

To the Graduate Council:

I am submitting herewith a thesis written by Jia Hou entitled "Artificial Neural Network for Spectrum unfolding Bonner Sphere Data." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

Laurence F. Miller, Major Professor

We have read this thesis
and recommend its acceptance:

Ronald E. Pevey

J. Wesley Hines

Accepted for the Council:

Carolyn R. Hodges, Vice Provost and
Dean of the Graduate School

(Original signatures are on file with official student records)

Artificial Neural Network for Spectrum Unfolding Bonner Sphere Data

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Jia Hou

December 2007

DEDICATION

This thesis is dedicated to my loving mother and girlfriend, without whose love and support, not a word would have been written.

ACKNOWLEDGEMENTS

I would sincerely like to thank my research advisor, Dr. Laurence Miller, for this opportunity and for his guidance and support throughout the project. I would also like to thank my faculty committee members Dr. Ronald Pevey and Dr. Wesley Hines. In addition, I would like to thank Dr. Harold L. Dodds and the entire staff of the Nuclear Engineering department at the University of Tennessee for making me feel welcome during my educational experience. I would like to thank fellow student Jeff Preston for all his help on this research project. This has been a tremendous experience and I am truly grateful to all.

I must also thank, in the deepest sense of the word, my friends Fan Li, Mathew Francis, Jack Galloway, and Matt Humberstone, who have done their best to make me feel at home in Knoxville.

ABSTRACT

The use of Bonner Sphere Spectrometer (BSS) is a well-established method of measuring the energy distribution of neutron emission sources. The purpose of this research is to apply the Generalized Regression Neural Network (GRNN), a kind of Artificial Neural Network (ANN), to predict the neutron spectrum using the count rate data from a BSS. The BSS system was simulated with the MCNP5 Monte-Carlo code to calculate the response to neutrons of different energies for each combination of thermal neutron detector and polyethylene sphere. One hundred and sixty-three different types of neutron spectra were then investigated. GRNN Training and testing was carried out in the MATLAB environment. In the GRNN testing, eight-one predicted spectra were obtained as outputs of the GRNN. Comparison with standard spectra shows that 97.5% of the prediction errors were controlled below 1%, indicating ANN could be used as an alternative with high accuracy in neutron spectrum unfolding methodologies. Advantages and further improvements of this technique are also discussed.

TABLE OF CONTENTS

1. INTRODUCTION AND BACKGROUND	1
1.1. Bonner Sphere Spectrometer System	1
1.2. Previous Methodologies	2
1.2.1. Maximum Entropy	2
1.2.2. Neural Network Method with Multilayer Perceptron	3
2. METHODOLOGY	5
2.1. Response Function Calculation with MCNP5	5
2.2. Neutron Spectrum Data	6
2.2.1. Data Source	6
2.2.2. Neutron Spectra Re-binning and Interpolation	9
2.2.3. Pre-simulation Standardization	10
2.3. Neural Network	13
2.3.1. MATLAB Neural Network Toolbox	14
2.3.2. Basic Architecture and Features	14
2.3.3. MATLAB Function Description	17
2.3.4. Kernel Spread Constant Selection	18
2.3.5. Training and Testing Data Selection	19
3. RESULTS	21
3.1. Trained GRNN Architecture	21
3.2. Comparison of Outputs and Testing Spectrum Data	21
3.3. Error Analysis	26
3.4. Comparison with Other Methods (BUMS)	28
3.4.1. Introduction to BUMS	29
3.4.2. Comparison Results	30
4. CONCLUSIONS	34
5. FUTURE WORK	35
REFERENCES	36
APPENDICES	40
Appendix A Example of MCNP5 Input Deck (for 5" Bonner Sphere)	41
Appendix B Reference Spectra	44
Appendix C MATLAB Code	101
VITA	108

LIST OF TABLES

Table 1: Energy Boundaries for MCNP Calculation (MeV).....	7
Table 2: The Description of Parameters in newgrnn Function	18
Table 3: Prediction Errors of Test Data.....	27
Table 4: Measurements of Location #1 near CTI Cyclotron	31

LIST OF FIGURES

Figure 1: Visual Editor Image of 5-inch Bonner Sphere.....	6
Figure 2: Two-D plot of Response functions for a BSS system calculated by MCNP5	7
Figure 3: Three-D plot of Response functions for a BSS system calculated by MCNP5...	8
Figure 4: Neutron spectra of isotopic ^{241}Am –Be neutron source measured by PTB (from IAEA repot).....	10
Figure 5: Input and output data matrices	11
Figure 6: The input variable values before standardization process	13
Figure 7: The input variable values after standardization process	13
Figure 8: Generalized Regression Neural Network Architecture	16
Figure 9: Radial Basis Function (RBF)	16
Figure 10: Example of weighted sum of Radial Basis Transfer Function	17
Figure 11: Optimization of Kernel spread constant	20
Figure 12: An Example of GRNN Prediction on Continuous Neutron Spectrum	23
Figure 13: An Example of GRNN Prediction on Continuous Neutron Spectrum	24
Figure 14: An Example of GRNN Prediction on Continuous Neutron Spectrum	25
Figure 15: An Example of GRNN Prediction on Monoenergetic Spectrum.....	25
Figure 16: An Example of GRNN Prediction on 1/E Neutron Spectrum	26
Figure 17: The prediction error produced by GRNN on eighty-one test dataset	28
Figure 18: The prediction error produced by GRNN on seventy-nine test dataset (after removing the bad data)	29
Figure 19: Comparison between GRNN and BUMS (data measured near CTI cyclotron at location #1).....	32
Figure 20: Comparison between GRNN and BUMS (data measured near CTI cyclotron at location #2).....	32
Figure 21: Comparison between GRNN and BUMS (data measured near CTI cyclotron at location #3).....	33

1. INTRODUCTION AND BACKGROUND

1.1. Bonner Sphere Spectrometer System

The energy distribution of neutrons is measured for varying purposes. For instance, neutron spectrum is an important measure of power in nuclear power and research reactors. Most neutron detectors used in nuclear reactors are optimized to detect thermal neutrons. The energy distribution of neutrons can also provide specific technical information that could be used by radiation protection specialists for proper selection of dosimeters and survey instruments.

Since more than 40 years, the Bonner Sphere Spectrometer (BSS) has been used more extensively than any other system in the field of neutron dosimetry and spectrometry. The isotropy of the response, the wide energy range (from thermal to GeV neutrons) and the easy operation make these systems still applicable. This spectrometer, which was first described by Bramblett in 1960 [1], consists of a thermal neutron sensor which is used at the center of a number of different diameter-moderating spheres. These are almost invariably made of polyethylene, and are usually made to exact inch, or half-inch diameters. The thermal sensor plus moderating sphere combination has sensitivity to neutrons over a broad energy range. Each sphere–detector combination has a particular response; the whole set of responses defines the response matrix. [2] The spherical geometry provides for a reasonably non-directional detector response. Different modifications to moderating spheres have been realized to improve the efficiency for high-energy neutrons. [3] [4] By measuring the count rate with each sphere individually, an unfolding process can, in principle, provide some information about the energy distribution of the incident neutrons.

The BSS response matrix, the count rates and the neutron spectrum are related through the homogeneous Fredholm integral equation of the first kind, as shown in Equation (1.1). An energy bin structure with n energy bins that are labeled with the index j ; and assume m detectors that labeled with the index i . If sphere i has response

function, R_i , and is exposed in a neutron field with spectral fluence, ϕ , then the sphere reading, M_i , is obtained mathematically by folding R_i with ϕ_i i.e.:

$$M_i = \int R_i(E)\phi(E)dE \quad (1.1)$$

The integral extends over the range of neutron energies present in the field. Good approximations to $R_i(E)$ can be obtained from simulation calculations supported by measurements with well characterized monoenergetic source neutrons. Using these data, measurements with a BSS set in an unknown field will allow information on ϕ_i to be extracted.

$$M_i = \sum_{j=1}^n R_{ij} \cdot \phi_j \quad (1.2)$$

Neutron spectra are usually represented as an array, where element ϕ_j is the fluence in group j extending from energy E_j to E_{j+1} ; and the measured reading is then given by Equation (1.2) where R_{ij} represents $R_i(E)$ averaged over group j . The above equation is a discrete form of Equation (1.1).

1.2. Previous Methodologies

In general, such equations have no explicit solution, may have no unique solution, and are referred to as ill-posed. [5] Normally, researchers solve a discrete version of this equation, which gives an ill-conditioned system of equations. To solve this system of equations for Bonner sphere unfolding several approaches have been used: iterative procedures [6] [7] [8], Monte Carlo methods [9], and regularization [10]. Recently, more methodologies based on maximum entropy [11], genetic algorithms [12] and artificial neural network (ANN) have been developed. In this study, a kernel based Artificial Neural Network is utilized for spectrum unfolding.

1.2.1. Maximum Entropy

An example for those algorithms applying maximum entropy principle is Maximum Entropy Deconvolution (MAXED). The unfolding problem is formulated in discrete terms. This algorithm introduces an energy bin structure with n energy bins that we label with the index i ; and assume m detectors that we label with the index k . The set of admissible spectra are defined using two restrictions:

$$N_k + \varepsilon_k = \sum_i R_{ki} f_i \quad (1.3)$$

$$\sum_k \frac{\varepsilon_k^2}{\sigma_k^2} = \Omega \quad (1.4)$$

where N_k is the measurement and ε_k is the difference between the predicted value and the measured value for detector k ; R_{ki} is the response function for detector k ; f_i is the solution spectrum, σ_k is the estimated standard uncertainty, and Ω is a parameter set by the user. Equation (1.3) is an integral equation that relates the measurement to the detector's response function and the neutron spectrum, allowing for a measurement error. Equation (1.4) is a constraint for handling the ε_k ; and assumes that the chi-square statistic of the solution is equal to a value determined a priori by the user (typically, Ω is set equal to the number of detectors). From this set of admissible spectra, we want to select the one that maximizes the entropy S of the distribution

$$S = - \sum_i \left\{ f_i \ln \left(\frac{f_i}{f_i^{DEF}} \right) + f_i^{DEF} - f_i \right\} \quad (1.5)$$

where is the default spectrum that contains the a priori information. The maximization of S with constraints given by Equation (1.3) and (1.4) is equivalent to maximization of a potential function $Z(\lambda_k)$ with respect to a set of m parameters λ_k . The solution spectrum f_i and the solution for ε_k can be written in terms of the λ_k in closed form:

$$f_i = f_i^{DEF} \exp \left\{ - \sum_k \lambda_k R_{ki} \right\} \quad (1.6)$$

$$\varepsilon_k = \frac{\lambda_k \sigma_k^2}{2} \left(\frac{4\Omega}{\sum_j (\lambda_j \sigma_j)^2} \right)^{1/2} \quad (1.7)$$

To find the values of λ_k that maximize Z; a simulated annealing algorithm is used.

1.2.2. Neutral Network Method with Multilayer Perceptron

Previous researches on neutron spectrum unfolding with ANN use Multilayer Perceptron (MLP), which is a network of simple neurons called perceptron. The perceptron computes a single output from multiple real-valued inputs by forming a linear combination according to its input weights and then possibly putting the output through some nonlinear activation function. A MLP network consists of a set of source nodes forming the input layer, one or more hidden layers of computation nodes, and an output layer of nodes. The input signal propagates through the network layer-by-layer. By adapting all the weights and biases, a MLP is able to find optimal values for the given pairs, and then use these values for future prediction.

In the research performed by Cláudia C. Braga and Mauro S. Dias [13] [14], a set of twenty-seven continuous neutron spectra was used for training and validating the neural network. The final network consisted of 10:2:1 neurons in the input, hidden and output layers respectively.

2. METHODOLOGY

2.1. Response Function Calculation with MCNP5

The response functions characterize the response of a detector to a neutron source of certain energy. As shown in Equation (1.2), because the number of counts and uncertainties for each sphere diameter can be calculated by integration of the spectrum multiplied by a two dimensional kernel, the spectrum will be obtained from measurement data by deconvolution or unfolding methodologies, or the method used in this research. Thus the accuracy of the spectrum obtained is limited by the accuracy of the corresponding response functions. [15] Therefore the calculation of the response functions for different Bonner Spheres is essential.

The increased computing power available has made the Monte Carlo method an amenable approach to calculating response functions for years. Response values are calculated at discrete energies, the response function being derived by interpolation. Monte Carlo codes have the advantage of allowing the sphere plus detector to be geometrically modeled in detail, including nonspherically symmetric features, and comparisons with measurements have shown excellent agreement. [16]

The Bonner Sphere counting system simulated by MCNP includes a set of seven polyethylene spheres with diameters of 2", 3", 4", 5", 8", 10" and 12" with a density of 0.95 g/cm^3 . The response of a bare detector was also calculated. The detector consists of a $4\text{ mm} \times 4\text{ mm}$ $\text{Li}^6\text{I}(\text{Eu})$ enriched crystal coupled to a $\frac{3}{8}$ inch photomultiplier tube. The neutron interaction in the detector is $\text{Li}^6 + n \rightarrow \text{H}^3 + \alpha$. The neutron source was represented by a monoenergetic parallel beam emitted from a circular surface with a diameter equal to that of the diameter of the simulated sphere and at a distance of 22 cm from its center. The spheres were in vacuum in the simulations. Visual Editor for MCNP5 was used to graphically demonstrate the 5" sphere in Figure 1. The input deck to obtain this image is included in Appendix A.

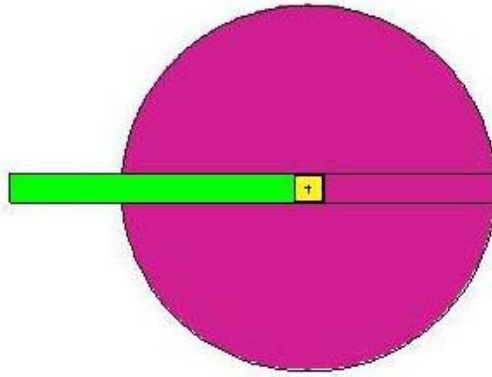


Figure 1: Visual Editor Image of 5-inch Bonner Sphere

The simulations were performed over the energy range of 1×10^{-9} MeV to 20 MeV, which is divided into forty-three energy bins for each Bonner Sphere, as shown in Table 1. The basic algorithm for this calculation is that for each of the eight Bonner Spheres, forty-four MCNP simulations are run to obtain the response; each simulation corresponds to one energy value. Batch files were created to control the MCNP5 to process the calculation automatically.

The Relative Dose Response Curves resulting from MCNP5 are given in Figure 2 and 3. The curves are in agreement with the shape and magnitude of published data for the Bonner Sphere Spectrometer. [17]

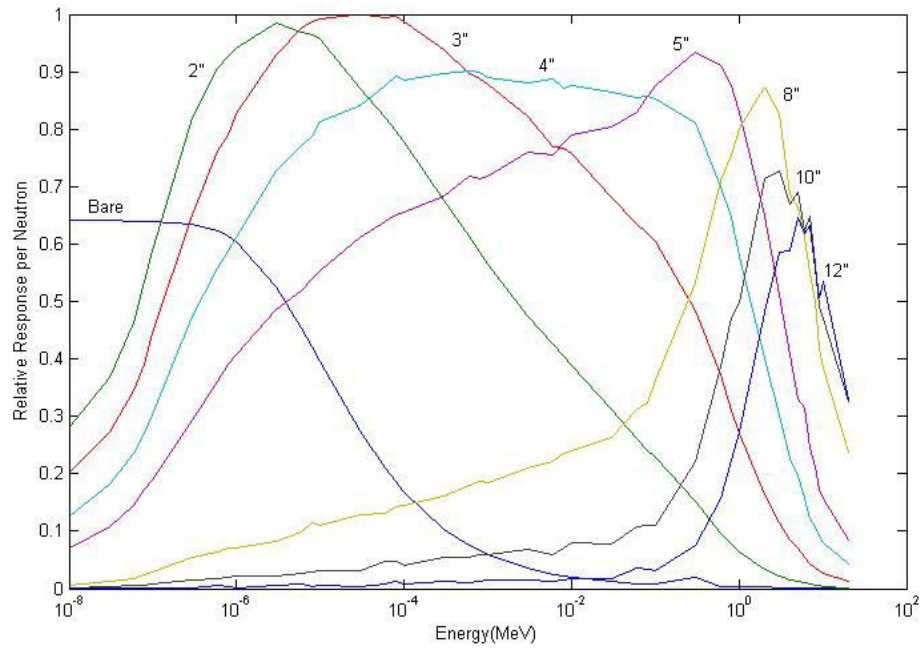
2.2. Neutron Spectrum Data

2.2.1. Data Source

There are mainly two sources of neutron spectra data: 1) published neutron spectra from Oak Ridge National Laboratory (ORNL) [18], and 2) published neutron spectra by International Atomic Energy Agency (IAEA). [19]

Table 1: Energy Boundaries for MCNP Calculation (MeV)

	Energy Boundary (MeV)		Energy Boundary (MeV)		Energy Boundary (MeV)		Energy Boundary (MeV)
1	1×10^{-9}	12	6×10^{-6}	23	3×10^{-3}	34	1
2	1×10^{-8}	13	8×10^{-6}	24	6×10^{-3}	35	2
3	3×10^{-8}	14	1×10^{-5}	25	8×10^{-3}	36	3
4	6×10^{-8}	15	3×10^{-5}	26	1×10^{-2}	37	4
5	8×10^{-8}	16	6×10^{-5}	27	3×10^{-2}	38	5
6	1×10^{-7}	17	8×10^{-5}	28	6×10^{-2}	39	6
7	3×10^{-7}	18	1×10^{-4}	29	8×10^{-2}	40	7
8	6×10^{-7}	19	3×10^{-4}	30	1×10^{-1}	41	8
9	8×10^{-7}	20	6×10^{-4}	31	3×10^{-1}	42	9
10	1×10^{-6}	21	8×10^{-4}	32	6×10^{-1}	43	10
11	3×10^{-6}	22	1×10^{-3}	33	8×10^{-1}	44	20

**Figure 2: Two-D plot of Response functions for a BSS system calculated by MCNP5**

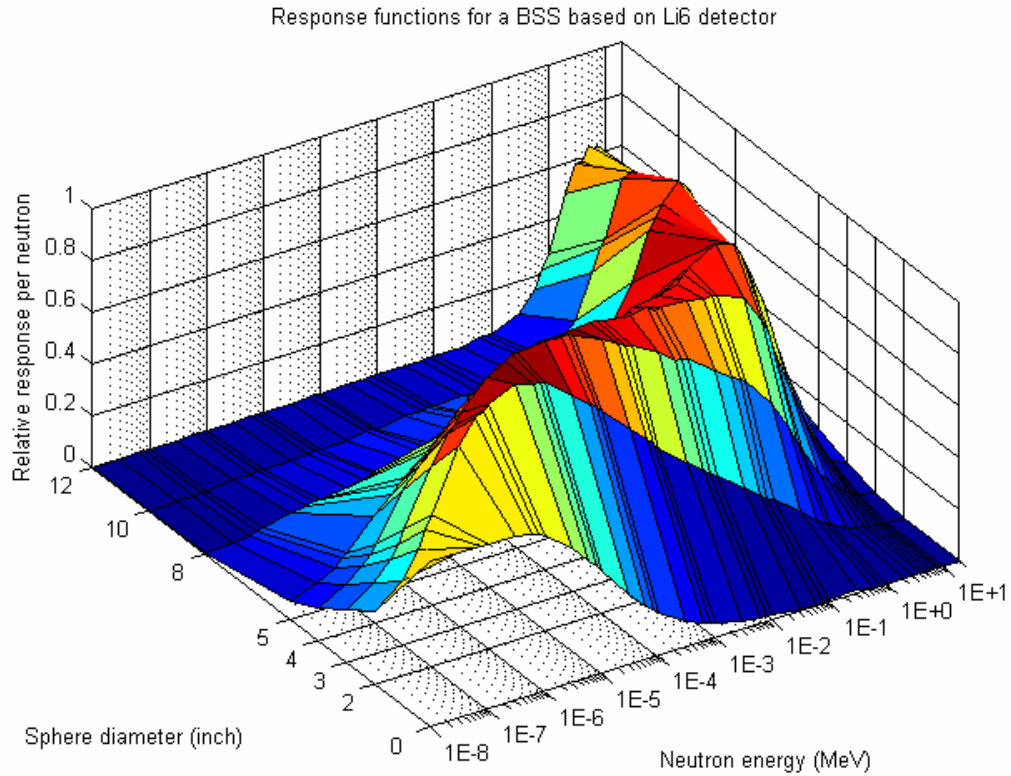


Figure 3: Three-D plot of Response functions for a BSS system calculated by MCNP5

The ORNL report “Determination of Neutron Dose from Criticality Accidents with Bioassays for Sodium-24 in Blood and Phosphorus-32 in Hair” was published in 1993. [20] It supplies neutron spectra calculated by Monte Carlo method for fission neutrons, which have been transmitted through different thickness of various materials. All the spectra were interpolated with similar energy groups because each original spectrum has unique energy groups and energy boundaries. The interpolated energy boundaries formed 620 groups ranging from 1×10^{-10} MeV to 18 MeV. A linear interpolation was used. The number of neutron spectra suitable for this research is fifty-five.

The IAEA report, as called the “Compendium of Neutron Spectra and Detector Responses for Radiation Protection Purposes (Technical Reports Series No. 318)” published in 1990 contains a large collection of detector responses and spectra. The major motivation for development of that report was the need to provide specific

technical information that could be used by radiation protection specialists for proper selection of dosimeters and survey instruments, and for interpretation of data obtained with these detectors. The original spectra in this report were defined per unit lethargy in 60 energy groups ranging from thermal to 630 MeV. Totally eighty-eight neutron spectra were selected to add to this research.

2.2.2. Neutron Spectra Re-binning and Interpolation

All one hundred and sixty-three spectra need to be re-binned into same forty-three energy groups used in the response matrices, ranging from 1×10^{-9} to 20 MeV. In most cases measured or computed neutron spectra were originally obtained as group fluences in energy standard energy grid. Any bin is described by its lower boundary, E_i , and its upper boundary, E_{i+1} . As shown in Table 1, forty-three energy bins were used with $E_1 = 1 \times 10^{-9} \text{ MeV}$ and $E_{44} = 20 \text{ MeV}$. The group fluence in the i th energy bin is given by

$$\varphi_i = \int_{E_i}^{E_{i+1}} dE \Phi_E(E) \quad (2.1)$$

However, throughout this research, it is understood that the values representing neutron spectra, $\Phi_E(E)$, in tables and figures are group fluences divided by the lethargy interval (i.e. $\ln E_{i+1} - \ln E_i$) and are normalized. Figure 4 shows such an example, where the logarithm of the neutron energy is used as the abscissa. These are the neutron spectra of isotopic neutron sources of $^{241}\text{Am}/\text{Be}$ measured by Physikalisch-Technische Bundesanstalt (PTB). In this case it is appropriate to show the fluence per unit lethargy.

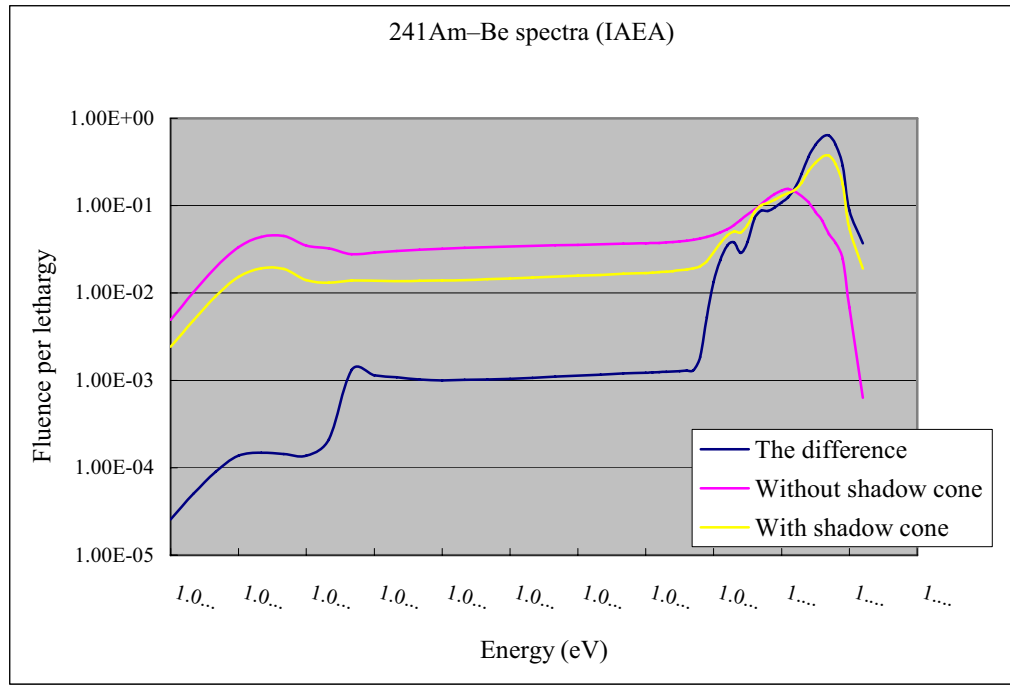


Figure 4: Neutron spectra of isotopic ^{241}Am -Be neutron source measured by PTB (from IAEA report)

The lethargy unit is preferred since neutron spectra, when plotted as fluence per unit energy, often display a steep negative slope at lower energies due to a roughly inverse-energy type of dependence and require many decades on the fluence axis for complete presentation. The lethargy unit essentially weights the fluence by the corresponding neutron energy, so the negative slope is changed to an approximately horizontal line which permits the results to be viewed with better resolution.

Besides the spectrum data collected from published reports, ten monoenergetic spectra and other ten $1/E$ shaped spectra were also produced by MATLAB and imported into the database. This is because the reliability of the neural network prediction depends heavily on the diversity of the database, which is the selected neutron spectrum information. Therefore increasing the diversity of the neutron spectra by adding more spectra is essential.

2.2.3. Pre-simulation Standardization

After all one hundred and sixty-three spectra were reformed into preset energy bins; they were then folded with response functions to obtain the Bonner Spheres' count rate data and the uncertainties. For each spectrum, there were sixteen predictor variables stored, including eight variables for count rates, and another eight variables for uncertainties of these count rates. The basic structure of input and output database can be seen in Figure 5.

In data analysis, it is always essential to standardize the dataset before any calculation. One of the most commonly used standardization methods is to form all variables to unit variances and zero means. To do this, one substrates the mean or expected value and divides by the standard deviation. The first step “centers” the variable or the data by giving them a zero mean, and the second step expresses the variable or data in terms of numbers of standard deviation from the mean. In symbols, the transformation is expressed in Equation (2.2),

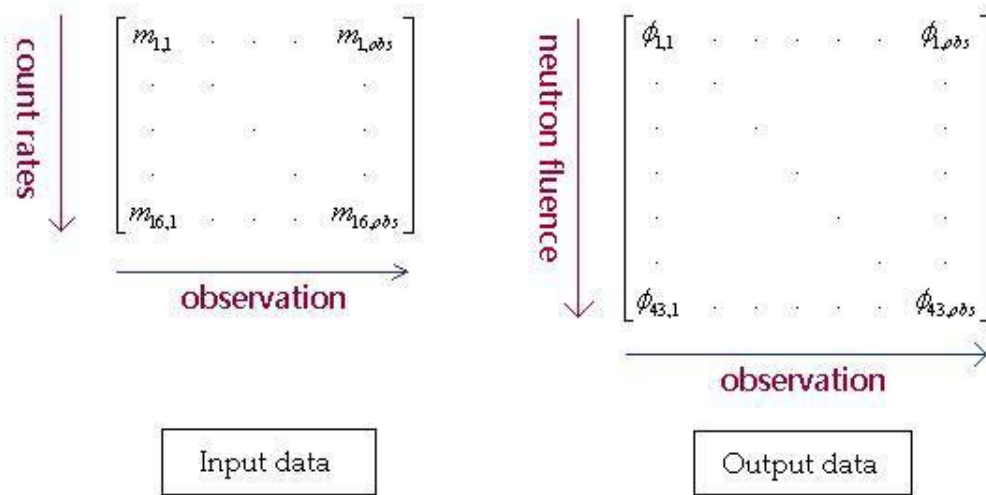


Figure 5: Input and output data matrices

$$X^* = \frac{X - \mu}{\sigma} \quad (2.2)$$

where μ stands for the mean and σ is the standard deviation. Here X is one of the sixteen predictor variables (different rows in the left matrix in Figure 5) or one of the forty-three outputs (different rows in the right matrix in Figure 5), while X^* is the standardized version.

In this research, both input and output data were standardized so that the resulting variables have a unit variance and zero means. The original sixteen input variables, including count rates and uncertainties, are plotted in Figure 6, where x-axis indicates different observations, and y-axis stands for variable values. In the standardization process, all the variables were transformed and the result shows better distribution, as shown in Figure 7.

This process is important because the standardization makes each variable play the role as important as the others, thus can reduce the prediction errors given by neural network. The code *zscore1.m* used in this process was created by Dr. Wesley Hines at the University of Tennessee, which is available in Appendix C.

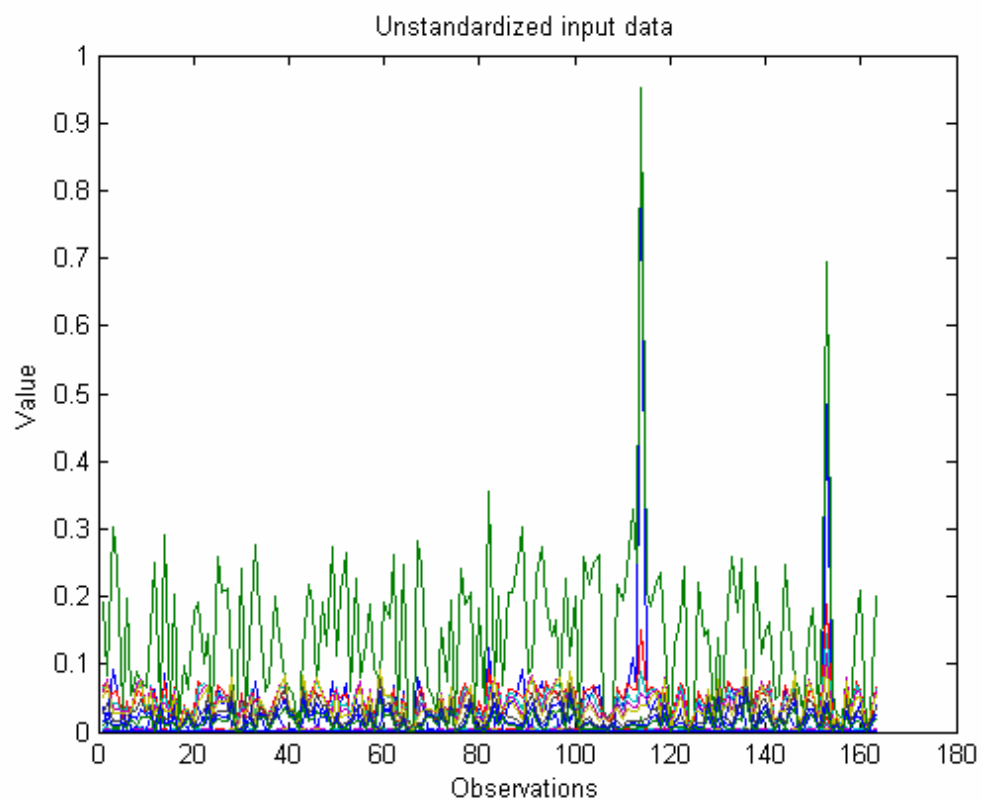


Figure 6: The input variable values before standardization process

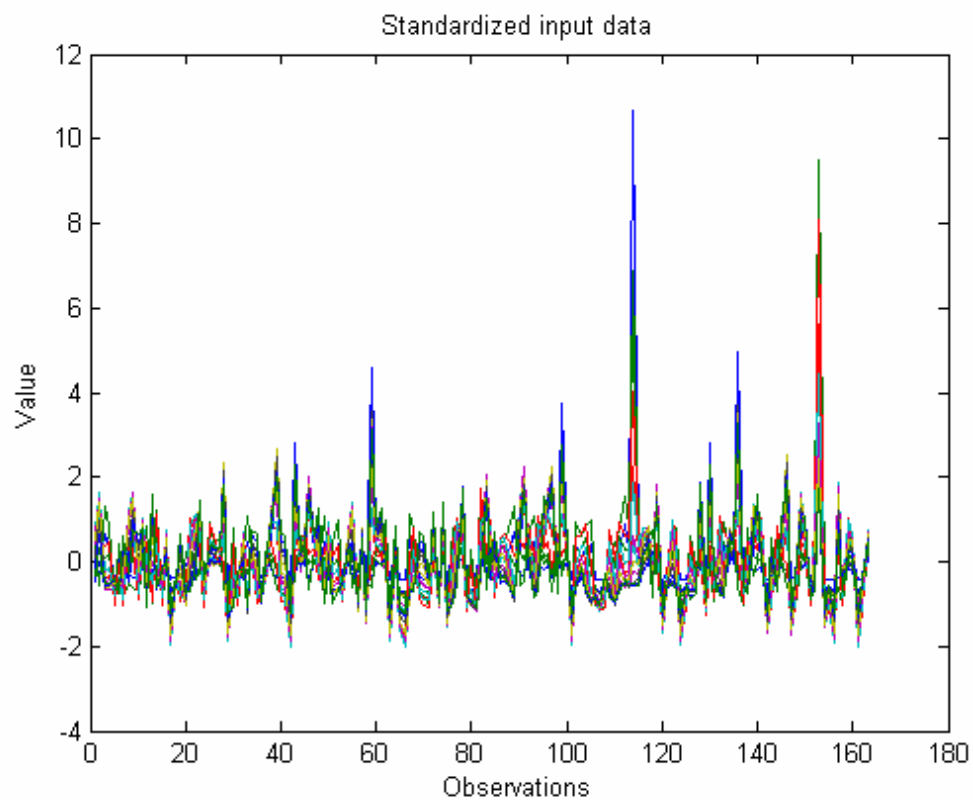


Figure 7: The input variable values after standardization process

2.3. Neural Network

ANNs are non-linear black-box model structures that can be used with conventional parameter estimation methods. ANN technology is widely recognized as a powerful modeling tool. [21] An ANN is a massively parallel distributed processor that through a learning process acquires experiential knowledge, making it available for use.

An ANN simulates a highly interconnected, parallel computational structure with many individual processing elements or neurons. It learns through an iterative process of adjustments to its synaptic weights and thresholds. A defined set of rules for the solution of a learning problem is the learning algorithm.

In general, an ANN is a set of input nodes that links directly to a series of output nodes or indirectly through one or more hidden layers. The use of an ANN requires the training of the network and the testing of the trained network. During training a set of synaptic weights is obtained, where the knowledge is stored.

