurement of ^{151,153}Eu Neutron Capture Cross-Sections using a pair of C_6D_6 Detectors

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-Abstract-

Recently, a great interest has been taken in burn-up credit for criticality safety in the transportation, storage, and treatment of spent nuclear fuel. Burn-up credit is a concept in criticality safety evaluation that takes into account for the reduction in reactivity of spent fuel due to the composition change during irradiation. Neutron capture cross-section data of fission product (FP) play an important role in burn-up credit. According to the reference of [1], twelve FP isotopes (^{95}Mo, ^{99}Tc, ^{103}Rh, ^{133}Cs, $^{143,\ 145}$Nd, $^{147,\ 149,\ 150,\ 152}$Sm, ^{153}Eu, ^{155}Gd) are recommended to be considered in burn-up credit. The objective of this work is to measure neutron capture cross sections of ^{153}Eu and ^{151}Eu. ^{153}Eu is one of the most important FPs for burn-up credit application. ^{151}Eu has a large capture cross section and is contained in the sample of enriched ^{153}Eu that used in this work. Therefore, the experimental data of ^{151}Eu are also necessary to correct the ^{153}Eu capture yield including the effect of ^{151}Eu as an impurity in the sample.

We have measured the neutron capture cross sections of ^{151}Eu and ^{153}Eu by the time-of-flight (TOF) method in the range of 0.004 eV to 100 keV using a 46 MeV electron linear accelerator (linac) at the Research Reactor Institute, Kyoto University (KURRI). We employed a pair of C_6D_6 liquid scintillators for the capture gamma-ray measurement. The energy dependent neutron flux was derived with the standard cross sections of the ^{10}B(n,••) reaction. A pulse-height weighting technique was applied to observed gamma-ray spectra to determine the capture yields of $^{151,\ 153}$Eu. The weighting functions were obtained using the response functions of a pair of C_6D_6 liquid scintillators that were calculated with a Monte-Carlo simulation code EGS5 (Electron Gamma Shower Version 5) [2].

The present data were compared with the evaluated data of JENDL-4.0 [3] and the previous experimental data.

References

[1] Nuclear Fuel Cycle Facility Safety Research Committee, “A Guide Introducing Burnup Credit, Preliminary Version”, JAERI-Tech 2001-055, 2001.

[2] H. Hirayama, *et al.*, The EGS5 Code System, Stanford Linear Accelerator Center Report SLAC-R-730, 2005.

[3] K. Shibata, *et al.*, “JENDL-4.0: A New Library for Innovative Nuclear Energy Systems”, Proc. of the Int. Conf. on Nuclear Data for Science and Technology, Apr. 26-30, 2010, Jeju Island, Korea (ND2010).

P- 3

Resonance Parameter Measurements and Analysis of $^{155,156,157,158,160}Gd$ From 10 eV to 1 keV at the RPI LINAC

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The electron linear accelerator facility at the Rensselaer Polytechnic Institute(RPI) was used to explore neutron interactions with Gadolinium in the energy region from 10 eV to 1 keV. The neutron capture measurements were performed by the time-of-flight technique. Resonance parameters were extracted from the data using the multilevel R-matrix Bayesian code SAMMY 8.0. A table of resonance parameters and their uncertainties is presented. The neutron capture measurements were made at a 25 m with a 16-segment sodium iodide multiplicity detector. High pure isotopic samples of ^{155}Gd, ^{156}Gd, ^{157}Gd, ^{158}Gd, ^{160}Gd as well as two natural gadolinium samples with thickness of 0.254 mm and 5.08 mm were prepared for this measurement. The samples are placed in the center of a cylindrical 16-segment thallium activated sodium iodide NaI(Tl) detector. Each NaI(Tl) piece is pie shaped and optically separated from each other. All of the NaI(Tl) pieces are housed within an aluminum can with photomultipliers attached to each pie shaped segment. Many new resonances of the epithermal region are proposed, and other resonances previously identified in the literature have been revised. The poor match of the ENDF/B-VII.0 parameters to the current data is significant, and substantial improvement to the understanding of gadolinium cross sections is presented, particularly above 180.4 eV where the ENDF/B-VII.0 resolved region for ^{155}Gd ends. As a result, fitting data above 180.4 eV was performed without initial estimates for resonance locations and widths as a challenging task. Also new fitting result of ^{157}Gd above 306.4eV of the upper limit of ENDF/B-VII.0 will be presented.

P- 4

Measurement of Deuteron Induced Thick Target Neutron Yields at 5 MeV and 9 MeV

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Thick target neutron yields(TTNY) from low energy deuteron incidence has been studied for the realization of IFMIF-EVEDA(International Fusion Material IrradiationFacility-Engineering Validation and Engineering Design Activity), BNCT(Boron Neutron Capture Therapy) and so on. Within a framework of IFMIF-EVEDA, the 9 MeV - 125 mA deuteron acceleration experiment is planned. However, the experimental data of deuteron-incident neutron yields are scarce in the beam energy below 10 MeV, the prediction accuracy of the calculation codes has not been verified.

The main purpose of this study is measurements of neutron thick target yields for 9 and 5 MeV deuteron incidence on thick target, and comparison measurement data with calculation ones.

The experiment was performed at the Kyushu University Tandem Accelerator Laboraotory. We adopted thick Cu,Ti and Nb foils which thicknesses are 0.1 to 0.3 mm enough for a deuteron to stop. An NE213 liquid organic scintillator of 2" in diameter and 2" in thickness is employed to detect neutrons emitted from the targets. The measurement angles were 0, 15, 30, 45, 60, 75, 90, 120 and 140 degrees. To consider the contribution of scattered neutrons from the floor, we also measured neutron yields with an Fe shadow bar located in front of the scintillator. Because incident deuteron beam was not pulsed and the time-of-flight method was not applied, the neutron energy spectrum was derived from unfolding the light output spectrum using the FORIST code. The responce function of NE213 scintillator was calculated with the SCINFUL-QMD code. To validate this analyzing method, we measured neutrons from an Am-Be neutron source and got energy spectra consistent with Am-Be neutron energy spectra by Marsh et al.[1].

The experimental results were compared with the calculation data of the TALYS and the PHITS2 codes, and it turned out that the calculation data do not reproduce the experimental ones acceptably.

The proton induced experiment will be arranged before deuteron acceleration. It is helpful to see the differences of TTNY between deuteron and proton incidence. We estimated Cu(p,xn) TTNY using the PHITS2 code with JENDL-HE nuclear data library, and compared them with measurment data of Cu(d,xn) TTNY. The 9 MeV proton induced TTNY is much smaller than experimental data of the 9 MeV deuteron incident one.

ACKNOWLEDGMENTS

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REFERENCES

[1] J.W. Marsh, D.J. Thomas and M. Burke, “High resolution measurements of neutron energy spectra from Am-Be and Am-B neutron sources,” Nucl. Instrum. Meth., A366, 340(1977).

