An Analysis on the Radioactivity Uncertainty Caused by Monte Carlo Stochastic Errors Using Sampling Based Method for the Accelerator Activation Problem

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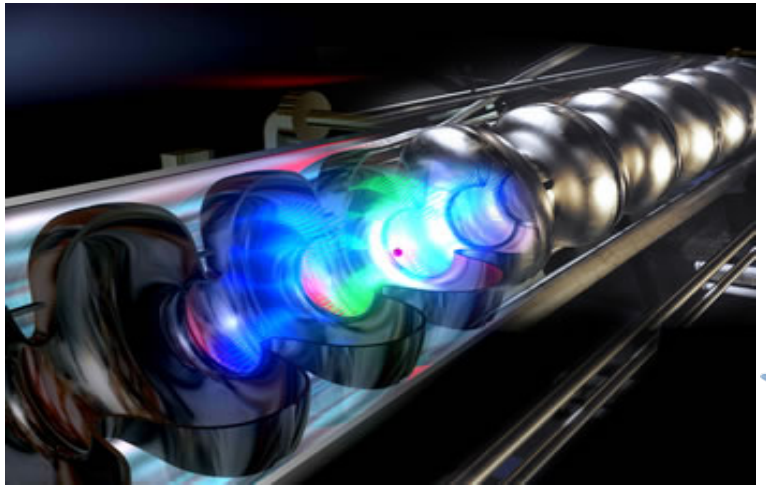
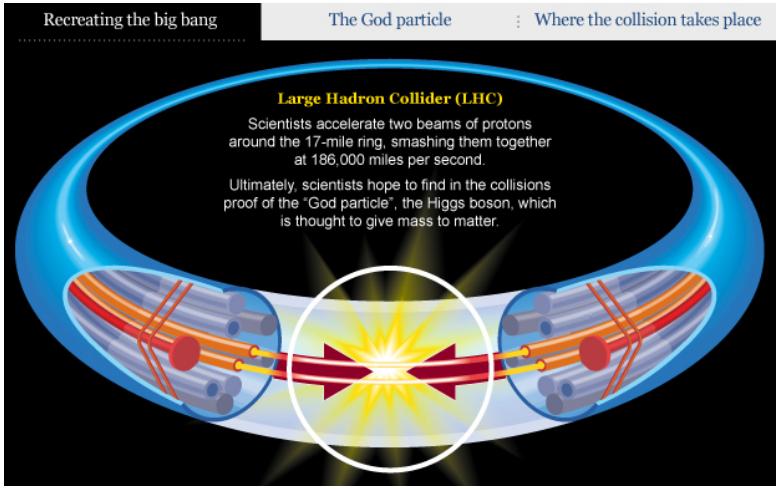
Context

1. Background
2. Motivation
3. Objective of Research
4. Method and Results
5. Conclusion

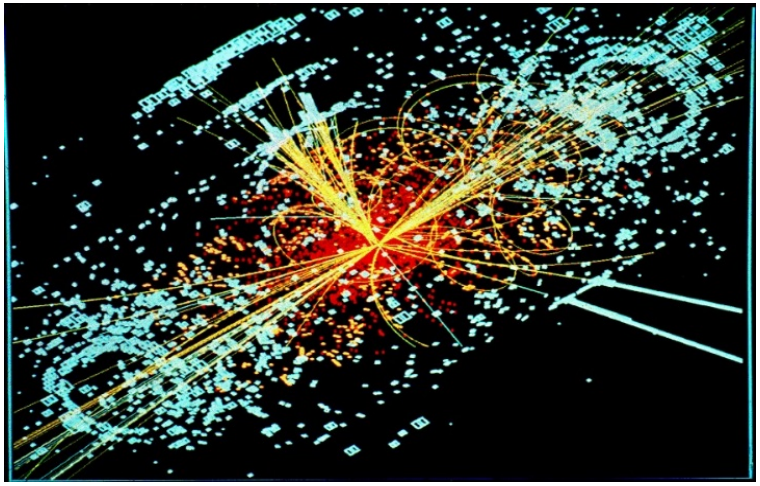


Background

◈ Activation Analysis in Accelerator Facilities



LHC (Large Hadron Collider)