2.3.1. MATLAB Neural Network Toolbox

The MATLAB embedded Neural Network Toolbox 5.1 was implemented to conduct this research. [22] The Neural Network Toolbox extends MATLAB with tools for designing, implementing, visualizing, and simulating neural networks. The Neural Network Toolbox supports the most commonly used supervised and unsupervised network architectures, as well as comprehensive set of training and learning functions. It also provides comprehensive support for many proven network paradigms, as well as graphical user interfaces (GUIs) that enable users to design and manage their networks. The modular, open, and extensible design of the toolbox simplifies the creation of customized functions and networks.

2.3.2. Basic Architecture and Features

In this research, the Generalized Regression Neural Network (GRNN) is trained and tested as the ANN with MATLAB development environment. GRNN, developed by Specht, [23] is a feedforward neural network based on nonlinear regression theory consisting of four layers: the input layer, the pattern layer, the summation layer, and the output layer (see Figure 8) [24]. It is suited to function approximation tasks such as system modeling and prediction. While the neurons in the first three layers are fully connected, each output neuron is connected only to some processing units in the summation layer.

The first layer is the input layer and is fully connected to the pattern layer. The second layer is the pattern layer and has one neuron for each input pattern. The neuron stores the values of the predictor variables for the case along with the target value.

The function of the pattern layers of the GRNN is a Radial Basis Function (RBF), typically the Gaussian kernel function. The activations of pattern units essentially characterize the distances of centers of radial basis functions thus produce localized, bounded, and rapidly symmetric activations, that is, activations rapidly decreasing with the distance from the function's centers. The radial basis function is so named because the radius distance is the argument to the function, as seen in Figure 9.

The summation layer has two different types of processing units: the summation units and the single division unit. The number of the summation units is always the same as the number of the GRNN output units. The summation unit adds up the weight values coming from each of the pattern neurons. The division unit only sums the weighted activations of the pattern units without using any activation function.

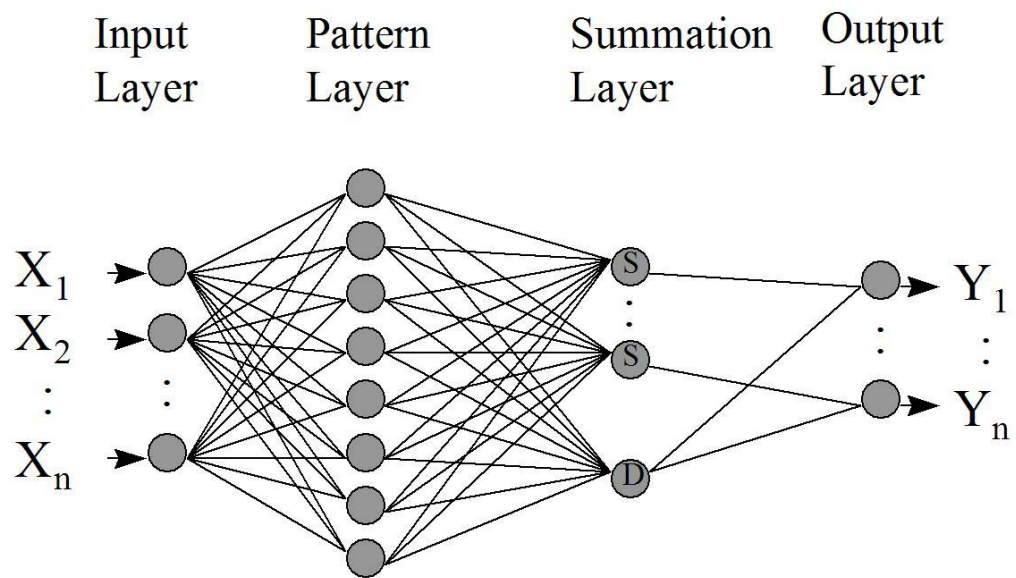


Figure 8: Generalized Regression Neural Network Architecture

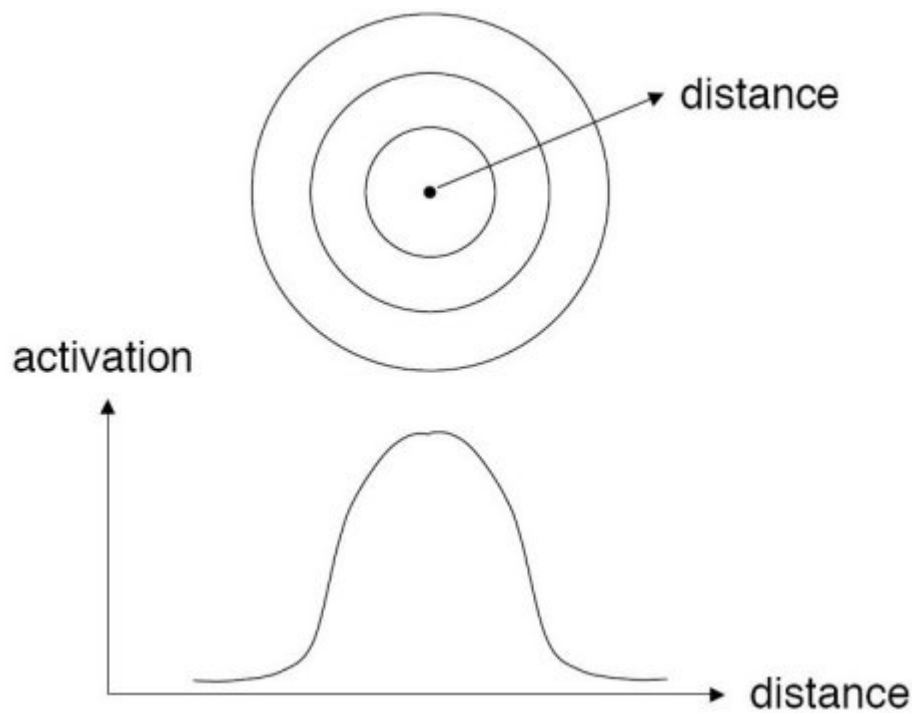


Figure 9: Radial Basis Function (RBF)

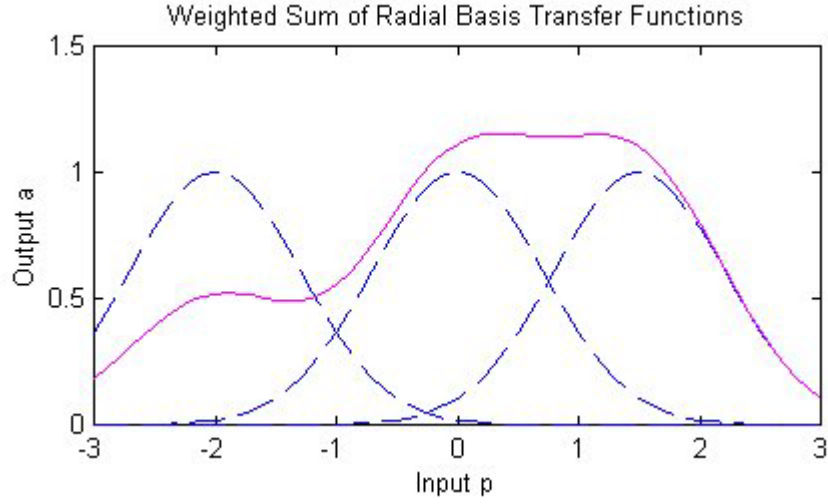


Figure 10: Example of weighted sum of Radial Basis Transfer Function

Each of the GRNN output units is connected only to its corresponding summation unit and to the division unit, where a simple division is carried out by dividing the signal coming from the summation unit by the signal coming from the division unit. Hence, the summation layer always has exactly one more unit than the output layer. Figure 10 shows that the best predicted value for the new point is found by summing the values of the other points weighted by the RBF function.

Theoretically, Y , the output of a GRNN is the condition mean given by:

$$Y = \frac{\sum_{j=1}^T Y^T \exp\left(-\frac{D_j^2}{2\sigma^2}\right)}{\sum_{j=1}^T \exp\left(-\frac{D_j^2}{2\sigma^2}\right)} \quad (2.3)$$

where the Y is the output of a stored vector, and the exponential function is a Gaussian function with a spread constant σ . D is the distance between the query and the target.

The width of radial basis functions of the pattern units, also known as the spread constant σ , is an important parameter allowing the user to influence generalization capabilities of the GRNN. In general, larger values of the spread constant results in a

smoother interpolation of the output vectors values among the values corresponding to the centers of radial basis functions of the individual pattern units.

Previous researches on neutron spectrum unfolding with neural network indicated that Multilayer Perceptron (MLP) neural networks perform well. Comparing to MLP, it's usually much faster to train a GRNN network than a MLP network. That's mainly because spread constant σ is the only parameter used in GRNN. Another characteristic of GRNN, which makes it fast in training, is that there is only the linear output layer beyond the first hidden layer; this guarantees that the network will converge to a global minimum. In addition, GRNN networks often are more accurate than MLP networks in prediction. These characteristics make GRNN be of great interest recently.

2.3.3. MATLAB Function Description

The basic function utilized for neural network creation is *newgrnn(P,T,spread)*. It takes three inputs, listed in Table 2, and returns a new generalized regression neural network.

newgrnn creates a two-layer network. The first layer has radbas neurons, and calculates weighted inputs with *dist* and net input with *netprod*. The second layer has *purelin* neurons, calculates weighted input with *normprod*, and net inputs with *netsum*. Only the first layer has biases.

Table 2: The Description of Parameters in newgrnn Function

Newgrnn inputs	Description
P	R x Q matrix of Q input vectors
T	S x Q matrix of Q target class vectors
spread	Spread of radial basis functions (default = 1.0)

newgrnn sets the first layer weights to P' , and the first layer biases are all set to $0.8326/\text{spread}$, resulting in radial basis functions that cross 0.5 at weighted inputs of $\pm \text{spread}$. The second layer weights W_2 are set to T .

2.3.4. Kernel Spread Constant Selection

As an important parameter of GRNN, kernel spread constant should be selected prior to establishing the neural network. Generally speaking, to fit data very closely, use a spread smaller than the typical distance between input vectors. To fit the data more smoothly, use a larger spread. But too large spread would cause over-fitting, while too small one would cause under-fitting. Therefore, spread constant can be considered as a regularization parameter.

Leave-one-out cross-validation (LOOCV) technique was used when choosing the optimal spread constant for the neural network, which selects a single observation from the original sample and keeps it as the validating data, and the remaining observations as the training data. The kernel spread constant is setup in the range of 0.01 to 2 with the step of 0.01 firstly. Once the neural network is trained with the training sets, the stored data is applied to validate the system. The sum of squared error (SSE) is then calculated between each predicted spectrum and expected spectrum. As soon as all the SSE is collected, the mean is given as the corresponding value for this specific kernel spread constant.

This is repeated when the kernel spread constant increases, such that each observation in the sample is used once as the testing data. Therefore, each time one hundred and eighty-two sets of count rates data is applied as input and one hundred and eighty-two sets of corresponding neutron fluence are used as outputs. The remaining subset of one BSS count rates is reserved to test the GRNN's performance and is not included during the GRNN training.

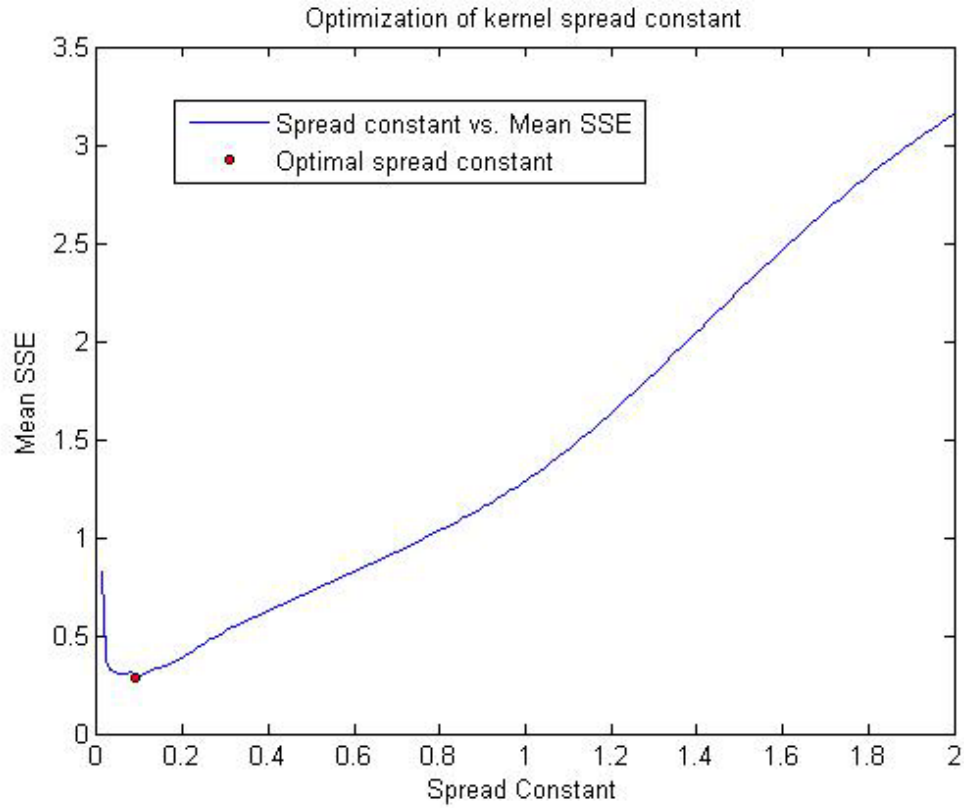


Figure 11: Optimization of Kernel spread constant

In the end, a plot is created below showing this relationship in Figure 11, where relative mean sum of square error of the prediction with selected spread constant is calculated and compared to each other. The optimal number, 0.09, is obtained at the minimum of the curve and applied to neural network as it produces the least mean sum of square error.

2.3.5. Training and Testing Data Selection

One hundred and sixty-three data sets were spitted into two sets - training set and test set. As the data was randomly distributed, odd-and-oven method was utilized to separate the database. Thus a subset of eighty-two BSS count rate data was selected as inputs in training sets and eight-two sets of neutron fluence are used as outputs. The remaining subset of eight-one BSS count rates was reserved to test the performance of GRNN and was not included during the GRNN training. When prediction is finished,

the code will automatically produce the unfolded neutron fluence per unit lethargy in both tabular and graphical form.

3. RESULTS

Eight-one sets of spectra were produced as the outputs of GRNN, which was trained with other eight-two data sets. Good results with small errors were observed showing GRNN is able to process the training data to control the error, as well as to predict the unknown neutron spectrum presented to the network with good accuracy.

3.1. Trained GRNN Architecture

Since there is only one parameter in GRNN, this type of ANN also called a non-parametric model. It stores the training data as the parameter, rather than calculating and modifying the weights and bias in each hidden layers as the input data imported into the model. As described above, when the query comes, the model will calculate the value by summing the values of the other points weighted by the RBF function. Therefore, unlike parametric model such as MLP, there are no weights and bias information produced to characterize the trained model.

3.2. Comparison of Outputs and Testing Spectrum Data

Two examples chosen from the prediction is given and compared with the desired neutron spectrum. Good results are obtained indicating GRNN is able to predict the unknown neutron spectrum presented to the network with good accuracy.

For continuous neutron spectrum, Figure 12 gives an example of unfolded such a spectrum based on the count rate data with GRNN. The original spectrum is “PE shielded stray neutron simulation fields” published in IAEA report (marked as No. 122 in spectrum dataset). It was measured in SILENE reactor, located at Valduc (France). As can be seen, there is a general agreement with the spectrum from combined unfolding with the exception of more neutron fluence near peak, and a knee at 1×10^{-6} MeV.

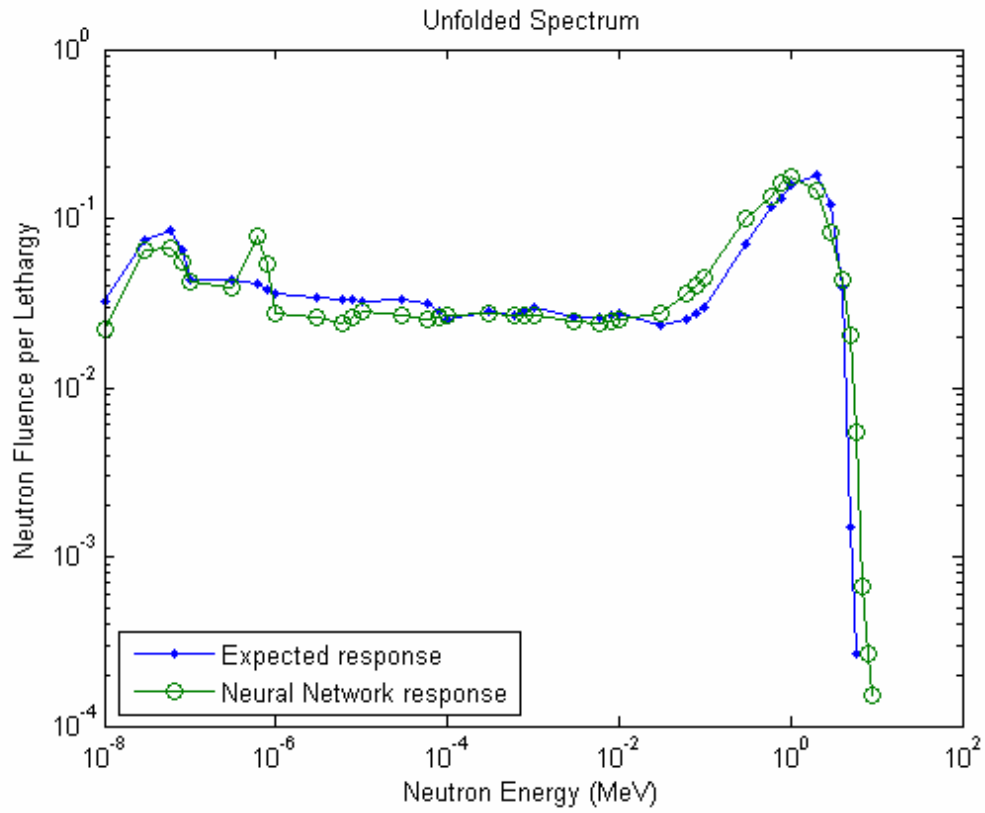


Figure 12: An Example of GRNN Prediction on Continuous Neutron Spectrum

The second example of continuous spectrum prediction is shown in Figure 13. This is a H₂O moderated fission spectrum (marked as No. 40 in spectrum dataset) selected from ORNL report. All data was measured through 40 cm concrete. A general agreement and more structure in predicted spectrum below 1×10^{-5} MeV is observed. In addition, there exists a relative large variance at the last energy bin 20 MeV, meaning at this point the GRNN failed to find the correct value. This is because only fluence values of energy bins below it are available, thus when GRNN sums the values of the points weighted by the RBF from both below and above this one, the information above it is unavailable. Likewise, the prediction for the first energy bin also contains larger variance.

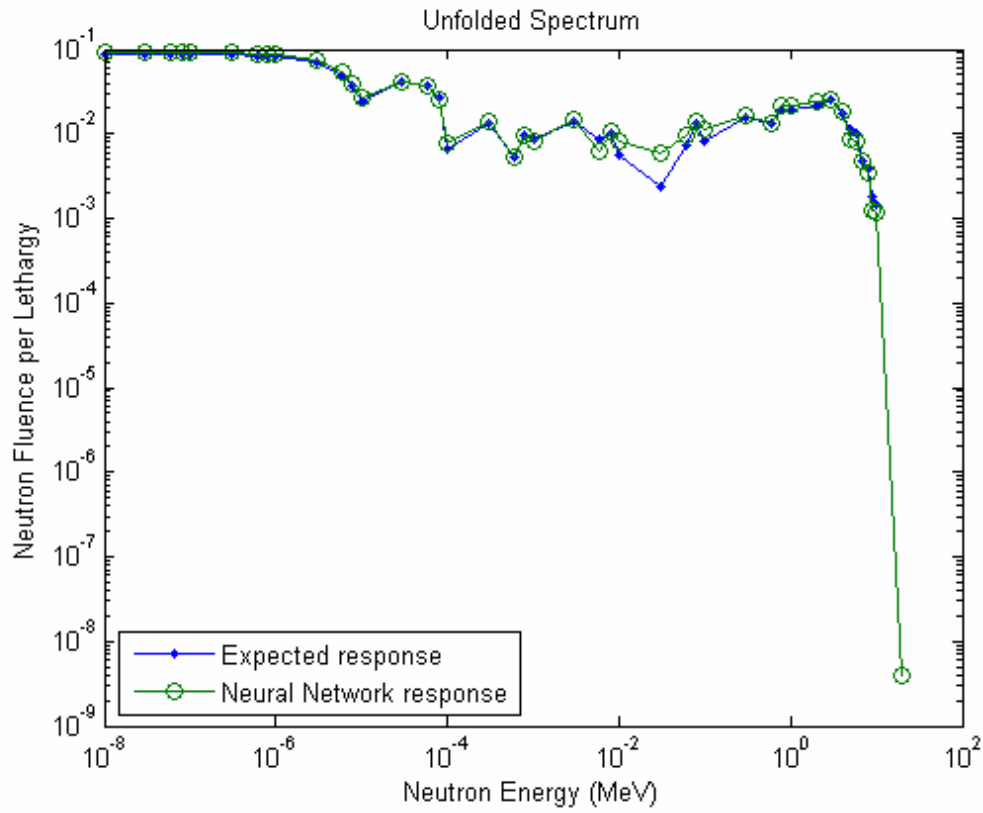


Figure 13: An Example of GRNN Prediction on Continuous Neutron Spectrum

Another example of the prediction results of continuous spectrum is shown in Figure 14. The spectrum is slightly changed, but suppressed at the low and amplified at the high energy end, showing relatively worse accuracy. This behavior is not completely unexpected because there are very limited spectra in the training data similar to this one.

Comparing to continuous neutron spectra, which usually have more complex structure such as peaks and knees, monoenergetic spectra generated in MATLAB have more pattern to follow, thus will be predicted with higher accuracy. In Figure 15, it can be seen that the GRNN output spectrum agrees perfectly with original spectrum.

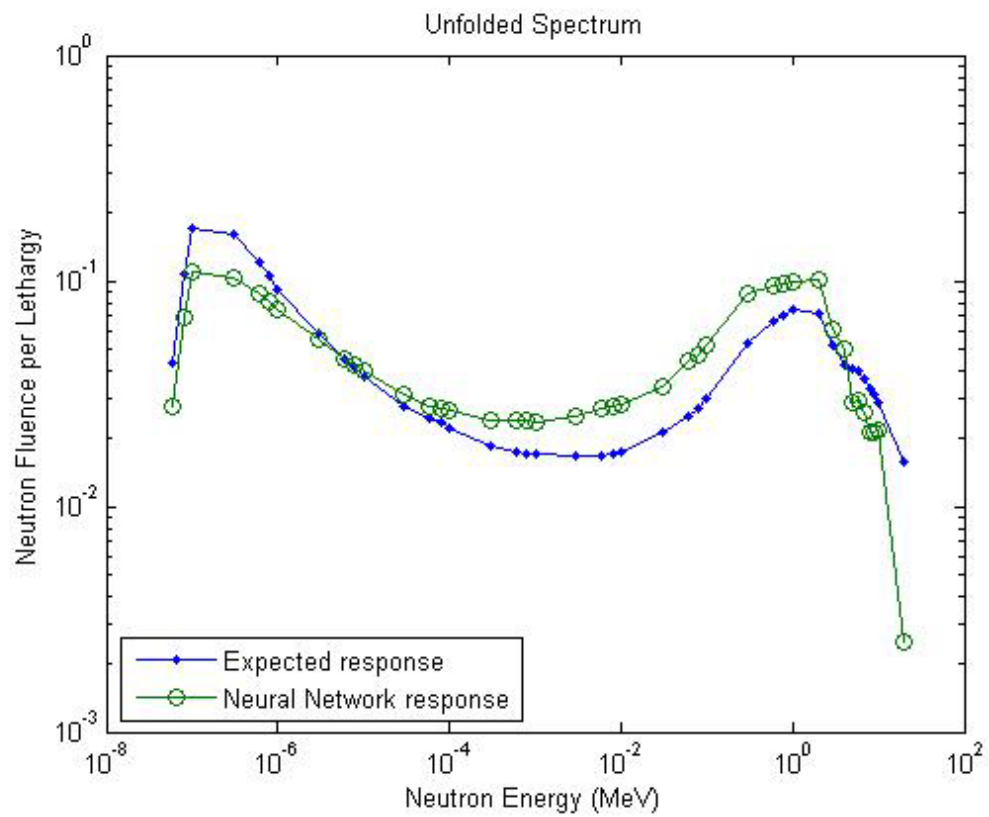


Figure 14: An Example of GRNN Prediction on Continuous Neutron Spectrum

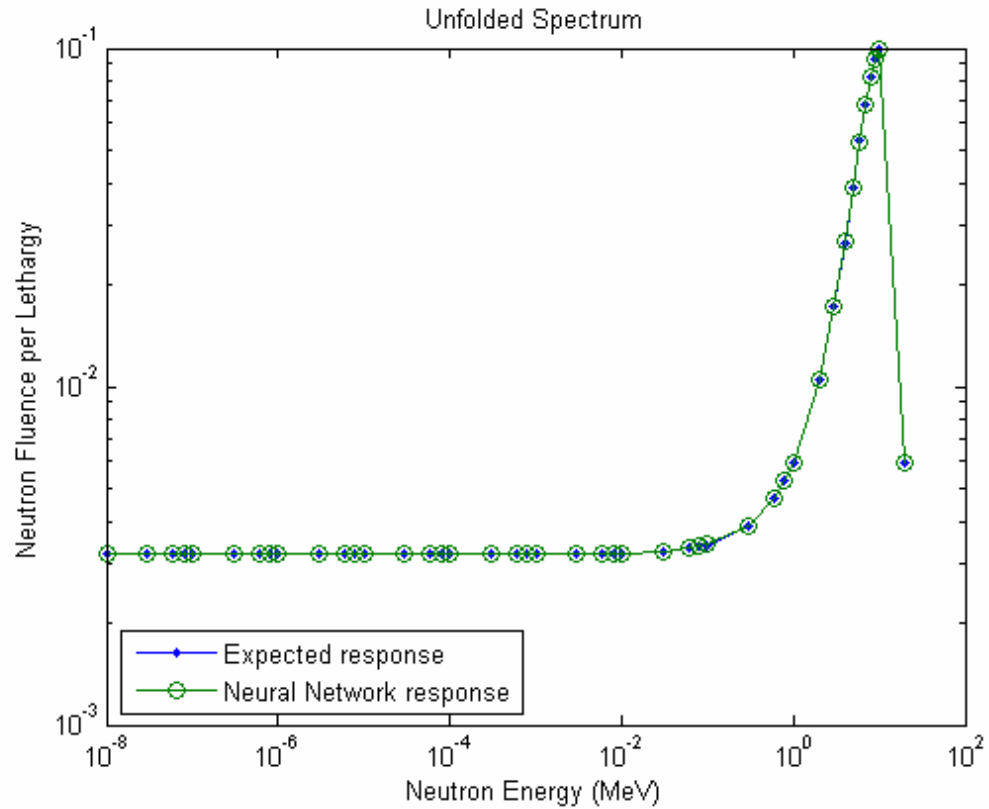


Figure 15: An Example of GRNN Prediction on Monoenergetic Spectrum

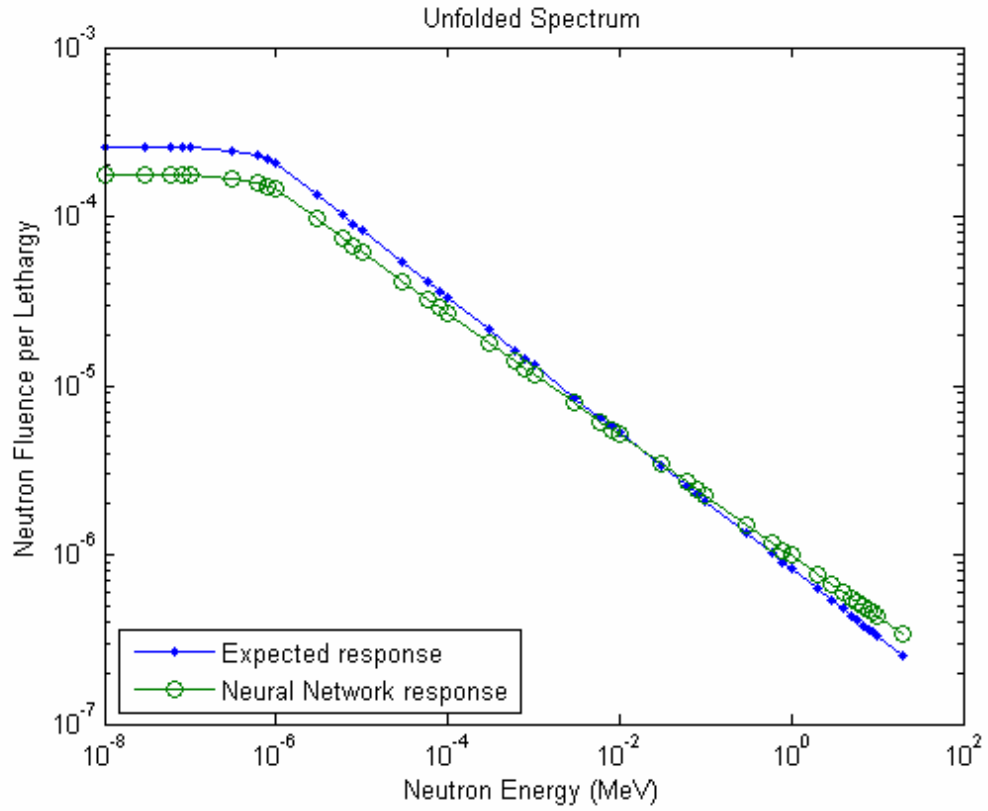


Figure 16: An Example of GRNN Prediction on 1/E Neutron Spectrum

For the prediction of 1/E shaped spectrum, the slopes of the spectra are slightly changed and a migration from lower energy bins to higher energy ones is observed. Figure 16 shows one of these examples.

3.3. Error Analysis

Average prediction errors between the expected responses and GRNN responses were calculated following the equation,

$$error = \frac{\sum_{i=1}^N |Y_i - \phi_i|}{N} \quad (3.1)$$

where Y_i is the i th output of the GRNN, ϕ_i is the corresponding expected spectrum, and N indicates the total number of energy bins used in the calculation, i.e., forty-three in this case. Table 3 shows the average error for each spectrum in test data. Demonstrations in more details are shown in Figure 17.

Table 3: Prediction Errors of Test Data

Test data	Error	Test Data	Error	Test Data	Error
1	5.02E-04	28	1.14E-03	55	5.50E-04
2	6.30E-06	29	8.47E-04	56	1.20E-03
3	1.04E-03	30	8.03E-04	57	2.66E-04
4	5.86E-03	31	1.59E-03	58	2.61E-03
5	5.16E-06	32	4.00E-04	59	4.25E-04
6	5.11E-04	33	2.14E-03	60	3.12E-03
7	7.28E-04	34	3.16E-03	61	4.37E-04
8	5.11E-04	35	5.45E-04	62	1.85E-03
9	5.27E-04	36	2.15E-04	63	8.50E-04
10	7.68E-04	37	3.73E-03	64	1.98E-04
11	5.25E-04	38	1.41E-03	65	8.07E-03
12	7.00E-04	39	6.21E-04	66	4.06E-04
13	2.37E-05	40	9.13E-03	67	2.34E-03
14	3.70E-03	41	3.59E-03	68	2.90E-03
15	5.12E-03	42	3.23E-02	69	4.40E-04
16	4.06E-03	43	2.25E-03	70	1.56E-03
17	4.95E-04	44	2.81E-03	71	3.06E-04
18	5.46E-04	45	3.68E-03	72	8.30E-05
19	2.33E-04	46	6.63E-03	73	8.35E-05
20	4.51E-04	47	4.46E-04	74	8.98E-05
21	4.96E-05	48	1.07E-03	75	1.02E-04
22	5.71E-04	49	1.41E-03	76	1.22E-04
23	2.04E-04	50	1.02E-03	77	1.31E-01
24	4.97E-04	51	6.88E-04	78	2.17E-04
25	3.19E-04	52	4.50E-04	79	7.56E-06
26	6.06E-04	53	4.37E-04	80	5.67E-06
27	6.94E-04	54	3.65E-04	81	5.11E-06

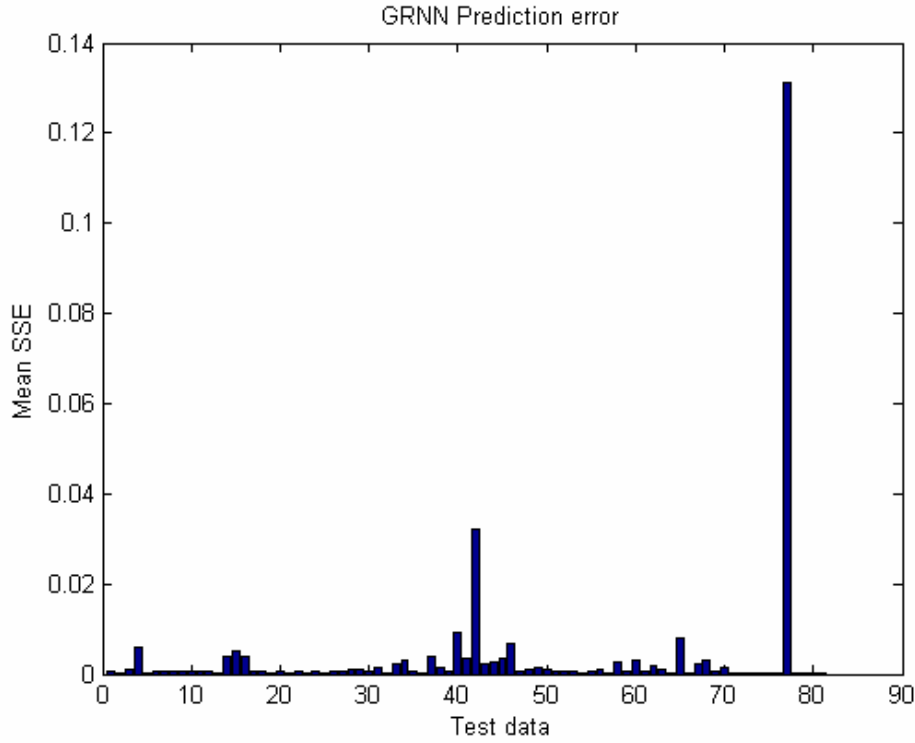


Figure 17: The prediction error produced by GRNN on eighty-one test dataset

As can be seen in Figure 17, the prediction errors of two of the test sets are relatively large comparing to the others. This might be because these two spectra have fewer similarities with those of used in the training sets. After removing these two spectra from the test data, the error produced by GRNN will decrease dramatically, as shown in Figure 18. As can be seen, 97.5% of the prediction results control the average error below 1% (seventy-nine out of eighty-one).

3.4. Comparison with Other Methods (BUMS)

Comparing the results of different unfolding algorithm is not an easy task. Typically most unfolding algorithms are contained in unique programs with differing input requirements for the response matrices and starting spectra. In this approach, a package of code, Bonner sphere Unfolding Made Simple (BUMS) software [25] was selected to compare the prediction results given by GRNN.