P- 5

Systematic Measurement of Neutron and Gamma-ray Yields on Thick Targets Bombarded with 18 MeV Protons

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Nuclear data on proton-induced neutron and γ-ray production in the energy range from 10 to 20 MeV is important to execute the shield design and to estimate activation of low-energy accelerator facilities for medical use such as production of radiopharmaceuticals in positron emission tomography (PET) using $^{18}O(p,n)^{18}F$ reaction and a neutron source of an accelerator-based boron neutron capture therapy (BNCT) using $^{9}Be(p,n)$ reaction. Neutrons produced though these nuclear reactions severely activate the accelerator components and the cyclotron room. The energy and angular distribution of neutrons should be estimated for radiation safety as well as clearance of the facility decommission. However, the experimental data on the energy and angular distribution for production of neutrons as well as γ-rays are very scarce especially for proton energies from 10 to 20 MeV. Currently, shielding of the neutrons and γ-rays as well as activation of accelerator components and the room wall are calculated by using calculation codes such as PHITS [1] and MCNPX [2]. The accuracy of the codes for such a low energy region should be checked by experimental data, because most of physical models implemented in the codes were developed to describe reactions of high-energy particles. In this paper, we describe the measurement of neutron and γ-ray energy spectra from various targets (^{9}Be, ^{nat}C, ^{27}Al, ^{nat}Cu, ^{181}Ta and $^{18}H_2O$) induced by protons, and comparisons between the experimental data and calculation results.

The experiments were carried out with 18 MeV proton beams delivered to the HB-1 beam line at the AVF cyclotron of TIARA. The targets are installed in a vacuum chamber at the end of the HB-1 beam line. NE213 organic liquid scintillators (5.08 cm in diameter and 5.08 cm in length) were placed in directions of 0, 15, 30, 45, 60, 90, 120 and 150^{o} at a distance of 2.0 - 4.0 m from the target position. The neutrons and γ-rays emitted from the targets were measured with a pulse shape discrimination technique and these energy spectra were analyzed by the TOF method and the unfolding method with FERDOU code [3], respectively. Figure 1 shows the typical neutron energy spectra with comparison between measured and calculation results using MCNPX with ENDF/B-VII data library and implemented physical models (Bertini + Dresner model) for beryllium. The calculation results generally well reproduce the measured energy spectra.

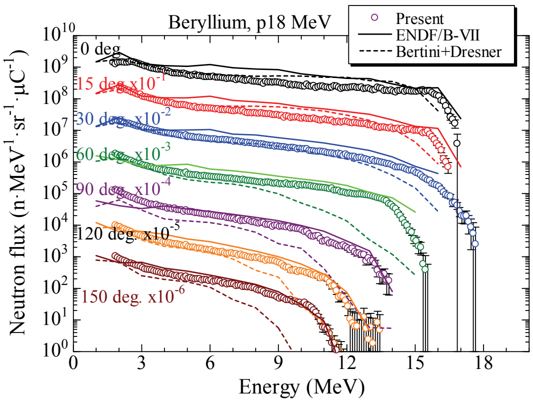

Fig. 1 Energy spectra of neutrons from thick beryllium target induced by 18 MeV proton bombardment.

References

[1] H. Iwase et al., J. Nucl. Sci. Tech. 39 (2002) 1142.

[2] M. B. Chadwick et al., Nucl. Sci. Eng. 131 (1999) 293.

[3] K. Shin et al., Nucl. Tech. 53 (1981) 78.

P- 6

Production of light charged particles from silicon bombarded by 175 MeV quasi mono-energetic neutrons

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In recent years, the importance of single event effects (SEEs) caused by cosmic-ray neutrons in logic and memory circuits have been increasing as one of key reliability issues for advanced CMOS technology. The primary process of SEEs is production of secondary ions by nuclear reactions with atomic nuclei in materials. Therefore, more reliable nuclear data of neutron-induced charged particles production from silicon at intermediate energies of 20 to 200 MeV are strongly required to simulate accurately the SEEs. However, there is no measurement for neutron-induced light-ions (p, d, t, ^{3}He, α) production from silicon in the energy range of more than 100 MeV. In the present work, to benchmark nuclear reaction models, we have measured double-differential cross sections (DDX) for light-ion production from silicon induced by 175 MeV quasi mono-energetic neutrons at the The Svedberg Laboratory (TSL) in Uppsala by TOF method. The measured DDX are compared with the model calculations.

Details of the experimental procedure have been described in Refs.[1,2]. The MEDLEY setup used in the measurement were composed of eight telescopes placed at angles from 20° to 160° in steps of 20°. Each telescope consisted in two silicon surface barrier detectors as ΔE detector and a CsI(Tl) detector as E detector. Light ions produced from a thin silicon target placed at the center were detected by the eight telescopes. Moreover, the incident neutron spectrum was measured using the same setup with a CH_2 target by means of a conventional proton recoil method.

The measured DDX are compared with the pre-equilibrium model calculations incorporated Iwamoto-Harada-Sato coalescence model[3]. To analyze production of light charged particles in the pre-equilibrium process, we employ the exciton model (EM) using the GNASH code, and the quantum molecular dynamics (QMD) using PHITS code. Details of the benchmarking are reported.

REFERENCES

[1]. S. Hirayama, Y. Watanabe, Y. Naitou et al., Proc. Int. Conf. on Nuclear Data for Science and Technology, Jeju Island, Korea, April 26-30, 2010, in press.
[2]. U. Tippawan, S. Pomp, J. Blomgren et al., Phys. Rev. C79, 064611 (2009).
[3]. A. Iwamoto and K. Harada, Phys. Rev. C26, 1821 (1982).

P- 7

Measurement of deuteron-production double differential cross sections by 290 MeV/u oxygen beams on C, Al and Cu targets at forward angles

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Recently, heavy ion induced reactions are of great interest in the field of medicine and engineering. Light fragments such as hydrogen and helium produced from the reactions are especially important in the treatment planning of cancer therapy and the dose estimation for manned space flights due to their long ranges in human bodies or constructional materials. Therefore the nuclear data on light fragments are eagerly needed.

In addition, it has been known that there are differences between measured results and simulated ones with existing calculation codes such as PHITS code. For this reason, the experimentally measured nuclear data will be useful as the benchmark of existing simulation codes and for the future improvements.

We measured deuteron-production double differential cross sections (DDXs) by 290 MeV/u oxygen beams on carbon, aluminium and copper targets at forward angles. The measured DDXs were compared with the calculated ones with PHITS code. Fig. 1 shows the DDXs obtained in our study. The simulation results generally agreed with the measured ones. The measured results will be useful as the benchmark of existing simulation codes and for the future improvements.