CMS Higgs Event

Quantitative Activation Analysis Demand

Activation Calculation Using Computational Codes

Background

◈ Computational Method for Activation Calculation

Monte Carlo Transport Code
(ex. MCNPX, PHITS, FLUKA)
Complicated Geometry

+

Activation Analysis Code
(ex. SP-FISPACT, CINDER90)
Irradiation/Decay History (Time)

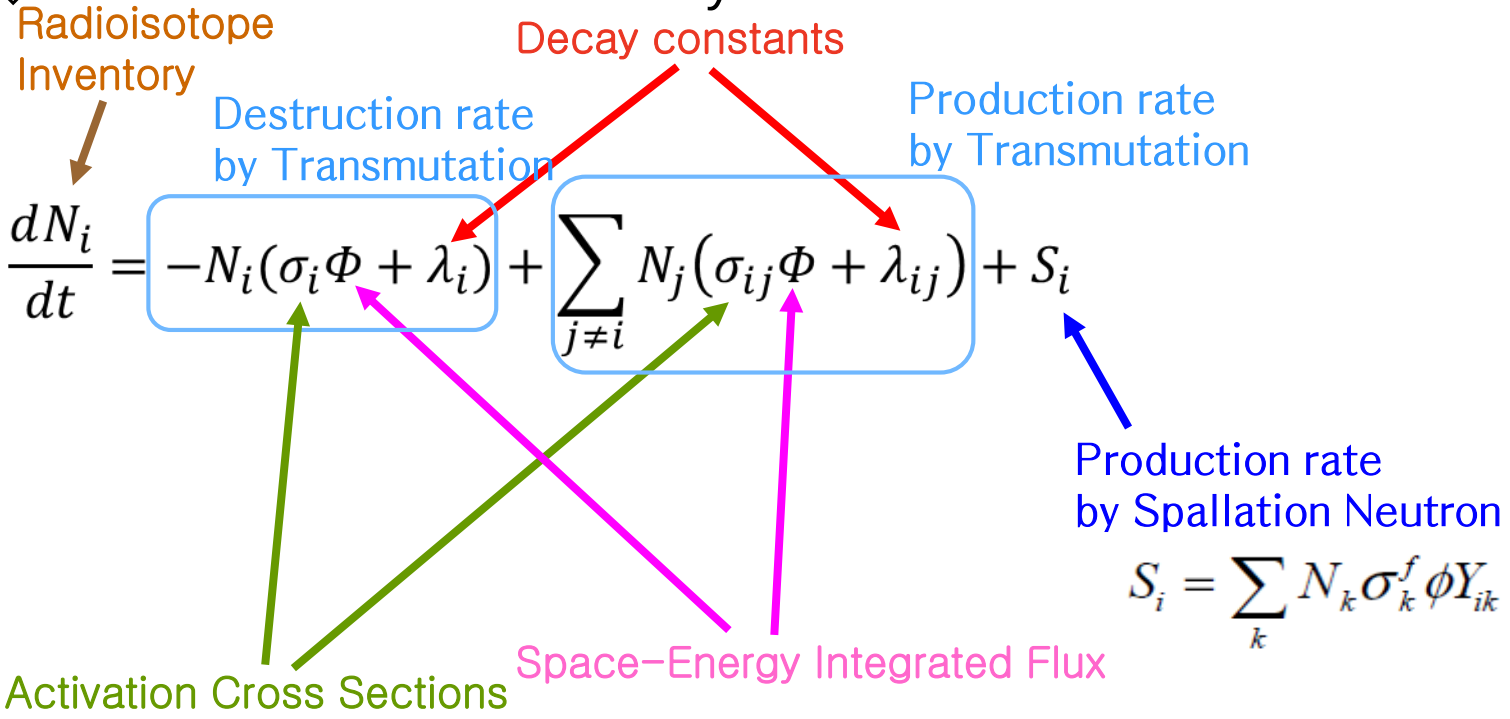
STEP 1 Particle transport simulated at steady-state conditions ⟺ Particle Spectra, Spallation Production Rate $\emptyset(E,\vec{r}), S_i$