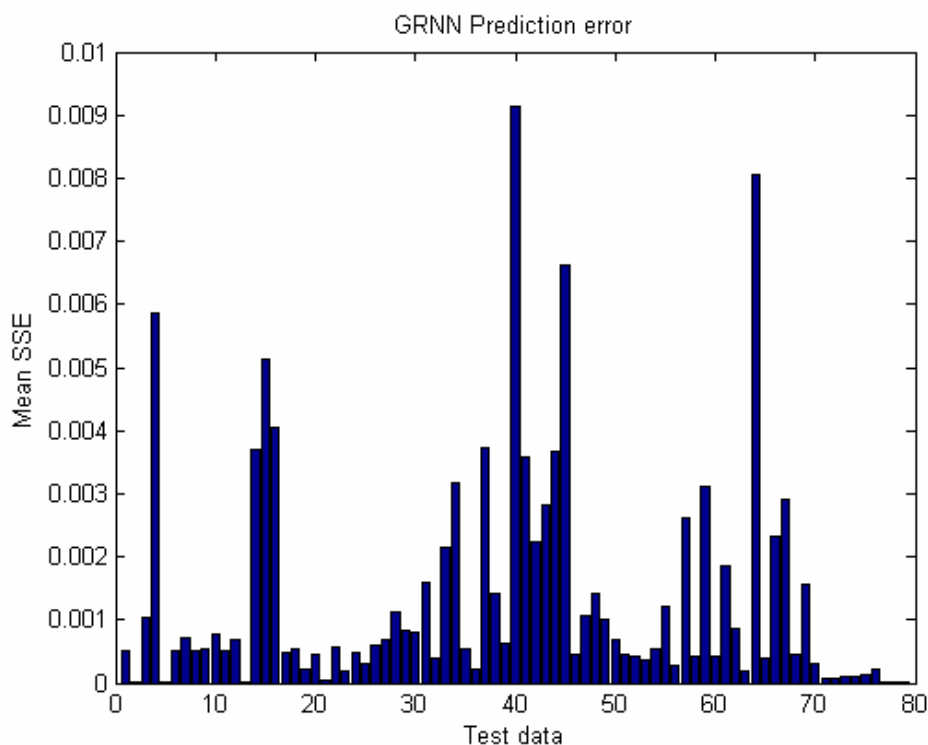


Figure 18: The prediction error produced by GRNN on seventy-nine test dataset (after removing the bad data)

3.4.1. Introduction to BUMS

BUMS is built on the framework of the BUNKI code developed by Johnson and Lowry at the Naval Research Lab. [26] In contrast to the command line interface of BUNKI, BUMS is designed to run on a web server, and uses an HTML based interface that provides access to BUMS from any computer with Internet access. The goal of BUMS is to simplify the process of unfolding multisphere neutron spectrometer data, while providing access to a wide array of unfolding algorithms, response matrices, starting spectra, dose response functions, and detector response functions. The BUMS package contains four unfolding algorithms. These unfolding algorithms include SPUNIT, BON, MAXED, and SAND-II.

SPUNIT was written as stand-alone unfolding code which uses iterative recursion methods to unfold the spectrum by minimizing the deviation between measured and calculated detector responses. It was developed by K. A. Lowry and T. L. Johnson of

the Naval Research Laboratory in 1983. [27] Its incorporation into BUNKI allows the applications of any a priori knowledge of the spectrum such as the spectral shape. The user can specify an initial spectrum or direct a subroutine to calculate a maxwellian and 1/E spectrum as an initial guess.

BON was developed by Scofield and Gold in 1960. [28] The homogeneous Fredholm equation is solved by the iterative method. The technique had been adapted to the problem of unfolding neutron spectra from multi-sphere spectrometer data.

SAND-II is another code using iterative algorithm. It was distributed by the Nuclear Section Data-IAEA, [29] and needs an initial spectrum for the iteration procedure. It is usually assumed to be a superposition of a Maxwell distribution for thermal neutrons, a 1/E slowing down part and a fission neutron spectrum for the fast neutron part. The solution is obtained by minimizing χ^2 , reduced Chi-squared, by applying a non-linear least-squares procedure. The code uses diagonal covariance matrices of the logarithm of the count-rate, which includes also the uncertainties attributed to the response matrix. A trial spectrum is specified by the user and then modified iteratively until acceptable fitting errors of count rates are reached.

3.4.2. Comparison Results

The Bonner Sphere data used in this comparison was originally from a technical report by Dr. Laurence Miller at the University of Tennessee. [30] Measurements were obtained in the first of three locations near the CTI cyclotron facility. The BSS was established 22 inches in front of the target wing, 22 inches off the floor, and 84 inches from the shield. As an example, the measurements of count rates at location #1 near CTI cyclotron is listed in Table 4.

Table 4: Measurements of Location #1 near CTI Cyclotron

Bonner Sphere Size (in)	Count Time (sec)	Counts	Count Rates (sec ⁻¹)
0	100	1777	17.77
2	100	3546	35.46
3	100	4100	41.00
5	100	3431	34.31
8	100	1444	14.44
10	100	622	6.22
12	100	309	3.09

The count rate data was imported as input into GRNN, which was trained in the same way as described above. BUMS was then run with exactly the same input data as was used in the GRNN unfolding. Since there are only seven Bonner Spheres available in BUMS, the count rate data for 4-inch Bonner Sphere required in GRNN was determined manually. Both predicted spectra were produced and plotted in Figure 19, showing the agreements and differences between the two methods. Comparing to BUMS, GRNN gave compressed fluence at lower energy bins, which is possibly because of the extrapolation issue. In addition, the lack of 4-inch Bonner Sphere is also a possible reason corresponding for the slight disagreement.

Same results could be observed when the measurements at 2nd and 3rd were imported into GRNN and the predicted spectra were compared with those from BUMS, as shown in Figure 20 and 21.

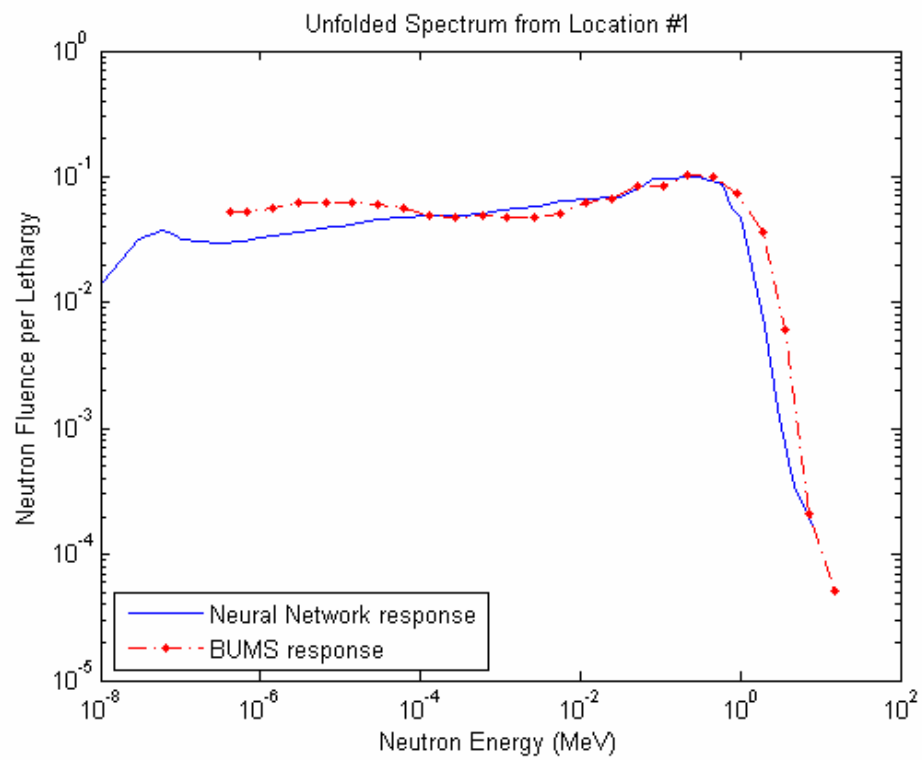


Figure 19: Comparison between GRNN and BUMS (data measured near CTI cyclotron at location #1)

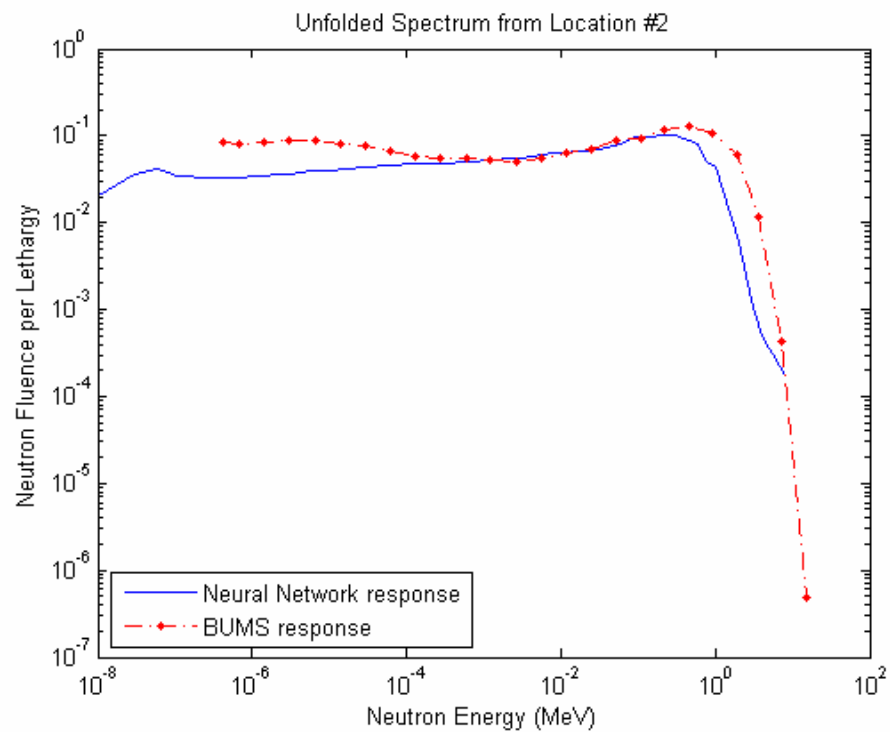


Figure 20: Comparison between GRNN and BUMS (data measured near CTI cyclotron at location #2)

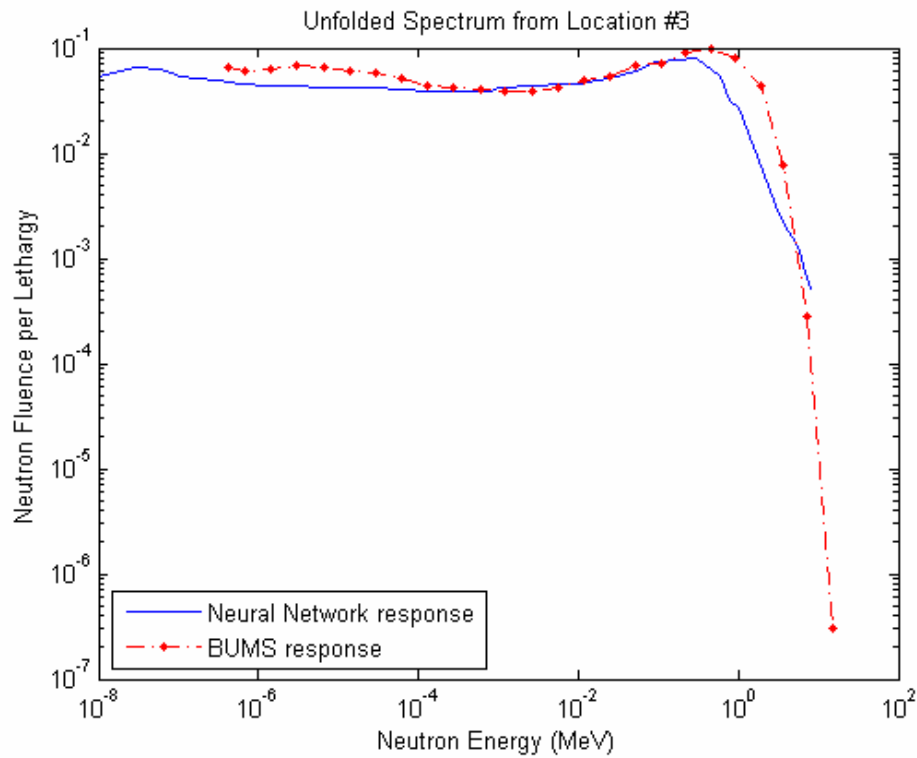


Figure 21: Comparison between GRNN and BUMS (data measured near CTI cyclotron at location #3)

Comparing to other algorithm, unfolding neutron spectrum with neural network (GRNN) has many advantages. Once the response matrix is calculated and the neutron spectrum database is correctly created, GRNN is able to produce prediction for any unseen count rate data, as long as it lies in the training range. Unlike other methodology, in this process, previous data is useful as it has important influence on the prediction, thus theoretically the model created by GRNN will be modified and optimized with the increase of correct data. Additionally, with the computing and plotting capability of MATLAB, users are able to obtain and analysis unfolding results conveniently.

4. CONCLUSIONS

Measurements that obtain neutron spectra are often accomplished almost directly by using time of flight techniques and indirectly by methods that require significant data processing to determine a neutron spectrum, such as, through methods that utilize mathematical unfolding techniques. One of the well-established methods uses Bonner Spheres of several sizes to obtain data that can be used to estimate a spectrum. This problem is ill-conditioned since the number of groups in the estimated spectrum is greater than the number of basis functions used by the spectral unfolding code. In order to solve this problem, GRNN, as a kind of ANN had been successfully utilized to predict neutron spectrum directly from BSS count rates using MATLAB in this research.

The Bonner Sphere Spectrometer system was firstly simulated with the MCNP5 Monte-Carlo code to determine the response to neutrons of different energies for each polyethylene sphere. The neutron energy covered by the response functions goes from 1×10^{-9} MeV to 20 MeV. A total of One hundred and sixty-three neutron spectra were processed to obtain the BSS count rates; this information is in turn used as input and output during the following process. Leave-one-out cross-validation (LOOCV) technique was used when choosing optimal spread constant σ , which helps improve the GRNN performance.

The database was then divided into two parts-training data and test data with odd-and-even method. After the internal weights and bias were calculated and stored in GRNN, its performance was evaluated in test process by comparing the original spectra with those predicted by the GRNN. Comparison shows that 97.5% of the individual prediction errors were controlled below 1%, which indicates the use of ANNs in neutron spectrum unfolding is an alternative procedure that overcomes the drawbacks associated with this ill-conditioned problem.

5. FUTURE WORK

Since GRNN's prediction ability relies on the amount of training data set gathered. Thus the increase of diversity of neutron spectra will improve the performance of neural network significantly. Current research includes one hundred and forty-three continuous neutron spectra, twenty monoenergetic spectra and twenty $1/E$ shaped spectra. Future upgrades of this research will include the addition of more neutron spectra.

The upper limit of the response matrix used in this approach is 20 MeV, which is determined by MCNP calculation requirement. This is the main reason why the GRNN prediction of the last energy point usually gives relatively large error. In the next step of our research, a broadening of the energy bins in response matrix will be implemented so that the accuracy of the prediction in high energy level is expected to be increased. This might involve the change of the MCNP default setting.

More detector responses will be calculated and added to the library in order to broaden the use of this methodology. Additionally, a form will be included that provides a way for the user to input a custom response matrix.

REFERENCES

- [1] R.L. Bramblett, R.I. Ewing, and T.W. Bonner. A new type of neutron spectrometer. *Nuclear Instruments and Methods*, 9:1 (1960).
- [2] Vega-Carrillo, H. R. TLD pairs, as thermal neutron detector, in neutron multisphere spectrometry. *Radiat. Meas.* 35, 251–254 (2002).
- [3] Hsu, H. H., Alvar, K. R. and Vasilik, D. G. A new Bonner-sphere set for high energy neutron measurements: Monte Carlo simulation. *IEEE Trans. Nucl. Sci.* 41, 938–940 (1994).
- [4] Sannikov, A. V., Mares, V. and Schraube, H. High energy response functions of Bonner spectrometers. *Radiat. Prot. Dosim.* 70, 291–294 (1997).
- [5] G. M. Wing. A Primer on Integral Equations of the First Kind. Philadelphia, PA: *Soc. Ind. and Appl. Math.* (1991).
- [6] G. L. Watkins and G. R. Holeman. “The evaluation of an iterative technique’s use in unfolding neutron spectra data,” *Health Phys.*, vol. 15, pp. 535–539 (1968).
- [7] R. S. Sanna, A Manual for BON: A Code for Unfolding Multisphere Spectrometer Neutron Measurements, Environmental Measurements Laboratory, US—DOE (1981).
- [8] K. A. Lowry and T. L. Johnson. Modifications to recursion unfolding algorithms to find more appropriate neutron spectra. *Health Phys.*, vol. 47, no. 4, p. 587, 1984.
- [9] R. Sanna and K. O’Brien, Monte Carlo unfolding of neutron spectra. *Nuclear Instruments and Methods*, vol. 91, pp. 573–576 (1971).
- [10] Routti, J. T. and Sandberg, J. V. General purpose unfolding program LOUHI78 with linear and non-linear regularizations. *Comp. Phys. Comm.* 21, 119–144 (1980).
- [11] Reginatto, M., Goldhagen, P. and Neumann, S. Spectrum unfolding sensitivity analysis and propagation of uncertainties with the maximum entropy deconvolution code MAXED. *Nucl. Instrum. Meth. Phys. Res. A* 476, 242–246 (2002).
- [12] Mukherjee, B. A high-resolution neutron spectra unfolding method using the genetic algorithm technique. *Nucl. Instrum. Meth. Phys. Res. A* 476, 247–251 (2002).
- [13] Braga, C. C. and Dias, M. S. Application of neural networks for unfolding neutron spectra measured by means of Bonner spheres. *Nucl. Instrum. Meth. Phys. Res. A* 476, 252–255 (2002).

- [14] H. R. Vega-Carrillo, V. M. Hernandez-Davila, E. Manzanares-Acuna, G. A. Mercado, E. Gallego, A. Lorente, W. A. Perales-Mun˜oz and J. A. Robles-Rodri˜guez. Artificial neural networks in neutron dosimetry. *Radiation Protection Dosimetry*, Vol. 118, No. 3, pp. 251–259 (2006).
- [15] V. Mares and H. Schraube. Evaluation of the response matrix of a bonner sphere spectrometer with lii detector from thermal energy to 100 mev. *Nuclear Instruments and Methods*, A337:461C473 (1994).
- [16] B. Wiegel, A. V. Alevra, and B. R. L. Siebert. Calculations of the response functions of bonner spheres with a spherical 3he proportional counter using a realistic detector model. Technical report, Physikalisch-Technische Bundesanstalt (1994).
- [17] Glenn F. Knoll. *Radiation Detection and Measurement, Third Edition*. John Wiley & Sons (1999).
- [18] Y. Feng, K.S. Brown, W.H. Casson, G.T. Mei, L.F. Miller and M. Thein, Determination of Neutron Dose from Criticality Accidents with Bioassays for Sodium-24 in Blood and Phosphorus-32 in Hair, Oak Ridge National Laboratory, ORNL/TM-12028, National Technical Information Service Springfield, VA (June 1993).
- [19] International Atomic Energy Agency. Compendium of neutron spectra and detector response for radiation protection purpose. *Supplement to Technical Reports Series No. 318. IAEA Technical Report Series No. 403* (2001).
- [20] Ying, Feng, Determination of neutron dose from criticality accidents with bioassays for blood ^{24}Na and hair ^{32}P [M.S. thesis]: Knoxville, University of Tennessee (1991).
- [21] Feˆraund, R. and Cleˆrot, F. A methodology to explain neural network classification. *Neural Networks*. 15, 237–246 (2002).
- [22] The Mathwork - <http://www.mathworks.com/products/neuralnet/>
- [23] D.F. Specht, A General Regression Neural Network, *IEEE Transactions on Neural Networks*, vol. 2, pp. 568-576 (1991).
- [24] Wesley Hines, Lecture Notes “Generalized Regression Neural Network”, NE577 Neutral Network
- [25] Jeremy Sweezy, Nolan Hertel, Ken Veinot, Bonner sphere Unfolding Made

Simple (BUMS), *Nuclear Instruments and Methods in Physics Research Section A*, Vol476, Issue 1-2, p.263-269, (2002).

[26] K.A. Lowry, T.L. Johnson, Modifications to recursion unfolding algorithms to find more appropriate neutron spectra, *Health Phys.* 47 (4) (1984) 587.

[27] Lowry, K. A. and Johnson, T. L. Modification to Iterative Recursion Unfolding Algorithms and Computer Codes to Find More Appropriate Neutron Spectra, *Naval Research Laboratory Memorandum Report* 5340 (1984).

[28] N.E. Scofield and R.E. Gold, Iterative Solution for the Matrix Representation of Detector Systems, *USAEC Report TID-18304* (1960).

[29] Kocherov, N. P. *Neutron Metrology File NMF-90*. IAEA Report INDC(NDS)-347 (1996). PC Package Received from the IAEA Nuclear Data Section, 2001.

[30] Laurence Miller, Neutron Spectra near a CTI Cyclotron, December (2005).

APPENDICES

Appendix A Example of MCNP5 Input Deck (for 5" Bonner Sphere)

The geometry of MCNP treats an arbitrary 3-dimensional configuration of user-defined materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori. The cells are defined by the intersections, unions, and complements of the regions bounded by the surfaces. Surfaces are defined by supplying coefficients to the analytic surface equations or, for certain types of surfaces, known points on the surfaces. The material cards specify the isotopic composition of the materials in the cells. This, in turn, determines which cross-section evaluation will be used.

The thermal neutron detector is centered in the polyethylene spheres, whose radius and the energies are varied to obtain the Relative Dose Response Curves for the Bonner Sphere Spectrometer. In this case, the neutron source is represented by a monoenergetic parallel beam emitted from a circular surface with a diameter equal to that of the diameter of the simulated sphere and at a distance of 20 cm from its center. The spheres are in vacuum in the simulations.

5" Bonner Sphere Rev 0 ERG=Cf-252

c Source placed at 20 cm

c

c

c ===== Cell Cards =====

c

1 4 -2.2 -2 +3 -4 imp:n=1 \$Glass approx to PMT

2 3 -2.5 -1 +4 -5 imp:n=1 \$Detector volume

3 2 -2.7 +1 -2 +4 -5 imp:n=1 \$AL housing

4 2 -2.7 -2 +5 -6 imp:n=1 \$AL face

5 1 -0.92 +2 -7 imp:n=1 \$Poly

6 1 -0.92 -2 -7 +6 imp:n=1 \$Poly

7 0 -8 #1 #2 #3 #4 #5 #6 imp:n=1

8 0 +8 imp:n=0

c ===== Surface Cards =====

1 cx 0.47625 \$3/8" dia. detector
2 cx 0.50 \$Poly borehole and Al can
3 px -10.16 \$Far end of PMT
4 px -0.47625 \$End of Li-6
5 px 0.47625 \$Front face of Li-6
6 px 0.50 \$Front face of detector
7 so 6.35 \$5" sphere
8 so 500 \$Cosmos
9 px 20 \$Surface for Source

c ===== Material Cards =====

m1 1001.50c 0.6667 6000.50c 0.3333 \$Polyethylene
mt1 poly.01t \$SAB treatment at 300K
m2 13027.50c 1.0 \$Aluminum
m3 3006.50c 0.02162 3007.50c 0.00114 &
14000.50c 0.02276 8016.50c 0.04552 \$GS20 Li Glass Detector
m4 14000.50c 1.0 8016.50c 2.0 \$Glass

c

c ===== Source Card =====

c

sdef erg=d2 par=1 sur=9 pos=22 0 0 rad=d1 dir=-1

sil 3.81

sp2 -2 1.42

c ===== Tally Cards =====

c

f4:n 2 \$Avg. Flux in Cell tally

fm4 0.07435 3 105 \$Normalization, Material,

c

c===== Control Cards =====

mode n $\$Neutron$ problem

```
cut:n 30000 1e-09
```

```
prtmp 10000001 -600
```

[illegible]

Appendix B Reference Spectra

Part 1. Available Neutron Spectrum from ORNL Report [18]

CF-252 Bare		CF-252 D ₂ O Moderated		Fissile Solution, 2 cm Radius Sphere, D ₂ O	
Energy in MeV	Fluence	Energy in MeV	Fluence	Energy in MeV	Fluence
4.13E-07	4.44E-04	4.13E-07	6.85E-02	1.00E-05	0.00E+00
1.00E-02	4.41E-03	1.00E-06	6.31E-02	5.00E-05	0.00E+00
5.00E-02	8.60E-03	1.00E-05	6.04E-02	1.00E-04	0.00E+00
1.00E-01	2.31E-02	5.00E-05	3.17E-02	2.00E-04	0.00E+00
2.00E-01	1.35E-02	1.00E-04	3.41E-02	4.00E-04	1.00E-04
2.50E-01	1.44E-02	2.00E-04	3.82E-02	7.00E-04	1.00E-04
3.00E-01	3.08E-02	4.00E-04	3.28E-02	1.00E-03	1.00E-04
4.00E-01	3.26E-02	7.00E-04	2.24E-02	3.00E-03	4.00E-04
5.00E-01	3.35E-02	1.00E-03	7.56E-02	6.00E-03	1.20E-03
6.00E-01	3.41E-02	3.00E-03	5.09E-02	1.00E-02	2.20E-03
7.00E-01	3.41E-02	6.00E-03	3.79E-02	2.00E-02	4.70E-03
8.00E-01	6.72E-02	1.00E-02	5.47E-02	4.00E-02	1.07E-02
1.00E+00	6.44E-02	2.00E-02	5.12E-02	6.00E-02	1.25E-02
1.20E+00	6.09E-02	4.00E-02	2.96E-02	8.00E-02	1.11E-02
1.40E+00	2.89E-02	6.00E-02	2.00E-02	1.00E-01	1.23E-02
1.50E+00	2.79E-02	8.00E-02	1.46E-02	1.50E-01	2.69E-02
1.60E+00	5.25E-02	1.00E-01	2.47E-02	2.00E-01	2.41E-02
1.80E+00	4.83E-02	1.50E-01	1.59E-02	2.50E-01	2.45E-02
2.00E+00	4.40E-02	2.00E-01	1.14E-02	3.00E-01	2.15E-02
2.20E+00	2.05E-02	2.50E-01	8.90E-03	3.50E-01	2.10E-02
2.30E+00	1.95E-02	3.00E-01	6.57E-03	4.00E-01	2.04E-02
2.40E+00	3.63E-02	3.50E-01	4.89E-03	4.50E-01	1.65E-02
2.60E+00	3.28E-02	4.00E-01	2.65E-03	5.00E-01	1.66E-02
2.80E+00	2.95E-02	4.50E-01	3.14E-03	5.50E-01	1.84E-02
3.00E+00	5.02E-02	5.00E-01	4.20E-03	6.00E-01	1.81E-02
3.40E+00	3.09E-02	5.50E-01	4.12E-03	7.00E-01	3.56E-02
3.70E+00	4.12E-02	6.00E-01	7.83E-03	8.00E-01	3.61E-02
4.20E+00	2.53E-02	7.00E-01	6.78E-03	9.00E-01	3.49E-02
4.60E+00	1.99E-02	8.00E-01	5.75E-03	1.00E+00	2.88E-02
5.00E+00	1.90E-02	9.00E-01	3.57E-03	1.20E+00	5.58E-02
5.50E+00	1.40E-02	1.00E+00	7.48E-03	1.40E+00	5.38E-02
6.00E+00	1.02E-02	1.20E+00	8.43E-03	1.60E+00	5.18E-02
6.50E+00	7.49E-03	1.40E+00	9.13E-03	1.80E+00	4.55E-02

7.00E+00	5.46E-03	1.60E+00	8.55E-03	2.00E+00	4.17E-02
7.50E+00	3.98E-03	1.80E+00	8.07E-03	2.30E+00	5.74E-02
8.00E+00	2.89E-03	2.00E+00	1.34E-02	2.60E+00	5.28E-02
8.50E+00	2.09E-03	2.30E+00	1.45E-02	3.00E+00	5.52E-02
9.00E+00	1.51E-03	2.60E+00	1.49E-02	3.50E+00	5.35E-02
9.50E+00	1.09E-03	3.00E+00	1.24E-02	4.00E+00	3.83E-02
1.00E+01	1.35E-03	3.50E+00	8.19E-03	4.50E+00	2.93E-02
1.10E+01	7.00E-04	4.00E+00	8.10E-03	5.00E+00	2.12E-02
1.20E+01	3.61E-04	4.50E+00	6.54E-03	6.00E+00	2.33E-02
1.30E+01	1.85E-04	5.00E+00	8.70E-03	7.00E+00	1.09E-02
1.40E+01	1.44E-04	6.00E+00	4.93E-03	8.00E+00	5.30E-03
1.60E+01	3.80E-05	7.00E+00	2.42E-03	9.00E+00	2.60E-03
		8.00E+00	1.30E-03	1.00E+01	1.30E-03
		9.00E+00	7.70E-04	1.10E+01	3.00E-04
		1.00E+01	4.40E-04	1.20E+01	3.00E-04
		1.10E+01	1.60E-04	1.30E+01	1.00E-04
		1.20E+01	1.20E-04	1.40E+01	1.00E-04
		1.30E+01	6.00E-05	1.50E+01	1.00E-04
		1.40E+01	3.00E-05		

Energy in MeV	Through 20 cm Concrete with 10% Iron	Through 60 cm Concrete with 10% Iron	Through 100 cm Concrete with 10% Iron	Through 100% Iron
1.87E-07	3.13E-02	4.50E-03	9.20E-05	2.00E-06
2.49E-07	1.20E-03	1.00E-04	1.00E-06	3.00E-06
4.99E-07	3.10E-03	1.00E-04	2.00E-06	1.20E-05
1.00E-06	3.20E-03	1.00E-04	2.00E-06	2.50E-05
2.00E-06	3.40E-03	1.00E-04	2.00E-06	4.50E-05
5.00E-06	4.80E-03	2.00E-04	2.00E-06	8.80E-05
1.00E-05	3.90E-03	1.00E-04	2.00E-06	8.70E-05
2.20E-05	4.70E-03	1.00E-04	2.00E-06	1.29E-04
4.70E-05	4.60E-03	1.00E-04	2.00E-06	1.34E-04
1.00E-04	4.90E-03	1.00E-04	2.00E-06	1.46E-04
2.14E-04	4.80E-03	1.00E-04	1.00E-06	1.61E-04
4.65E-04	5.30E-03	1.00E-04	1.00E-06	1.58E-04
1.00E-03	5.40E-03	1.00E-04	1.00E-06	1.74E-04
2.15E-03	5.60E-03	1.00E-04	1.00E-06	2.78E-04
4.65E-03	5.80E-03	1.00E-04	1.00E-06	5.16E-04
1.00E-02	5.90E-03	1.00E-04	1.00E-06	2.47E-04
1.30E-02	2.10E-03	3.56E-05	4.53E-07	2.08E-04
1.60E-02	1.70E-03	2.88E-05	3.67E-07	2.42E-04
2.00E-02	1.90E-03	3.12E-05	3.94E-07	2.14E-04
2.50E-02	1.90E-03	3.10E-05	3.94E-07	1.49E-04
3.20E-02	2.10E-03	3.45E-05	4.39E-07	6.50E-05

4.00E-02	2.20E-03	3.45E-05	4.37E-07	1.50E-05
5.00E-02	2.30E-03	3.65E-05	4.61E-07	3.00E-05
6.30E-02	2.60E-03	4.02E-05	1.00E-06	6.60E-05
7.90E-02	2.70E-03	4.20E-05	1.00E-06	9.50E-05
1.00E-01	3.00E-03	4.59E-05	1.00E-06	1.16E-04
1.26E-01	3.00E-03	4.59E-05	1.00E-06	1.16E-04
1.58E-01	3.20E-03	4.84E-05	1.00E-06	1.34E-04
1.99E-01	3.50E-03	1.00E-04	1.00E-06	1.43E-04
2.51E-01	3.60E-03	1.00E-04	1.00E-06	1.30E-04
3.16E-01	3.80E-03	1.00E-04	1.00E-06	1.23E-04
3.98E-01	4.10E-03	1.00E-04	1.00E-06	1.06E-04
5.01E-01	4.40E-03	1.00E-04	1.00E-06	6.80E-05
6.31E-01	4.80E-03	1.00E-04	1.00E-06	2.00E-05
7.94E-01	5.20E-03	1.00E-04	1.00E-06	1.30E-05
1.00E+00	5.90E-03	1.00E-04	1.00E-06	7.00E-06
1.26E+00	6.90E-03	1.00E-04	1.00E-06	3.83E-07
1.58E+00	9.10E-03	1.00E-04	2.00E-06	2.30E-07
1.99E+00	1.24E-02	1.00E-04	2.00E-06	4.96E-08
2.51E+00	1.28E-02	2.00E-04	2.00E-06	1.79E-09
3.16E+00	1.07E-02	1.00E-04	2.00E-06	7.59E-10
3.98E+00	8.50E-03	1.00E-03	1.00E-06	1.32E-10
5.01E+00	6.10E-03	1.00E-04	1.00E-06	6.40E-11
6.31E+00	3.80E-03	4.45E-05	1.00E-06	1.60E-11
7.94E+00	2.40E-03	2.45E-05	3.01E-07	5.40E-12
1.00E+01	7.00E-04	6.29E-06	7.33E-08	3.20E-12
1.26E+01	1.00E-04	3.18E-06	1.60E-09	8.00E-13
1.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.99E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Fission Spectra

Energy in MeV	Through 5 cm Concrete with 50% Iron	Through 10 cm Concrete with 50% Iron	Through 20 cm Concrete with 50% Iron	Through 100 cm Concrete with 50% Iron	Through 60 cm Concrete with 50% Iron
1.87E-07	1.00E-04	2.30E-03	9.82E-02	5.10E-04	4.27E-06
2.49E-07	1.57E-05	3.00E-04	9.00E-04	3.50E-05	2.78E-07
4.99E-07	4.76E-05	7.00E-04	2.30E-03	8.70E-05	6.90E-07
1.00E-06	1.00E-04	9.00E-04	2.50E-03	9.00E-05	7.02E-07
2.00E-06	1.00E-04	1.10E-03	2.70E-03	9.00E-05	7.07E-07
5.00E-06	2.00E-04	1.70E-03	3.90E-03	1.18E-04	9.16E-07
1.00E-05	2.00E-04	1.50E-03	3.20E-03	9.10E-05	7.07E-07
2.20E-05	3.00E-04	2.00E-03	3.90E-03	1.02E-04	7.82E-07
4.70E-05	4.00E-04	2.30E-03	3.90E-03	9.50E-05	7.21E-07
1.00E-04	5.00E-04	2.70E-03	4.20E-03	9.40E-05	7.05E-07
2.14E-04	7.00E-04	3.10E-03	4.20E-03	8.80E-05	6.50E-07
4.65E-04	1.10E-03	3.80E-03	4.70E-03	9.10E-05	6.78E-07
1.00E-03	1.50E-03	4.50E-03	5.00E-03	9.10E-05	6.69E-07
2.15E-03	2.10E-03	5.50E-03	5.50E-03	9.40E-05	6.85E-07
4.65E-03	3.10E-03	6.80E-03	6.10E-03	9.60E-05	6.98E-07

