# Status Report of KAERI Nuclear Data Evaluation Lab
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Nuclear Data Evaluation Laboratory (NDEL) of Korea Atomic Energy Research Institute (KAERI/ NDEL) has 9 Staffs and 1 Secretary (Evaluation 5, Processing and Benchmark 4). KAERI/NDEL's main project is "Establishment of Nuclear Data for Future Nuclear R&D" funded by government as a long term nuclear energy development program. The nuclear data needs from the program are as follows;

- Advanced Reactor Development (Liquid Metal Fast Reactor and High Temperature Gas Cooled reactor) requires quantification of cross section uncertainties in their reactor designs.
- Advanced Fuel Development (Extended Burnup, Thorium cycle) needs up-to-date neutron cross sections of fission products.
- Proton Accelerator Development (100 MeV, 20 mA) requires high energy neutron and proton nuclear data relevant to the radiological safety of the accelerator.
- Medical Cyclotron Application needs nuclear data of charged particles.
- Beside the R&D program, usual activities for the nuclear power plant operation, the space satellite development project, and the radioisotope applications, are requesting up-to-date nuclear data.

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 contacting with Pohang Accelerator Laboratory and Van de Graff laboratory of Korea Institute of Geology and Mineral

## 1. Facility

### 1.1. Pohang Accelerator Laboratory

Major upgrade plan of The Pohang TOF has initiated which includes extension of Fight length to 20m and improvement of electric gun and pulsing system. Measurements were

performed for neutron total cross sections for energies from thermal to hundreds eV for 12 samples such as Ta, W, Ti, Dy, Sm, Ag, Hf, Zr, In, Cu, Mo, and Bi.

### 1.2 Korea Institute of Geology and Mineral

The 1.4 MV Van de Graaf of Geoscinece and Mineral Resources (KIGAM) is equipped with a pulsing and bunching system to measure neutron capture cross section at 1 – 2 MeV range. their characteristics such as the response function of gamma-ray detecting system, its weight function and optimum conditions for generating MeV neutrons, were studied. Tthe neutron energy spectrum, which was obtained by these optimum conditions, was characterized for the neutron energy of 2.2 MeV. Also the neutron TOF spectra were measured as a function of the scattering angle and the incident proton beam energy.

## 2. Measurement

Neutron total cross sections of natural Mo, Cd and Bi were measured in the energy range 0.01 - 100 eV at Pohang TOF. Photo-neutron production cross sections and isomeric cross section ratio were measured by gamma activation analysis at Pohang facility.

Cross sections for residual radio-nuclide production by proton-induced reactions on natural molybdenum were measured from their respective thresholds up to 35 MeV using MC-50 cyclotrons at KIRAMS. The activation method and the stacked foil technique using high-resolution HPGe gamma-ray spectrometry were applied to determine the excitation functions. The detector energy resolution and full energy photo-peak efficiency were measured using standard calibrated γ-ray point sources. The measurements were performed in a low background radiation environment. The data were analyzed by using *EG&G-ORTEC* gamma vision software. The proton beam energy along the stacks were measured experimentally employing $^{nat}$Cu(p, xn)$^{62}$Zn / $^{nat}$Cu(p, xn)$^{65}$Zn method as well as theoretically, by using computer program *SRIM-2003*, and found a good agreement

The neutron capture cross-sections and the capture γ-ray spectra of $^{155}$Gd and $^{157}$Gd were measured at the energy 550 keV by using the 3-MeV Pelletron accelerator of the Research

Laboratory for Nuclear Reactors at the Tokyo Institute of Technology. Pulsed keV-neutrons were produced from the $^{7}$Li(p,n)$^{7}$Be reaction by bombarding the lithium target with the 1.5-ns bunched proton beam from the Pelletron accelerator. The incident neutron spectrum on a capture sample was measured by means of a time-of-flight (TOF) method with a $^{6}$Li-glass detector. Capture γ-rays were detected with a large anti-Compton NaI(Tl) spectrometer by employing a TOF method. A pulse-height weighting technique was applied to the observed capture γ-ray pulse-height spectra to derive the capture yields. The neutron capture cross-sections were determined relative to the standard capture cross-section of $^{197}$Au.