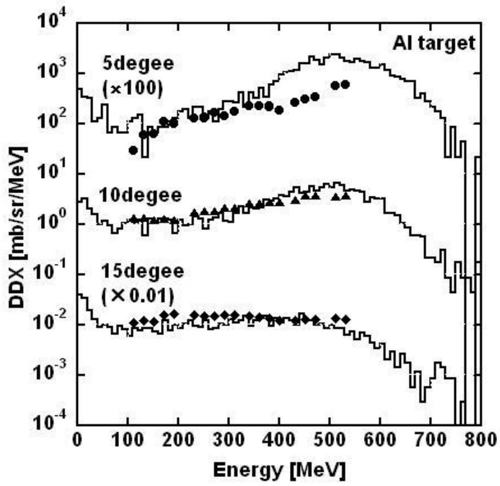

Fig.1. Deuteron production DDXs for 290 MeV/u oxygen incidence on aluminium target, together with the PHITS code calculations (solid lines)

P- 8

Study of the BGO detector for the measurement of the double differential cross sections of cluster production reactions

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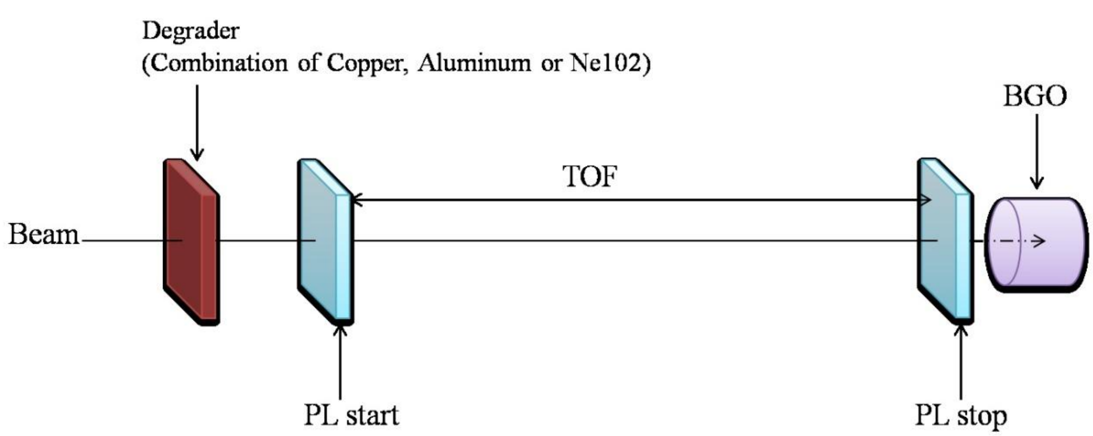
A new crystal array detector has been proposed for conducting the charged particle cross section measurements with actinide targets for a study of accelerator transmutation of the nuclear waste. The detector enables both the Time-of-Flight and the Pulse-Height measurements in an energy range from 10 MeV to 600 MeV. Test experiments with a prototype demonstrated that the detector has great potential to realize a moderate energy resolution and a wide energy acceptance. Since the detector is planned to cover secondary particles from protons to ^{4}He, we investigated characteristics of BGO crystals in terms of the light output and the peak efficiency for charged particle bombardments in the present research.

The light output response of a BGO crystal was measured using proton and ^{4}He ions of energy ranges from 25 MeV up to 100 MeV. Experiments were made at the cyclotron facility National Institute of Radiological Sciences (NIRS), Japan. The energy dependence is found to be interpreted well by the Birks equation. The peak efficiency of the BGO detector was also investigated in terms of nuclear reactions and multiple Coulomb scattering. We have developed a simple Monte Calro code, which has been proved to explain the experimental results of NaI(Tl) and GSO(Ce) crystals with reasonable accuracy.



The crystal detector concept is illustrated briefly in the presented figure, it consists of two sections: one is a crystal detector and another is the TOF section following the plastic scintillator. The detector proposed presently is expected to offer the best characteristics to fulfill required specifications, such as energy resolution and energy acceptance.

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P- 9

Measurement of Neutron-Production Double-Differential Cross Sections for 290 MeV/u Oxygen Ion Incidence

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Carbon ion incident neutron-production double-differential cross sections (DDX) in high energy region on biological elements are required for sophistication of cancer radiotherapy because effect of dose by secondary neutrons has been attracted attention. Therfore, we measured the neutron-production double-differential cross sections for 290 MeV/u oxygen ions incidence on a carbon target of natural isotopic composition. Because of difficulty in preparation of a oxygen target, we performed the ^{nat}C(^{16}O, xn) DDX measurement to conduct inverse reaction analysis. The experiment was carried out at the PH2 beam line at the heavy-ion accelerator facility HIMAC of the National Institute of Radiological Sciences. An 1.5 cm thick carbon plate was placed at an angle of 45° to the beam line as a target. Emitted neutrons were detected with the NE213 liquid organic scintillators, having the dimension of 12.7 cm in diameter and 12.7 cm thick. A plastic scintillators of 2 mm thick was set in front of each NE213 detector to eliminate charged-particle events. A 0.5 mm thick plastic scintillator was set upstream of the target to measure the number of incident particles and to discriminate single incident particle events from multiple ones. In order to reduce neutrons from a beam dump, an iron and a concrete shield was placed between the detectors and beam dump. For measurement of background, a shadow bar was put between the target and each detector. To discriminate between neutron events and γ-ray events, the two-gate charge integration method was adopted. The energy of neutrons produced in the target was determined by the time-of-flight method. The typical flight path length was 4 m. The neutron-detection efficiencies were calculated by the SCINFUL-QMD code. The cross sections were obtained for neutron energy more than 3.4 MeV. The experimental results were compared with the calculation data of the PHITS code. It is show that the PHITS code reasonably reproduces the experimental data.

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P- 10

Neutron and proton yields for reaction induced by 120 GeV proton on thick copper target

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The double differential neutron and proton yields for 120 GeV proton incidence on a thick copper target were measured to validate the descriptions of neutron and proton production models implemented in simulation codes for high energy region.

The experiment was performed with 120 GeV proton beam which was delivered to the Muon Test (MTest) beam line at the Fermilab Test Beam Facility (FTBF) of Fermi National Accelerator Laboratory. The copper target with a thickness of 60 cm was set on the beam line. Incident proton number was counted by three thin plastic scintillators which were located upstream of the target. Neutrons and protons emitted from the target were measured by an NE213 liquid scintillator which was placed at 5.5 m from the target and 30° with respect to the beam axis. A thin plastic scintillator as a veto detector was placed in front of the NE213 scintillator to distinguish charged particles from uncharged particles.

Neutron and proton energies were determined by the time-of-flight method. Neutron detection efficiencies of the NE213 scintillator were experimentally obtained at Los Alamos Neutron Science Center (LANSCE) of Los Alamos National Laboratory. The peak detection efficiencies for proton of the NE213 scintillator were calculated based on the proton stopping powers and the proton total cross sections excluding Rutherford scattering. The proton energy attenuation in the air, the veto detector and the aluminum case of the scintillator were considered based on the proton stopping powers.