STEP 2 Activation parameters collapsed using the output spectra ⟺ Activation Parameter $< \emptyset >, < \sigma\emptyset >$

STEP 3 Activation parameters introduced in the system : time-dependent equations solved. ⟺ Bateman Equation $\frac{dN}{dt} = \mathbf{A} \times N$

Motivation

◈ Sources of Uncertainty in Activation Calculation



▶ Sources of Uncertainties $\Delta_N = f(\Delta_{\sigma^{eff}}, \Delta_\Phi, \Delta_\lambda, \Delta_S) = f(\Delta_{\phi_g}, \Delta_{\sigma_g}, \Delta_\lambda, \Delta_S)$

Particle Histories $\propto$ Calculation Time $\propto \frac{1}{(R.E(=\Delta_{\phi_g}))^2}$

1. Data uncertainty
2. MC stochastic uncertainty

Objectives of Research

To Estimate the Activity Uncertainty Caused by Monte Carlo Stochastic Error, the Estimation Procedure was Constructed Using Sampling Based Method and Guideline of Monte Carlo Stochastic Error For Reliable Activation Results was Proposed

Method and Results

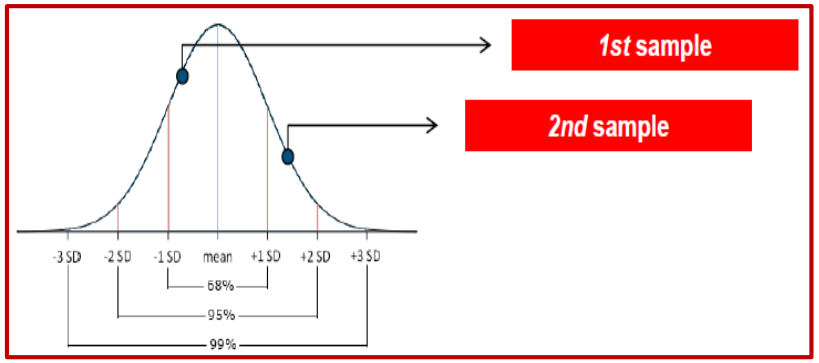
◈ Sampling Based Sensitivity & Uncertainty Analysis Method

If there is relation between x and y like 'y=y(x)=f(x)'

Uncertain Input $X = [\, x_1, x_2, \ldots, x_n]$

Uncertain Output $Y = [f(x_1)\ f(x_2)\ \ldots,\ f(x_n)]$

$= [\, y_1, y_2, \ldots, y_n]$



$[\, x_n, y_n]$
Statistical Analysis

Uncertainty Analysis

Cons : High Computational Load for Reliability
Pros : Easy to Approach in Complicated System

Adequate Method for Activation Problem

Method and Results

◈ Analysis Scheme Based on Sampling Based Method

STEP1. Uncertainty Analysis
What is the uncertainty in y(x) given the uncertainty in x?

⇔ **Characteristics of Activity R.E**

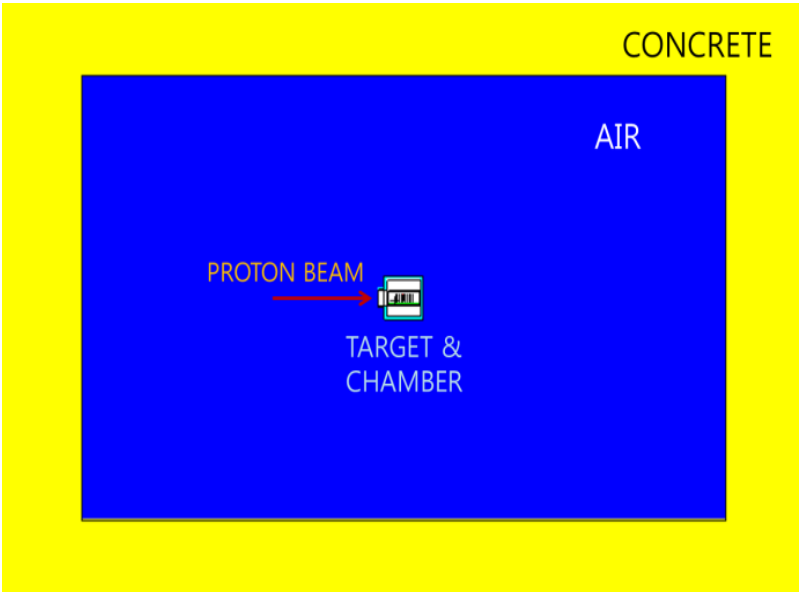
STEP2. Sensitivity Analysis
How important are the individual elements of x with respect to the uncertainty in y(x)?