1.00E-02	4.10E-03	7.50E-03	5.90E-03	8.60E-05	6.15E-07
1.30E-02	1.90E-03	3.10E-03	2.30E-03	2.80E-05	2.28E-07
1.60E-02	1.70E-03	2.70E-03	1.90E-03	2.90E-05	1.92E-07
2.00E-02	2.00E-03	3.00E-03	2.00E-03	2.80E-05	1.94E-07
2.50E-02	2.10E-03	2.90E-03	2.00E-03	2.70E-05	1.84E-07
3.20E-02	2.50E-03	3.20E-03	1.90E-03	2.30E-05	1.75E-07
4.00E-02	2.70E-03	3.20E-03	1.90E-03	2.50E-05	1.70E-07
5.00E-02	3.20E-03	3.70E-03	2.20E-03	2.90E-05	1.94E-07
6.30E-02	4.00E-03	4.60E-03	2.70E-03	3.30E-05	2.33E-07
7.90E-02	4.80E-03	5.30E-03	3.00E-03	3.70E-05	2.60E-07
1.00E-01	6.00E-03	6.30E-03	3.50E-03	4.10E-05	2.89E-07
1.26E-01	7.00E-03	6.90E-03	3.60E-03	4.10E-05	2.88E-07
1.58E-01	8.40E-03	7.80E-03	3.90E-03	4.40E-05	3.05E-07
1.99E-01	1.03E-02	9.00E-03	4.30E-03	4.60E-05	3.20E-07
2.51E-01	1.22E-02	9.94E-02	4.50E-03	4.70E-05	3.25E-07
3.16E-01	1.46E-02	1.12E-02	4.80E-03	4.80E-05	3.27E-07
3.98E-01	1.75E-02	1.27E-02	5.20E-03	5.10E-05	3.46E-07
5.01E-01	2.07E-02	1.42E-02	5.50E-03	5.20E-05	3.52E-07
6.31E-01	2.47E-02	1.59E-02	5.90E-03	5.40E-05	3.62E-07
7.94E-01	2.94E-02	1.77E-02	6.20E-03	5.60E-05	3.74E-07
1.00E+00	3.48E-02	2.01E-02	6.80E-03	5.90E-05	3.92E-07
1.26E+00	4.23E-02	2.36E-02	7.70E-03	6.60E-05	4.36E-07
1.58E+00	4.68E-02	2.65E-02	8.70E-03	7.30E-05	4.79E-07
1.99E+00	5.61E-02	3.23E-02	1.05E-02	8.80E-05	5.69E-07
2.51E+00	5.73E-02	3.23E-02	1.01E-02	7.70E-05	4.85E-07
3.16E+00	5.07E-02	2.74E-02	8.00E-03	5.30E-05	3.10E-07
3.98E+00	4.20E-02	2.19E-02	6.00E-03	3.40E-05	1.76E-07
5.01E+00	2.99E-02	1.55E-02	4.10E-03	2.20E-05	1.13E-07
6.31E+00	1.87E-02	9.60E-03	2.50E-03	1.50E-05	8.51E-08
7.94E+00	1.17E-02	6.00E-03	1.80E-03	7.00E-06	3.99E-08
1.00E+01	3.70E-03	1.90E-03	5.00E-04	2.00E-06	6.59E-09
1.26E+01	4.87E-05	2.91E-05	9.52E-06	8.78E-08	6.65E-10
1.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.99E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	Through 5 cm Iron	Through 10 cm Iron	Through 20 cm Iron	Through 30 cm Iron	Through 50 cm Iron
5.00E-06	0.00E+00	0.00E+00	2.30E-05	0.00E+00	1.10E-04
1.00E-05	0.00E+00	0.00E+00	8.00E-06	0.00E+00	1.44E-04
4.00E-05	0.00E+00	0.00E+00	2.37E-04	3.60E-04	4.06E-04
8.00E-05	0.00E+00	0.00E+00	1.21E-04	2.17E-04	2.34E-04
1.00E-04	0.00E+00	0.00E+00	3.00E-06	8.10E-05	8.90E-05
2.00E-04	0.00E+00	0.00E+00	1.65E-04	2.36E-04	3.24E-04
3.00E-04	0.00E+00	0.00E+00	9.70E-05	1.56E-04	2.47E-04
4.00E-04	0.00E+00	1.00E-04	1.02E-04	1.96E-04	1.79E-04
5.00E-04	0.00E+00	1.00E-04	1.04E-04	1.30E-04	1.52E-04
6.00E-04	0.00E+00	0.00E+00	4.90E-05	1.08E-04	1.16E-04
8.00E-04	5.70E-05	0.00E+00	1.40E-04	2.36E-04	2.62E-04
1.00E-03	4.00E-06	0.00E+00	2.17E-04	1.25E-04	1.79E-04

2.00E-03	6.20E-05	2.00E-04	4.88E-04	8.18E-04	9.01E-04
3.00E-03	8.00E-06	2.00E-04	8.11E-04	6.37E-04	6.77E-04
4.00E-03	6.00E-06	3.00E-04	4.11E-04	5.12E-04	4.95E-04
5.00E-03	1.19E-04	4.00E-04	6.49E-04	6.74E-04	8.19E-04
6.00E-03	2.50E-04	5.00E-04	5.51E-04	3.77E-04	4.30E-04
8.00E-03	1.87E-04	1.00E-04	8.20E-05	1.34E-04	2.22E-04
1.00E-02	1.81E-04	1.00E-04	1.60E-04	3.24E-04	2.14E-04
1.50E-02	7.91E-04	1.10E-03	1.10E-03	1.55E-03	1.59E-03
2.20E-02	9.31E-04	1.60E-03	3.22E-03	5.36E-03	6.43E-03
2.60E-02	2.76E-03	7.50E-03	2.02E-02	2.41E-02	2.16E-02
3.00E-02	4.79E-04	3.00E-04	1.97E-04	1.62E-04	3.00E-05
3.50E-02	3.76E-04	3.00E-04	4.56E-04	2.31E-04	9.10E-05
4.00E-02	1.06E-03	7.00E-04	7.66E-04	5.93E-04	1.43E-04
5.00E-02	2.13E-03	2.20E-03	1.61E-03	9.98E-03	3.84E-04
6.00E-02	1.56E-03	1.20E-03	8.93E-04	6.16E-04	3.12E-04
8.00E-02	4.57E-03	3.60E-03	2.67E-03	2.18E-03	1.08E-03
1.00E-01	3.28E-03	3.30E-03	3.66E-03	3.62E-03	2.02E-03
1.50E-01	1.60E-02	2.02E-02	2.90E-02	2.87E-02	1.77E-02
2.00E-01	2.14E-02	2.87E-02	4.09E-02	4.17E-02	2.50E-02
2.50E-01	2.01E-02	2.81E-02	3.97E-02	3.88E-02	2.12E-02
3.00E-01	2.37E-02	3.37E-02	5.54E-02	5.98E-02	3.14E-02
3.50E-01	3.25E-02	5.95E-02	9.63E-02	9.56E-02	4.27E-02
4.00E-01	3.18E-02	4.18E-02	4.66E-02	3.54E-02	9.99E-02
4.50E-01	2.04E-02	2.03E-02	1.76E-02	1.16E-02	3.29E-03
5.00E-01	2.47E-02	3.25E-02	3.23E-02	2.17E-02	5.91E-03
5.50E-01	2.31E-02	2.89E-02	3.00E-02	1.96E-02	4.40E-03
6.00E-01	2.68E-02	3.01E-02	3.27E-02	2.29E-02	5.26E-03
7.00E-01	6.12E-02	7.91E-02	7.28E-02	4.39E-02	8.71E-03
8.00E-01	4.02E-02	3.67E-02	2.12E-02	9.47E-03	1.25E-03
9.00E-01	4.17E-02	4.11E-02	2.61E-02	1.26E-02	1.93E-03
1.00E+00	4.12E-02	4.36E-02	2.82E-02	1.42E-02	2.14E-03
1.20E+00	7.24E-02	6.42E-02	3.28E-02	1.21E-02	1.29E-03
1.40E+00	6.09E-02	4.90E-02	2.17E-02	6.78E-03	5.63E-04
1.60E+00	5.50E-02	4.35E-02	1.75E-02	5.82E-03	4.77E-04
1.80E+00	5.17E-02	3.95E-02	1.66E-02	5.14E-03	3.09E-04
2.00E+00	4.37E-02	3.30E-02	1.10E-02	3.02E-03	1.42E-04
2.30E+00	4.82E-02	3.21E-02	1.01E-02	2.25E-03	1.12E-04
2.60E+00	4.05E-02	2.43E-02	6.56E-03	1.58E-03	3.70E-05
3.00E+00	4.16E-02	2.28E-02	6.50E-03	1.38E-03	4.50E-05
3.50E+00	3.53E-02	2.07E-02	4.92E-03	8.45E-04	2.20E-05
4.00E+00	2.50E-02	1.21E-02	3.14E-03	5.96E-04	7.00E-06
4.50E+00	1.50E-02	7.20E-03	1.94E-03	2.73E-04	8.00E-06
5.00E+00	1.17E-02	5.70E-03	1.24E-03	3.16E-04	7.00E-06
6.00E+00	1.33E-02	6.50E-03	1.21E-03	3.10E-04	7.00E-06
7.00E+00	5.94E-03	4.20E-03	6.18E-04	1.27E-04	0.00E+00
8.00E+00	3.67E-03	1.50E-03	3.20E-04	8.30E-05	0.00E+00
9.00E+00	1.81E-03	5.00E-04	1.72E-04	2.60E-05	6.00E-06
1.00E+01	4.76E-04	3.00E-04	5.10E-05	1.20E-05	0.00E+00
1.10E+01	3.49E-04	3.00E-04	5.40E-05	1.00E-05	0.00E+00
1.20E+01	1.16E-04	0.00E+00	2.70E-05	0.00E+00	0.00E+00

1.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.40E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	Through 5 cm Copper	Through 10 cm Lead	Through 20 cm Lead	Through 30 cm Lead	Through 50 cm Lead
5.00E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-05
4.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-05
8.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04
1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-05
2.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-04
3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-04
4.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-04
5.00E-04	0.00E+00	0.00E+00	0.00E+00	6.00E-05	3.60E-04
6.00E-04	0.00E+00	0.00E+00	0.00E+00	6.00E-05	3.00E-04
8.00E-04	0.00E+00	6.00E-05	0.00E+00	6.00E-05	5.40E-04
1.00E-03	0.00E+00	6.00E-05	0.00E+00	0.00E+00	4.80E-04
2.00E-03	1.00E-04	0.00E+00	6.00E-05	2.40E-04	3.18E-03
3.00E-03	1.00E-04	6.00E-05	1.20E-04	2.80E-04	2.92E-03
4.00E-03	1.00E-04	6.00E-05	0.00E+00	3.00E-04	2.47E-03
5.00E-03	2.00E-04	6.00E-05	1.20E-04	1.80E-04	2.72E-03
6.00E-03	2.00E-04	0.00E+00	6.00E-05	3.00E-04	2.77E-03
8.00E-03	3.00E-04	6.00E-05	2.40E-04	4.70E-04	4.57E-03
1.00E-02	3.00E-04	1.20E-04	5.50E-04	7.50E-04	4.28E-03
1.50E-02	1.30E-03	3.70E-04	1.03E-03	1.98E-03	1.07E-02
2.20E-02	2.00E-03	4.90E-04	1.90E-03	3.80E-03	1.59E-02
2.60E-02	6.00E-04	3.70E-04	6.10E-04	2.51E-03	8.97E-03
3.00E-02	2.00E-04	1.12E-03	1.53E-03	2.88E-03	1.06E-02
3.50E-02	1.00E-03	6.20E-04	1.53E-03	4.18E-03	1.30E-02
4.00E-02	1.50E-03	1.91E-03	2.20E-03	3.65E-03	1.20E-02
5.00E-02	2.60E-03	1.37E-03	3.39E-03	5.27E-03	1.35E-02
6.00E-02	3.50E-03	2.06E-03	4.14E-03	9.61E-03	1.74E-02
8.00E-02	8.30E-03	4.78E-03	8.49E-03	1.20E-02	2.44E-02
1.00E-01	7.70E-03	4.73E-03	9.37E-03	1.58E-02	2.66E-02
1.50E-01	2.37E-02	1.60E-02	2.48E-02	3.54E-02	5.72E-02
2.00E-01	3.02E-02	1.92E-02	2.75E-02	4.34E-02	5.75E-02
2.50E-01	3.08E-02	2.12E-02	3.44E-02	4.35E-02	5.00E-02
3.00E-01	3.04E-02	2.33E-02	3.14E-02	3.83E-02	4.19E-02
3.50E-01	2.84E-02	2.61E-02	3.58E-02	4.04E-02	4.38E-02
4.00E-01	3.28E-02	2.24E-02	2.70E-02	3.14E-02	3.69E-02
4.50E-01	3.53E-02	2.34E-02	2.91E-02	3.91E-02	5.34E-02
5.00E-01	2.81E-02	2.32E-02	3.71E-02	5.50E-02	7.84E-02
5.50E-01	2.83E-02	2.75E-02	4.27E-02	5.62E-02	5.95E-02
6.00E-01	2.96E-02	2.64E-02	3.64E-02	4.08E-02	3.93E-02
7.00E-01	5.46E-02	5.03E-02	6.52E-02	7.28E-02	6.20E-02
8.00E-01	5.06E-02	5.17E-02	6.52E-02	6.56E-02	4.38E-02
9.00E-01	4.76E-02	4.44E-02	4.64E-02	4.48E-02	2.84E-02
1.00E+00	4.19E-02	4.68E-02	5.03E-02	4.00E-02	2.66E-02

1.20E+00	7.58E-02	8.31E-02	8.55E-02	7.53E-02	3.76E-02
1.40E+00	5.90E-02	7.00E-02	6.57E-02	5.12E-02	2.34E-02
1.60E+00	4.75E-02	6.38E-02	5.52E-02	4.43E-02	1.76E-02
1.80E+00	3.80E-02	5.64E-02	4.03E-02	2.79E-02	9.60E-03
2.00E+00	3.54E-02	4.71E-02	3.88E-02	2.59E-02	7.67E-03
2.30E+00	4.28E-02	5.58E-02	3.86E-02	2.28E-02	5.42E-03
2.60E+00	3.46E-02	4.62E-02	2.82E-02	1.40E-02	2.84E-03
3.00E+00	3.63E-02	4.19E-02	2.18E-02	8.50E-03	1.28E-03
3.50E+00	3.18E-02	3.47E-02	1.51E-02	4.62E-03	6.20E-04
4.00E+00	2.02E-02	1.88E-02	7.93E-03	2.63E-03	2.50E-04
4.50E+00	1.61E-02	1.20E-02	3.93E-03	1.44E-03	1.90E-04
5.00E+00	1.14E-02	9.68E-03	2.43E-03	5.00E-04	1.60E-04
6.00E+00	1.30E-02	1.01E-02	3.01E-03	1.12E-03	1.90E-04
7.00E+00	5.90E-03	5.19E-03	1.62E-03	5.00E-04	1.30E-04
8.00E+00	2.60E-03	2.75E-03	1.06E-03	5.00E-04	3.00E-05
9.00E+00	1.60E-03	1.94E-03	3.70E-04	6.00E-05	3.00E-05
1.00E+01	8.00E-04	3.80E-04	3.10E-04	1.30E-04	0.00E+00
1.10E+01	3.00E-04	3.70E-04	0.00E+00	6.00E-05	0.00E+00
1.20E+01	0.00E+00	6.00E-05	0.00E+00	0.00E+00	0.00E+00
1.30E+01	0.00E+00	6.00E-05	0.00E+00	0.00E+00	0.00E+00
1.40E+01	0.00E+00	6.00E-05	0.00E+00	0.00E+00	0.00E+00
1.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	Through 5 cm U-238	Through 10 cm U-238	Through 20 cm U-238	Through 30 cm U-238	Through 50 cm U-238
5.00E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-06
3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5.00E-04	0.00E+00	0.00E+00	3.32E-08	0.00E+00	0.00E+00
6.00E-04	0.00E+00	0.00E+00	1.70E-04	0.00E+00	0.00E+00
8.00E-04	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00
1.00E-03	0.00E+00	0.00E+00	0.00E+00	2.40E-06	2.32E-06
2.00E-03	0.00E+00	0.00E+00	2.92E-06	3.45E-06	2.65E-06
3.00E-03	0.00E+00	0.00E+00	9.00E-05	2.00E-05	2.78E-07
4.00E-03	5.00E-05	1.00E-05	4.00E-05	2.00E-05	1.00E-04
5.00E-03	0.00E+00	4.20E-04	1.90E-04	1.10E-04	6.00E-05
6.00E-03	0.00E+00	2.30E-04	2.80E-04	8.00E-05	2.00E-05
8.00E-03	1.40E-04	9.00E-05	5.40E-04	2.10E-04	1.10E-04
1.00E-02	4.10E-04	1.60E-04	2.30E-04	5.50E-04	7.00E-05
1.50E-02	6.30E-04	1.06E-03	1.67E-03	1.59E-03	6.40E-04
2.20E-02	1.33E-03	2.73E-03	5.29E-03	5.32E-03	1.39E-03
2.60E-02	4.90E-04	2.71E-03	3.69E-03	3.99E-03	8.10E-04
3.00E-02	1.18E-03	2.15E-03	4.25E-03	4.64E-03	1.09E-03
3.50E-02	1.44E-03	3.61E-03	7.49E-03	6.57E-03	1.99E-03

4.00E-02	2.27E-03	2.78E-03	7.82E-03	7.49E-03	1.47E-03
5.00E-02	2.52E-03	1.09E-02	1.83E-02	1.42E-02	2.92E-03
6.00E-02	4.43E-03	1.09E-02	1.48E-02	1.42E-02	2.92E-03
8.00E-02	8.95E-03	1.99E-02	3.17E-02	3.05E-02	5.52E-03
1.00E-01	8.75E-03	2.25E-02	3.26E-02	2.15E-02	3.01E-03
1.50E-01	3.18E-02	5.15E-02	6.33E-02	4.06E-02	7.10E-03
2.00E-01	3.25E-02	5.96E-02	5.75E-02	3.86E-02	4.49E-03
2.50E-01	3.39E-02	5.82E-02	6.09E-02	3.26E-02	3.17E-03
3.00E-01	4.05E-02	5.43E-02	5.71E-02	2.68E-02	2.37E-03
3.50E-01	4.29E-02	5.77E-02	4.79E-02	2.25E-02	3.04E-03
4.00E-01	4.49E-02	4.87E-02	4.14E-02	1.94E-02	1.52E-03
4.50E-01	3.73E-02	4.85E-02	3.72E-02	1.50E-02	1.85E-03
5.00E-01	4.05E-02	4.89E-02	3.28E-02	1.34E-02	1.41E-03
5.50E-01	3.99E-02	4.78E-02	3.06E-02	1.00E-02	3.50E-04
6.00E-01	3.70E-02	3.98E-02	2.58E-02	7.51E-03	4.50E-04
7.00E-01	6.80E-02	7.35E-02	3.42E-02	1.37E-02	8.70E-04
8.00E-01	5.25E-02	5.21E-02	2.14E-02	7.29E-03	5.90E-04
9.00E-01	4.82E-02	4.36E-02	1.73E-02	4.98E-03	1.20E-04
1.00E+00	4.43E-02	3.89E-02	1.45E-02	3.37E-03	6.80E-04
1.20E+00	7.60E-02	5.25E-02	1.52E-02	4.01E-03	0.00E+00
1.40E+00	4.98E-02	3.02E-02	9.96E-02	1.60E-03	0.00E+00
1.60E+00	3.98E-02	2.58E-02	6.37E-03	1.13E-03	0.00E+00
1.80E+00	3.43E-02	2.14E-02	5.16E-03	8.00E-04	1.10E-04
2.00E+00	2.98E-02	1.64E-02	3.01E-03	8.30E-04	1.90E-04
2.30E+00	3.90E-02	2.15E-02	3.59E-03	1.31E-03	0.00E+00
2.60E+00	4.01E-02	2.22E-02	4.33E-03	1.30E-04	3.10E-04
3.00E+00	3.38E-02	2.05E-02	3.12E-03	6.40E-04	0.00E+00
3.50E+00	3.81E-02	1.91E-02	5.81E-03	1.37E-03	0.00E+00
4.00E+00	2.26E-02	1.43E-02	1.35E-03	6.10E-04	0.00E+00
4.50E+00	1.70E-02	8.57E-03	1.77E-03	2.60E-04	0.00E+00
5.00E+00	1.15E-02	4.32E-03	1.34E-03	1.50E-04	0.00E+00
6.00E+00	1.64E-02	7.75E-03	1.53E-03	1.70E-04	0.00E+00
7.00E+00	6.06E-03	2.79E-03	1.32E-03	4.30E-04	0.00E+00
8.00E+00	4.82E-03	2.99E-03	6.50E-04	1.90E-04	0.00E+00
9.00E+00	1.81E-03	1.70E-04	0.00E+00	4.00E-05	0.00E+00
1.00E+01	2.50E-04	5.60E-04	1.20E-04	0.00E+00	0.00E+00
1.10E+01	0.00E+00	2.50E-04	1.70E-04	0.00E+00	0.00E+00
1.20E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.40E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	H ₂ O Moderated through 2 cm Iron	H ₂ O Moderated through 20 cm Iron	H ₂ O Moderated through 50 cm Iron
5.00E-06	5.60E-02	5.46E-03	3.00E-04
1.00E-05	2.41E-02	5.79E-03	3.30E-04
4.00E-05	4.82E-02	1.48E-02	1.05E-03
8.00E-05	2.62E-02	6.72E-03	6.80E-04
1.00E-04	6.76E-03	1.97E-03	1.50E-04

2.00E-04	2.53E-02	6.45E-03	5.00E-04
3.00E-04	1.35E-02	4.38E-03	3.70E-04
4.00E-04	1.15E-02	2.54E-03	3.90E-04
5.00E-04	7.54E-03	2.14E-03	2.70E-04
6.00E-04	5.41E-03	1.86E-03	2.60E-04
8.00E-04	9.49E-03	3.31E-03	3.30E-04
1.00E-03	8.70E-03	2.92E-03	2.60E-04
2.00E-03	2.68E-02	1.10E-02	1.17E-03
3.00E-03	1.43E-02	7.78E-03	1.08E-03
4.00E-03	9.93E-02	4.83E-03	8.50E-04
5.00E-03	7.50E-03	4.08E-03	1.32E-03
6.00E-03	8.68E-03	2.10E-03	6.30E-04
8.00E-03	1.04E-02	1.03E-03	5.10E-04
1.00E-02	5.56E-03	7.80E-04	3.40E-04
1.50E-02	1.53E-02	4.83E-03	2.76E-03
2.20E-02	1.56E-02	1.23E-02	9.81E-02
2.60E-02	1.41E-02	4.76E-02	3.01E-02
3.00E-02	2.32E-03	3.00E-04	3.00E-05
3.50E-02	4.13E-03	4.40E-04	1.50E-04
4.00E-02	4.62E-03	9.93E-03	1.00E-04
5.00E-02	8.81E-03	1.84E-03	2.00E-04
6.00E-02	7.22E-03	9.00E-04	1.30E-04
8.00E-02	1.35E-02	2.17E-03	5.90E-04
1.00E-01	8.26E-03	2.90E-03	1.04E-03
1.50E-01	2.41E-02	2.05E-02	9.77E-03
2.00E-01	2.10E-02	2.62E-02	1.34E-02
2.50E-01	1.86E-02	2.28E-02	1.07E-02
3.00E-01	1.56E-02	3.15E-02	1.59E-02
3.50E-01	1.68E-02	5.29E-02	2.16E-02
4.00E-01	1.39E-02	2.44E-02	5.07E-03
4.50E-01	1.38E-02	9.76E-03	1.45E-03
5.00E-01	1.56E-02	1.78E-02	2.90E-03
5.50E-01	1.06E-02	1.39E-02	2.48E-03
6.00E-01	1.30E-02	1.81E-02	2.75E-03
7.00E-01	2.94E-02	3.72E-02	4.16E-03
8.00E-01	1.94E-02	1.01E-02	7.40E-04
9.00E-01	1.96E-02	1.26E-02	9.79E-03
1.00E+00	1.97E-02	1.29E-02	8.90E-04
1.20E+00	3.32E-02	1.59E-02	4.70E-04
1.40E+00	3.18E-02	1.04E-02	4.20E-04
1.60E+00	2.48E-02	7.68E-03	3.20E-04
1.80E+00	2.84E-02	6.50E-03	1.40E-04
2.00E+00	2.14E-02	4.28E-03	1.80E-04
2.30E+00	2.53E-02	4.43E-03	0.00E+00
2.60E+00	1.48E-02	2.91E-03	6.00E-05
3.00E+00	2.59E-02	2.90E-03	3.00E-05
3.50E+00	1.94E-02	2.05E-03	0.00E+00
4.00E+00	1.75E-02	1.38E-03	3.00E-05
4.50E+00	1.08E-02	9.10E-04	0.00E+00
5.00E+00	1.11E-02	6.40E-04	3.00E-05

6.00E+00	1.01E-02	1.02E-03	0.00E+00
7.00E+00	4.84E-03	3.20E-04	0.00E+00
8.00E+00	3.79E-03	2.30E-04	2.00E-05
9.00E+00	1.80E-03	3.00E-05	0.00E+00
1.00E+01	1.48E-03	0.00E+00	0.00E+00
1.10E+01	1.80E-04	0.00E+00	0.00E+00
1.20E+01	1.80E-04	0.00E+00	0.00E+00
1.30E+01	0.00E+00	0.00E+00	0.00E+00
1.40E+01	0.00E+00	0.00E+00	0.00E+00
1.50E+01	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	H ₂ O Moderated through 5 cm Copper	H ₂ O Moderated through 10 cm Copper	H ₂ O Moderated through 20 cm Copper	H ₂ O Moderated through 30 cm Copper	H ₂ O Moderated through 50 cm Copper
5.00E-06	1.67E-02	1.82E-02	4.88E-03	1.33E-03	1.60E-04
1.00E-05	1.88E-02	1.37E-02	4.98E-03	1.51E-03	2.20E-04
4.00E-05	3.99E-02	3.06E-02	1.17E-02	3.20E-03	7.90E-04
8.00E-05	2.19E-02	1.80E-02	5.26E-03	1.71E-03	5.80E-04
1.00E-04	7.54E-03	5.33E-03	1.32E-03	5.40E-04	2.50E-04
2.00E-04	2.19E-02	1.35E-02	4.26E-03	1.90E-03	8.40E-04
3.00E-04	1.23E-02	7.87E-03	2.87E-03	1.64E-03	8.30E-04
4.00E-04	9.35E-03	5.84E-03	2.46E-03	1.60E-03	8.80E-04
5.00E-04	7.25E-03	3.95E-03	2.02E-03	1.37E-03	6.90E-04
6.00E-04	3.66E-03	2.81E-03	1.73E-03	1.52E-03	7.30E-04
8.00E-04	8.06E-03	6.24E-03	4.60E-03	4.17E-03	2.32E-03
1.00E-03	6.36E-03	6.31E-03	4.89E-03	4.66E-03	1.99E-03
2.00E-03	3.42E-02	2.89E-02	2.47E-02	2.00E-02	1.03E-02
3.00E-03	6.57E-03	4.58E-03	3.78E-03	3.50E-03	1.70E-03
4.00E-03	1.01E-02	1.11E-02	9.58E-03	9.03E-03	4.26E-03
5.00E-03	6.87E-03	7.36E-03	7.12E-03	6.27E-03	2.77E-03
6.00E-03	4.94E-03	5.07E-03	4.30E-03	3.90E-03	1.97E-03
8.00E-03	1.54E-02	2.00E-02	2.37E-02	2.06E-02	9.18E-03
1.00E-02	7.92E-03	6.90E-03	5.76E-03	5.31E-03	1.87E-03
1.50E-02	1.45E-02	1.30E-02	1.15E-02	1.10E-02	3.20E-03
2.20E-02	1.69E-02	1.36E-02	1.22E-02	1.05E-02	3.37E-03
2.60E-02	3.73E-03	2.92E-03	3.61E-03	3.04E-03	6.40E-04
3.00E-02	2.66E-03	2.25E-03	2.89E-03	2.43E-03	5.10E-04
3.50E-02	5.69E-03	4.96E-03	6.61E-03	6.17E-03	1.96E-03
4.00E-02	4.75E-03	4.01E-03	6.26E-03	6.09E-03	1.47E-03
5.00E-02	9.15E-03	1.07E-02	1.53E-02	1.17E-02	3.55E-03
6.00E-02	9.37E-03	9.99E-02	1.38E-02	1.17E-02	3.37E-03
8.00E-02	1.69E-02	1.92E-02	2.22E-02	1.81E-02	4.32E-03
1.00E-01	1.31E-02	1.55E-02	1.96E-02	1.24E-02	4.08E-03
1.50E-01	3.31E-02	3.36E-02	4.03E-02	3.02E-02	6.85E-03
2.00E-01	2.64E-02	3.25E-02	3.68E-02	2.45E-02	3.77E-03
2.50E-01	2.34E-02	2.92E-02	2.72E-02	1.68E-02	2.90E-03
3.00E-01	2.04E-02	2.70E-02	2.59E-02	1.63E-02	1.88E-03
3.50E-01	2.11E-02	2.36E-02	2.36E-02	1.36E-02	1.99E-03

4.00E-01	2.04E-02	2.58E-02	2.46E-02	1.22E-02	1.47E-03
4.50E-01	2.19E-02	2.79E-02	2.14E-02	1.17E-02	1.44E-03
5.00E-01	1.67E-02	1.98E-02	1.53E-02	7.51E-03	9.50E-04
5.50E-01	1.60E-02	1.86E-02	1.37E-02	6.96E-03	3.90E-04
6.00E-01	1.77E-02	1.98E-02	1.46E-02	5.09E-03	1.08E-03
7.00E-01	2.79E-02	2.94E-02	1.91E-02	8.00E-03	6.40E-04
8.00E-01	2.54E-02	2.60E-02	1.58E-02	5.17E-03	3.40E-04
9.00E-01	2.40E-02	2.14E-02	1.28E-02	3.84E-03	2.90E-04
1.00E+00	1.99E-02	1.88E-02	7.83E-03	2.78E-03	2.30E-04
1.20E+00	3.14E-02	2.84E-02	1.03E-02	3.74E-03	1.20E-04
1.40E+00	2.94E-02	2.07E-02	6.17E-03	1.51E-03	6.00E-05
1.60E+00	2.00E-02	1.26E-02	4.03E-03	1.32E-03	0.00E+00
1.80E+00	1.85E-02	1.19E-02	3.04E-03	7.10E-04	0.00E+00
2.00E+00	1.56E-02	9.48E-03	2.96E-03	4.80E-04	0.00E+00
2.30E+00	1.82E-02	1.10E-02	2.24E-03	7.20E-04	0.00E+00
2.60E+00	1.14E-02	6.73E-03	1.92E-03	5.20E-04	0.00E+00
3.00E+00	1.72E-02	9.37E-03	1.33E-03	4.10E-04	0.00E+00
3.50E+00	1.44E-02	6.35E-03	1.56E-03	2.40E-04	6.00E-05
4.00E+00	1.28E-02	5.30E-03	1.12E-03	6.00E-05	0.00E+00
4.50E+00	8.12E-03	3.52E-03	5.90E-04	5.00E-05	0.00E+00
5.00E+00	6.10E-03	3.60E-03	5.90E-04	5.00E-05	0.00E+00
6.00E+00	5.58E-03	3.15E-03	7.50E-04	1.70E-04	5.00E-05
7.00E+00	3.92E-03	1.57E-03	2.90E-04	1.10E-04	6.00E-05
8.00E+00	2.15E-03	1.01E-03	2.30E-04	5.00E-05	0.00E+00
9.00E+00	8.60E-04	2.40E-04	0.00E+00	5.00E-05	0.00E+00
1.00E+01	4.20E-04	1.70E-04	1.70E-04	0.00E+00	0.00E+00
1.10E+01	1.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.20E+01	6.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.40E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	H ₂ O Moderated through 5 cm Lead	H ₂ O Moderated through 10 cm Lead	H ₂ O Moderated through 30 cm Lead	H ₂ O Moderated through 50 cm Lead
5.00E-06	5.94E-02	5.55E-02	4.93E-02	3.73E-02
1.00E-05	2.61E-02	2.34E-02	2.11E-02	1.68E-02
4.00E-05	5.03E-02	5.09E-02	4.34E-02	3.48E-02
8.00E-05	2.47E-02	2.47E-02	2.14E-02	1.75E-02
1.00E-04	7.63E-03	7.88E-03	7.56E-03	6.43E-03
2.00E-04	2.54E-02	2.59E-02	2.12E-02	1.97E-02
3.00E-04	1.41E-02	1.38E-02	1.16E-02	1.19E-02
4.00E-04	1.09E-02	1.05E-02	8.86E-03	9.46E-03
5.00E-04	6.92E-03	7.59E-03	8.14E-03	7.27E-03
6.00E-04	5.29E-03	5.38E-03	5.32E-03	7.17E-03
8.00E-04	9.67E-03	8.69E-03	1.67E-02	1.00E-02
1.00E-03	8.19E-03	8.10E-03	8.52E-03	8.03E-03
2.00E-03	2.51E-02	2.66E-02	2.35E-02	2.34E-02
3.00E-03	1.51E-02	1.46E-02	1.26E-02	1.40E-02

