Recent Activities of the neutron standardization at KRISS
Hyeonseo Park, Jungho Kim
Korea Research Institute of Standards and Science (KRISS), Korea

Thermal neutron field

Graphite pile
We have constructed the thermal neutron field using a graphite pile and $^{241}$Am-Be neutron source (Fig. 1). The graphite pile is 1.4 m long, 1.2 m wide, and 1.2 m high and the neutron source position is 35 cm off-centered in length to increase thermal neutron fraction. Total 139 pure graphite blocks of $40 \times 20 \times 10 \text{ cm}^3$ are used and the mass of each block is measured on by one. Boron concentration in the graphite was measured with 16 samples by the PGAA(prompt gamma activation analysis) method in NG7 neutron beam line at NCNR of NIST. The average and standard deviation of 16 measurements are 0.628 $\mu$g/g and 0.028 $\mu$g/g. The impurities were checked by GDMS analysis and all impurities are below 0.1 $\mu$g/g. The density of the graphite block is determined by the measured mass and the size and it is $1.786 \pm 0.015 \text{ g/cm}^3$. The emission rate of neutron from $^{241}$Am-Be source is $1.227 \times 10^7 \text{ s}^{-1}$.

Neutron fluence measurement
The thermal neutron fluence was measured by neutron activation method with thin gold foil through Westcott convention. The gold foil is 50 $\mu$m thick and 2 cm in diameter. To measure the cadmium ratio, two sets of foil case made by aluminum and cadmium of same dimension were used during the activation.

The most of correction factors like self-shielding factor or cross-section differences were evaluated by MCNPX calculation. The neutron energy distribution at 70 cm position from the source center is calculated by MCNPX, shown in Fig. 2. The temperature of our system is determined by maximum likelihood fit for the neutron spectrum estimated by MCNPX calculation and is 307 K with the uncertainty of about 2 %.

Gold activity determination
The activity of gold foil activated by neutrons were measured by well-type NaI($Tl$) scintillation detector ($\varphi 19.0 \text{ cm} \times 19.8 \text{ cm}$) (Fig. 3). Figure 4 shows the gamma energy spectrum from $^{198}$Au decay measured by well-type NaI($Tl$) scintillation detector. The
411.8 keV gamma peak is clearly seen. The efficiency calibration is done with standard Gold foil activated in NPL thermal neutron field. The efficiency for 411.8 keV gamma is 0.766 (0.13 %, k=2). Now, we are developing $\beta$-$\gamma$ coincidence counting methods using this well-type NaI(Tl) detector for $\gamma$ counting and plastic scintillation counter for $\beta$ counting. After this work, we will have our own traceability.

**Thermal neutron fluence at the reference position**

The reference position for thermal neutron standards is the 70 cm position from the neutron source. This position is selected because of the reasonably good thermal neutron fraction (about 0.96 %) and the acceptable amount of thermal neutron fluence (about 3000 n/s) if $^{241}$Am-Be source of $1.227 \times 10^7$ s$^{-1}$ emission rate is used. The evaluated neutron fluence below cadmium cutoff energy at the reference position is 2689.3 n/s (1.8 %, k=1) and the temperature of Maxwell distribution is 307 K.

![Figure 1. Graphite pile to produce thermal neutron field](image)
Figure 2. Neutron energy spectrum at 70 cm from the source estimated by MCNPX calculation

![Neutron energy spectrum](image1)

Figure 3. Shielding system for well-type NaI(Tl) scintillation detector

![Shielding system](image2)

Figure 4. \( \gamma \) energy spectrum from \(^{198}\)Au decay measured by well-type NaI(Tl) scintillation detector

![\( \gamma \) energy spectrum](image3)

**Neutron Spectrometry with BSS**

KRISS has 10 Bonner spheres manufactured by Centronic Ltd., UK. It is consisted of 10 polyethylene spheres of 3", 3.5", 4", 4.5", 5", 6", 7", 8", 10", and 12" diameter. For the extension of the neutron energy up to 1 GeV, 4 multi-shell structure spheres with copper and lead were included. The response functions with the \(^3\)He proportional counter SP9 and activation foils(gold and dysprosium) were calculated by using...
MCNPX (Figure 5). The responses were found to be stable within 0.5 % for parallel, normal and isotropic incidence directions.