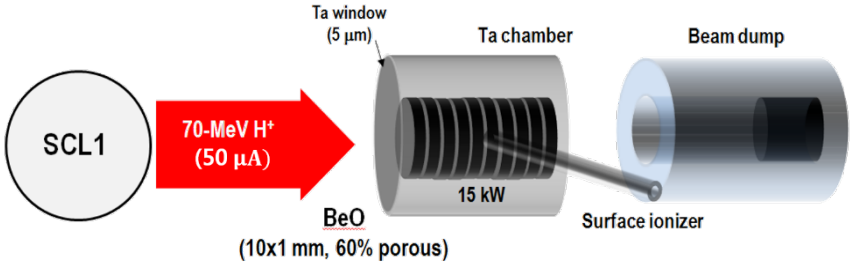
⇔ **Basis Data for Flux Error Guideline**

STEP3. Proposal of Guideline for Flux Error Spectrum

Method and Results

◈ Sample **Problem : Air Activation in βNMR Facility**





Calculation Condition

- **Source** : 70 MeV Proton Beam
  50μA Current
  σ=1cm, Gaussian Profile
- **Target** : BeO (porous 60%)
- **Chamber** : Ta (Inner), SUS304 (Outer)
- **Air :** Dry Air at Room Temperature
- **Surroundings**
  : Sealed Room (=No Streaming)
  Surrounded by Concrete Wall
- **Irradiation/Cooling History**
  : 8 hours Irradiation twice, 8 hours Cooling
  (3 Time-Step)

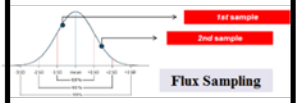
Method and Results

◈ STEP1. Uncertainty Analysis Procedure

INPUT Sample Ø(E)

cell 301

energy		
1.0000E-07	1.09139E-06	0.0014
4.1399E-07	2.73763E-07	0.0016
5.3158E-07	2.74562E-08	0.0034
6.8256E-07	2.72617E-08	0.0034
8.7643E-07	2.74894E-08	0.0033
1.1253E-06	2.73563E-08	0.0033
1.4450E-06	2.75309E-08	0.0033
1.8554E-06	2.78024E-08	0.0033
2.3824E-06	2.79681E-08	0.0033
3.0590E-06	2.82532E-08	0.0032
3.9279E-06	2.84744E-08	0.0032
5.0435E-06	2.87043E-08	0.0032
6.4760E-06	2.89207E-08	0.0032
8.3153E-06	2.89636E-08	0.0032
1.0677E-05	2.94093E-08	0.0031
1.3710E-05	2.93683E-08	0.0031
1.7603E-05	2.97182E-08	0.0031
2.2603E-05	3.01399E-08	0.0031
2.9023E-05	3.03434E-08	0.0031
3.7266E-05	3.07010E-08	0.0031
4.7851E-05	3.09298E-08	0.0030
6.1442E-05	3.11915E-08	0.0030
7.8893E-05	3.13203E-08	0.0030
1.0130E-04	3.15604E-08	0.0030
1.3007E-04	3.20093E-08	0.0030
1.6702E-04	3.21494E-08	0.0030
2.1445E-04	3.24905E-08	0.0030
2.7536E-04	3.27921E-08	0.0030
3.5358E-04	3.30112E-08	0.0030
4.5400E-04	3.31332E-08	0.0029
5.8295E-04	3.35521E-08	0.0029
7.4852E-04	3.38854E-08	0.0029
9.6112E-04	3.42721E-08	0.0029