4.00E-03	1.02E-02	9.98E-02	1.06E-02	1.01E-02
5.00E-03	9.51E-03	7.81E-03	7.65E-03	8.72E-03
6.00E-03	6.13E-03	6.36E-03	6.34E-03	6.96E-03
8.00E-03	1.03E-02	1.04E-02	1.12E-02	1.17E-02
1.00E-02	8.17E-03	8.06E-03	7.99E-03	9.46E-03
1.50E-02	1.51E-02	1.61E-02	1.53E-02	1.90E-02
2.20E-02	1.66E-02	1.53E-02	1.65E-02	2.17E-02
2.60E-02	7.30E-03	5.85E-03	8.27E-03	1.08E-02
3.00E-02	5.92E-03	5.72E-03	9.20E-03	1.02E-02
3.50E-02	5.50E-03	6.91E-03	1.08E-02	1.26E-02
4.00E-02	6.85E-03	6.88E-03	8.23E-03	1.00E-02
5.00E-02	9.24E-03	9.77E-02	8.72E-03	1.12E-02
6.00E-02	9.55E-03	9.85E-02	1.13E-02	1.39E-02
8.00E-02	1.37E-02	1.46E-02	1.57E-02	1.73E-02
1.00E-01	1.12E-02	1.35E-02	1.64E-02	1.74E-02
1.50E-01	2.65E-02	2.76E-02	3.30E-02	3.60E-02
2.00E-01	2.07E-02	2.40E-02	3.02E-02	3.28E-02
2.50E-01	1.96E-02	1.89E-02	2.79E-02	2.97E-02
3.00E-01	1.64E-02	1.75E-02	2.37E-02	2.35E-02
3.50E-01	1.71E-02	1.82E-02	2.34E-02	2.45E-02
4.00E-01	1.24E-02	1.33E-02	1.71E-02	1.90E-02
4.50E-01	1.30E-02	1.40E-02	2.17E-02	2.80E-02
5.00E-01	1.62E-02	1.78E-02	3.02E-02	4.09E-02
5.50E-01	1.24E-02	1.63E-02	3.07E-02	3.01E-02
6.00E-01	1.30E-02	1.44E-02	2.05E-02	1.96E-02
7.00E-01	2.65E-02	3.13E-02	4.04E-02	2.81E-02
8.00E-01	2.14E-02	2.64E-02	3.18E-02	2.10E-02
9.00E-01	2.33E-02	2.33E-02	2.18E-02	1.24E-02
1.00E+00	2.20E-02	2.32E-02	2.12E-02	1.30E-02
1.20E+00	3.48E-02	3.81E-02	3.30E-02	1.74E-02
1.40E+00	3.35E-02	3.39E-02	2.42E-02	1.06E-02
1.60E+00	2.30E-02	2.51E-02	1.87E-02	7.21E-03
1.80E+00	2.51E-02	2.31E-02	1.17E-02	3.49E-03
2.00E+00	2.40E-02	2.24E-02	1.20E-02	3.84E-03
2.30E+00	2.73E-02	2.61E-02	9.29E-03	2.77E-03
2.60E+00	1.95E-02	1.85E-02	5.84E-03	1.34E-03
3.00E+00	2.49E-02	1.90E-02	3.94E-03	4.10E-04
3.50E+00	1.93E-02	1.59E-02	2.40E-03	1.60E-04
4.00E+00	1.87E-02	1.07E-02	1.31E-03	2.20E-04
4.50E+00	9.56E-03	5.50E-03	8.40E-04	9.00E-05
5.00E+00	8.57E-03	5.37E-03	5.30E-04	3.00E-05
6.00E+00	8.31E-03	5.56E-03	5.30E-04	6.00E-05
7.00E+00	4.69E-03	3.87E-03	3.70E-04	9.00E-05
8.00E+00	3.38E-03	1.87E-03	2.50E-04	0.00E+00
9.00E+00	1.25E-03	1.00E-02	1.20E-04	3.00E-05
1.00E+01	1.19E-03	4.40E-04	9.00E-05	0.00E+00
1.10E+01	3.10E-04	6.00E-05	0.00E+00	0.00E+00
1.20E+01	6.00E-05	1.30E-04	0.00E+00	0.00E+00
1.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.40E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

1.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
----------	----------	----------	----------	----------

Energy in MeV	H ₂ O Moderated through 2.5 cm Beryllium	H ₂ O Moderated through 5 cm Beryllium	H ₂ O Moderated through 10 cm Beryllium	H ₂ O Moderated through 20 cm Beryllium
1.87E-07	9.84E-01	8.45E-02	7.32E-02	8.15E-02
2.49E-07	2.61E-03	1.85E-03	1.27E-03	8.60E-04
4.99E-07	6.60E-03	4.64E-03	6.32E-03	4.24E-03
1.00E-06	6.85E-03	4.79E-03	0.00E+00	0.00E+00
2.00E-06	7.00E-03	4.88E-03	3.38E-03	2.17E-03
5.00E-06	9.35E-03	6.59E-03	4.65E-03	2.90E-03
1.00E-05	7.49E-03	5.33E-03	3.81E-03	2.30E-03
2.20E-05	8.83E-03	6.28E-03	4.52E-03	2.63E-03
4.70E-05	8.73E-03	6.18E-03	4.50E-03	2.51E-03
1.00E-04	8.91E-03	6.37E-03	4.71E-03	2.51E-03
2.14E-04	8.98E-03	6.52E-03	4.94E-03	2.49E-03
4.65E-04	9.47E-03	6.93E-03	5.27E-03	2.50E-03
1.00E-03	9.57E-03	7.17E-03	5.56E-03	2.47E-03
2.00E-03	8.87E-03	7.54E-03	5.88E-03	2.42E-03
5.00E-03	1.20E-02	8.02E-03	6.23E-03	2.37E-03
1.00E-02	9.57E-03	8.58E-03	6.51E-03	2.28E-03
1.30E-02	3.70E-03	3.04E-03	2.26E-03	7.50E-04
1.60E-02	3.05E-03	2.51E-03	1.84E-03	5.90E-04
2.00E-02	3.39E-03	2.81E-03	2.02E-03	6.30E-04
2.50E-02	3.53E-03	2.90E-03	2.06E-03	6.30E-04
3.20E-02	4.10E-03	3.36E-03	2.34E-03	7.00E-04
4.00E-02	4.17E-03	3.44E-03	2.37E-03	6.90E-04
5.00E-02	4.44E-03	3.61E-03	2.43E-03	7.00E-04
6.30E-02	4.92E-03	3.98E-03	2.63E-03	7.30E-04
7.90E-02	5.21E-03	4.19E-03	2.69E-03	7.30E-04
1.00E-01	5.80E-03	4.62E-03	2.90E-03	7.70E-04
1.26E-01	6.08E-03	4.78E-03	2.94E-03	7.50E-04
1.58E-01	6.74E-03	5.30E-03	3.15E-03	7.90E-04
1.99E-01	8.10E-03	6.32E-03	3.67E-03	9.00E-04
2.51E-01	9.33E-03	7.15E-03	4.04E-03	9.70E-04
3.16E-01	1.10E-02	8.31E-03	4.58E-03	1.07E-03
3.98E-01	1.25E-02	9.27E-03	4.91E-03	1.11E-03
5.01E-01	1.39E-02	1.00E-02	5.09E-03	1.12E-03
6.31E-01	1.56E-02	1.09E-02	5.33E-03	1.15E-03
7.94E-01	1.74E-02	1.21E-02	5.84E-03	1.26E-03
1.00E+00	1.96E-02	1.35E-02	6.53E-03	1.42E-03
1.26E+00	2.30E-02	1.60E-02	7.81E-03	1.68E-03
1.58E+00	2.44E-02	1.74E-02	8.62E-03	1.95E-03
1.99E+00	2.82E-02	2.04E-02	1.04E-02	2.40E-03
2.51E+00	2.58E-02	1.78E-02	8.52E-03	1.87E-03
3.16E+00	1.96E-02	1.21E-02	4.77E-03	8.60E-04
3.98E+00	1.47E-02	7.66E-03	2.38E-03	2.50E-04
5.01E+00	1.09E-02	6.03E-03	2.08E-03	2.60E-04
6.31E+00	7.80E-03	5.44E-03	1.94E-03	3.00E-04

7.94E+00	5.03E-03	3.06E-03	1.19E-03	1.70E-04
1.00E+01	3.30E-04	1.60E-04	9.00E-05	2.00E-05
1.26E+01	1.00E-05	1.00E-05	1.00E-05	2.33E-06
1.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.99E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	H ₂ O Moderated through 2.5 cm Aluminum	H ₂ O Moderated through 5 cm Aluminum	H ₂ O Moderated through 10 cm Aluminum	H ₂ O Moderated through 20 cm Aluminum
1.87E-07	1.10E-01	9.20E-02	6.64E-02	3.69E-02
2.49E-07	5.01E-03	4.36E-03	3.39E-03	2.29E-03
4.99E-07	1.30E-02	2.25E-02	1.76E-02	1.19E-02
1.00E-06	1.37E-02	0.00E+00	0.00E+00	0.00E+00
2.00E-06	1.41E-02	1.23E-02	9.84E-02	6.91E-03
5.00E-06	1.91E-02	1.67E-02	1.34E-02	9.44E-03
1.00E-05	1.48E-02	1.30E-02	1.05E-02	7.42E-03
2.20E-05	1.77E-02	1.55E-02	1.25E-02	8.99E-03
4.70E-05	1.75E-02	1.54E-02	1.24E-02	8.96E-03
1.00E-04	1.81E-02	1.60E-02	1.29E-02	9.36E-03
2.14E-04	1.83E-02	1.62E-02	1.31E-02	9.49E-03
4.65E-04	1.93E-02	1.68E-02	1.37E-02	9.87E-02
1.00E-03	1.95E-02	1.72E-02	1.39E-02	1.01E-02
2.00E-03	1.98E-02	1.75E-02	1.42E-02	1.04E-02
5.00E-03	2.06E-02	1.84E-02	1.54E-02	1.17E-02
1.00E-02	1.80E-02	1.42E-02	9.80E-02	6.08E-03
1.30E-02	7.37E-03	6.90E-03	6.30E-03	6.22E-03
1.60E-02	6.52E-03	6.50E-03	6.71E-03	6.87E-03
2.00E-02	6.63E-03	6.40E-03	6.29E-03	1.00E-02
2.50E-02	5.87E-03	5.27E-03	4.82E-03	1.02E-02
3.20E-02	5.43E-03	4.25E-03	3.31E-03	1.33E-02
4.00E-02	4.80E-03	3.30E-03	2.12E-03	1.31E-02
5.00E-02	5.38E-03	3.86E-03	2.61E-03	1.03E-02
6.30E-02	6.31E-03	4.71E-03	3.35E-03	7.07E-03
7.90E-02	7.02E-03	5.41E-03	3.98E-03	3.28E-03
1.00E-01	7.59E-03	5.82E-03	4.27E-03	3.42E-03
1.26E-01	7.77E-03	5.87E-03	4.25E-03	3.40E-03
1.58E-01	8.35E-03	6.34E-03	4.62E-03	3.53E-03
1.99E-01	9.92E-02	7.77E-03	5.91E-03	4.48E-03
2.51E-01	1.15E-02	9.26E-03	7.22E-03	5.59E-03
3.16E-01	1.34E-02	1.11E-02	8.89E-03	6.91E-03
3.98E-01	1.54E-02	1.28E-02	1.02E-02	7.61E-03
5.01E-01	1.74E-02	1.45E-02	1.14E-02	8.15E-03
6.31E-01	1.98E-02	1.66E-02	1.29E-02	8.72E-03
7.94E-01	2.28E-02	1.94E-02	1.52E-02	9.95E-02
1.00E+00	2.58E-02	2.14E-02	1.64E-02	1.02E-02
1.26E+00	2.87E-02	2.43E-02	1.86E-02	1.10E-02
1.58E+00	2.97E-02	2.44E-02	1.74E-02	9.19E-03
1.99E+00	3.02E-02	2.40E-02	1.61E-02	7.41E-03
2.51E+00	2.97E-02	2.32E-02	1.48E-02	6.31E-03

3.16E+00	2.63E-02	2.05E-02	1.29E-02	5.20E-03
3.98E+00	2.14E-02	1.67E-02	1.03E-02	3.92E-03
5.01E+00	1.49E-02	1.16E-02	7.13E-03	2.69E-03
6.31E+00	9.09E-03	7.08E-03	4.31E-03	1.61E-03
7.94E+00	5.17E-03	3.95E-03	2.22E-03	7.70E-04
1.00E+01	2.65E-03	2.24E-03	1.37E-03	6.50E-04
1.26E+01	3.46E-06	1.13E-06	2.20E-04	8.00E-05
1.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.99E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Energy in MeV	H ₂ O Moderated through 10 cm Concrete	H ₂ O Moderated through 20 cm Concrete	H ₂ O Moderated through 30 cm Concrete	H ₂ O Moderated through 40 cm Concrete	H ₂ O Moderated through 60 cm Concrete
1.00E-05	8.11E-02	6.40E-02	3.68E-02	1.69E-02	2.80E-03
3.00E-05	3.66E-02	3.03E-02	1.61E-02	6.60E-03	1.10E-03
1.00E-04	4.20E-02	3.20E-02	1.64E-02	7.20E-03	9.90E-03
3.00E-04	3.91E-02	2.94E-02	1.53E-02	6.30E-03	9.00E-04
1.00E-03	4.32E-02	3.13E-02	1.58E-02	5.70E-03	9.00E-04
2.00E-03	2.47E-02	1.79E-02	7.60E-03	3.80E-03	5.00E-04
5.00E-03	3.22E-02	2.31E-02	1.02E-02	4.20E-03	6.00E-04
1.00E-02	2.61E-02	1.62E-02	8.20E-03	2.80E-03	5.00E-04
2.00E-02	2.66E-02	1.66E-02	7.30E-03	2.50E-03	5.00E-04
4.00E-02	2.85E-02	1.73E-02	7.00E-03	2.70E-03	5.00E-04
6.00E-02	1.91E-02	1.14E-02	4.50E-03	2.00E-03	3.00E-04
1.00E-01	2.59E-02	1.55E-02	6.10E-03	2.20E-03	5.00E-04
1.50E-01	2.60E-02	1.40E-02	6.00E-03	2.60E-03	4.00E-04
2.00E-01	1.90E-02	9.64E-03	3.90E-03	1.50E-03	3.00E-04
2.50E-01	1.14E-02	6.05E-03	2.00E-03	1.10E-03	1.00E-04
3.00E-01	1.28E-02	6.07E-03	2.50E-03	1.00E-03	3.00E-04
3.50E-01	1.10E-02	4.35E-03	2.40E-03	8.00E-04	1.00E-04
4.00E-01	7.78E-03	3.95E-03	1.60E-03	6.00E-04	1.00E-04
4.50E-01	4.00E-03	2.25E-03	1.00E-03	4.00E-04	1.00E-04
5.00E-01	6.88E-03	4.02E-03	1.40E-03	7.00E-04	1.00E-04
5.50E-01	1.01E-02	5.61E-03	2.70E-03	1.20E-03	2.00E-04
6.00E-01	1.01E-02	4.14E-03	2.60E-03	1.10E-03	1.00E-04
7.00E-01	1.93E-02	1.15E-02	5.00E-03	2.00E-03	4.00E-04
8.00E-01	2.16E-02	8.41E-03	3.90E-03	1.70E-03	4.00E-04
9.00E-01	1.31E-02	5.85E-03	2.00E-03	1.10E-03	2.00E-04
1.00E+00	6.14E-03	2.50E-03	1.10E-03	5.00E-04	1.00E-04
1.20E+00	1.79E-02	7.75E-03	3.60E-03	1.70E-03	4.00E-04
1.40E+00	1.68E-02	7.45E-03	3.30E-03	1.50E-03	3.00E-04
1.60E+00	1.58E-02	7.36E-03	3.50E-03	1.60E-03	2.00E-04
1.80E+00	1.58E-02	7.14E-03	3.80E-03	1.70E-03	3.00E-04
2.00E+00	1.16E-02	5.69E-03	3.10E-03	1.40E-03	3.00E-04
2.30E+00	2.14E-02	1.23E-02	7.10E-03	3.80E-03	9.00E-04
2.60E+00	1.95E-02	1.45E-02	9.10E-03	5.20E-03	1.20E-03
3.00E+00	2.25E-02	1.27E-02	6.90E-03	2.90E-03	6.00E-04
3.50E+00	1.65E-02	8.00E-03	3.60E-03	1.30E-03	3.00E-04

4.00E+00	1.11E-02	5.29E-03	2.00E-03	1.00E-03	2.00E-04
4.50E+00	8.50E-03	4.45E-03	2.10E-03	1.00E-03	2.00E-04
5.00E+00	6.72E-03	4.30E-03	2.20E-03	9.90E-03	2.00E-04
6.00E+00	8.10E-03	4.21E-03	2.20E-03	1.30E-03	2.00E-04
7.00E+00	4.72E-03	2.45E-03	1.40E-03	9.00E-04	1.00E-04
8.00E+00	2.63E-03	1.43E-03	6.00E-04	3.00E-04	1.00E-04
9.00E+00	1.14E-03	4.80E-04	3.00E-04	1.00E-04	8.60E-06
1.00E+01	6.30E-04	3.70E-04	2.00E-04	1.00E-04	1.73E-05
1.10E+01	1.20E-04	2.20E-04	3.74E-05	2.46E-05	1.48E-05
1.20E+01	3.00E-05	3.00E-05	0.00E+00	1.35E-05	0.00E+00
1.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.40E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.50E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Part 2. Available Neutron Spectrum from IAEA Report [19]

Table B1. ISO REFERENCE SPECTRA

Energy in eV	²⁵² Cf	D ₂ O moderated Cf	Am-Be	Am-B
1.00E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.64E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.64E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-07	0.00E+00	2.39E-02	0.00E+00	0.00E+00
4.64E-07	0.00E+00	2.41E-02	0.00E+00	0.00E+00
1.00E-06	0.00E+00	2.46E-02	0.00E+00	0.00E+00
2.15E-06	0.00E+00	2.56E-02	0.00E+00	0.00E+00
4.64E-06	0.00E+00	2.80E-02	0.00E+00	0.00E+00
1.00E-05	0.00E+00	3.35E-02	0.00E+00	0.00E+00
2.15E-05	0.00E+00	4.35E-02	0.00E+00	0.00E+00
4.64E-05	0.00E+00	5.15E-02	0.00E+00	0.00E+00
1.00E-04	0.00E+00	5.58E-02	0.00E+00	0.00E+00
2.15E-04	0.00E+00	6.38E-02	0.00E+00	0.00E+00
4.64E-04	0.00E+00	6.87E-02	0.00E+00	0.00E+00
1.00E-03	0.00E+00	7.80E-02	0.00E+00	0.00E+00
2.15E-03	0.00E+00	6.93E-02	0.00E+00	0.00E+00
4.64E-03	0.00E+00	8.51E-02	0.00E+00	0.00E+00
1.00E-02	9.22E-04	8.74E-02	0.00E+00	0.00E+00
1.25E-02	1.29E-03	8.95E-02	0.00E+00	0.00E+00
1.58E-02	1.79E-03	9.14E-02	0.00E+00	0.00E+00
1.99E-02	2.48E-03	8.76E-02	0.00E+00	0.00E+00
2.51E-02	3.39E-03	8.38E-02	0.00E+00	0.00E+00
3.16E-02	4.64E-03	8.32E-02	0.00E+00	0.00E+00
3.98E-02	6.38E-03	8.37E-02	0.00E+00	0.00E+00
5.01E-02	8.81E-03	8.29E-02	0.00E+00	0.00E+00
6.30E-02	1.21E-02	7.98E-02	0.00E+00	0.00E+00
7.94E-02	1.69E-02	7.54E-02	0.00E+00	0.00E+00
1.00E-01	2.37E-02	7.14E-02	1.66E-02	0.00E+00
1.25E-01	3.26E-02	6.80E-02	2.21E-02	0.00E+00
1.58E-01	4.45E-02	6.34E-02	2.87E-02	0.00E+00
1.99E-01	6.05E-02	5.91E-02	3.67E-02	0.00E+00
2.51E-01	8.22E-02	5.53E-02	4.65E-02	0.00E+00
3.16E-01	1.09E-01	4.56E-02	5.77E-02	0.00E+00
3.98E-01	1.45E-01	2.77E-02	7.06E-02	0.00E+00
5.01E-01	1.89E-01	5.44E-02	8.48E-02	0.00E+00
6.30E-01	2.41E-01	5.92E-02	9.61E-02	0.00E+00
7.94E-01	3.00E-01	4.92E-02	1.06E-01	5.19E-02
1.00E+00	3.59E-01	5.07E-02	1.18E-01	2.93E-02
1.25E+00	4.14E-01	7.32E-02	1.27E-01	1.18E-01
1.58E+00	4.52E-01	8.53E-02	1.81E-01	4.85E-01
1.99E+00	4.62E-01	1.20E-01	2.43E-01	1.06E+00

2.51E+00	4.34E-01	1.18E-01	4.21E-01	1.40E+00
3.16E+00	3.66E-01	7.69E-02	5.71E-01	8.43E-01
3.98E+00	2.71E-01	7.75E-02	6.86E-01	3.41E-01
5.01E+00	1.69E-01	5.18E-02	6.50E-01	5.67E-03
6.30E+00	8.61E-02	2.68E-02	5.78E-01	0.00E+00
7.94E+00	3.35E-02	1.06E-02	1.66E-01	0.00E+00
1.00E+01	4.27E-03	1.71E-03	1.72E-02	0.00E+00
1.58E+01	4.31E-04	0.00E+00	0.00E+00	0.00E+00
2.51E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

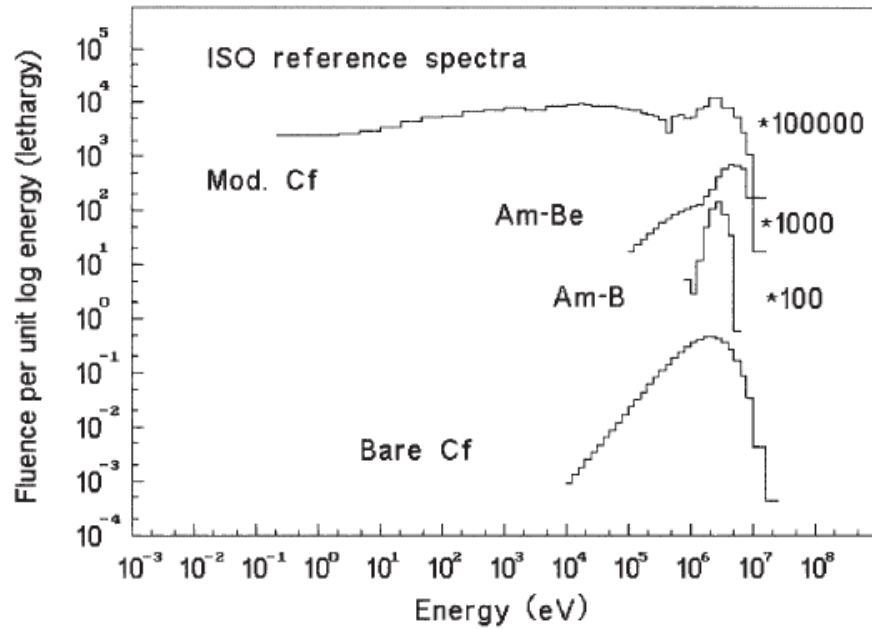


Figure B1. ISO reference spectra

Table B2. BARE Cf SPECTRA (PTB)

Energy in eV	Measured without shadow cone	Measured with shadow cone	The difference
1.00E-09	1.09E-03	2.41E-03	3.99E-05
2.15E-09	2.73E-03	5.94E-03	8.23E-05
4.64E-09	7.02E-03	1.48E-02	1.54E-04
1.00E-08	1.72E-02	3.47E-02	2.39E-04
2.15E-08	3.34E-02	6.39E-02	2.52E-04

4.64E-08	3.61E-02	6.67E-02	2.27E-04
1.00E-07	1.52E-02	2.88E-02	1.88E-04
2.15E-07	1.17E-02	2.28E-02	1.52E-04
4.64E-07	1.04E-02	2.01E-02	1.26E-04
1.00E-06	1.10E-02	2.12E-02	1.10E-04
2.15E-06	1.18E-02	2.25E-02	1.05E-04
4.64E-06	1.26E-02	2.41E-02	1.01E-04
1.00E-05	1.35E-02	2.59E-02	1.02E-04
2.15E-05	1.44E-02	2.78E-02	1.05E-04
4.64E-05	1.54E-02	3.02E-02	1.11E-04
1.00E-04	1.65E-02	3.25E-02	1.19E-04
2.15E-04	1.76E-02	3.51E-02	1.29E-04
4.64E-04	1.89E-02	3.79E-02	1.46E-04
1.00E-03	2.02E-02	4.10E-02	1.81E-04
2.15E-03	2.17E-02	4.42E-02	2.67E-04
4.64E-03	2.34E-02	4.78E-02	5.17E-04
1.00E-02	2.46E-02	5.05E-02	9.10E-04
1.25E-02	2.54E-02	5.17E-02	1.22E-03
1.58E-02	2.62E-02	5.30E-02	1.64E-03
1.99E-02	2.71E-02	5.42E-02	2.25E-03
2.51E-02	2.82E-02	5.56E-02	3.09E-03
3.16E-02	2.94E-02	5.70E-02	4.28E-03
3.98E-02	3.10E-02	5.87E-02	5.95E-03
5.01E-02	3.30E-02	6.03E-02	8.28E-03
6.30E-02	3.56E-02	6.20E-02	1.16E-02
7.94E-02	3.89E-02	6.39E-02	1.61E-02
1.00E-01	4.34E-02	6.60E-02	2.24E-02
1.25E-01	4.92E-02	6.83E-02	3.10E-02
1.58E-01	5.69E-02	7.13E-02	4.28E-02
1.99E-01	6.72E-02	7.45E-02	5.90E-02
2.51E-01	8.04E-02	7.83E-02	8.03E-02
3.16E-01	9.73E-02	8.27E-02	1.08E-01
3.98E-01	1.19E-01	8.81E-02	1.44E-01
5.01E-01	1.44E-01	9.44E-02	1.88E-01
6.30E-01	1.75E-01	1.02E-01	2.41E-01
7.94E-01	2.08E-01	1.10E-01	3.00E-01
1.00E+00	2.41E-01	1.19E-01	3.62E-01
1.25E+00	2.73E-01	1.28E-01	4.17E-01
1.58E+00	2.91E-01	1.33E-01	4.55E-01
1.99E+00	2.90E-01	1.24E-01	4.65E-01
2.51E+00	2.60E-01	9.37E-02	4.32E-01
3.16E+00	2.10E-01	6.64E-02	3.60E-01
3.98E+00	1.51E-01	4.87E-02	2.60E-01
5.01E+00	8.28E-02	2.53E-02	1.44E-01
6.30E+00	4.20E-02	1.33E-02	7.26E-02
7.94E+00	6.11E-03	4.11E-03	8.10E-03
1.00E+01	1.15E-02	5.23E-03	1.77E-02
1.58E+01	1.38E-02	4.30E-03	2.39E-02
2.51E+01	1.79E-05	4.57E-06	3.22E-05

3.98E+01	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00

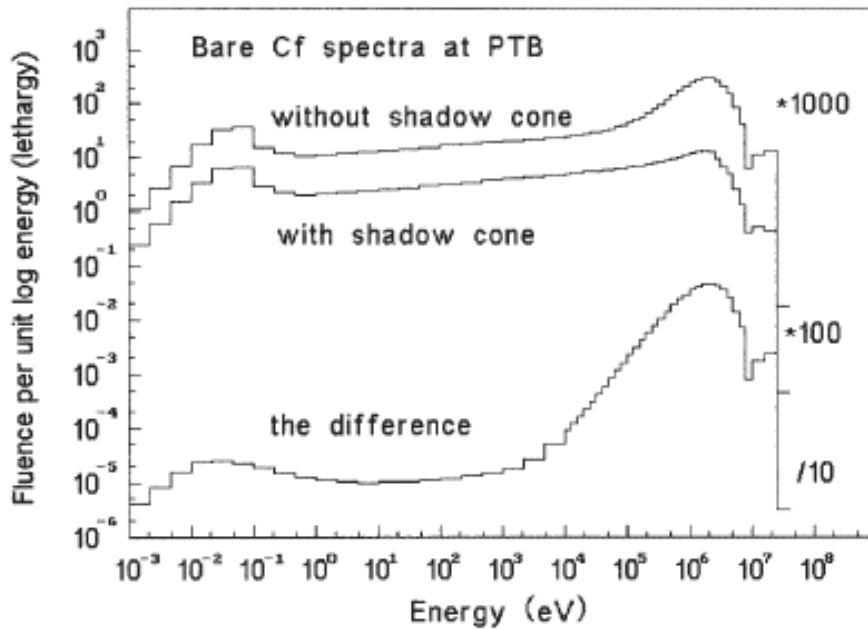


Figure B2. Unmoderated (bare) ^{252}Cf spectra (PTB).

Table B3. HEAVY WATER MODERATED Cf SPECTRA (PTB)

Energy in eV	Measured without shadow cone	Measured with shadow cone	The difference
1.00E-09	2.66E-03	6.70E-03	9.91E-05
2.15E-09	5.89E-03	1.41E-02	3.06E-04
4.64E-09	1.29E-02	2.82E-02	9.93E-04
1.00E-08	2.65E-02	5.04E-02	3.00E-03
2.15E-08	4.43E-02	6.98E-02	6.78E-03
4.64E-08	4.88E-02	7.69E-02	7.35E-03
1.00E-07	2.84E-02	6.34E-02	1.96E-03
2.15E-07	2.51E-02	6.15E-02	9.25E-04
4.64E-07	3.23E-02	6.07E-02	1.74E-02
1.00E-06	3.35E-02	6.02E-02	1.84E-02
2.15E-06	3.62E-02	5.87E-02	2.30E-02
4.64E-06	3.90E-02	5.72E-02	2.82E-02

1.00E-05	4.23E-02	5.55E-02	3.48E-02
2.15E-05	4.57E-02	5.37E-02	4.18E-02
4.64E-05	4.89E-02	5.19E-02	4.88E-02
1.00E-04	5.24E-02	5.01E-02	5.66E-02
2.15E-04	5.67E-02	4.84E-02	6.60E-02
4.64E-04	5.89E-02	4.66E-02	7.10E-02
1.00E-03	6.04E-02	4.49E-02	7.50E-02
2.15E-03	6.36E-02	4.33E-02	8.25E-02
4.64E-03	6.60E-02	4.17E-02	8.87E-02
1.00E-02	6.66E-02	4.07E-02	9.04E-02
1.25E-02	6.65E-02	4.03E-02	9.03E-02
1.58E-02	6.64E-02	3.98E-02	9.04E-02
1.99E-02	6.60E-02	3.93E-02	8.98E-02
2.51E-02	6.58E-02	3.88E-02	8.95E-02
3.16E-02	6.53E-02	3.84E-02	8.87E-02
3.98E-02	6.48E-02	3.79E-02	8.81E-02
5.01E-02	6.39E-02	3.74E-02	8.62E-02
6.30E-02	6.23E-02	3.69E-02	8.29E-02
7.94E-02	6.03E-02	3.65E-02	7.83E-02
1.00E-01	5.75E-02	3.59E-02	7.23E-02
1.25E-01	5.47E-02	3.54E-02	6.60E-02
1.58E-01	5.23E-02	3.48E-02	6.06E-02
1.99E-01	4.96E-02	3.43E-02	5.43E-02
2.51E-01	4.70E-02	3.36E-02	4.81E-02
3.16E-01	4.32E-02	3.29E-02	3.83E-02
3.98E-01	3.88E-02	3.23E-02	2.72E-02
5.01E-01	4.28E-02	3.16E-02	3.69E-02
6.30E-01	5.63E-02	3.09E-02	7.08E-02
7.94E-01	5.78E-02	3.03E-02	7.35E-02
1.00E+00	4.35E-02	2.96E-02	3.55E-02
1.25E+00	4.84E-02	2.90E-02	4.70E-02
1.58E+00	7.23E-02	2.78E-02	1.09E-01
1.99E+00	8.02E-02	2.32E-02	1.39E-01
2.51E+00	6.91E-02	1.40E-02	1.32E-01
3.16E+00	5.35E-02	7.60E-03	1.09E-01
3.98E+00	2.56E-02	5.75E-03	4.39E-02
5.01E+00	6.98E-03	2.79E-03	6.21E-03
6.30E+00	1.14E-02	1.46E-03	2.35E-02
7.94E+00	6.03E-03	1.20E-03	1.25E-02
1.00E+01	1.58E-03	1.08E-03	1.23E-03
1.58E+01	3.33E-03	4.41E-04	6.72E-03
2.51E+01	0.00E+00	0.00E+00	0.00E+00
3.98E+01	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00

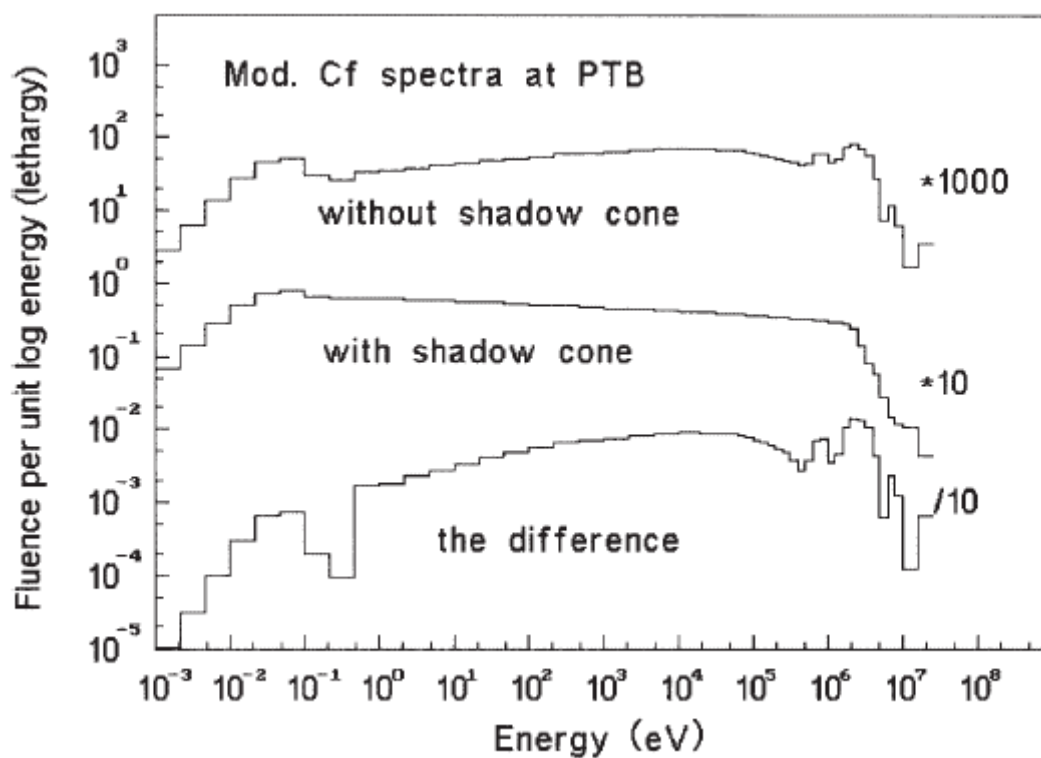


Figure B3. Unmoderated Heavy water (D₂O) moderated Cf spectra (PTB).