Three sets of $^{197}$Au foils were prepared for the measurements: $\varphi 12.7 \text{ mm} \times 50.8 \mu \text{m}$, $\varphi 15.0 \text{ mm} \times 100 \mu \text{m}$ and $\varphi 20.0 \text{ mm} \times 100 \mu \text{m}$. The dimension of the natural abundant Dy foil is $\varphi 12.7 \text{ mm} \times 25.4 \mu \text{m}$. A well-type NaI($Tl$) with $\varphi 17.78 \text{ cm} \times 17.78 \text{ cm}$ is used for the activity measurements.

We have measured the accelerator-produced neutrons with the extended BSS at three laboratories in Korea.

![Figure 5](image)

**Figure 5.** Response functions of KRISS BSS with $^{197}$Au foil ($\varphi 20.0 \text{ mm} \times 100 \mu \text{m}$)

**Neutron energy spectrum measurement at KIRAMS**

In 2013, we have measured neutrons from the $^9$Be($p$,n)$^{9}$B reaction by 50-MeV cyclotron at Korea Institute of Radiological & Medical Sciences (KIRAMS). $^{197}$Au and Dy foils were used as thermal detectors and the measurement were carried out using 11 spheres including 2 extended spheres. The incident proton energy was 30 MeV and the spheres were placed 100 cm from the $^9$Be target at $0^\circ$ beam direction. The beam current was 10.0 $\mu$A and the fluctuation was stable within 1.5% ($k=1$). The saturation specific activities were measured by the $\varphi 17.78 \text{ cm} \times 17.78 \text{ cm}$ well-type NaI($Tl$) detector. Figure 6 shows the measurement at KIRAMS and the neutron energy spectra for both $^{197}$Au and Dy foils.
Neutron energy spectrum measurement at KRISS
KRISS has an electron LINAC manufactured by Elekta Synergy which could produce X-rays from 6 MV, 10 MV and 18 MV modes. We have measured the secondary neutrons by X-rays from 18 MV mode in 2014. The positions 50 cm from the isocenter and near the entrance gate were chosen to measure the accelerator-produced neutrons. $^{197}$Au foils ($\phi 20.0 \, \text{mm} \times 100 \, \mu\text{m}$) and 9 Bonner spheres of 3", 3.5", 4", 4.5", 5", 6", 7", 8" and 10" diameter were used for the measurement. The total dose for each sphere was 10 Gy with the dose rate of 3 Gy/min. The beam size of X-ray was 10.0 cm $\times$ 10.0 cm which is standard irradiation condition. Neutron dose were 0.697 mSv Gy$^{-1}$ and 0.067 mSv Gy$^{-1}$ for the isocenter 50 cm and the entrance gate. Figure 7 shows the measurement at KRISS and the neutron energy spectra.
Neutron energy spectrum measurement at hospital

Secondary neutrons during 230-MeV proton therapy was measured at Samsung Medical Center in 2015. The neutron spectrum at flat panel position was measured using an extended BSS while irradiating proton beam to plastic water phantom instead of patient at isocenter. The extended BSS used for this study comprises 14 detectors, i.e., a $^3$He proportional counter SP9, 9 PE spheres (3", 3.5", 4", 4.5", 5", 6", 7", 8" and 10") and 4 modified multi-shell spheres. The proton beam was operated with wobbling mode (passive scattering method using ridge filter, MLC, compensator, block and etc.) using multipurpose nozzle of Sumitomo Heavy Industry and the beam size was set to 10.0 cm $\times$ 10.0 cm. The total dose for each sphere was 0.03 Gy and the dose rate was set to 0.03 Gy/min in order to use active detector. Neutron dose were 2.22 mSv Gy$^{-1}$ and 2.46 mSv Gy$^{-1}$ for with phantom and without phantom. Figure 8 shows the measurement at KRISS and the neutron energy spectra.