Fig. 1 shows the double differential neutron and proton yields at 30° for 120 GeV proton incidence on the thick copper target. The results were compared with the yields calculated by the PHITS and the FLUKA codes. The two calculations were carried out. The broken lines and dotted lines in Fig. 1 are the double differential yields calculated with the simple system containing the target and a ring detector (Ring). The solid line shows the calculations of the double differential neutron yield from the neutron time spectrum for the system including the target, the NE213 scintillator, the beam dump, the floor and the wall (TOF). The low energy neutrons are from the surrounding materials. However, both codes and calculations underestimate the experimental results for protons and high energy neutrons in spite of the low contribution from the surrounding materials.

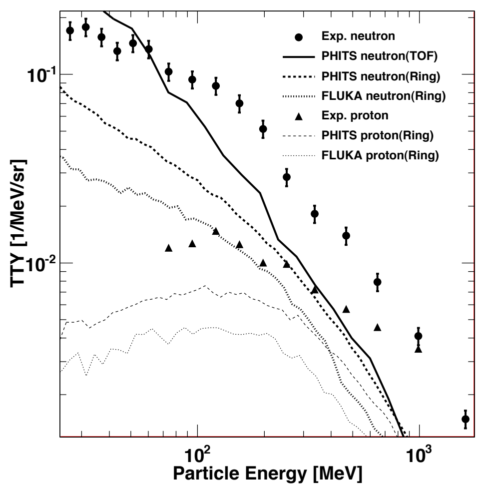

Fig. 1 The double differential neutron and proton yields at 30° for 120 GeV proton incidence on the thick copper target.

P- 11

Comparison of Neutron Production from Heavy-ion Reaction using PHITS and FLUKA

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Key Words: PHITS, FLUKA, MCNPX, Heavy Ion Transport, Secondary Particle Production, Residuals

ABSTRACT

With increasing multi-purpose use of high energy heavy ion accelerators, secondary particle production and transport by high-energy heavy ions are an important issue in the design of the heavy ion accelerator rooms and facility. At present, the development of a heavy ions accelerator with the acceleration energy of 400 MeV/n is under consideration in Korea. And we have a plan to build a n_TOF measurements room in the heavy ion accelerator facility. But there have been no experience to construct a heavy ion accelerator of the high energy above 100 MeV/n and perform the radiation shielding design in Korea. This study is a preliminary analysis of the simulation codes for the heavy ion transport through the benchmark calculations for the evaluation of the secondary radiation source terms and the difference of the calculation for the shielding design. Heavy ion transport codes, PHITS and FLUKA were compared in the view of the radiation shielding. The neutron production rates were calculated using these two codes and the results were compared with the measurement. C-12 ion beam with the energy of 400 MeV/n and graphite target was used in the calculation of the neutron production. The angular distributions of the secondary neutrons from the thick target were compared and applied in the shielding calculations. By using these neutron source terms, the differences of the dose rate behind of the shield materials, concrete, due to the neutron spectrum was evaluated.

P- 12

DPA calculations for heavy-ion and proton incident reactions using the PHITS code.

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Radiation damage measured as a function of “displacements per atom (DPA)” is one of the critical issues for high-intensity beams, especially heavy-ions. The DPA model in the Particle and Heavy Ion Transport code System (PHITS) has recently been extended to include all contributions from inelastic nuclear reactions, nucleon-nucleus nuclear elastic interactions and Coulomb elastic scattering of transported charged particles. For the Coulomb elastic scattering, a universal one-parameter differential scattering cross section equation introduced by J. Lindhard et. al. is employed instead of the differential Rutherford cross section which is a function of six parameters; charge and mass number of incident and produced particles, kinetic energy of incident particle and scattered angle. In this work, we compare PHITS results for the 130 MeV/u ^{76}Ge+^{184}W reaction with calculated results of TRIM which is two-dimensional damage calculation code. Then we calculate DPA for different ions, targets and energies in the energy region from 100 MeV/u to 1 GeV/u and evaluate the systematics of DPA. We also show a table of the physics processes for these results.

P- 13

Developments in INC model for extension for low energy region and cluster-induced reactions

Study of intranuclear cascade model down to 20 MeV and cluster-induced reactions

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Since the intranuclear cascade (INC) model gives good overall agreements with experimental double-differential cross section data of nucleon productions in the proton energy range above a few hundred of MeV, it has been used in transport code, such as PHITS. It is strongly requested to make INC applicable in an energy range down to 20 MeV to realize the event generator mode of PHITS. Although a considerable number of studies were made in an intermediate-energy range, only few attempts have so far been made at below 100 MeV. To this end, we investigated the applicability of INC below 100 MeV. Moreover, we studied the possibility of INC to extend to cluster-induced reactions. Although the quantum molecular dynamics model has given satisfactory interpretation on heavy-ion induced reactions, it showed rather large discrepancy in light-cluster induced reactions. In the present work, the INC model is extended to deuteron- and alpha-induced reactions.

P- 14

A Study of Pre-equilibrium Reaction Induced by Neutron for Nickel

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Young-Ouk Lee, Korea Atomic Energy Research Institute
Hyeong Il Kim, Korea Atomic Energy Research Institute

Nuclear reaction models play an important role in producing the reasonable nuclear data which needs for not only fundamental research in nuclear physics but also practical applications in the field such as nuclear technology, medicine and industry. The reaction models can be divided into three parts, direct, pre-equilibrium and compound, according to reaction time. The direct and compound models have been developed well so as to reproduce experimental data, but the pre-equilibrium model is sometimes in discrepancies with the measurements available.

Because of this, we study for the pre-equilibrium reaction employing the semi-classical model. With a focus on improvement of pre-equilibrium models, we have performed nuclear reaction calculations for natural nickel induced by neutron in the incident energy up to 150 MeV using the talys code. As shown in figure, the emitted neutron spectra are in good agreements with the measurements by adjusting the internal transition rates with energy-dependent matrix element of two-component exciton model..

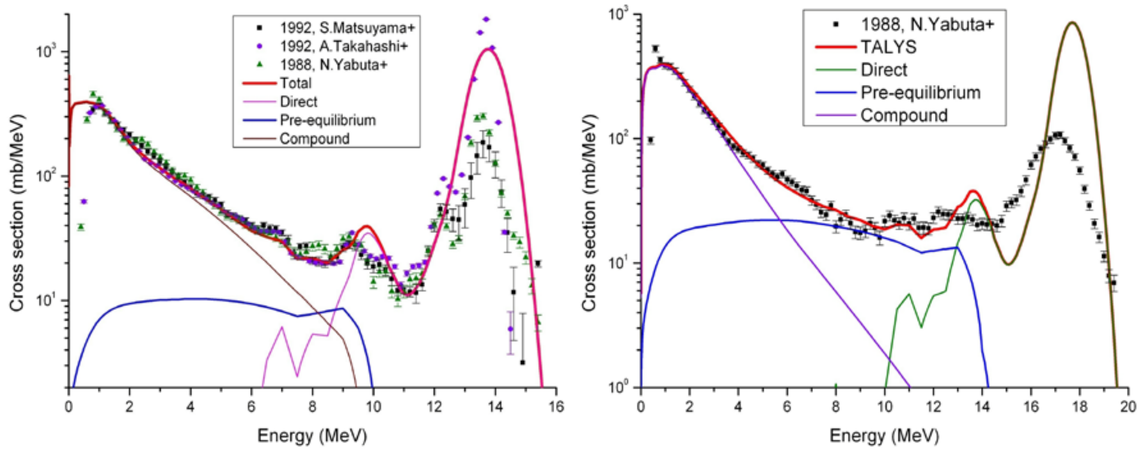

Fig. 1. The emitted neutron spectra for natural nickel in the incident energies 14 and 18 MeV.