Table B4. MODERATED Cf SPECTRA (TOHOKO UNIVERSITY AND JINR)

Energy in eV	Fe moderated Cf	C moderated Cf	PE moderated Cf	PE moderated Cf, <i>D</i> = 29.2 cm	PE moderated Cf, <i>D</i> = 12.7 cm
1.00E-09	2.11E-11	4.67E-06	3.13E-02	0.00E+00	0.00E+00
2.15E-09	1.16E-10	6.83E-06	3.13E-02	0.00E+00	0.00E+00
4.64E-09	2.09E-10	1.14E-05	3.10E-02	1.83E-01	1.09E-01
1.00E-08	1.18E-09	2.12E-05	3.02E-02	1.61E-01	9.87E-02
2.15E-08	3.30E-09	4.16E-05	2.90E-02	1.39E-01	8.82E-02
4.64E-08	7.89E-09	8.32E-05	2.66E-02	1.14E-01	7.69E-02
1.00E-07	1.55E-08	2.22E-04	1.53E-02	8.94E-02	6.51E-02
2.15E-07	3.96E-08	2.96E-04	1.53E-02	6.29E-02	5.28E-02
4.64E-07	8.93E-08	4.22E-04	1.53E-02	3.42E-02	3.86E-02
1.00E-06	2.99E-07	6.08E-04	1.53E-02	1.14E-02	2.37E-02
2.15E-06	7.38E-07	8.74E-04	1.53E-02	2.04E-03	1.12E-02
4.64E-06	1.75E-06	1.25E-03	1.53E-02	9.39E-04	2.81E-03
1.00E-05	3.63E-06	1.80E-03	1.54E-02	7.65E-04	5.92E-04
2.15E-05	7.47E-06	2.59E-03	1.54E-02	8.48E-04	8.82E-04
4.64E-05	1.31E-05	3.72E-03	1.54E-02	8.94E-04	9.36E-04
1.00E-04	2.63E-05	5.32E-03	1.56E-02	9.09E-04	9.62E-04
2.15E-04	4.47E-05	7.62E-03	1.57E-02	9.16E-04	9.73E-04

4.64E-04	1.04E-04	1.09E-02	1.59E-02	9.16E-04	6.43E-04
1.00E-03	3.68E-04	1.54E-02	1.62E-02	9.32E-04	5.12E-03
2.15E-03	1.10E-03	2.18E-02	1.68E-02	9.85E-04	1.27E-02
4.64E-03	1.65E-03	3.07E-02	1.76E-02	7.47E-03	2.24E-02
1.00E-02	3.65E-03	3.81E-02	1.88E-02	1.32E-02	2.92E-02
1.25E-02	3.71E-03	4.18E-02	1.92E-02	1.61E-02	3.22E-02
1.58E-02	5.90E-03	4.56E-02	1.98E-02	1.92E-02	3.57E-02
1.99E-02	2.25E-02	5.04E-02	2.07E-02	2.24E-02	3.91E-02
2.51E-02	1.06E-02	5.52E-02	2.17E-02	2.58E-02	4.26E-02
3.16E-02	5.67E-03	6.03E-02	2.29E-02	2.90E-02	4.61E-02
3.98E-02	1.44E-02	6.59E-02	2.44E-02	3.26E-02	5.01E-02
5.01E-02	2.05E-02	7.19E-02	2.63E-02	3.61E-02	5.36E-02
6.30E-02	4.17E-02	7.85E-02	2.85E-02	3.96E-02	5.76E-02
7.94E-02	3.75E-02	8.55E-02	3.13E-02	4.29E-02	6.11E-02
1.00E-01	7.05E-02	9.44E-02	3.50E-02	4.63E-02	6.49E-02
1.25E-01	6.43E-02	1.03E-01	3.93E-02	4.94E-02	6.81E-02
1.58E-01	1.07E-01	1.07E-01	4.24E-02	5.28E-02	7.18E-02
1.99E-01	1.40E-01	1.25E-01	5.18E-02	5.60E-02	7.53E-02
2.51E-01	1.50E-01	1.38E-01	5.98E-02	5.97E-02	7.99E-02
3.16E-01	3.44E-01	1.56E-01	7.17E-02	6.34E-02	8.44E-02
3.98E-01	2.11E-01	1.73E-01	8.25E-02	6.80E-02	9.06E-02
5.01E-01	4.02E-01	1.97E-01	9.85E-02	7.26E-02	9.68E-02
6.30E-01	4.37E-01	2.24E-01	1.17E-01	7.73E-02	1.04E-01
7.94E-01	4.34E-01	2.59E-01	1.39E-01	8.18E-02	1.10E-01
1.00E+00	4.51E-01	2.97E-01	1.65E-01	8.56E-02	1.16E-01
1.25E+00	3.52E-01	3.31E-01	1.94E-01	8.79E-02	1.20E-01
1.58E+00	3.18E-01	3.43E-01	2.26E-01	8.86E-02	1.21E-01
1.99E+00	2.39E-01	2.86E-01	2.45E-01	8.63E-02	1.19E-01
2.51E+00	1.74E-01	1.69E-01	2.29E-01	8.18E-02	1.14E-01
3.16E+00	1.19E-01	9.76E-02	2.06E-01	7.48E-02	1.04E-01
3.98E+00	7.31E-02	1.41E-01	2.64E-01	6.54E-02	9.11E-02
5.01E+00	4.44E-02	9.13E-02	2.21E-01	5.28E-02	7.40E-02
6.30E+00	2.34E-02	5.33E-02	1.57E-01	4.01E-02	5.63E-02
7.94E+00	9.13E-03	1.45E-02	6.26E-02	2.58E-02	3.62E-02
1.00E+01	1.14E-03	1.43E-03	9.16E-03	2.00E-02	2.92E-02
1.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

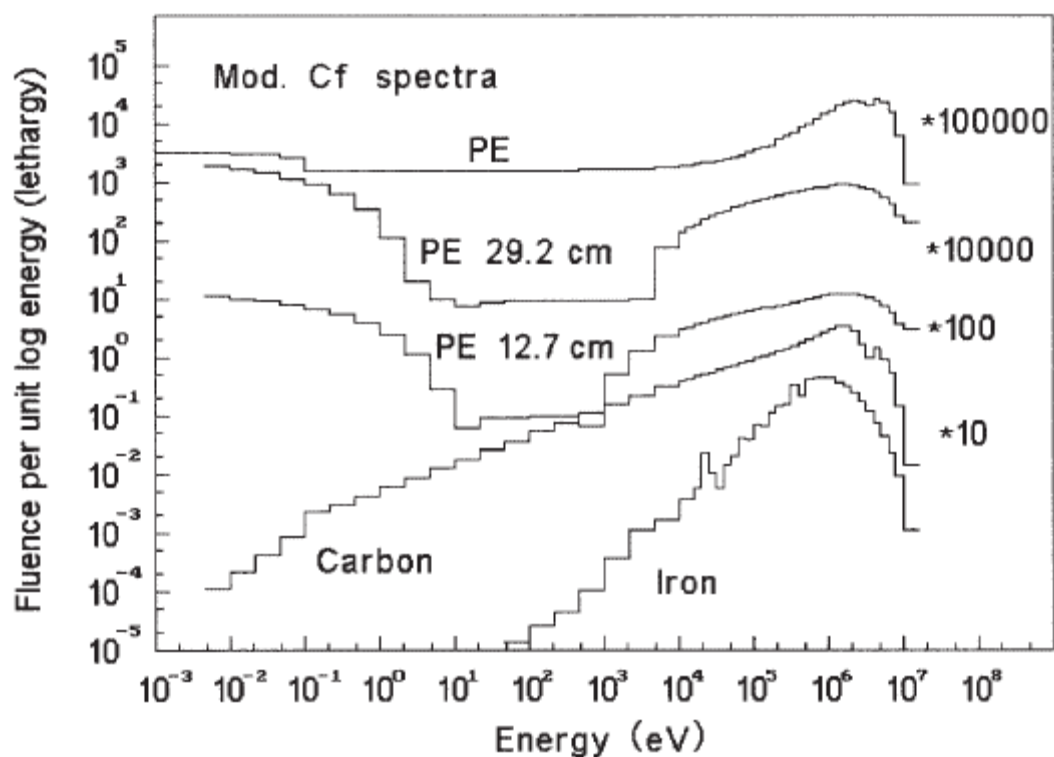


Figure B3. Moderated ^{252}Cf spectra (Tohoko University and JINR).

Table B4. ^{241}Am -Be spectra (PTB)

Energy in eV	Difference with and without shadow cone	Measured with shadow cone	Measured without shadow cone
1.00E-09	2.57E-05	4.96E-03	2.43E-03
2.15E-09	5.04E-05	1.02E-02	4.87E-03
4.64E-09	9.06E-05	1.97E-02	9.21E-03
1.00E-08	1.37E-04	3.36E-02	1.53E-02
2.15E-08	1.48E-04	4.38E-02	1.92E-02
4.64E-08	1.43E-04	4.50E-02	1.89E-02
1.00E-07	1.38E-04	3.49E-02	1.41E-02
2.15E-07	2.12E-04	3.25E-02	1.31E-02
4.64E-07	1.32E-03	2.78E-02	1.39E-02
1.00E-06	1.14E-03	2.90E-02	1.38E-02
2.15E-06	1.08E-03	3.02E-02	1.37E-02
4.64E-06	1.02E-03	3.13E-02	1.38E-02
1.00E-05	1.00E-03	3.22E-02	1.39E-02
2.15E-05	1.01E-03	3.29E-02	1.41E-02
4.64E-05	1.02E-03	3.36E-02	1.44E-02
1.00E-04	1.04E-03	3.41E-02	1.47E-02
2.15E-04	1.07E-03	3.46E-02	1.50E-02
4.64E-04	1.10E-03	3.51E-02	1.54E-02
1.00E-03	1.13E-03	3.56E-02	1.58E-02
2.15E-03	1.16E-03	3.60E-02	1.61E-02
4.64E-03	1.20E-03	3.66E-02	1.66E-02

1.00E-02	1.22E-03	3.70E-02	1.69E-02
1.25E-02	1.23E-03	3.73E-02	1.71E-02
1.58E-02	1.24E-03	3.75E-02	1.73E-02
1.99E-02	1.25E-03	3.79E-02	1.75E-02
2.51E-02	1.26E-03	3.83E-02	1.78E-02
3.16E-02	1.27E-03	3.89E-02	1.82E-02
3.98E-02	1.29E-03	3.97E-02	1.86E-02
5.01E-02	1.30E-03	4.07E-02	1.92E-02
6.30E-02	1.84E-03	4.20E-02	2.02E-02
7.94E-02	5.31E-03	4.37E-02	2.32E-02
1.00E-01	1.34E-02	4.62E-02	2.92E-02
1.25E-01	2.37E-02	4.93E-02	3.70E-02
1.58E-01	3.48E-02	5.36E-02	4.58E-02
1.99E-01	3.79E-02	6.00E-02	5.08E-02
2.51E-01	2.88E-02	6.88E-02	4.95E-02
3.16E-01	3.83E-02	7.89E-02	6.00E-02
3.98E-01	7.13E-02	8.99E-02	8.48E-02
5.01E-01	8.74E-02	1.04E-01	1.01E-01
6.30E-01	8.66E-02	1.20E-01	1.07E-01
7.94E-01	9.52E-02	1.36E-01	1.17E-01
1.00E+00	1.09E-01	1.49E-01	1.29E-01
1.25E+00	1.25E-01	1.55E-01	1.39E-01
1.58E+00	1.59E-01	1.44E-01	1.52E-01
1.99E+00	2.33E-01	1.28E-01	1.84E-01
2.51E+00	3.62E-01	1.10E-01	2.48E-01
3.16E+00	4.97E-01	8.45E-02	3.10E-01
3.98E+00	6.05E-01	6.74E-02	3.62E-01
5.01E+00	6.36E-01	4.75E-02	3.73E-01
6.30E+00	4.96E-01	3.74E-02	2.96E-01
7.94E+00	2.85E-01	2.46E-02	1.74E-01
1.00E+01	8.86E-02	6.84E-03	5.44E-02
1.58E+01	3.72E-02	6.31E-04	1.91E-02
2.51E+01	0.00E+00	0.00E+00	0.00E+00
3.98E+01	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00

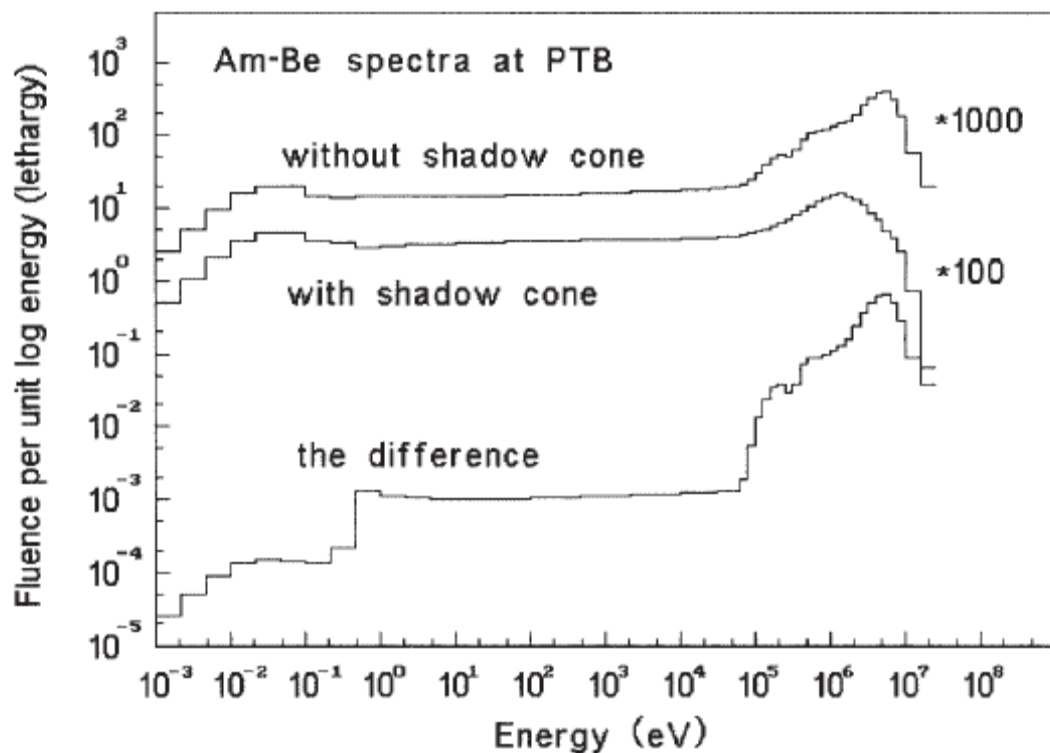


Figure B4. ^{241}Am -Be spectra (PTB).

Table B5. Pu-Be CALIBRATION SPECTRA (CERN)

Energy in eV	At 1 m distance	At 2 m distance	At 3 m distance	Shielded by PE, at 1 m distance	Shielded by PE, at 2 m distance
1.00E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-09	1.81E-02	8.83E-02	1.10E-01	1.71E-01	1.29E-01
4.64E-09	1.81E-02	8.63E-02	1.10E-01	1.61E-01	1.29E-01
1.00E-08	1.81E-02	8.23E-02	1.00E-01	1.51E-01	1.29E-01
2.15E-08	1.70E-02	7.42E-02	9.00E-02	1.31E-01	1.19E-01
4.64E-08	1.60E-02	5.91E-02	6.80E-02	9.59E-02	1.09E-01
1.00E-07	1.40E-02	3.41E-02	3.40E-02	3.53E-02	8.26E-02
2.15E-07	8.32E-03	1.40E-02	1.10E-02	2.52E-02	4.87E-02
4.64E-07	4.51E-03	1.30E-02	1.40E-02	7.37E-03	2.78E-02
1.00E-06	1.40E-02	4.11E-02	4.50E-02	4.24E-02	2.58E-02
2.15E-06	3.51E-03	8.93E-03	1.00E-02	9.80E-03	3.38E-02
4.64E-06	2.61E-03	7.42E-03	8.00E-03	4.45E-03	1.49E-02
1.00E-05	1.20E-02	3.31E-02	3.60E-02	2.22E-02	1.89E-02
2.15E-05	7.12E-03	1.90E-02	2.10E-02	1.51E-02	2.38E-02
4.64E-05	5.01E-03	1.30E-02	1.40E-02	1.11E-02	1.69E-02
1.00E-04	4.51E-03	1.20E-02	1.30E-02	9.59E-03	1.39E-02
2.15E-04	7.02E-03	1.70E-02	1.90E-02	1.51E-02	1.89E-02
4.64E-04	1.60E-02	3.41E-02	3.90E-02	3.33E-02	2.38E-02
1.00E-03	8.22E-03	1.70E-02	1.90E-02	1.61E-02	2.38E-02

2.15E-03	7.42E-03	1.40E-02	1.60E-02	1.31E-02	1.49E-02
4.64E-03	9.13E-03	1.60E-02	1.70E-02	1.41E-02	1.29E-02
1.00E-02	7.92E-03	1.30E-02	1.40E-02	1.21E-02	1.09E-02
1.25E-02	6.12E-03	1.00E-02	1.10E-02	9.09E-03	8.75E-03
1.58E-02	5.01E-03	8.03E-03	8.40E-03	7.07E-03	5.67E-03
1.99E-02	1.20E-03	2.00E-03	2.10E-03	1.71E-03	4.87E-03
2.51E-02	5.72E-03	8.83E-03	9.10E-03	7.58E-03	4.07E-03
3.16E-02	3.91E-03	5.51E-03	5.70E-03	4.65E-03	9.85E-03
3.98E-02	1.91E-02	2.81E-02	2.80E-02	2.22E-02	1.29E-02
5.01E-02	1.60E-02	2.10E-02	2.10E-02	1.61E-02	1.49E-02
6.30E-02	1.10E-02	1.40E-02	1.30E-02	1.01E-02	1.09E-02
7.94E-02	1.10E-02	1.20E-02	1.10E-02	8.08E-03	9.55E-03
1.00E-01	1.81E-02	2.00E-02	1.90E-02	1.41E-02	1.29E-02
1.25E-01	3.21E-02	3.41E-02	3.10E-02	2.22E-02	2.38E-02
1.58E-01	7.42E-02	7.42E-02	6.70E-02	4.75E-02	3.48E-02
1.99E-01	7.62E-02	7.32E-02	6.60E-02	4.65E-02	3.87E-02
2.51E-01	5.62E-02	5.11E-02	4.60E-02	3.03E-02	3.48E-02
3.16E-01	6.72E-02	5.61E-02	4.80E-02	3.03E-02	2.98E-02
3.98E-01	7.62E-02	6.01E-02	5.10E-02	3.13E-02	3.18E-02
5.01E-01	8.93E-02	6.61E-02	5.50E-02	3.23E-02	2.88E-02
6.30E-01	5.42E-02	3.91E-02	3.20E-02	1.92E-02	3.68E-02
7.94E-01	1.91E-01	1.30E-01	1.00E-01	5.96E-02	5.07E-02
1.00E+00	2.81E-01	1.70E-01	1.40E-01	7.68E-02	6.47E-02
1.25E+00	2.21E-01	1.30E-01	1.00E-01	5.86E-02	6.07E-02
1.58E+00	1.81E-01	1.00E-01	8.10E-02	4.55E-02	3.78E-02
1.99E+00	2.41E-02	1.30E-02	1.00E-02	5.86E-03	2.68E-02
2.51E+00	1.50E-01	7.42E-02	5.80E-02	3.33E-02	4.57E-02
3.16E+00	6.22E-01	2.91E-01	2.30E-01	1.31E-01	7.16E-02
3.98E+00	4.81E-01	2.10E-01	1.70E-01	1.01E-01	8.65E-02
5.01E+00	4.31E-01	1.80E-01	1.40E-01	8.89E-02	6.17E-02
6.30E+00	2.81E-01	1.10E-01	8.60E-02	5.66E-02	4.27E-02
7.94E+00	1.30E-01	5.01E-02	3.90E-02	2.62E-02	2.29E-02
1.00E+01	7.82E-03	3.01E-03	2.30E-03	1.51E-03	7.76E-03
1.58E+01	4.11E-04	1.40E-04	1.10E-04	8.08E-05	0.00E+00
2.51E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

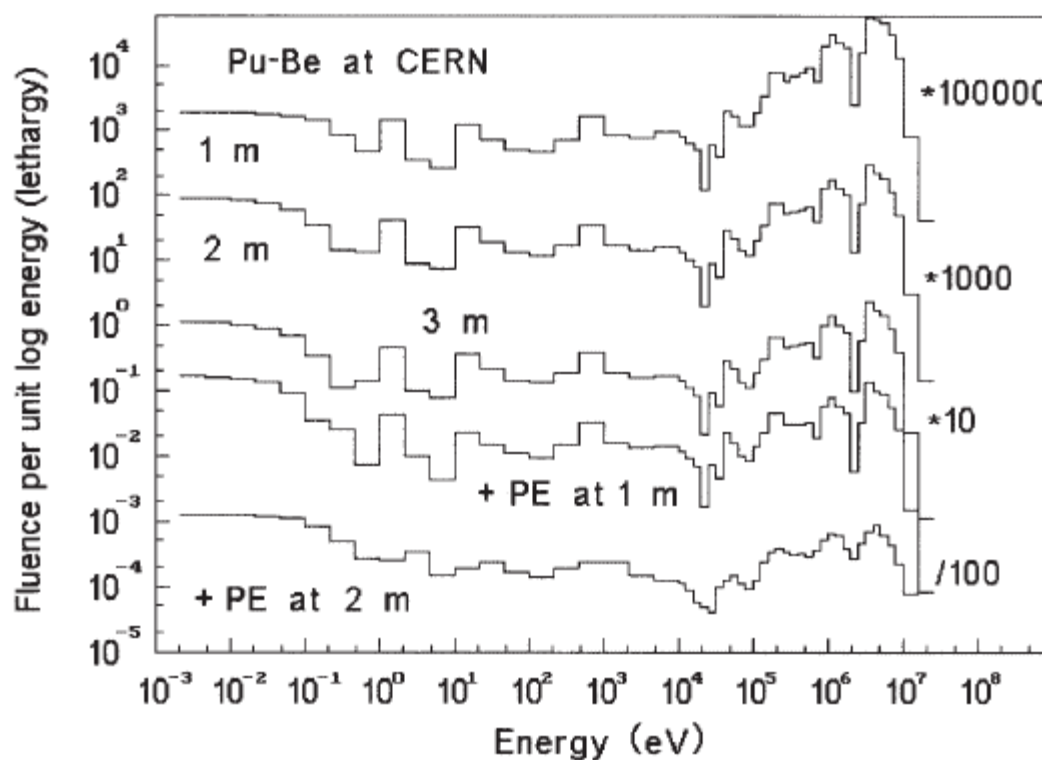


Figure B5. ^{238}Pu -Be calibration spectra (CERN).

Table B6. Pu SPECTRA (LLNL AND PNL)

Energy in eV	Bare Pu-Be source, room scatter	H2O moderated Pu- Be, R = 25 cm, room scatter	D2O moderated Pu- Be, R = 25 cm, room scatter	Bare PuO ₂ at 100 cm	Bare Pu metal at 50 cm
1.00E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.64E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-08	8.08E-03	5.42E-02	0.00E+00	0.00E+00	0.00E+00
2.15E-08	1.02E-02	8.29E-02	1.58E-01	0.00E+00	0.00E+00
4.64E-08	1.31E-02	1.02E-01	2.02E-01	0.00E+00	0.00E+00
1.00E-07	1.46E-02	1.12E-01	2.19E-01	3.04E-01	8.81E-02
2.15E-07	1.38E-02	9.02E-02	1.79E-01	1.46E-01	7.04E-02
4.64E-07	9.93E-03	2.70E-02	4.02E-02	2.78E-02	4.40E-02
1.00E-06	7.63E-03	1.54E-02	1.37E-02	1.18E-01	2.44E-02
2.15E-06	6.25E-03	1.07E-02	7.67E-03	1.85E-02	1.56E-02
4.64E-06	4.87E-03	6.26E-03	6.01E-03	1.39E-02	1.13E-02
1.00E-05	4.09E-03	6.62E-03	6.12E-03	1.05E-02	4.99E-03
2.15E-05	2.65E-03	5.58E-03	8.21E-03	7.56E-03	2.13E-03
4.64E-05	2.64E-03	6.47E-03	1.27E-02	5.20E-03	8.90E-04
1.00E-04	2.06E-03	7.20E-03	2.05E-02	4.66E-03	4.10E-04
2.15E-04	1.70E-03	8.40E-03	3.07E-02	3.61E-03	9.15E-05
4.64E-04	1.38E-03	1.04E-02	4.09E-02	2.82E-03	2.99E-05

1.00E-03	1.32E-03	1.11E-02	4.33E-02	2.24E-03	9.49E-06
2.15E-03	1.27E-03	1.19E-02	3.54E-02	2.78E-03	5.49E-06
4.64E-03	1.33E-03	1.18E-02	2.69E-02	3.71E-03	4.75E-06
1.00E-02	1.45E-03	1.18E-02	2.18E-02	3.83E-03	5.82E-06
1.25E-02	1.63E-03	1.14E-02	1.73E-02	4.21E-03	7.58E-06
1.58E-02	1.64E-03	1.05E-02	1.52E-02	5.05E-03	9.91E-06
1.99E-02	1.72E-03	1.08E-02	1.43E-02	5.91E-03	1.38E-05
2.51E-02	1.88E-03	1.13E-02	1.36E-02	6.89E-03	1.98E-05
3.16E-02	2.14E-03	1.11E-02	1.23E-02	8.01E-03	2.94E-05
3.98E-02	2.32E-03	1.14E-02	1.12E-02	9.42E-03	4.68E-05
5.01E-02	2.65E-03	1.23E-02	9.78E-03	1.16E-02	8.12E-05
6.30E-02	3.38E-03	1.21E-02	9.13E-03	1.48E-02	1.49E-04
7.94E-02	4.15E-03	1.25E-02	9.77E-03	1.95E-02	3.11E-04
1.00E-01	5.11E-03	1.32E-02	1.05E-02	2.61E-02	7.66E-04
1.25E-01	6.42E-03	1.42E-02	9.23E-03	3.60E-02	1.85E-03
1.58E-01	8.05E-03	1.49E-02	9.63E-03	5.06E-02	4.64E-03
1.99E-01	1.02E-02	1.57E-02	1.03E-02	7.18E-02	1.30E-02
2.51E-01	1.49E-02	1.76E-02	1.13E-02	1.02E-01	3.37E-02
3.16E-01	1.60E-02	1.87E-02	1.30E-02	1.44E-01	7.69E-02
3.98E-01	2.53E-02	2.24E-02	1.63E-02	1.88E-01	1.33E-01
5.01E-01	3.52E-02	3.25E-02	1.96E-02	2.18E-01	2.13E-01
6.30E-01	4.97E-02	3.86E-02	2.40E-02	1.99E-01	3.10E-01
7.94E-01	7.87E-02	5.22E-02	3.23E-02	1.93E-01	4.22E-01
1.00E+00	1.20E-01	6.73E-02	4.78E-02	1.74E-01	4.94E-01
1.25E+00	1.22E-01	1.04E-01	6.38E-02	1.64E-01	4.07E-01
1.58E+00	2.39E-01	1.51E-01	8.24E-02	1.08E-01	3.51E-01
1.99E+00	4.06E-01	2.27E-01	9.36E-02	5.52E-02	2.44E-01
2.51E+00	4.57E-01	3.01E-01	8.39E-02	7.71E-02	1.47E-01
3.16E+00	6.83E-01	2.80E-01	8.41E-02	3.52E-02	1.26E-01
3.98E+00	5.96E-01	2.84E-01	6.22E-02	5.55E-03	8.65E-02
5.01E+00	5.67E-01	2.77E-01	2.17E-02	3.20E-02	7.61E-02
6.30E+00	4.64E-01	2.73E-01	6.09E-03	3.52E-02	8.06E-02
7.94E+00	5.20E-02	7.04E-02	1.68E-03	4.20E-02	1.13E-01
1.00E+01	3.38E-03	7.87E-03	7.60E-04	1.48E-02	2.76E-02
1.58E+01	3.38E-04	8.03E-04	0.00E+00	1.54E-02	3.76E-02
2.51E+01	0.00E+00	0.00E+00	0.00E+00	1.70E-04	1.91E-04
3.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

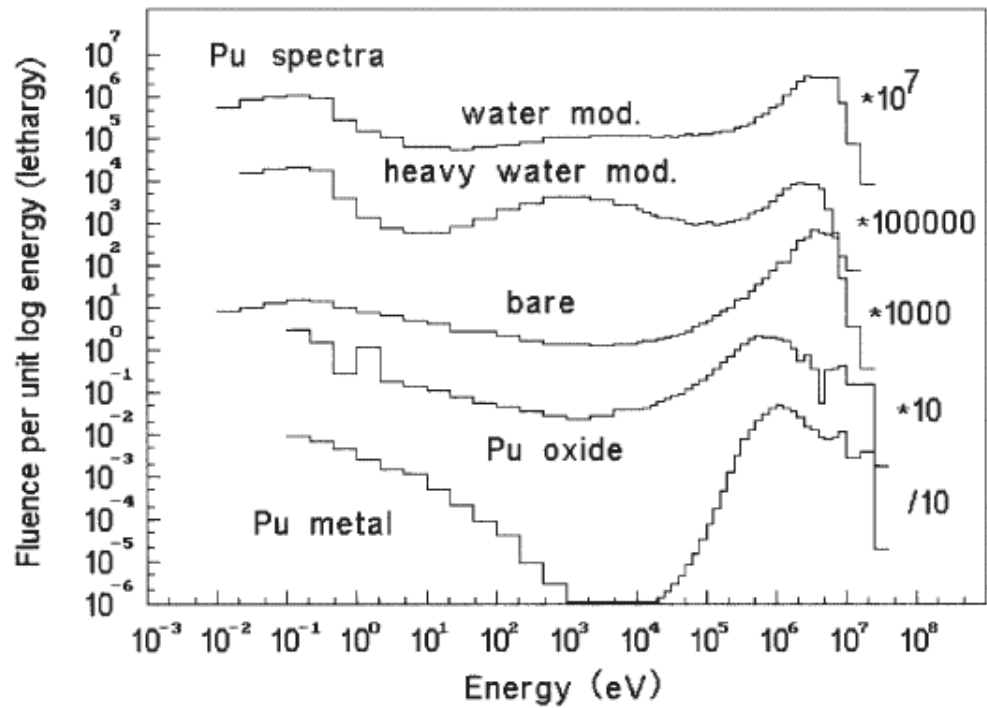


Figure B6. Pu spectra (LLNL and PNL).

Table B7. Pu FLUORIDE SPECTRA (PNL)

Energy in eV	Bare at 50 cm	1" acrylic moderated at 50 cm	2" acrylic moderated at 50 cm	Bare at 100 cm	2" acrylic moderated at 100 cm
1.00E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.64E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.64E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-07	2.04E-02	6.61E-02	2.19E-01	5.67E-02	2.05E-01
2.15E-07	1.36E-02	4.57E-02	1.49E-01	3.94E-02	1.43E-01
4.64E-07	6.06E-03	2.30E-02	7.11E-02	2.02E-02	7.25E-02
1.00E-06	3.19E-03	1.43E-02	4.08E-02	1.26E-02	4.25E-02
2.15E-06	3.82E-03	1.63E-02	4.69E-02	1.39E-02	4.40E-02
4.64E-06	2.36E-04	5.89E-03	9.93E-03	4.75E-03	9.87E-03
1.00E-05	2.51E-04	5.74E-03	8.97E-03	4.09E-03	6.66E-03
2.15E-05	2.88E-04	5.63E-03	8.30E-03	3.49E-03	4.46E-03
4.64E-05	3.30E-04	5.32E-03	7.51E-03	2.79E-03	2.92E-03
1.00E-04	3.75E-04	4.87E-03	6.84E-03	2.18E-03	2.00E-03
2.15E-04	4.22E-04	4.49E-03	6.47E-03	1.73E-03	1.47E-03
4.64E-04	4.38E-04	3.93E-03	5.97E-03	1.22E-03	9.26E-04
1.00E-03	4.42E-04	3.32E-03	5.56E-03	8.41E-04	6.36E-04
2.15E-03	4.83E-04	3.21E-03	6.12E-03	6.60E-04	5.01E-04
4.64E-03	5.85E-04	3.58E-03	7.60E-03	6.14E-04	8.47E-04

1.00E-02	6.55E-04	3.74E-03	8.68E-03	5.71E-04	1.64E-03
1.25E-02	7.00E-04	3.85E-03	9.32E-03	5.67E-04	1.91E-03
1.58E-02	7.90E-04	4.30E-03	1.06E-02	6.33E-04	1.88E-03
1.99E-02	9.21E-04	4.91E-03	1.22E-02	7.22E-04	1.64E-03
2.51E-02	1.07E-03	5.63E-03	1.40E-02	8.49E-04	1.87E-03
3.16E-02	1.25E-03	6.46E-03	1.60E-02	1.01E-03	2.57E-03
3.98E-02	1.51E-03	7.59E-03	1.86E-02	1.27E-03	3.70E-03
5.01E-02	1.93E-03	9.33E-03	2.23E-02	1.68E-03	5.35E-03
6.30E-02	2.62E-03	1.21E-02	2.76E-02	2.40E-03	7.80E-03
7.94E-02	3.73E-03	1.64E-02	3.52E-02	3.72E-03	1.19E-02
1.00E-01	5.53E-03	2.34E-02	4.57E-02	6.25E-03	1.89E-02
1.25E-01	8.47E-03	3.47E-02	6.03E-02	1.12E-02	3.09E-02
1.58E-01	1.31E-02	5.29E-02	8.01E-02	2.06E-02	5.14E-02
1.99E-01	1.98E-02	8.19E-02	1.07E-01	3.85E-02	8.44E-02
2.51E-01	2.97E-02	1.27E-01	1.42E-01	7.14E-02	1.36E-01
3.16E-01	5.04E-02	1.91E-01	1.83E-01	1.23E-01	2.05E-01
3.98E-01	9.82E-02	2.72E-01	2.21E-01	1.97E-01	2.76E-01
5.01E-01	2.04E-01	3.57E-01	2.35E-01	2.90E-01	3.09E-01
6.30E-01	3.61E-01	4.38E-01	2.24E-01	3.97E-01	3.05E-01
7.94E-01	5.32E-01	4.87E-01	1.88E-01	4.94E-01	2.60E-01
1.00E+00	5.94E-01	4.42E-01	1.56E-01	5.09E-01	2.07E-01
1.25E+00	5.61E-01	2.96E-01	1.09E-01	4.36E-01	1.52E-01
1.58E+00	4.30E-01	1.64E-01	8.45E-02	2.85E-01	1.07E-01
1.99E+00	2.96E-01	8.76E-02	5.71E-02	1.73E-01	7.58E-02
2.51E+00	1.70E-01	8.72E-02	5.65E-02	9.96E-02	5.01E-02
3.16E+00	8.56E-02	4.46E-02	3.93E-02	7.56E-02	3.97E-02
3.98E+00	7.33E-02	3.13E-02	2.84E-02	6.02E-02	3.09E-02
5.01E+00	8.15E-02	3.89E-02	2.58E-02	6.41E-02	3.00E-02
6.30E+00	1.31E-01	6.99E-02	2.85E-02	9.99E-02	3.09E-02
7.94E+00	1.35E-01	8.19E-02	3.12E-02	1.06E-01	3.91E-02
1.00E+01	1.08E-01	6.34E-02	2.42E-02	8.49E-02	3.01E-02
1.58E+01	2.41E-02	1.13E-02	7.02E-03	1.95E-02	5.59E-03
2.51E+01	6.71E-03	3.07E-03	1.31E-03	5.33E-03	1.37E-03
3.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

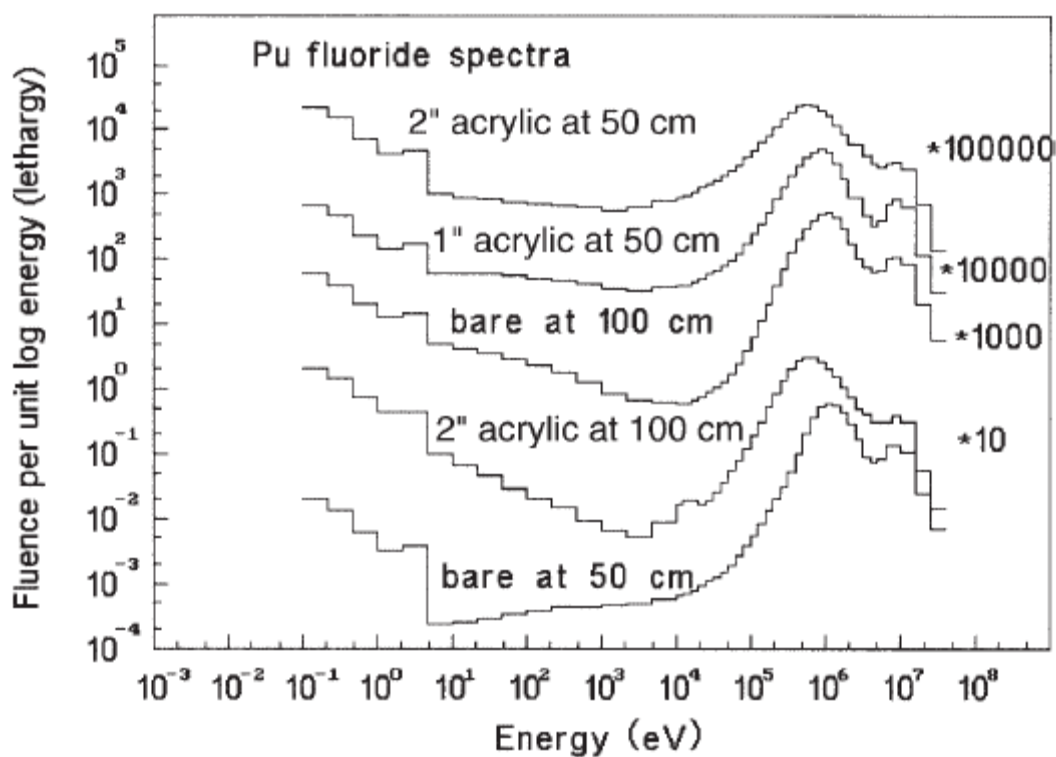


Figure B7. Pu fluoride spectra (PNL).