![Image](image_url)

Figure 8. Measurement at Samsung Medical Center(left) and the energy spectra(right)

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>KIRAM</th>
<th>KRISS</th>
<th>Samsung Medical Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary radiation</td>
<td>Proton cyclotron</td>
<td>Electron LINAC</td>
<td>Proton cyclotron</td>
</tr>
<tr>
<td>Primary energy</td>
<td>proton</td>
<td>X-ray</td>
<td>proton</td>
</tr>
<tr>
<td>Beam size</td>
<td>$^9$Be(p,n) at 0°</td>
<td>10.0 cm $\times$ 10.0 cm</td>
<td>10.0 cm $\times$ 10.0 cm</td>
</tr>
<tr>
<td>Position</td>
<td>100 cm</td>
<td>Isocenter 50 cm, gate</td>
<td>flat panel position</td>
</tr>
</tbody>
</table>

Table 1. Summary of the accelerator-produced neutron measurements
### Plans

1. **Neutron generator**
   
   In this year, we will install DD neutron generator (DD-109, Adelphi) which has $10^9$ n/s emission rate. This is purchased by Center for Underground Physics, Institute of Basic Science, Korea and will be used mainly for the quenching factor measurement of crystal detector for the Dark matter search.

2. **Neutron Spectrometry with LSC (Liquid Scintillation Counter)**
   
   Because the energy resolution of BSS is very much limited, we are preparing LSC (liquid scintillation counter) system for the high resolution neutron spectrometry.

3. **Neutron emission rate measurement**
   
   Present manganese bath can measure the neutron emission rate up to $10^5$ n/s. In order to expand this range to $10^3$ or $10^4$ n/s, the mini-Manganese bath will be constructed.

4. **Workplace field**
   
   The workplace field to simulate nuclear power plant and also the neutron field produced around electron accelerator will be constructed.

### Staff Members
Three research scientists and one research associate are fully involved for the neutron standardization.
- Hyeonseo Park, ph.D in Nuclear Physics
- Jung Ho Kim, ph.D in Nuclear Physics

Facilities
- **Radioactive neutron sources**
  - two $^{252}$Cf source: the emission rates of $\approx 2 \times 10^7$ n/s and $\approx 2 \times 10^5$ n/s
  - three $^{241}$Am-Be source: the emission rate of two $\approx 1.2 \times 10^7$ n/s, and $\approx 2 \times 10^5$ n/s
- **Low background neutron irradiation room**: size of 6.7x7.6x6.4 m$^3$
- **Manganese Sulphate Bath system for neutron emission rate measurement**
- **Bonner sphere system with 10 PE spheres**
- **4 extended Bonner spheres with Pb and Cu shells**
- **Neutron detectors**
  - Long counter with one He-3 proportional counter and one BF$_3$ proportional counter
  - three REM counter (two EG&G Ortec LB123 and one Studsvik 2002A),
  - two H$_2$ proportional counter
  - Liquid scintillation detector (BC501a)
  - two BF$_3$ proportional counter
Publications and Communications of KRISS

2013-2014

2011-2012

2009-2010

2007-2008


2005-2006


1987-2004


- “Correction equations of coincidence summing using $^{75}$Se radionuclide in the efficiency of HPGe detector”, Y. Lee et al, Jour. of Radioanalytical and Nuclear Chemistry 242, pp105, 1999.
- “Collisional processes in muon catalyzed fusion as studied by the classical collision theory”, G. P. Lee et al, Jour. of Radioanalytical & nuclear chemistry 178, pp121, 1994.