100 Randomly sampled

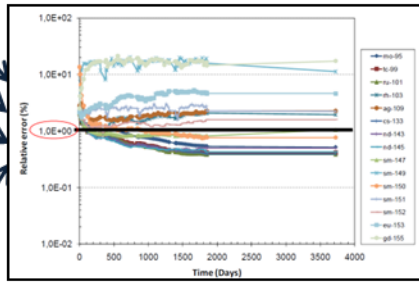
Activation calculation

Flux Set1 → Acti_output1
Flux Set2 → Acti_output2
Flux Set3 → Acti_output3
⋮ ⋮
Flux Set 100 → Acti_output100

Arrangement & Merging

• Inventory/Activity Analysis

OUTPUT

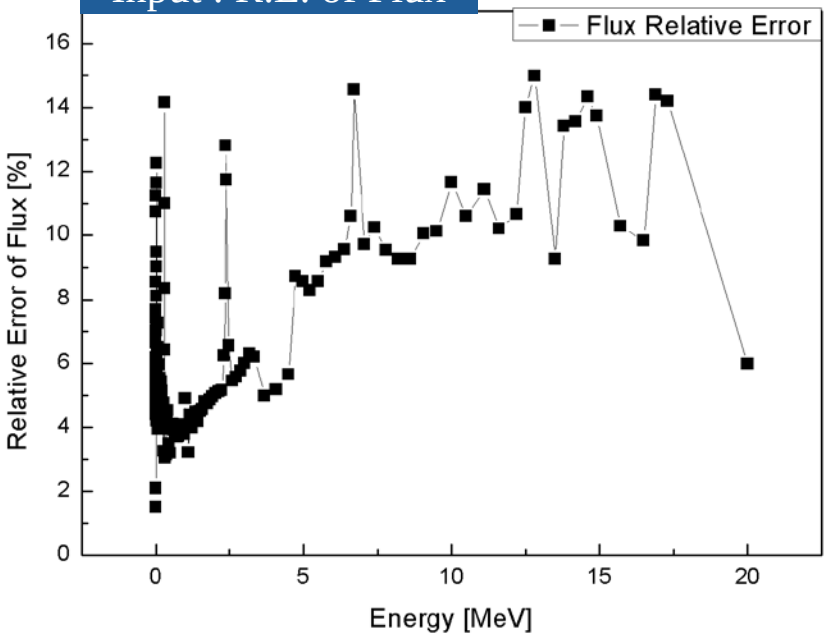


▶ Activation Cross Section : VITAMIN-J 175 group
▶ Assumption : No Correlation between Energy Group Flux