Table B8. Fe AND PE MODERATED Cf SPECTRA (NRI, REŽ)

Energy in eV	Cf + 5 cm Fe,10 cm PE	Cf + 25 cm Fe,10 cm PE	Cf + 5 cm Fe	Cf + 25 cm Fe
1.00E-09	6.64E-03	1.36E-02	0.00E+00	0.00E+00
2.15E-09	1.03E-02	1.97E-02	0.00E+00	0.00E+00
4.64E-09	2.90E-02	3.21E-02	0.00E+00	0.00E+00
1.00E-08	1.01E-01	1.30E-01	0.00E+00	0.00E+00
2.15E-08	2.43E-01	3.08E-01	0.00E+00	0.00E+00
4.64E-08	2.97E-01	4.36E-01	0.00E+00	0.00E+00
1.00E-07	9.96E-02	9.81E-02	0.00E+00	0.00E+00
2.15E-07	1.86E-02	2.05E-02	0.00E+00	0.00E+00
4.64E-07	1.19E-02	1.23E-02	0.00E+00	0.00E+00
1.00E-06	1.33E-02	9.62E-03	0.00E+00	0.00E+00
2.15E-06	1.15E-02	1.17E-02	0.00E+00	0.00E+00
4.64E-06	9.30E-03	6.61E-03	0.00E+00	0.00E+00
1.00E-05	1.16E-02	4.83E-03	0.00E+00	2.89E-03
2.15E-05	7.95E-03	1.51E-03	0.00E+00	2.89E-03
4.64E-05	7.95E-03	6.99E-03	0.00E+00	2.89E-03
1.00E-04	7.75E-03	4.95E-03	1.43E-04	2.89E-03
2.15E-04	4.88E-03	2.83E-03	8.54E-04	3.11E-03
4.64E-04	5.29E-03	2.24E-03	1.22E-03	5.22E-03
1.00E-03	5.29E-03	5.79E-04	2.60E-03	3.53E-03
2.15E-03	5.29E-03	6.99E-03	2.02E-03	4.06E-03
4.64E-03	5.29E-03	2.21E-03	2.08E-03	5.65E-03

1.00E-02	5.29E-03	3.09E-03	2.15E-03	1.12E-02
1.25E-02	5.29E-03	3.52E-03	2.20E-03	2.24E-02
1.58E-02	5.29E-03	2.05E-03	2.30E-03	3.90E-02
1.99E-02	5.50E-03	1.58E-03	2.52E-03	3.91E-02
2.51E-02	6.81E-03	3.25E-03	2.96E-03	3.23E-02
3.16E-02	8.30E-03	5.05E-03	3.71E-03	2.51E-02
3.98E-02	8.96E-03	7.70E-03	7.69E-03	4.78E-02
5.01E-02	9.37E-03	8.40E-03	1.95E-02	7.05E-02
6.30E-02	9.27E-03	9.11E-03	2.11E-02	1.01E-01
7.94E-02	9.79E-03	1.12E-02	3.88E-02	1.38E-01
1.00E-01	1.44E-02	1.72E-02	7.81E-02	1.73E-01
1.25E-01	1.99E-02	2.50E-02	8.54E-02	2.15E-01
1.58E-01	2.56E-02	3.18E-02	1.06E-01	2.70E-01
1.99E-01	3.07E-02	4.05E-02	1.78E-01	3.61E-01
2.51E-01	4.18E-02	5.04E-02	2.25E-01	4.48E-01
3.16E-01	4.88E-02	5.96E-02	2.66E-01	4.89E-01
3.98E-01	5.78E-02	6.61E-02	2.97E-01	4.58E-01
5.01E-01	7.16E-02	6.36E-02	3.23E-01	3.65E-01
6.30E-01	8.16E-02	5.41E-02	3.37E-01	3.33E-01
7.94E-01	9.37E-02	3.93E-02	3.70E-01	2.04E-01
1.00E+00	1.04E-01	3.26E-02	3.64E-01	2.04E-01
1.25E+00	1.18E-01	1.80E-02	3.43E-01	7.61E-02
1.58E+00	1.22E-01	8.85E-03	3.16E-01	6.49E-02
1.99E+00	1.13E-01	5.59E-03	2.96E-01	2.33E-02
2.51E+00	1.00E-01	4.82E-03	2.42E-01	9.18E-03
3.16E+00	7.57E-02	1.17E-04	1.68E-01	8.11E-03
3.98E+00	5.36E-02	8.72E-05	1.24E-01	1.59E-03
5.01E+00	3.30E-02	4.12E-05	7.09E-02	5.24E-04
6.30E+00	1.59E-02	0.00E+00	2.03E-02	0.00E+00
7.94E+00	4.22E-03	0.00E+00	1.30E-03	0.00E+00
1.00E+01	5.46E-04	0.00E+00	0.00E+00	0.00E+00
1.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

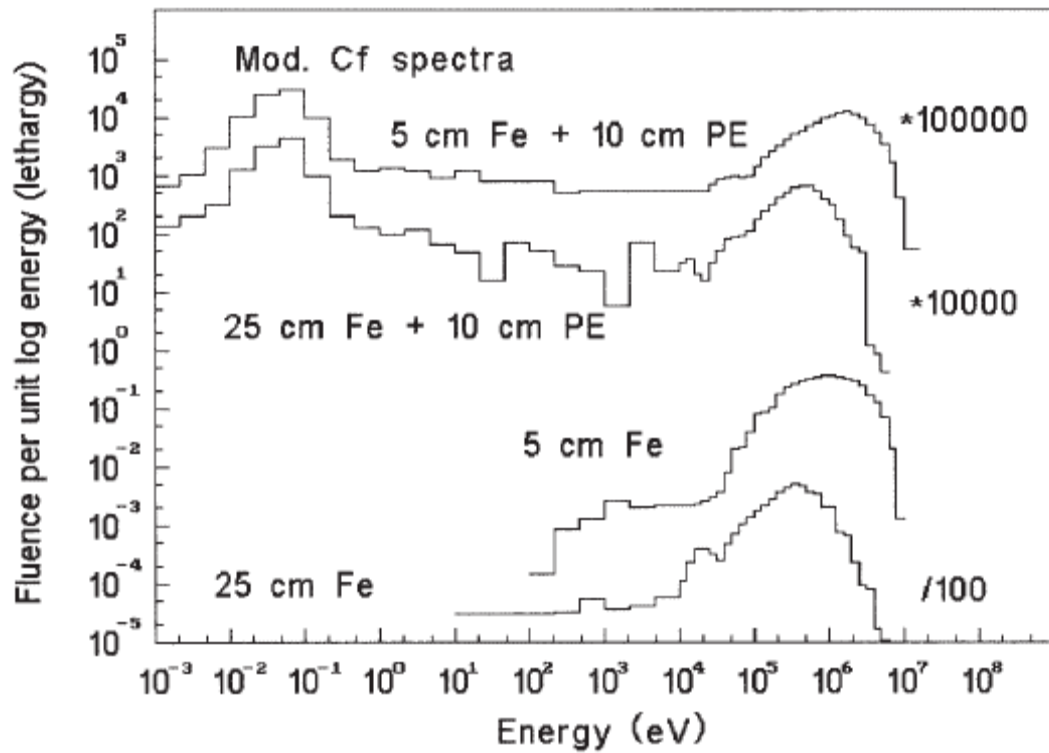


Figure B8. Fe and PE moderated Cf spectra (NRI, REŽ)

Table B9. WORKPLACE SIMULATION SPECTRA (CADARACHEAND GSF)

Energy in eV	Cadarache, spectrum 1	Cadarache, spectrum 2	GRENF, position A	GRENF, position B	GRENF, position C
1.00E-09	2.85E-03	1.90E-03	0.00E+00	0.00E+00	0.00E+00
2.15E-09	7.39E-03	6.53E-03	0.00E+00	0.00E+00	0.00E+00
4.64E-09	2.04E-02	2.29E-02	0.00E+00	0.00E+00	0.00E+00
1.00E-08	5.55E-02	7.47E-02	7.07E-03	3.37E-03	1.78E-03
2.15E-08	1.19E-01	1.82E-01	2.32E-02	2.53E-02	1.69E-02
4.64E-08	1.36E-01	2.17E-01	5.07E-02	3.75E-02	3.46E-02
1.00E-07	4.76E-02	7.55E-02	3.96E-02	3.46E-02	3.41E-02
2.15E-07	2.90E-02	4.46E-02	2.44E-02	1.89E-02	2.37E-02
4.64E-07	1.96E-02	2.15E-02	2.54E-02	2.44E-02	2.46E-02
1.00E-06	1.98E-02	2.60E-02	2.88E-02	2.85E-02	2.90E-02
2.15E-06	2.01E-02	3.00E-02	3.18E-02	3.30E-02	3.54E-02
4.64E-06	2.05E-02	2.98E-02	3.72E-02	3.89E-02	4.01E-02
1.00E-05	2.07E-02	2.93E-02	4.04E-02	4.31E-02	4.65E-02
2.15E-05	2.08E-02	3.04E-02	4.45E-02	4.86E-02	5.27E-02
4.64E-05	2.09E-02	3.12E-02	4.90E-02	5.18E-02	5.71E-02
1.00E-04	2.10E-02	3.20E-02	5.53E-02	5.56E-02	6.03E-02
2.15E-04	2.09E-02	3.26E-02	5.44E-02	5.97E-02	6.17E-02
4.64E-04	2.09E-02	3.32E-02	5.44E-02	5.87E-02	6.38E-02
1.00E-03	2.10E-02	3.40E-02	5.86E-02	6.41E-02	6.82E-02

2.15E-03	2.14E-02	3.47E-02	4.45E-02	5.82E-02	5.35E-02
4.64E-03	2.29E-02	3.56E-02	6.07E-02	6.60E-02	6.47E-02
1.00E-02	2.53E-02	3.64E-02	6.07E-02	6.47E-02	6.51E-02
1.25E-02	2.71E-02	3.67E-02	5.86E-02	6.21E-02	5.96E-02
1.58E-02	3.37E-02	3.72E-02	6.28E-02	6.31E-02	6.87E-02
1.99E-02	6.45E-02	3.77E-02	7.56E-02	8.50E-02	8.60E-02
2.51E-02	1.17E-01	3.83E-02	7.98E-02	8.82E-02	8.60E-02
3.16E-02	1.09E-01	3.91E-02	5.40E-02	5.21E-02	1.89E-02
3.98E-02	1.99E-02	4.00E-02	6.73E-02	6.91E-02	6.25E-02
5.01E-02	6.33E-03	4.12E-02	5.99E-02	7.04E-02	6.65E-02
6.30E-02	8.61E-02	4.26E-02	7.48E-02	7.80E-02	8.84E-02
7.94E-02	1.12E-01	4.43E-02	6.98E-02	7.99E-02	1.12E-01
1.00E-01	1.10E-01	4.63E-02	7.02E-02	8.43E-02	8.60E-02
1.25E-01	1.31E-01	4.86E-02	8.52E-02	9.89E-02	1.04E-01
1.58E-01	1.51E-01	5.11E-02	8.10E-02	8.56E-02	9.41E-02
1.99E-01	1.68E-01	5.35E-02	6.86E-02	8.24E-02	7.56E-02
2.51E-01	1.77E-01	5.53E-02	8.85E-02	9.77E-02	9.97E-02
3.16E-01	1.73E-01	5.61E-02	7.73E-02	7.99E-02	7.06E-02
3.98E-01	1.51E-01	5.43E-02	6.69E-02	7.67E-02	7.84E-02
5.01E-01	1.17E-01	4.62E-02	1.10E-01	1.04E-01	1.01E-01
6.30E-01	8.14E-02	3.09E-02	1.26E-01	1.35E-01	1.20E-01
7.94E-01	4.06E-02	1.81E-02	7.15E-02	7.99E-02	6.39E-02
1.00E+00	1.99E-02	1.29E-02	9.31E-02	7.86E-02	6.61E-02
1.25E+00	2.09E-03	5.86E-03	1.07E-01	1.23E-01	7.53E-02
1.58E+00	5.36E-03	3.29E-03	1.95E-01	2.85E-03	3.26E-02
1.99E+00	8.61E-03	2.17E-03	5.57E-03	0.00E+00	0.00E+00
2.51E+00	3.90E-03	1.34E-03	0.00E+00	0.00E+00	0.00E+00
3.16E+00	8.12E-03	2.51E-03	0.00E+00	0.00E+00	0.00E+00
3.98E+00	7.19E-04	6.08E-04	0.00E+00	0.00E+00	0.00E+00
5.01E+00	1.38E-03	1.18E-03	0.00E+00	0.00E+00	0.00E+00
6.30E+00	8.15E-05	1.34E-04	0.00E+00	0.00E+00	0.00E+00
7.94E+00	9.83E-05	2.01E-04	0.00E+00	0.00E+00	0.00E+00
1.00E+01	5.98E-03	2.71E-03	0.00E+00	0.00E+00	0.00E+00
1.58E+01	3.80E-02	1.70E-02	0.00E+00	0.00E+00	0.00E+00
2.51E+01	1.56E-03	7.01E-04	0.00E+00	0.00E+00	0.00E+00
3.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

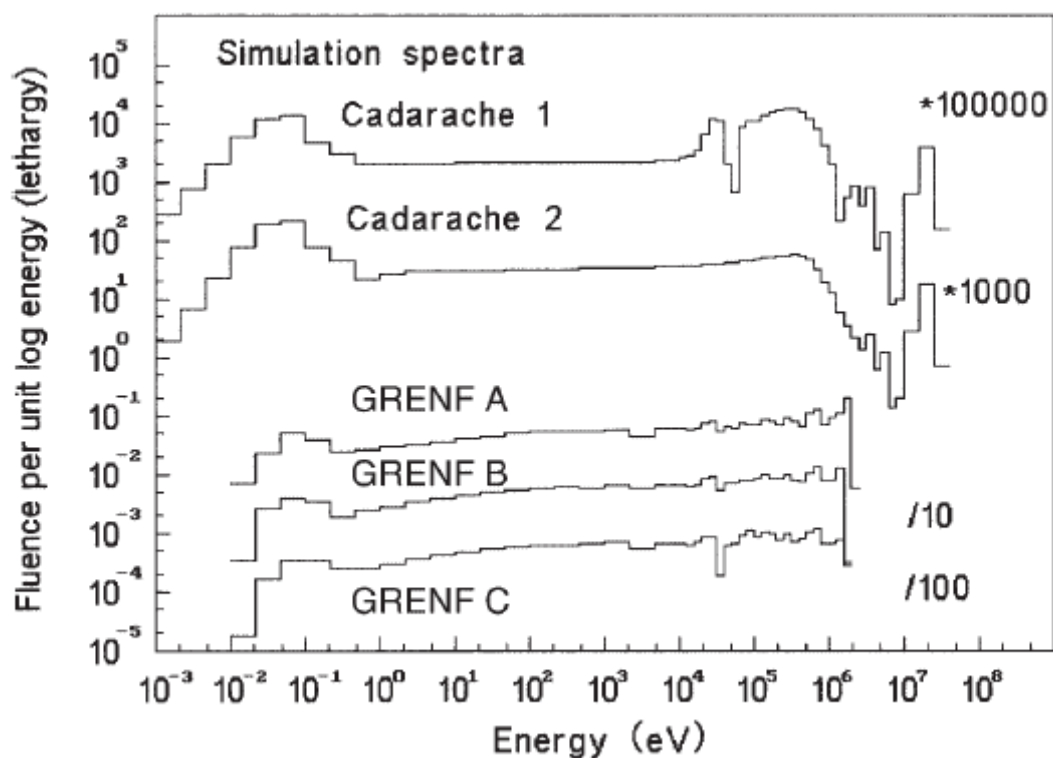


Figure B9. Workplace simulation spectra (Cadache and GSF).

Table B10. WORKPLACE SIMULATION SPECTRA (GSF AND PTB)

Energy in eV	GRENF, 30 cm D ₂ O sphere	GRENF, 10 cm Fe slab	GRENF, 10 cm PE slab	PTB, Li(p,n)Be, 2.5 MeV	PTB, Li(p,n)Be, 3.3 MeV
1.00E-03	0.00E+00	0.00E+00	0.00E+00	8.45E-03	8.76E-03
2.15E-03	0.00E+00	0.00E+00	0.00E+00	1.71E-02	2.33E-02
4.64E-03	3.48E-04	0.00E+00	0.00E+00	8.86E-02	7.77E-02
1.00E-02	3.60E-03	7.16E-04	5.81E-02	2.35E-01	2.24E-01
2.15E-02	1.36E-02	7.56E-04	1.21E-01	2.59E-01	2.10E-01
4.64E-02	2.25E-02	1.55E-03	9.44E-02	8.42E-02	6.05E-02
1.00E-01	1.50E-02	1.32E-03	3.50E-02	6.52E-02	3.34E-02
2.15E-01	2.49E-02	5.61E-04	2.50E-02	5.91E-02	2.50E-02
4.64E-01	3.10E-02	1.56E-03	2.21E-02	2.85E-02	4.25E-02
1.00E+00	3.57E-02	1.00E-03	1.94E-02	2.67E-02	2.40E-02
2.15E+00	3.87E-02	1.12E-03	1.59E-02	2.62E-02	2.40E-02
4.64E+00	4.26E-02	8.71E-04	1.33E-02	2.29E-02	2.40E-02
1.00E+01	4.47E-02	9.55E-04	1.55E-02	2.66E-02	2.40E-02
2.15E+01	4.61E-02	9.55E-04	1.37E-02	2.48E-02	2.40E-02
4.64E+01	4.96E-02	9.28E-04	1.37E-02	2.62E-02	2.18E-02
1.00E+02	5.14E-02	1.34E-03	1.37E-02	2.55E-02	2.38E-02
2.15E+02	5.28E-02	1.58E-03	1.73E-02	2.63E-02	2.59E-02
4.64E+02	5.31E-02	1.84E-03	1.56E-02	2.65E-02	2.53E-02
1.00E+03	5.17E-02	2.75E-03	2.02E-02	2.92E-02	2.71E-02

2.15E+03	5.14E-02	3.86E-03	1.99E-02	2.43E-02	3.05E-02
4.64E+03	5.12E-02	9.42E-03	2.21E-02	3.27E-02	3.61E-02
1.00E+04	5.64E-02	1.42E-02	2.65E-02	2.93E-02	3.50E-02
1.25E+04	5.55E-02	1.52E-02	2.86E-02	2.86E-02	3.53E-02
1.58E+04	5.64E-02	1.75E-02	2.74E-02	2.92E-02	3.58E-02
1.99E+04	5.93E-02	2.38E-02	2.78E-02	2.94E-02	3.91E-02
2.51E+04	5.93E-02	3.12E-02	2.97E-02	3.02E-02	4.25E-02
3.16E+04	5.85E-02	3.52E-02	3.12E-02	3.10E-02	4.22E-02
3.98E+04	5.79E-02	3.76E-02	3.20E-02	3.12E-02	4.28E-02
5.01E+04	5.73E-02	4.08E-02	3.25E-02	3.05E-02	4.47E-02
6.30E+04	6.02E-02	5.39E-02	3.33E-02	3.01E-02	4.60E-02
7.94E+04	6.91E-02	6.98E-02	3.82E-02	3.19E-02	4.73E-02
1.00E+05	7.59E-02	8.97E-02	4.16E-02	3.21E-02	5.06E-02
1.25E+05	1.04E-01	1.08E-01	4.46E-02	2.86E-02	5.20E-02
1.58E+05	9.33E-02	1.20E-01	4.73E-02	2.49E-02	5.32E-02
1.99E+05	1.10E-01	1.34E-01	5.05E-02	2.60E-02	5.58E-02
2.51E+05	1.14E-01	1.88E-01	5.88E-02	2.57E-02	6.24E-02
3.16E+05	1.42E-01	2.12E-01	6.39E-02	2.16E-02	6.21E-02
3.98E+05	1.44E-01	2.37E-01	6.45E-02	7.25E-03	6.20E-02
5.01E+05	1.51E-01	3.00E-01	8.81E-02	5.87E-04	5.67E-02
6.30E+05	1.50E-01	3.91E-01	1.29E-01	0.00E+00	5.65E-02
7.94E+05	1.36E-01	4.25E-01	1.52E-01	0.00E+00	3.51E-02
1.00E+06	1.06E-01	4.51E-01	1.63E-01	0.00E+00	2.99E-03
1.25E+06	7.53E-02	4.15E-01	2.12E-01	0.00E+00	0.00E+00
1.58E+06	4.43E-02	3.62E-01	2.27E-01	0.00E+00	0.00E+00
1.99E+06	2.22E-02	2.72E-01	2.33E-01	0.00E+00	0.00E+00
2.51E+06	1.00E-02	1.14E-01	2.23E-01	0.00E+00	0.00E+00
3.16E+06	3.34E-03	5.04E-02	1.62E-01	0.00E+00	0.00E+00
3.98E+06	3.01E-03	4.05E-03	1.19E-01	0.00E+00	0.00E+00
5.01E+06	8.92E-04	9.64E-03	7.26E-02	0.00E+00	0.00E+00
6.30E+06	3.36E-04	1.09E-02	2.53E-02	0.00E+00	0.00E+00
7.94E+06	0.00E+00	2.38E-05	3.20E-03	0.00E+00	0.00E+00
1.00E+07	0.00E+00	0.00E+00	1.32E-04	0.00E+00	0.00E+00
1.58E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

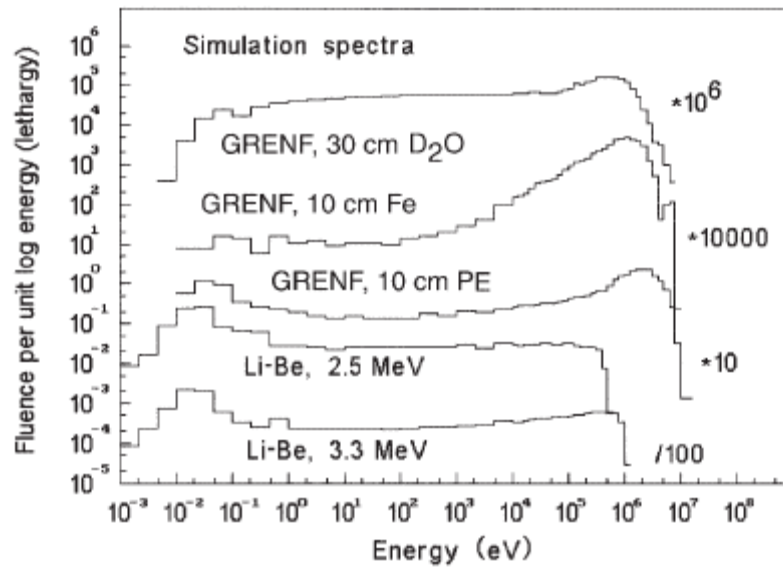


Figure B10. WORKPLACE SIMULATION SPECTRA (GSF AND PTB)

Table B11. WORKPLACE SIMULATION SPECTRA USING ^{238}U (CADARACHE)

Energy in eV	2.8 MeV neutrons on ^{238}U , no duct	2.8 MeV neutrons on ^{238}U , with PE duct	2.8 MeV neutrons on ^{238}U , with duct + 1 cm PE	Reference spectrum at TRU facility	3 MeV neutrons on ^{238}U , with duct + 10 cm H_2O
1.00E-03	0.00E+00	1.27E-02	8.53E-03	0.00E+00	4.53E-03
2.15E-03	0.00E+00	1.31E-02	1.03E-02	7.36E-03	1.22E-02
4.64E-03	0.00E+00	1.85E-02	2.11E-02	3.08E-02	5.17E-02
1.00E-02	0.00E+00	8.71E-02	7.65E-02	1.46E-01	1.49E-01
2.15E-02	0.00E+00	1.20E-01	6.73E-02	9.84E-02	2.61E-01
4.64E-02	0.00E+00	1.54E-01	1.06E-01	4.13E-02	3.46E-01
1.00E-01	0.00E+00	3.67E-02	3.00E-02	9.68E-02	1.32E-01
2.15E-01	0.00E+00	2.98E-02	1.97E-02	1.14E-01	3.95E-02
4.64E-01	0.00E+00	9.25E-03	1.43E-02	5.52E-02	3.09E-02
1.00E+00	0.00E+00	2.58E-02	1.71E-02	3.08E-02	1.08E-02
2.15E+00	0.00E+00	1.71E-02	1.54E-02	2.25E-02	1.23E-02
4.64E+00	0.00E+00	1.42E-02	1.50E-02	2.21E-02	1.47E-02
1.00E+01	0.00E+00	1.57E-02	1.88E-02	2.04E-02	9.18E-03
2.15E+01	0.00E+00	1.63E-02	1.74E-02	2.01E-02	1.21E-02
4.64E+01	0.00E+00	1.78E-02	1.75E-02	2.00E-02	1.40E-02
1.00E+02	0.00E+00	1.96E-02	1.96E-02	2.07E-02	1.06E-02
2.15E+02	0.00E+00	2.12E-02	1.99E-02	2.09E-02	1.07E-02
4.64E+02	0.00E+00	2.22E-02	1.95E-02	2.12E-02	9.33E-03

1.00E+03	0.00E+00	2.59E-02	1.81E-02	2.46E-02	1.08E-02
2.15E+03	0.00E+00	2.66E-02	1.83E-02	2.76E-02	1.20E-02
4.64E+03	4.30E-03	2.76E-02	1.91E-02	3.47E-02	1.22E-02
1.00E+04	1.69E-02	2.87E-02	2.46E-02	3.83E-02	1.51E-02
1.25E+04	2.34E-02	3.03E-02	3.16E-02	4.19E-02	1.54E-02
1.58E+04	2.60E-02	3.59E-02	3.30E-02	4.56E-02	1.65E-02
1.99E+04	4.39E-02	4.71E-02	4.13E-02	4.83E-02	1.78E-02
2.51E+04	5.92E-02	4.52E-02	5.97E-02	5.25E-02	1.97E-02
3.16E+04	6.85E-02	5.20E-02	5.17E-02	5.67E-02	2.19E-02
3.98E+04	9.24E-02	6.04E-02	5.86E-02	6.25E-02	2.38E-02
5.01E+04	1.03E-01	6.93E-02	7.72E-02	6.64E-02	2.44E-02
6.30E+04	1.15E-01	7.32E-02	8.46E-02	6.91E-02	2.46E-02
7.94E+04	1.21E-01	7.37E-02	7.85E-02	7.90E-02	2.60E-02
1.00E+05	1.57E-01	8.51E-02	9.48E-02	8.42E-02	2.67E-02
1.25E+05	1.57E-01	9.50E-02	1.06E-01	8.72E-02	2.74E-02
1.58E+05	2.23E-01	1.09E-01	1.15E-01	9.11E-02	2.76E-02
1.99E+05	2.64E-01	1.15E-01	1.21E-01	9.14E-02	2.74E-02
2.51E+05	2.30E-01	1.18E-01	1.33E-01	9.14E-02	2.76E-02
3.16E+05	3.32E-01	1.21E-01	1.57E-01	8.96E-02	2.79E-02
3.98E+05	3.69E-01	1.48E-01	1.67E-01	8.09E-02	2.59E-02
5.01E+05	3.62E-01	1.34E-01	1.52E-01	7.30E-02	1.86E-02
6.30E+05	3.59E-01	1.23E-01	1.77E-01	3.08E-02	1.70E-02
7.94E+05	3.71E-01	8.71E-02	1.50E-01	4.37E-02	1.00E-02
1.00E+06	1.84E-01	8.46E-02	1.10E-01	3.98E-02	4.53E-03
1.25E+06	1.42E-01	4.18E-02	6.43E-02	2.28E-02	1.82E-03
1.58E+06	6.51E-02	2.46E-02	5.10E-02	1.31E-02	3.88E-03
1.99E+06	4.75E-02	2.08E-02	3.37E-02	1.19E-02	4.52E-03
2.51E+06	2.35E-01	4.19E-02	1.71E-01	6.79E-03	2.42E-03
3.16E+06	7.87E-02	1.74E-02	1.73E-02	1.03E-03	1.73E-04
3.98E+06	3.26E-02	7.87E-03	6.06E-02	1.88E-03	3.38E-04
5.01E+06	1.89E-02	5.64E-03	1.06E-02	9.72E-04	3.71E-04
6.30E+06	1.75E-02	5.20E-03	6.97E-03	1.10E-03	5.62E-04
7.94E+06	1.33E-02	3.14E-03	3.62E-03	4.98E-04	1.53E-04
1.00E+07	0.00E+00	0.00E+00	0.00E+00	3.50E-04	3.11E-05
1.58E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

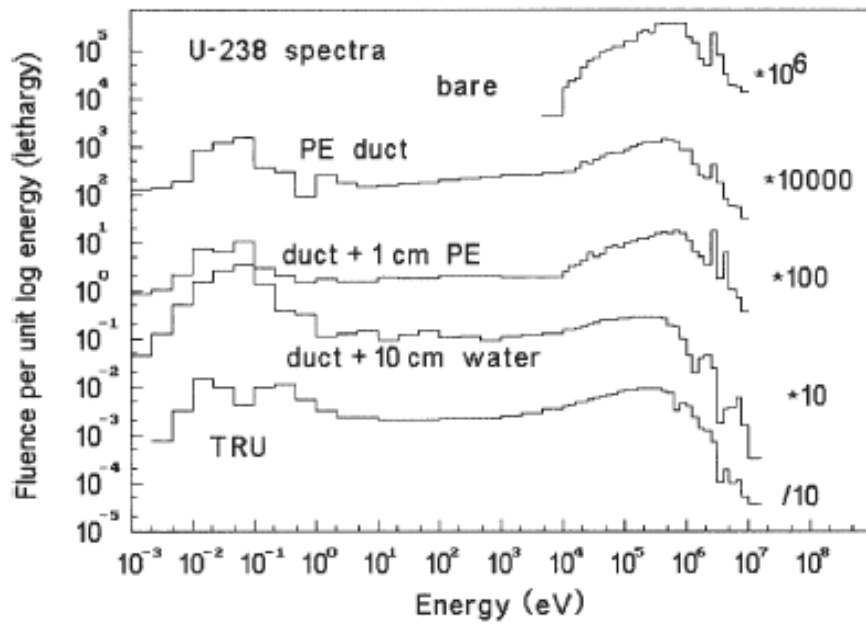


Figure B11. WORKPLACE SIMULATION SPECTRA USING ^{238}U (CADARACHE)

Table B12. WORKPLACE SIMULATION SPECTRA, 14 MeV NEUTRONS (CADARACHE)

Energy in eV	PE duct + 5 cm D ₂ O shield	Simulated fuel transport container	Bare beam	5 cm H ₂ O shield	20 cm H ₂ O shield
1.00E-03	2.61E-02	3.73E-02	1.20E-02	1.74E-02	1.73E-02
2.15E-03	2.69E-02	4.25E-02	1.20E-02	1.77E-02	1.61E-02
4.64E-03	2.65E-02	5.30E-02	1.17E-02	2.23E-02	1.64E-02
1.00E-02	7.54E-02	5.85E-02	9.26E-02	8.59E-02	2.55E-01
2.15E-02	7.92E-02	6.09E-02	1.53E-01	2.61E-01	2.33E-01
4.64E-02	9.95E-02	5.82E-02	1.44E-01	2.20E-01	1.63E-01
1.00E-01	3.39E-02	5.52E-02	5.13E-02	6.91E-02	7.78E-02
2.15E-01	1.57E-01	5.30E-02	1.65E-02	6.54E-02	1.55E-02
4.64E-01	2.89E-02	5.05E-02	1.50E-02	1.86E-02	7.06E-02
1.00E+00	3.17E-02	4.58E-02	1.43E-02	1.97E-02	1.41E-02
2.15E+00	3.07E-02	4.39E-02	1.48E-02	1.48E-02	1.90E-02
4.64E+00	2.99E-02	3.92E-02	1.63E-02	1.96E-02	1.13E-02
1.00E+01	3.19E-02	3.79E-02	1.26E-02	1.96E-02	1.34E-02
2.15E+01	3.01E-02	3.54E-02	1.52E-02	1.96E-02	1.67E-02
4.64E+01	3.05E-02	3.29E-02	1.61E-02	1.97E-02	1.71E-02
1.00E+02	3.15E-02	3.32E-02	1.78E-02	2.21E-02	1.61E-02
2.15E+02	3.19E-02	2.88E-02	1.67E-02	2.29E-02	1.50E-02
4.64E+02	3.15E-02	2.94E-02	2.01E-02	2.38E-02	1.77E-02
1.00E+03	3.65E-02	2.91E-02	2.30E-02	2.41E-02	2.04E-02
2.15E+03	3.65E-02	2.88E-02	2.67E-02	2.46E-02	2.50E-02
4.64E+03	3.73E-02	2.88E-02	3.05E-02	3.11E-02	2.53E-02
1.00E+04	3.85E-02	3.13E-02	3.74E-02	3.01E-02	2.88E-02