P- 15

Preliminary evaluations and covariances of neutron-induced reactions for ^{237}Np and ^{240}Pu above resonance region

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Preliminary evaluations of neutron-induced cross section data including covariance matrices for ^{237}Np and ^{240}Pu above resonance region have been performed. Historically, the major actinides such as ^{235}U, ^{238}U, and ^{239}Pu have been largely focused on the improvements of the evaluated data, while the evaluations of minor actinides had been performed few decades ago and have been rarely modified. However, the needs of evaluation data with high accuracy for minor actinides are increasing for Advanced Fuel Cycle (AFC) and nuclear safeguards applications. In this situation, KAERI commenced on nuclear data evaluations with covariance data for ^{237}Np and ^{240}Pu above resonance region.

The nuclear data evaluations above resonance region have been performed with the EMPIRE code system that has been used to provide a number of consistent, complete evaluations. The EMPIRE code calculates cross sections for all relevant reaction channels, angular distributions, exclusive and inclusive particle- and γ-spectra, double-differential cross sections, and spectra of recoils. In addition to calculation of these physical quantities, this code system includes the several utility codes which generate and check the ENDF-6 formatted files, extract the experimental data from the EXFOR library, and compare the calculated results with the measurements and existing libraries.

Covariance data have been generated by the KALMAN code implemented in the EMPIRE system (EMPIRE-KALMAN). To generate covariance data, the KALMAN employs a sensitivity matrix calculated by the EMPIRE. The sensitivity matrices are obtained by variations of most relevant model parameters such as optical model, level densities, and the strengths of fission barriers. In this work, 2~10 % variations of model parameters around the optimal value were applied to determine their effects on total, elastic, inelastic, capture, fission, (n,2n) cross sections in the full energy range of evaluation.

As results, our evaluations are always compared with the available experimental data and the existing libraries such as ENDF/B-VII.0, JEFF-3.1 and JENDL-4 and the uncertainties of neutron cross sections generated by the EMPIRE-KALMAN module are compared with the measurements.

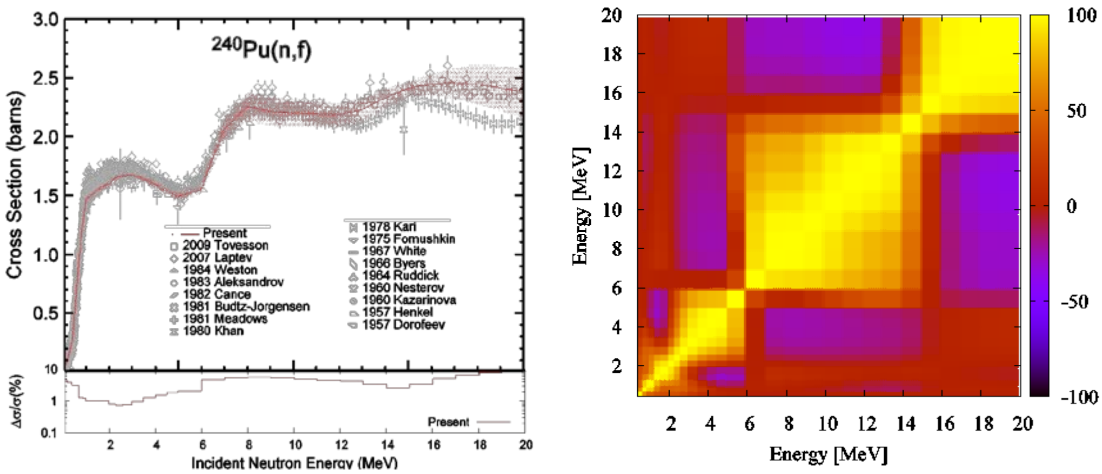

Fig. 1. Uncertainties and Correlations of fission cross sections for ^{240}Pu.

P- 16

Effect of Newly-Measured Cross Sections of ^{157}Gd on Burnup Characteristics of High Burnup BWR UO_2 and MOX Assemblies

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G. Leinweber *et al.*[1] have reported new measurement data of neutron capture, total cross sections and resonance parameters of Gd isotopes. One of prominent results was that the thermal (2200m/s) capture cross section of ^{157}Gd was 11% smaller compared with that in ENDF/B-VI.8[2]. F. Jatuffa *et al.*[3] have tested the newly-measured Gd isotope cross sections in the analysis of measured fission reaction rates of Gd_2O_3-UO_2 rod in tested BWR UO_2 fuel assemblies in core physics experiments and reported that the new cross sections improved the ratios of the theoretically analyzed results to the measurements.

During the evaluation study of JENDL-4 [4], adoption of the new measurement data was assessed. For this purpose a preliminary cross section library for a continuous energy Monte Carlo calculation code MVP[5] was prepared to test the new data of ^{157}Gd in the analysis of integral experiments. [6]. Under this background, the present study was performed to evaluate the effect of the new data of ^{157}Gd on burnup characteristics of high burnup BWR UO_2 and MOX assemblies.

In the burnup calculations in an assembly geometrical model were performed by a general purpose neutronic calculation code SRAC[7] with a 107 neutron energy group cross section library prepared from JENDL-3.3 as base cases. A modified cross section library for the new cross sections of ^{157}Gd was obtained through calculations of a Gd_2O_3-UO_2 rod cell by using MVP and comparison of micro cross sections of ^{157}Gd between the original JENDL-3.3 and that accepting the new data of ^{157}Gd.

The present analysis results shows that the relative fission rates of Gd_2O_3-UO_2 rods at the beginning of burnup with the new library are 2% larger for a high burnup UO_2 fuel assembly and 1% larger for a high burnup MOX assembly than those with the original library. The infinite neutron multiplication factors k_{inf} 's of the assemblies at the beginning of burnup are 0.35% Δk larger in the UO_2 fuel assembly and 0.30% Δk larger in the MOX assembly than those with the original library.