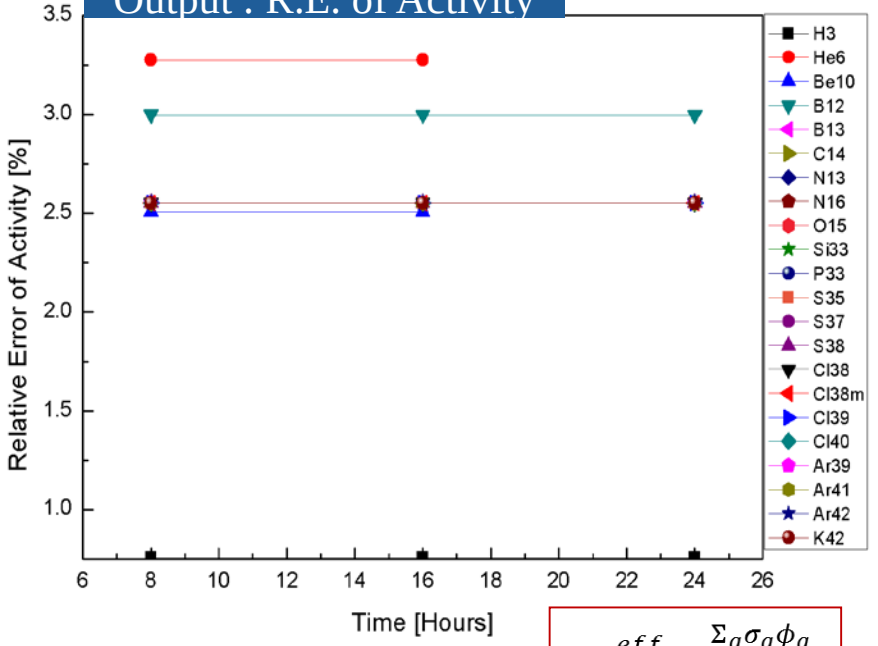
Method and Results

◈ STEP1. Uncertainty Analysis Result

Input : R.E. of Flux



Output : R.E. of Activity



- $\sigma^{eff} = \frac{\Sigma_g \sigma_g \phi_g}{\Sigma_g \varphi_g}$

Characteristics

- **Different R.E. of Activity for Each Produced Radionuclide**

- **XS Difference for Each Nuclide**
- **XS is Energy-Dependent**
- **Sensitivity Analysis Required**

Method and Results

◈ STEP2. Sensitivity Analysis Procedure

- **Sensitivity** $= \dfrac{\textbf{\textit{R.E of Activity}}\ \textit{for Each Nuclide}}{\textbf{\textit{R.E of Flux}}\ \textit{for Each Energy Bin}}$

Sampling Method for Uncertainty Analysis

$$\begin{bmatrix} m(E_1), rsd(E_1) \\ m(E_2), rsd(E_2) \\ \vdots \\ m(E_{175}), rsd(E_{175}) \end{bmatrix} \rightarrow \begin{matrix} \text{Flux Set 1} \\ \begin{bmatrix} \emptyset_1(E_1) \\ \emptyset_1(E_2) \\ \vdots \\ \emptyset_1(E_{175}) \end{bmatrix} \end{matrix} \begin{matrix} \text{Flux Set 2} \\ \begin{bmatrix} \emptyset_2(E_1) \\ \emptyset_2(E_2) \\ \vdots \\ \emptyset_2(E_{175}) \end{bmatrix} \end{matrix} \cdots \begin{matrix} \text{Flux Set 100} \\ \begin{bmatrix} \emptyset_{100}(E_1) \\ \emptyset_{100}(E_2) \\ \vdots \\ \emptyset_{100}(E_{175}) \end{bmatrix} \end{matrix}$$

Sampling Method for Sensitivity Analysis

Unit of Sensitivity Analysis

$$\begin{bmatrix} m(E_1), rsd(E_1) \\ m(E_2), rsd(E_2) \\ \vdots \\ m(E_{175}), rsd(E_{175}) \end{bmatrix} \rightarrow \begin{matrix} \text{Flux Set 1} \\ \begin{bmatrix} \emptyset_1(E_1) \\ m(E_2) \\ \vdots \\ m(E_{175}) \end{bmatrix} \end{matrix} \begin{matrix} \text{Flux Set 2} \\ \begin{bmatrix} \emptyset_2(E_1) \\ m(E_2) \\ \vdots \\ m(E_{175}) \end{bmatrix} \end{matrix} \cdots \begin{matrix} \text{Flux Set 100} \\ \begin{bmatrix} \emptyset_{100}(E_1) \\ m(E_2) \\ \vdots \\ m(E_{175}) \end{bmatrix} \end{matrix}$$

$$\begin{bmatrix} m(E_1), rsd(E_1) \\ m(E_2), rsd(E_2) \\ \vdots \\ m(E_{175}), rsd(E_{175}) \end{bmatrix} \rightarrow \begin{matrix} \text{Flux Set 1} \\ \begin{bmatrix} m(E_1) \\ \emptyset_1(E_2) \\ \vdots \\ m(E_{175}) \end{bmatrix} \end{matrix} \begin{matrix} \text{Flux Set 2} \\ \begin{bmatrix} m(E_1) \\ \emptyset_2(E_2) \\ \vdots \\ m(E_{175}) \end{bmatrix} \end{matrix} \cdots \begin{matrix} \text{Flux Set 100} \\ \begin{bmatrix} m(E_1) \\ \emptyset_{100}(E_2) \\ \vdots \\ m(E_{175}) \end{bmatrix} \end{matrix}$$