**3. Evaluation**

Neutron induced reactions on 32 major fission products isotopes such as $^{95}$Mo, $^{101}$Ru, $^{103}$Rh, $^{105}$Pd, $^{109}$Ag, $^{131}$Xe, $^{133}$Cs, $^{141}$Pr, $^{142,143,144,145,146,147,148,150}$Nd, $^{144,147,148,149,150,151,152,153,154}$Sm, and $^{156,158,160,161,162,163,164}$Dy for energies up to 20 MeV have been evaluated by the KAERI-BNL collaboration. Resonance regions were carefully analyzed using all available experimental information and systematics. In the fast neutron energy region, a modular system of nuclear reaction codes EMPIRE-2.19 was used to produce physical observables such as cross sections, spectra, angular distributions and double-differential cross sections. The evaluations in the fast neutron region are based on nuclear model calculations that allow for a reliable interpolation to the energy regions and/or reactions channels for which no experimental data are available. In the case of neodymium, samarium and dysprosium, we evaluated the entire families of isotopes. This approach ensures consistency among isotopes of the same element and allows for utilization of experimental data for all isotopes to constrain model parameters. The remaining nuclides have been evaluated individually, adjusting model calculations to the available experimental data

Neutron capture and gamma spectra were evaluated in view points of gamma strength functions, even though the level densities play great role to determine the these reactions. The data of iodine-127, cesium-133, gold-197, and gadolinium-155,156,157,158,160 were produced. The gold-197 with apparent anomalous bumps has the experimental data on double differential cross sections from 0.4 MeV to 18.57 MeV and energy spectra at 0.5 MeV. The

calculated gamma spectra describe the experimental data well in full energy ranges. The remaining nuclides were carefully evaluated employing the gamma strength functions describing anomalous bumps.

Carbon and copper in the proton accelerator, through actication, become radionuclides such as $^{7}$Be and $^{64}$Cu. Copper is a major element of the accelerator components and the carbon is planned to be used as a target material of the beam dump. A recent survey showed that the currently available cross sections create a large difference from the experimental data in the production of some residual nuclides by the proton-induced reactions for carbon and copper. To more accurately estimate the production of radioactive nuclides in the accelerator, proton cross sections for carbon and copper are evaluated. The TALYS code was used for the evaluation of the cross sections for the proton-induced reactions. To obtain the cross sections which the best fit the experimental data, optical model parameters for the neutron, proton and other complex particles such as the deuteron and alpha were successively adjusted.

Resonance parameters for $^{232}$Th, Pd-107 and Er-166 in resolved and unresolved energy regions were newly evaluated using the weighted average method, the Porter-Thomas distribution and the Bayesian approach. Recent measurements data and evaluation data were taken into account in this evaluation. In the resolved resonance energy region, quantum numbers and neutron reaction widths for each resonance were assigned and the upper energy of the resolved resonance region was adjusted so as to make the capture cross section be connected smoothly to that in the unresolved resonance region. In the unresolved resonance region, the neutron strength functions, average level spacings and average capture widths were determined, and then the evaluated resonance parameters were compiled into the ENDF format.

**4. Processing and Benchmarks**

Various libraries such as for MCNP4C code, WIMSD-5 code, fast reactor, shielding, fission product burnup, and reactor benchmark were generated, and a new resonance integral method was developed and applied for the heterogeneous reactor.

The covariance data processing and the nuclear data sensitivity and uncertainty (S/U) analysis of the $k_{eff}$ have been carried out using SUS3D-ERRORJ-NJOY-ANSN code system . The uncertainties of the $k_{eff}$ due to the U-235 and U-238 cross sections of JENDL-3.3 have been estimated for the 1-D fast benchmark GODIVA.. The elastic and inelastic scattering cross sections are highly and negatively sensitive in the fast energy region, while the fission and total nu-bar cross sections are positively sensitive. The U-235 cross sections were more sensitive to the $k_{eff}$ calculation for GODIVA than U-238. Especially, the elastic scattering cross section of U-235 can provide the largest uncertainties to the $k_{eff}$ calculation. As a result, the uncertainty of the $k_{eff}$ due to the U-235 and U-238 cross sections of JENDL-3.3 was evaluated to be ~1.4% for GODIVA (calculated $k_{eff}$ = 1.02516).

**4. Services**

As for the online nuclear data service at http://atom.kaeri.re.kr/, nuclear structure database, neutron data, charged particle data, and high energy service were upgraded in response to the relevant users' opinions from domestic laboratories, universities and industries. In the nuclear data service for the R&D, the WIMSD-5B library is constantly being updated and upgraded by responding users' demands, such as adding new nuclides and burnup chains. Libraries for the liquid metal reactor are also being upgraded, and the structure of the group constant is being revised according to the users' needs.