[1] G. Leinweber, D. O. Barry, M. J. Trbovich *et al.*,"Neutron Capture and Total Cross-Section Measurements and Resonance Parameters of Gadolinium," *Nucl. Sci. Eng.*, **154**, 261 (2006).
[2] P. F. Rose and C. L. Dunford, *ENDF-102 Date Formats and Procedures of the Evaluated Nuclear Data File ENDF-6*, BNL-NCS-44945, Rev.2, BNL (1997).
[3] F. Jatuffa *et al.*, "Impact of newly-measured gadolinium cross sections on BWR fuel rod reaction rate distributions, *Proc. Int. Conf. PHYSOR2008*, Interlaken, Switzerland, September 14-19, 2008, No. 219 (2008).
[4] K. Shibata, O. Iwamoto, T. Nakagawa *et al.*, "JENDL-4.0: A New Library for Nuclear Science and Engineering," (to be published to J. Nucl. Sci. Technol.).
[5] Y. Nagaya, K. Okumura, T. Mori *et al.*, *MVP/GMVP II: General Purpose Monte Carlo Codes for Neutron and Photon Transport Calculations Based on Continuous Energy and Multigroup Methods*, JAERI-1348 (2005).
[6] K. Okumura, private communication (2009)
[7] K. Okumura, T. Kugo, K. Kaneko *et al.*, *SRAC2006: A Comprehensive Neutronic Calculation Code system*, JAERI-Data/Code 2007-004 (JAERI), (2007).

P- 17

Improvement of FP Decay Heat Calculation by Introducing TAGS Data
I . Beta and Gamma Spectra

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Abstract.

Summation calculations are widely used to evaluate the fission product (FP) decay heat from a reactor core or spent fuels. This method is based on summing up all the recoverable energy contributions from all the FPs undergoing β-decay and subsequent γ-decay in a core or spent fuels. In order to establish a reliable and self-consistent data basis for this method, we need an accurate and extensive set of the average β-particle and γ-ray energies per decay. It is concluded that one of the best ways to measure the non-biased energy data for this purpose is the total absorption γ-ray spectrometer method (TAGS). This method enables us to measure the γ-ray energies without bias and to solve the pandemonium problem. The pandemonium problem, which is essentially the absence of our knowledge on the β-strength to the highly excited states of the daughter nuclides, is caused by the limitation of the current method. When the β-strength to the highly excited states are lost, the E_γ value is underestimated and the E_β value becomes too large. Recently a series of new TAGS measurement was started by a European group. In the mean time, we plan to include these new TAGS data into JENDL. This needs not only the average energies but also the energy spectra of the γ-rays and the β-particles. But TAGS data is consisted of the beta-feeding rate into energy-bins with finite width. So we have to estimate the energy spectra with aid of theoretical consideration along with the TAGS results. For this purposes the present study is aiming at establishing a way to estimate theoretical energy spectra with combined knowledge of the β-feeding data based on TAGS and the β-decay and γ-decay theory.

P- 18

Improvement of FP Decay Heat by Introducing TAGS Data II. Priority Proposal for Future Measurements

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Decay heat summation calculations are widely used to evaluate the fission products (FP) decay heat from a reactor core or spent fuels. Decay heat is the β-particle and the γ-ray energies released in the FP decay. Summation calculations need correct nuclear data such as half-lifves, fission yields, and mean β- and γ-ray energies released per decay. However β-particle and γ-ray data have a problem. To construct the level schemes, they use the high-precision γ-ray data obtained by Ge detectors. The β-feeding distribution is deduced from the measured γ-intensities. However high energy γ-rays are hard to be detected. Therefore β-feeding to high excited states of daughter nuclides are liable to be overlooked. As a result, the mean β-ray energies are undervalued and the mean γ-ray energies are overvalued. This problem is called the *pandemonium-problem*. Then, it is necessary to solve this problem, in order to improve the summation calculations. The total absorption gamma-ray spectroscopy (TAGS) is expected to be *pandemonium-problem* free, because TAGS enable us to measure the total γ-ray energies independent of the γ-decay mode. Recently a European group started a new series of TAGS measurements. It drastically improved the summation calculation for Pu-239 decay heat. However it did not improve the U-235 decay heat summation calculation. This is because the measured FP nuclides were selected on the basis of contribution to the Pu-239 decay heat. Here we propose a priority list of nuclides to be measured in the future TAGS program focusing our attention on the U-235 decay heat. Our list includes such nuclides as Br-89, Tc-103, and Xe-141 as the high-priority nuclides.

P- 19

Activation analyses by the beam losses in the IFMIF/EVEDA accelerator

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In the IFMIF/EVEDA accelerator, the engineering validation up to 9MeV by employing the deuteron beam of 125mA is planning at the BA site in Rokkasho, Aomori, Japan, activation analyses of the accelerator structural materials; Cu, SUS316, Fe etc., are indispensable for the safety review. As shown in Fig.1, because there was no experimental data for Cu (d,n) reaction in the range of 5MeV-9MeV, deuteron induced thick target neutron yield at 5MeV and 9MeV have been measured in collaboration with Kyushu University.

In this analysis, the experimental data at 9MeV is used for the source term in neutron transportation, radionuclide speciation of ^{65}Zn, ^{54}Mn and ^{60}Co are evaluated by PHITS and DCHAINSP2001 codes. The analysis results will be presented in details.

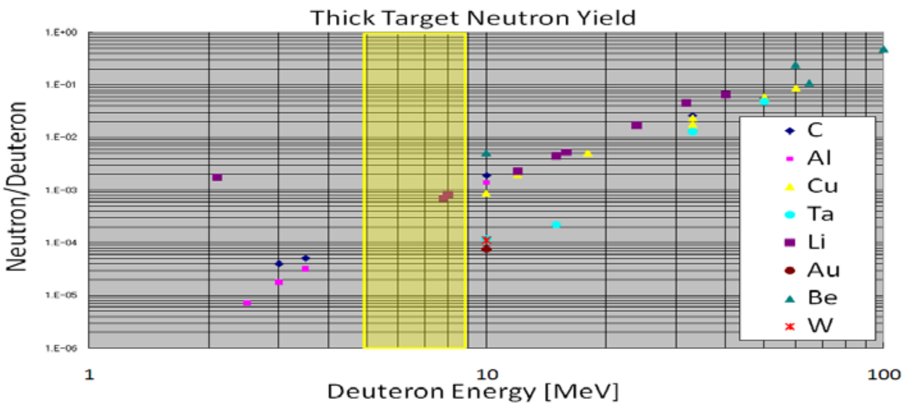

Fig.1 Deuteron induced thick target neutron yield

[1] N. Shigyo et.al., “Measurements of deuteron induced thick target neutron yield at 9MeV”, Proc. Int. Conf. of Nuclear Data for Science and Technology 2010 will be published.

P- 20

Evaluation of gamma-ray and neutron energy in the IFMIF/EVEDA accelerator building

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In the IFMIF/EVEDA, a prototype accelerator is developing and the engineering validation up to 9MeV is planning by employing the deuteron beam of 125mA at the BA site in Rokkasho.