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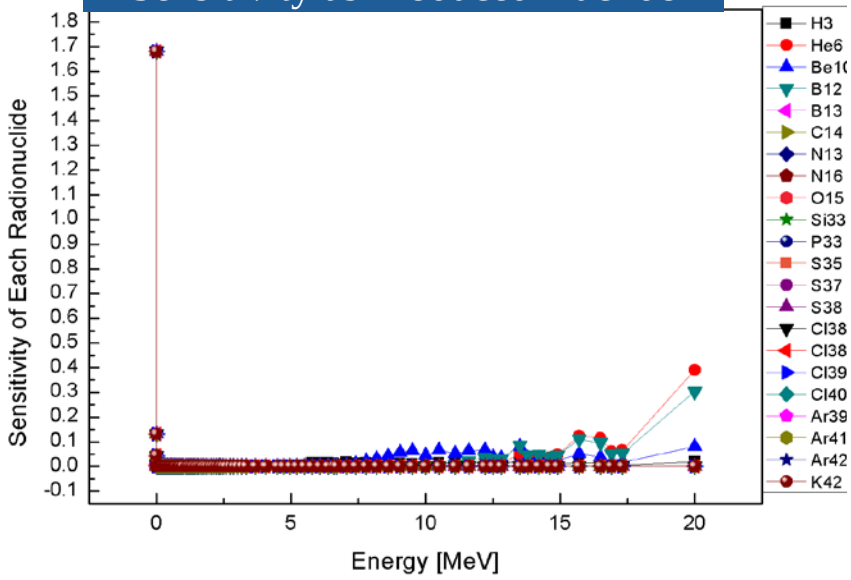
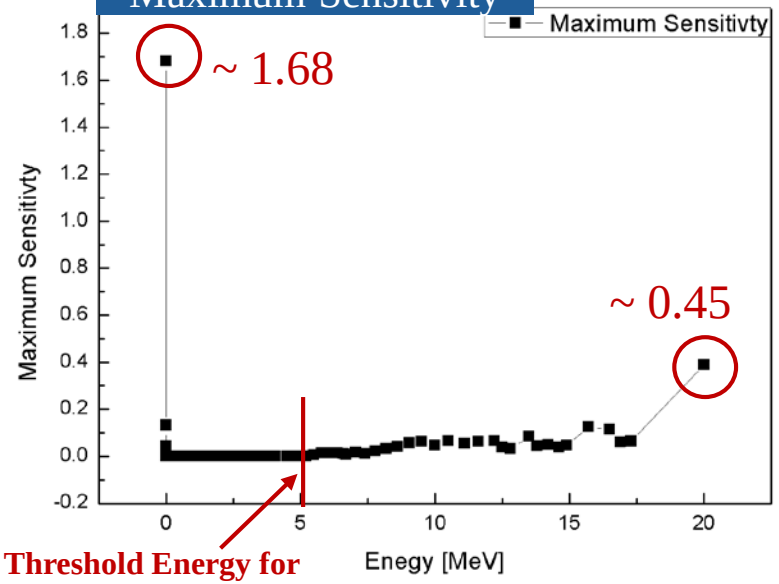
Method and Results