For the radiation controlled area of the accelerator building, effective dose rate has to be suppressed to be less than a 12.5 micro [Sv/h] with no neutron leakage. A design of this area monitoring system, comprising of Si semiconductors and ionization chambers for covering wide energy spectrum of gamma-rays and ^{3}He counters for neutrons, is now in progress. To establish an applicability of this system, photon and neutron energy has to be suppressed to the detector ranges of 1.5MeV and 15MeV, respectively. As the first step, neutron and photon energies throughout shield of water and concrete layer was evaluated by PHITS code, using experimental data of neutron source spectra. It was found that the photon energy range exceeded over 10MeV by water and concrete shielding material only [1]. As the second step, therefore, the efficacy with iron layer in order to decrease photon energy is evaluated.

In this poster session, the photon energy reduction by iron layer will be presented in details.

[1] H. Takahashi, et.al., “Design of Gamma-ray and Neutron Area Monitoring System for the IFMIF/EVEDA Accelerator Building", Proceedings of 26th Symposium on Fusion Technology will be published.

P- 21

Sensitivity Analysis for Curium Isotope Concentrations of Light Water Reactor Mixed-Oxide Burned Fuel

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With the help of the depletion perturbation theory for nuclide/neutron coupled field, sensitivities of curium isotope concentrations to nuclear data are calculated for light water reactor mixed-oxide burned fuel. Calculations are performed for a fuel pin cell model to represent a 17×17 pressurized water reactor fuel assembly with a multi-group library based on JENDL-4.0.

Through the present study, phenomenon of the curium isotope generations during a reactor operation is well understood. In addition, important nuclear data for accurate prediction of the curium isotope concentrations are specified. These information may be helpful to investigate a cause of discrepancy between experimental and calculation values for the curium isotope concentrations.

P- 22

Sensitivity Analysis for Higher Order Legendre Coefficients of Elastic Scattering Matrices

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We perform a sensitivity analysis focusing on higher order Legendre coefficients of elastic scattering matrices. Through the sensitivity analysis for various fast neutron systems described in the ICSBEP handbook, it is found that an attention should be paid to the kind of multi-group cross sections, i.e. infinite dilution cross sections or self-shielded cross sections, used for library effect calculations. Non-negligible library effects are observed in higher order Legendre coefficients of elastic scattering matrices of uranium-238 and iron-56 between JENDL-4.0 and other modern nuclear data files. It is concluded that higher order Legendre coefficients should be accounted for if accurate estimation of library effect is required.

P- 23

Detailed Evaluation of Criticality Change of MOX Cores Based on Sensitivity Analyis

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Detailed evaluation of the criticality change observed in MOX core was performed based on sensitivity analysis. It is found that the criticality change between JENDL-3.3 and JENDL-4.0 is mainly caused by the change of ^{241}Am capture cross section, and the criticality change caused by the change of ^{239}Pu cross section cancels among reaction types, while the change of ^{239}Pu cross section brings a relatively large impact on the criticality change for each reaction type.

1, Introduction

NUPEC has been performing conceptual design studies of high moderation full MOX LWR cores. In a series of experimental analyses, the overestimation of multiplication factors (keff) slightly increases and the difference of overestimation in keff (diff-k) between EPICURE MH1.2 (keff=k_1) and MISTRAL core4[1] (keff=k_2) is about 0.6%Δk/k by using the 107-group cross section data based on JENDL-3.3[2]. But, it was reported that "diff-k" can be reduced to about 0.4%Δk/k by using the data based on JENDL-4.0[3]. To clarify what nuclides and neutron types are dominant to the difference in "diff-k" between JENDL-3.3 and JENDL-4.0, sensitivity analysis was performed in this study.

2, Calculation

All calculations were performed in 107 energy groups: SRAC2006[4] was used to obtain the cell-wise cross section for both JENDL-3.3 and JENDL-4.0, and the cross sections were used in the generalized perturbation theory code SAGEP[5] to obtain the sensitivity coefficient for "diff-k" between EPICURE and MISTRAL. The difference in "diff-k" was evaluated by the following equation to obtain detailed information for the difference.

$$\langle S \rangle_{l,r,g} \equiv \frac{\delta(k_2 - k_1)}{\langle \delta\sigma/\sigma \rangle_{l,r,g}} = k_2 S_2 - k_1 S_1 \quad , \quad \delta(k_2 - k_1) = \langle S_{3.3} \rangle_{l,r,g} \times \left\langle \frac{(\sigma_{4.0} - \sigma_{3.3})}{\sigma_{3.3}} \right\rangle_{l,r,g} ,$$

where < >represents integration over nuclide, reaction type and energy group, $S_{3.3}$ is the sensitivity coefficient for diff-k based on JENDL-3.3, $\sigma_{3.3}$ and $\sigma_{4.0}$ are the cross section based on JENDL-3.3 and JENDL-4.0, respectively.

3, Results and Discussions

The contribution of nuclide and reaction type to "diff-k" is shown in Table 1. It shows that the main contribution to "diff-k" comes from the ^{241}Am capture reaction and mainly caused in the following energy ranges; 1.13eV~1.45eV, 0.47eV~0.62eV and 0.25eV~0.32eV. This contribution comes from the fact that there is a large difference in the cross section between JENDL-3.3 and JENDL-4.0 and the comparatively large sensitivity coefficient in such energy ranges.

Further discussions about other nuclides and reactions will be presented in the meeting.

Table 1 Contribution of each nuclide and reaction type to diff-k

	Fission	ν	Capture	Elastic	Total
			[%Δk/k]		
^{235}U	0.005	-0.006	-0.020	0.000	-0.022
^{238}U	0.006	-0.008	-0.049	0.004	-0.043
^{238}Pu	0.000	0.000	0.084	0.000	0.084
^{239}Pu	0.062	-0.101	0.035	0.000	-0.002
^{240}Pu	0.000	0.000	-0.001	0.000	-0.001
^{241}Pu	0.003	0.015	-0.011	0.001	0.008
^{242}Pu	0.000	0.000	-0.005	0.000	-0.005
^{241}Am	-0.001	0.002	-0.334	0.000	-0.333
^{1}H	-	-	0.000	-0.015	-0.015
^{16}O	-	-	0.000	0.014	0.014
Zr	-	-	0.000	-0.004	-0.020
					-0.333

References

[1]K. Ishii, M. Tatsumi, T. Kan et al., "Analysis of MOX corephysics experiments MISTRAL," Trans. At. Energy Soc. Jpn.,2, 39–54 (2003), [in Japanese]. [2]K. Shibata,"Japanese Evaluated Nuclear Data Library Version 3 Revision-3: JENDL-3.3," *J. Nucl. Sci. Technol.* **39**, 1125 (2002). [3]K. Shibata,"JENDL-4.0: A New Library for Nuclear Science and Engineering" (to be published to *J. Nucl. Sci. Technol.*). [4]Keisuke OKUMURA, "SRAC2006 : A Comprehensive Neutronics Calculation Code System, " JAEA-Data/Code 2007-004 (2007). [5]A. Hara, T. Takeda and Y. Kikuchi "SAGEP:Two-Dimensional Sensitivity Analysis Code Based on Generalize d Perturbation Theory" JAERI-M 84-027 (Jan. 1984) [in Japanese]

P- 24

Analysis of Sample Worth for Dy_2O_3, Ho_2O_3, Er_2O_3 and Tm_2O_3 Measured at KUCA by MVP with Recent Version of JENDL, ENDF and JEFF

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Analyses were performed to verify nuclear data of some rare-earth elements by using the continuous energy Monte-Carlo code: MVP with JENDL, ENDF and JEFF, and the C/E values are within the range from 0.97 to 1.12 with a standard deviation about 0.03.