◈ STEP2. Sensitivity Analysis Results

Sensitivity as Produced Nuclide



Maximum Sensitivity



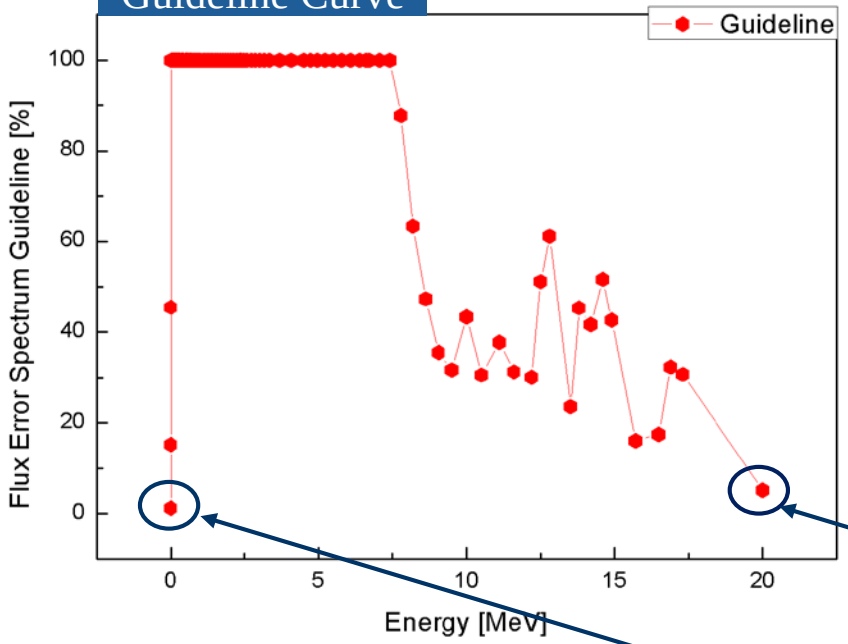
- **Reaction Characteristics of Produced Nuclide from Air Activation**
- **Max. Sensitivity Curve Provides Basis Data for Flux Error Guideline Curve**

Method and Results

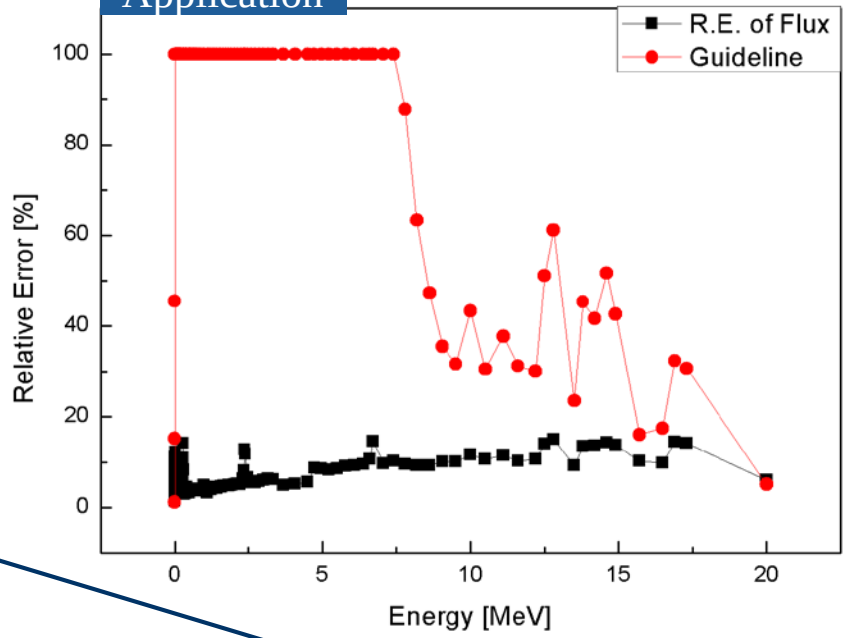
◈ STEP3. Proposal and Application of Guideline

- Guideline Criteria : Relative Error of Final Activity < 2%
- Guideline(E_n) = (R.E. of Final Activity) / S(E_n) : Inverse Function of S(E_n)

Guideline Curve



Application



➡ **Major Guideline : At First Energy bin < 1.19%, At Last Energy bin < 5.13%**

➡ **Flux Error Spectrum should be under the Guideline Curve for Reliable result**

Conclusion

- In this study, procedure and program to analyze the activity uncertainty caused by stochastic error of MC method were developed.
- Through Sensitivity and uncertainty analysis, the guideline for flux error spectrum was proposed to have confidence in activat ion calculation result.
- It is expected that the developed method and procedure will co ntribute to increasing the accuracy and reliability on the activat ion calculation.

Thank You