1. Introduction

Utilization of high burnup fuel, which contains higher-enrichment uranium, is considered as one of the solution to reduce the fuel cycle cost and number of discharged fuel assemblies. Since the high burnup fuel has large excess reactivity at beginning of life, burnable poisons are used to reduce the excess reactivity at initial burnup. Characteristics of rare-earth elements are suitable as burnable poisons thus their application has been widely investigated. However the accuracy of the cross section is not clear these elements, therefore the critical experiments to measure sample worth were performed at Kyoto University Critical Assembly (KUCA), and the analyses of the worth were done by the continuous energy Monte Carlo code : MVP to verify nuclear data of some rare-earth elements.

2. Experiments and Calculation

The target elements to measure the sample worth were Dy_2O_3, Ho_2O_3, Er_2O_3 and Tm_2O_3, and the worth was measured at two different cores named E3 (softer neutron spectrum) and EE1 (harder neutron spectrum) to evaluate the dependency of C/E values on neutron spectrum. MVP calculation was performed with rigorous treatment of the core geometries and material compositions as much as possible with 2500 million histories. The nuclear data libraries used in the MVP analyses were JENDL-3.3, JENDL-4.0, ENDF/B-VII.0 and JEFF-3.1. The sample worth of rare-earth elements was evaluated from difference of k_{eff} in two independent MVP results of with and without samples.

3. Results and Discussions

As shown in Figures 1 (E3) and 2 (EE1), all C/E values are roughly around 1.0 (from 0.97 to 1.12) by considering a standard deviation about 0.03. There is a small discrepancy observed in the case of Dy_2O_3 between E3 and EE1 cores and overestimation of Ho_2O_3 worth at both cores is expected. The C/E values for Er_2O_3 and Tm_2O_3 are close to 1.0 at both E3 and EE1 cores compared to the cases of Dy_2O_3 and Ho_2O_3. The large discrepancy of C/E value from 1.0 is not observed for all the results and this fact indicates the validity of cross section data for Dy, Er, Ho and Tm in the libraries (JENDL-3.3, JENDL-4.0, ENDF/B-VII.0 and JEFF-3.1).

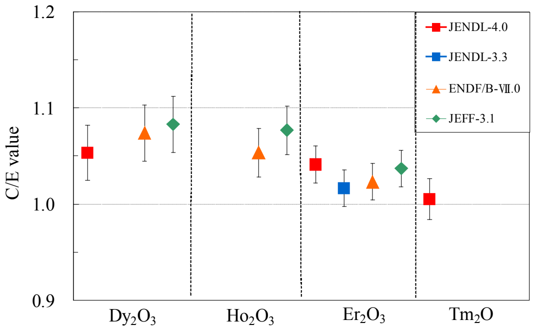

Fig. 1 C/E value of reactivity worth in MVP calculation
E3 : B3/8"P36EU(3) core

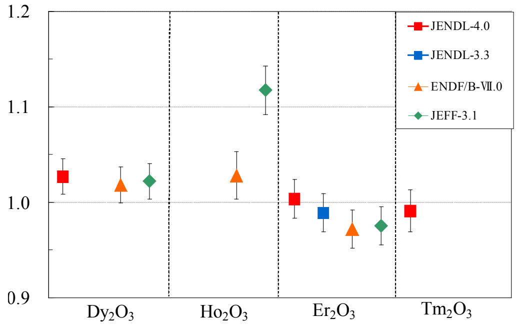

Fig. 2 C/E value of reactivity worth in MVP calculation
EE1 : B1/8"P60EU-EU(5) core

Reference

[1] K.Shimozato, K.Ieyama, T.Kitada et al., "Measurements and Analysis of Reactivity Worth of Rare-Earth Elements at Kyoto University Critical Assembly," Proc. Int. Conf. on the Physics of Reactors (PHYSOR2010), May 9-14, 2010, Pittsburgh, Pennsylvania, USA.

P- 25

Renewal of JENDL photonuclear data file 2004
(I) Elements of atomic number below 20

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For some nuclides, the first version of JENDL photonuclear data file (2004) was enable to reproduce experimental cross sections and may carelessly gave some production cross sections of nuclides which can not be allowed physically Now we are revising the data file to reproduce the experimental data of neutron production and photo-absorption cross sections. High resolution measurements made after the previous evaluation are also included for the renewal..

Formula of resonance plus quasi-deuteron model is applied to analyze experimental cross sections of the (γ,xn) reactions compiled by Dietrich and Berman [1)] and the (γ,abs) reactions[2)]. For the nuclides, no experimental data are available, relative resonance absorption cross sections are estimated using the parameters given in the RIPL-2 theoretical giant dipole resonances[3)]. In the case of no GDR parameters are given in the RIPL-2 for light nuclides, the GDR structures were estimated using the level scheme given in the ENSDF and neutron resonance parameters. The estimated relative cross sections are normalized to satisfy the sum rule of the giant dipole plus quasi deuteron cross sections. Branching ratios of the reactions of which experimental cross sections are not given presently are calculated with the ALICE-F code[4)]. Production cross sections of the radio isotopes which have half lives almost longer than one second are also calculated with the branching ratios calculated with the ALICE-F code. Details of the present renewal are

Revised;

^{12}C, ^{14}N, ^{16}O, ^{19}F, ^{23}Na, $^{24, 26, 26}$Mg, ^{27}Al, $^{28\ 29,\ 30}$Si, ^{31}P and $^{40, 48}$Ca

Newly evaluated;

^{13}C, ^{15}N, $^{17, 18}$O, $^{20, 21, 22}$Ne, $^{32, 33, 34, 36}$S, $^{35, 37}$Cl, $^{36, 38, 40}$Ar, $^{39, 42}$ and $^{42, 43, 44, 46}$Ca

References

1) S. S. Dietrich and B. L. Berman, Atomic Data and Nuclear Data Tables,38,199(1988)
2) J. Ahrens et al., Nucl. Physics A251,479(1975), J. Ahrens, Nucl. Physics A446, 229c(1985), H. Harada et al., Phys. Rev. Lett. 80, 33(1998) , H, Harada et al., J. Nucl. Sci. Eng. 35, 783(1998), H. Harada et al., J.Nucl.Sci.Eng.38,465(2001)
3) T. Fukahori et al., IAEA TECDOC 1506 (IAEA,2006) "Gamma-ray Segment Theoretical GDR Parameters"
4) T. Fukahori JAERI-M 92-039(1992), p.114