1.25E+04	4.09E-02	3.38E-02	4.70E-02	3.26E-02	2.56E-02
1.58E+04	4.45E-02	3.68E-02	9.07E-02	3.68E-02	3.18E-02
1.99E+04	4.55E-02	3.84E-02	9.40E-02	4.16E-02	4.79E-02
2.51E+04	4.35E-02	4.17E-02	3.76E-02	3.83E-02	2.12E-02
3.16E+04	4.43E-02	4.64E-02	5.11E-02	3.66E-02	3.77E-02
3.98E+04	4.81E-02	5.16E-02	5.02E-02	3.98E-02	8.19E-02
5.01E+04	4.97E-02	5.87E-02	7.95E-02	5.39E-02	5.94E-02
6.30E+04	4.39E-02	6.97E-02	8.38E-02	4.71E-02	4.31E-02
7.94E+04	4.87E-02	8.07E-02	8.56E-02	4.98E-02	4.79E-02
1.00E+05	5.14E-02	8.62E-02	1.02E-01	7.16E-02	5.50E-02
1.25E+05	5.06E-02	9.17E-02	1.19E-01	5.76E-02	5.26E-02
1.58E+05	5.44E-02	9.83E-02	1.19E-01	5.34E-02	4.59E-02
1.99E+05	5.42E-02	1.06E-01	1.78E-01	6.11E-02	4.96E-02
2.51E+05	6.16E-02	1.14E-01	1.76E-01	7.19E-02	5.50E-02
3.16E+05	5.58E-02	1.10E-01	1.04E-01	4.83E-02	2.50E-02
3.98E+05	4.05E-02	1.22E-01	1.33E-01	2.12E-02	2.23E-02
5.01E+05	5.34E-02	7.96E-02	1.18E-01	5.11E-02	2.14E-02
6.30E+05	3.87E-02	5.74E-02	7.38E-02	1.38E-02	7.81E-03
7.94E+05	2.83E-02	2.42E-02	4.52E-02	1.73E-02	0.00E+00
1.00E+06	3.01E-02	2.38E-02	1.62E-02	3.88E-03	0.00E+00
1.25E+06	2.61E-02	0.00E+00	8.61E-03	3.63E-03	0.00E+00
1.58E+06	2.33E-02	0.00E+00	7.04E-03	0.00E+00	0.00E+00
1.99E+06	2.17E-02	0.00E+00	2.71E-03	0.00E+00	0.00E+00
2.51E+06	2.01E-02	0.00E+00	4.76E-03	0.00E+00	0.00E+00
3.16E+06	1.95E-02	0.00E+00	2.85E-03	0.00E+00	0.00E+00
3.98E+06	1.94E-02	0.00E+00	3.68E-03	0.00E+00	0.00E+00
5.01E+06	1.94E-02	0.00E+00	4.43E-03	0.00E+00	0.00E+00
6.30E+06	2.01E-02	0.00E+00	3.93E-03	0.00E+00	0.00E+00
7.94E+06	1.99E-02	0.00E+00	1.77E-03	0.00E+00	0.00E+00
1.00E+07	2.13E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00
1.58E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

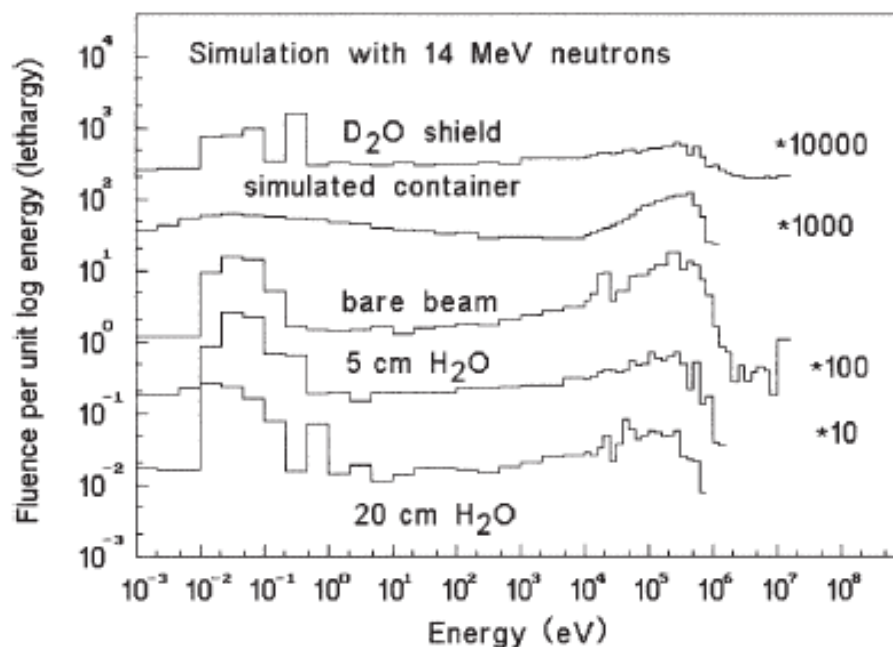


Figure B12. WORKPLACE SIMULATION SPECTRA, 14 MeV NEUTRONS (CADARACHE)

Table B13. FUSION ENVIRONMENT SIMULATION (TEXTOR)

Energy in eV	In the beam	With iron shield	With wooden shield, position 1	With wooden shield, position 2
1.00E-03	4.91E-05	3.05E-05	9.74E-05	9.26E-04
2.15E-03	1.46E-04	1.52E-04	5.04E-04	5.34E-03
4.64E-03	3.69E-04	4.57E-04	1.54E-03	1.65E-02
1.00E-02	8.32E-04	1.17E-03	3.97E-03	4.21E-02
2.15E-02	1.41E-03	2.10E-03	7.15E-03	7.43E-02
4.64E-02	1.60E-03	2.43E-03	8.30E-03	8.33E-02
1.00E-01	1.22E-03	1.75E-03	5.95E-03	5.61E-02
2.15E-01	6.32E-04	7.28E-04	2.37E-03	1.87E-02
4.64E-01	5.22E-04	5.44E-04	1.70E-03	1.14E-02
1.00E+00	5.07E-04	5.25E-04	1.60E-03	9.19E-03
2.15E+00	5.42E-04	5.94E-04	1.80E-03	1.01E-02
4.64E+00	5.82E-04	6.78E-04	2.03E-03	1.11E-02
1.00E+01	6.17E-04	7.78E-04	2.28E-03	1.24E-02
2.15E+01	6.62E-04	8.87E-04	2.56E-03	1.38E-02
4.64E+01	7.07E-04	1.01E-03	2.87E-03	1.55E-02
1.00E+02	7.52E-04	1.15E-03	3.21E-03	1.74E-02

2.15E+02	8.02E-04	1.31E-03	3.59E-03	1.96E-02
4.64E+02	8.58E-04	1.50E-03	4.01E-03	2.21E-02
1.00E+03	9.18E-04	1.72E-03	4.49E-03	2.49E-02
2.15E+03	9.88E-04	1.98E-03	4.99E-03	2.81E-02
4.64E+03	1.07E-03	2.33E-03	5.61E-03	3.21E-02
1.00E+04	1.14E-03	2.64E-03	6.14E-03	3.52E-02
1.26E+04	1.17E-03	2.79E-03	6.38E-03	3.65E-02
1.58E+04	1.21E-03	2.96E-03	6.62E-03	3.82E-02
2.00E+04	1.26E-03	3.15E-03	6.86E-03	3.95E-02
2.51E+04	1.30E-03	3.37E-03	7.15E-03	4.11E-02
3.16E+04	1.36E-03	3.62E-03	7.44E-03	4.28E-02
3.98E+04	1.43E-03	3.92E-03	7.77E-03	4.48E-02
5.01E+04	1.51E-03	4.27E-03	8.16E-03	4.65E-02
6.31E+04	1.60E-03	4.68E-03	8.59E-03	4.88E-02
7.94E+04	1.71E-03	5.15E-03	9.12E-03	5.08E-02
1.00E+05	1.84E-03	5.79E-03	9.70E-03	5.34E-02
1.26E+05	2.01E-03	6.49E-03	1.04E-02	5.61E-02
1.58E+05	2.21E-03	7.38E-03	1.13E-02	5.87E-02
2.00E+05	2.46E-03	8.47E-03	1.24E-02	6.21E-02
2.51E+05	2.76E-03	9.86E-03	1.37E-02	6.57E-02
3.16E+05	3.13E-03	1.15E-02	1.55E-02	7.00E-02
3.98E+05	3.59E-03	1.35E-02	1.76E-02	7.43E-02
5.01E+05	4.15E-03	1.61E-02	2.04E-02	7.96E-02
6.31E+05	4.84E-03	1.92E-02	2.40E-02	8.53E-02
7.94E+05	5.67E-03	2.30E-02	2.87E-02	9.16E-02
1.00E+06	6.72E-03	2.77E-02	3.47E-02	9.86E-02
1.26E+06	3.55E-02	5.89E-02	6.57E-02	1.11E-01
1.58E+06	2.48E-01	2.61E-01	2.55E-01	1.62E-01
2.00E+06	8.17E-01	7.87E-01	7.44E-01	2.79E-01
2.51E+06	1.32E+00	1.26E+00	1.18E+00	3.65E-01
3.16E+06	1.18E+00	1.12E+00	1.04E+00	3.00E-01
3.98E+06	5.62E-01	5.25E-01	4.89E-01	1.35E-01
5.01E+06	7.07E-02	6.73E-02	6.28E-02	2.01E-02
6.31E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.94E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.31E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00

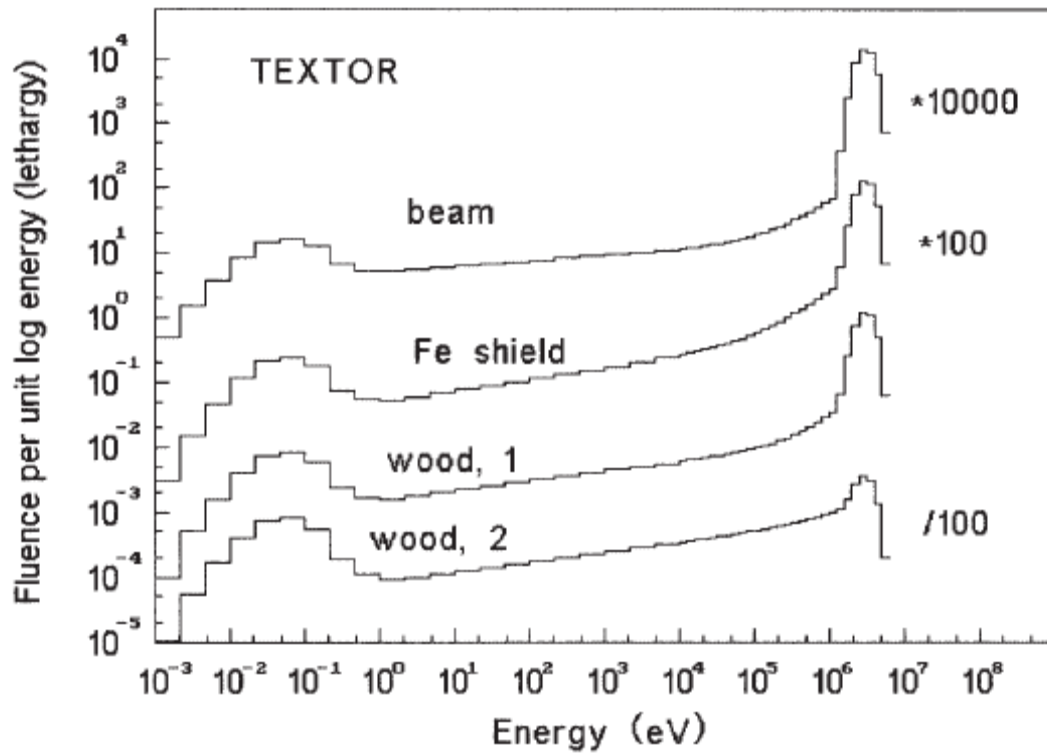


Figure B13. FUSION ENVIRONMENT SIMULATION (TEXTOR)

Table B14. FISSION ENVIRONMENT SIMULATION (UTR-KINKI FACILITY)

Energy in eV	Central void	Central void + fission plate	Central void + fission plate + B
1.00E-03	6.76E-04	1.39E-04	3.23E-05
2.15E-03	3.36E-02	6.29E-04	5.10E-05
4.64E-03	1.71E-02	7.46E-03	9.53E-04
1.00E-02	1.14E-01	1.77E-02	1.55E-03
2.15E-02	2.52E-01	5.83E-02	4.74E-03
4.64E-02	2.89E-01	8.70E-02	9.49E-03
1.00E-01	6.71E-02	6.46E-02	7.52E-03
2.15E-01	3.61E-02	3.43E-02	1.06E-02
4.64E-01	2.97E-02	3.64E-02	1.11E-02
1.00E+00	2.15E-02	2.84E-02	1.42E-02
2.15E+00	2.28E-02	9.97E-03	1.70E-02
4.64E+00	2.16E-02	2.41E-02	2.40E-02
1.00E+01	2.16E-02	2.62E-02	2.86E-02
2.15E+01	2.16E-02	2.82E-02	3.70E-02
4.64E+01	2.23E-02	2.91E-02	3.81E-02
1.00E+02	2.18E-02	2.93E-02	4.56E-02
2.15E+02	2.25E-02	3.21E-02	4.37E-02
4.64E+02	2.31E-02	3.27E-02	4.92E-02
1.00E+03	2.33E-02	3.23E-02	5.23E-02
2.15E+03	2.33E-02	3.56E-02	6.17E-02

4.64E+03	2.33E-02	3.90E-02	5.19E-02
1.00E+04	2.33E-02	4.05E-02	6.31E-02
1.25E+04	2.33E-02	4.18E-02	5.86E-02
1.58E+04	2.33E-02	4.27E-02	5.59E-02
1.99E+04	2.33E-02	4.27E-02	5.86E-02
2.51E+04	2.33E-02	4.34E-02	6.71E-02
3.16E+04	2.33E-02	4.57E-02	7.02E-02
3.98E+04	2.33E-02	4.70E-02	6.35E-02
5.01E+04	2.33E-02	4.81E-02	6.13E-02
6.30E+04	2.33E-02	4.81E-02	6.31E-02
7.94E+04	2.40E-02	4.97E-02	6.85E-02
1.00E+05	2.47E-02	5.47E-02	7.11E-02
1.25E+05	2.53E-02	5.75E-02	7.29E-02
1.58E+05	2.57E-02	5.66E-02	7.56E-02
1.99E+05	2.50E-02	5.83E-02	7.61E-02
2.51E+05	2.42E-02	6.33E-02	7.79E-02
3.16E+05	2.48E-02	7.26E-02	8.55E-02
3.98E+05	2.57E-02	8.37E-02	9.35E-02
5.01E+05	2.79E-02	8.80E-02	9.84E-02
6.30E+05	3.02E-02	9.45E-02	1.03E-01
7.94E+05	3.23E-02	1.03E-01	1.06E-01
1.00E+06	3.28E-02	1.11E-01	1.10E-01
1.25E+06	3.19E-02	1.19E-01	1.23E-01
1.58E+06	3.06E-02	1.30E-01	1.34E-01
1.99E+06	2.53E-02	1.37E-01	1.36E-01
2.51E+06	1.21E-02	1.38E-01	1.37E-01
3.16E+06	3.09E-03	1.17E-01	1.36E-01
3.98E+06	5.02E-03	8.70E-02	1.26E-01
5.01E+06	6.79E-03	5.64E-02	9.66E-02
6.30E+06	2.89E-03	4.36E-02	5.82E-02
7.94E+06	1.69E-03	2.56E-02	4.88E-02
1.00E+07	1.67E-04	9.24E-03	2.13E-02
1.58E+07	0.00E+00	0.00E+00	2.30E-03
2.51E+07	0.00E+00	0.00E+00	0.00E+00
3.98E+07	0.00E+00	0.00E+00	0.00E+00
6.30E+07	0.00E+00	0.00E+00	0.00E+00
1.00E+08	0.00E+00	0.00E+00	0.00E+00
1.58E+08	0.00E+00	0.00E+00	0.00E+00
2.51E+08	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00

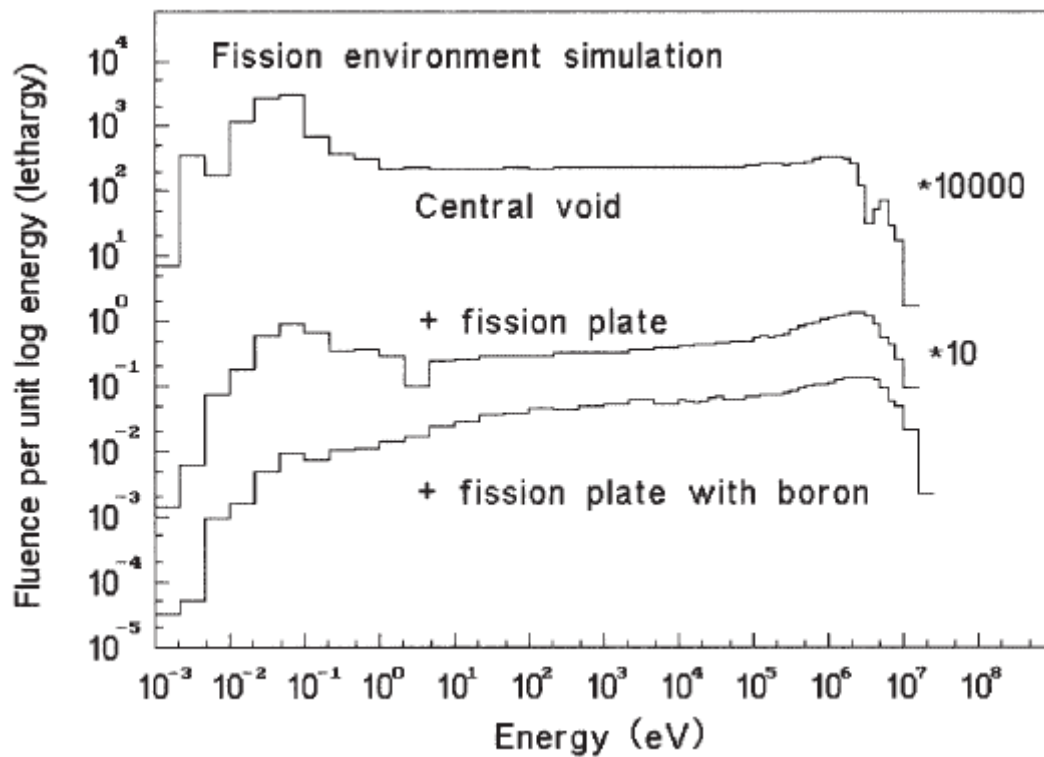


Figure B14. FISSION ENVIRONMENT SIMULATION (UTR-KINKI FACILITY)

Table B15. STRAY NEUTRON SIMULATION FIELDS (SILENE REACTOR)

Energy in eV	Unmoderated spectrum	Pb shield	PE shield	Steel shield
1.00E-03	0.00E+00	5.02E-03	0.00E+00	0.00E+00
2.15E-03	0.00E+00	3.06E-03	4.03E-03	5.27E-03
4.64E-03	0.00E+00	1.00E-02	1.32E-02	6.93E-03
1.00E-02	0.00E+00	2.19E-02	3.27E-02	2.29E-02
2.15E-02	0.00E+00	5.91E-02	6.26E-02	4.10E-02
4.64E-02	3.59E-02	7.52E-02	1.00E-01	6.94E-02
1.00E-01	4.61E-02	4.28E-02	4.29E-02	3.21E-02
2.15E-01	4.92E-02	9.78E-03	4.37E-02	2.90E-02
4.64E-01	4.70E-02	9.63E-02	4.24E-02	2.95E-02
1.00E+00	4.37E-02	2.78E-02	3.55E-02	3.25E-02
2.15E+00	4.45E-02	2.79E-02	3.44E-02	2.37E-02
4.64E+00	3.99E-02	2.26E-02	3.35E-02	3.10E-02
1.00E+01	3.75E-02	2.79E-02	3.27E-02	3.08E-02
2.15E+01	3.70E-02	2.81E-02	3.28E-02	3.27E-02
4.64E+01	3.42E-02	2.49E-02	3.29E-02	3.21E-02
1.00E+02	3.27E-02	2.69E-02	2.54E-02	3.08E-02
2.15E+02	3.11E-02	2.84E-02	2.93E-02	3.89E-02
4.64E+02	2.89E-02	2.65E-02	2.59E-02	2.97E-02
1.00E+03	2.73E-02	2.64E-02	3.01E-02	3.68E-02

2.15E+03	2.41E-02	2.51E-02	2.66E-02	3.75E-02
4.64E+03	2.21E-02	2.37E-02	2.57E-02	3.82E-02
1.00E+04	1.96E-02	2.50E-02	2.74E-02	4.05E-02
1.25E+04	1.88E-02	2.70E-02	2.44E-02	4.20E-02
1.58E+04	1.81E-02	2.63E-02	2.39E-02	4.28E-02
1.99E+04	1.84E-02	2.65E-02	2.35E-02	4.39E-02
2.51E+04	1.83E-02	2.68E-02	2.33E-02	4.54E-02
3.16E+04	1.75E-02	2.73E-02	2.32E-02	4.70E-02
3.98E+04	1.74E-02	2.95E-02	2.34E-02	4.89E-02
5.01E+04	1.75E-02	3.29E-02	2.41E-02	5.12E-02
6.30E+04	1.79E-02	3.67E-02	2.53E-02	5.54E-02
7.94E+04	1.86E-02	3.99E-02	2.72E-02	6.24E-02
1.00E+05	1.79E-02	4.46E-02	3.01E-02	6.93E-02
1.25E+05	1.89E-02	5.51E-02	3.55E-02	7.75E-02
1.58E+05	2.11E-02	6.94E-02	4.44E-02	8.61E-02
1.99E+05	2.47E-02	8.30E-02	5.62E-02	9.71E-02
2.51E+05	2.91E-02	9.22E-02	5.94E-02	1.16E-01
3.16E+05	3.62E-02	1.03E-01	7.41E-02	1.30E-01
3.98E+05	4.71E-02	1.10E-01	8.69E-02	1.44E-01
5.01E+05	5.96E-02	1.24E-01	9.97E-02	1.59E-01
6.30E+05	7.04E-02	1.39E-01	1.22E-01	1.70E-01
7.94E+05	8.63E-02	1.62E-01	1.30E-01	1.73E-01
1.00E+06	1.23E-01	1.77E-01	1.58E-01	1.65E-01
1.25E+06	1.65E-01	1.82E-01	1.81E-01	1.42E-01
1.58E+06	2.06E-01	1.80E-01	1.88E-01	1.08E-01
1.99E+06	2.05E-01	1.46E-01	1.80E-01	7.89E-02
2.51E+06	2.14E-01	1.06E-01	1.43E-01	2.64E-02
3.16E+06	2.32E-01	7.48E-02	1.13E-01	6.02E-03
3.98E+06	2.17E-01	4.40E-02	3.92E-02	1.00E-02
5.01E+06	2.04E-01	2.03E-02	1.14E-03	1.03E-03
6.30E+06	1.37E-01	8.74E-04	0.00E+00	0.00E+00
7.94E+06	9.02E-02	2.53E-04	0.00E+00	0.00E+00
1.00E+07	9.19E-03	0.00E+00	0.00E+00	0.00E+00
1.58E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.30E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.51E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00

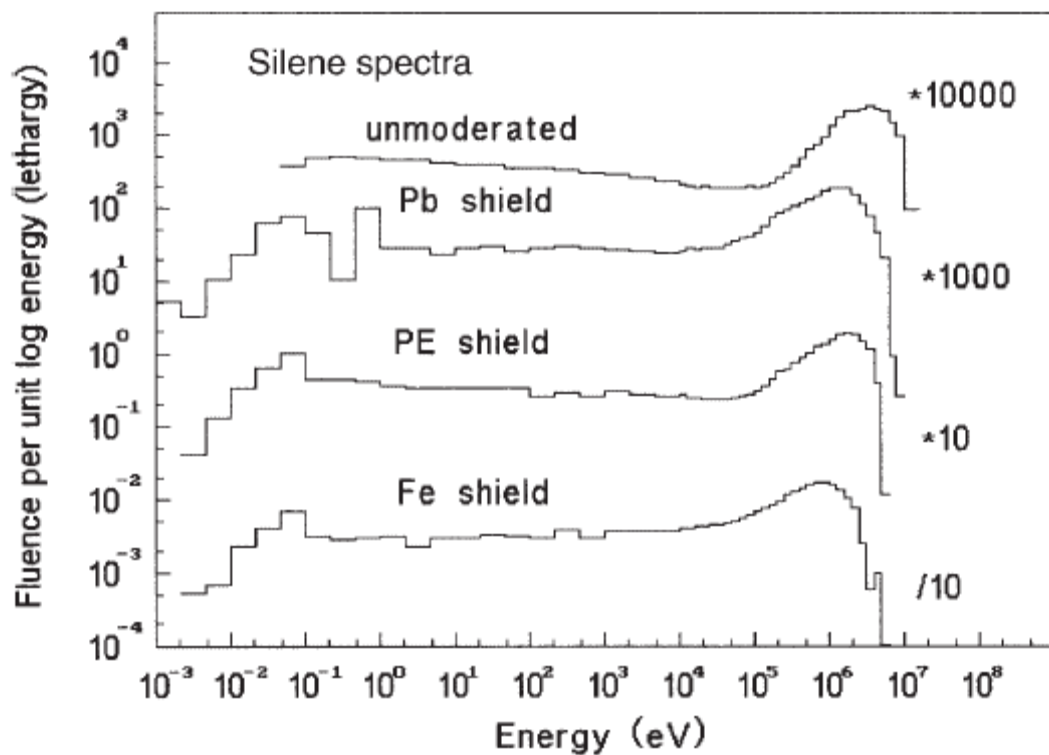


Figure B15. STRAY NEUTRON SIMULATION FIELDS (SILENE REACTOR)

Table B16. PWR STRAY NEUTRON SIMULATION FIELDS

Energy in eV	Experimental position 1	Experimental position 2	MOX element container
1.00E-03	0.00E+00	0.00E+00	0.00E+00
2.15E-03	0.00E+00	0.00E+00	0.00E+00
4.64E-03	0.00E+00	0.00E+00	0.00E+00
1.00E-02	5.50E-03	2.96E-03	7.01E-03
2.15E-02	9.84E-03	8.84E-03	1.36E-02
4.64E-02	1.31E-02	1.52E-02	1.14E-02
1.00E-01	1.32E-02	1.92E-02	6.61E-03
2.15E-01	2.13E-02	3.17E-02	1.06E-02
4.64E-01	2.68E-02	3.26E-02	7.19E-03
1.00E+00	2.91E-02	3.65E-02	7.87E-03
2.15E+00	2.93E-02	3.76E-02	6.43E-03
4.64E+00	3.02E-02	4.16E-02	9.52E-03
1.00E+01	3.00E-02	4.35E-02	8.05E-03
2.15E+01	3.48E-02	4.81E-02	5.71E-03
4.64E+01	3.50E-02	4.99E-02	8.95E-03
1.00E+02	3.27E-02	4.91E-02	5.68E-03
2.15E+02	3.25E-02	4.98E-02	7.33E-03
4.64E+02	3.50E-02	5.29E-02	7.33E-03
1.00E+03	3.64E-02	5.77E-02	7.69E-03

2.15E+03	4.52E-02	6.86E-02	8.77E-03
4.64E+03	5.80E-02	8.20E-02	1.05E-02
1.00E+04	6.36E-02	8.36E-02	1.08E-02
1.25E+04	6.80E-02	8.55E-02	1.03E-02
1.58E+04	7.14E-02	8.51E-02	1.09E-02
1.99E+04	7.32E-02	8.74E-02	1.25E-02
2.51E+04	7.36E-02	8.85E-02	1.59E-02
3.16E+04	7.07E-02	8.97E-02	1.61E-02
3.98E+04	6.70E-02	8.98E-02	1.79E-02
5.01E+04	6.91E-02	9.59E-02	2.44E-02
6.30E+04	8.16E-02	9.99E-02	3.45E-02
7.94E+04	9.98E-02	1.11E-01	4.17E-02
1.00E+05	1.19E-01	1.17E-01	4.71E-02
1.25E+05	1.37E-01	1.24E-01	6.14E-02
1.58E+05	1.53E-01	1.23E-01	8.66E-02
1.99E+05	1.65E-01	1.19E-01	1.13E-01
2.51E+05	1.73E-01	1.13E-01	1.36E-01
3.16E+05	2.17E-01	1.06E-01	1.97E-01
3.98E+05	2.22E-01	1.02E-01	2.07E-01
5.01E+05	2.05E-01	8.12E-02	2.36E-01
6.30E+05	1.76E-01	3.97E-02	2.75E-01
7.94E+05	1.24E-01	4.23E-02	3.06E-01
1.00E+06	7.39E-02	1.79E-02	3.74E-01
1.25E+06	5.11E-02	1.68E-03	4.71E-01
1.58E+06	2.48E-02	3.51E-03	3.47E-01
1.99E+06	1.66E-02	9.11E-03	3.23E-01
2.51E+06	1.12E-02	4.24E-04	1.98E-01
3.16E+06	6.64E-03	0.00E+00	1.27E-01
3.98E+06	3.16E-03	0.00E+00	5.53E-02
5.01E+06	5.50E-04	0.00E+00	3.92E-02
6.30E+06	5.86E-05	0.00E+00	1.40E-02
7.94E+06	0.00E+00	0.00E+00	1.81E-02
1.00E+07	0.00E+00	0.00E+00	5.78E-03
1.58E+07	0.00E+00	0.00E+00	2.09E-03
2.51E+07	0.00E+00	0.00E+00	1.58E-04
3.98E+07	0.00E+00	0.00E+00	0.00E+00
6.30E+07	0.00E+00	0.00E+00	0.00E+00
1.00E+08	0.00E+00	0.00E+00	0.00E+00
1.58E+08	0.00E+00	0.00E+00	0.00E+00
2.51E+08	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00

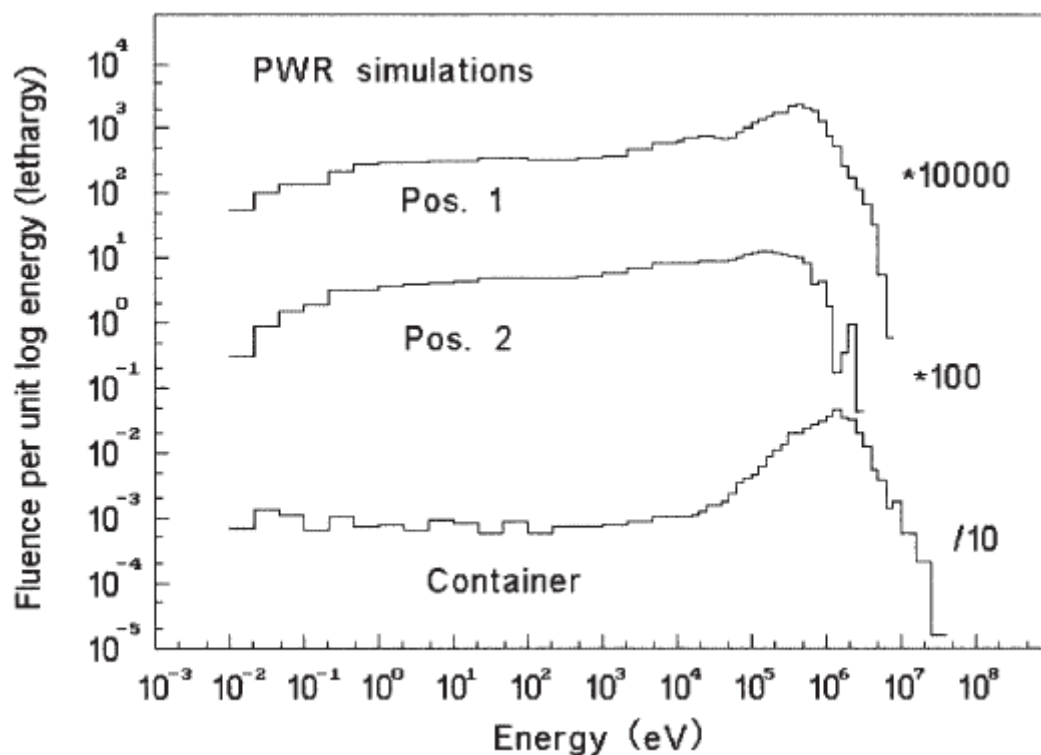


Figure B16. PWR STRAY NEUTRON SIMULATION FIELDS

Table B17. HIGH ENERGY REFERENCE SPECTRA (PSI AND CERN)

Energy in eV	PSI,60 MeV, pure beam	PSI,60 MeV, background	PSI,60 MeV, beam with background	CERN, Pb beam on Pb	CERN, concrete shield, proton beam on Cu
1.00E-03	3.18E-06	4.32E-03	1.08E-03	0.00E+00	0.00E+00
2.15E-03	7.61E-06	1.11E-02	2.78E-03	0.00E+00	0.00E+00
4.64E-03	1.59E-05	2.84E-02	7.14E-03	0.00E+00	4.54E-02
1.00E-02	2.62E-05	6.92E-02	1.73E-02	3.99E-02	5.16E-02
2.15E-02	2.77E-05	1.34E-01	3.36E-02	4.23E-02	5.69E-02
4.64E-02	2.40E-05	1.54E-01	3.84E-02	4.33E-02	5.16E-02
1.00E-01	1.95E-05	7.10E-02	1.77E-02	1.67E-02	1.84E-02
2.15E-01	1.72E-05	5.30E-02	1.33E-02	1.51E-02	1.56E-02
4.64E-01	1.72E-05	4.39E-02	1.10E-02	1.75E-02	1.59E-02
1.00E+00	2.01E-05	4.19E-02	1.05E-02	1.76E-02	1.93E-02
2.15E+00	2.66E-05	4.11E-02	1.03E-02	1.59E-02	1.54E-02
4.64E+00	3.64E-05	4.04E-02	1.01E-02	1.27E-02	1.23E-02
1.00E+01	5.21E-05	4.01E-02	1.01E-02	1.28E-02	1.15E-02
2.15E+01	7.61E-05	4.02E-02	1.01E-02	1.22E-02	9.58E-03
4.64E+01	1.13E-04	4.04E-02	1.02E-02	1.19E-02	9.63E-03
1.00E+02	1.69E-04	4.06E-02	1.02E-02	1.19E-02	9.31E-03
2.15E+02	2.54E-04	4.09E-02	1.04E-02	1.22E-02	1.00E-02
4.64E+02	3.84E-04	4.11E-02	1.05E-02	1.33E-02	1.23E-02

1.00E+03	5.78E-04	4.11E-02	1.07E-02	1.30E-02	1.43E-02
2.15E+03	8.66E-04	4.09E-02	1.09E-02	1.55E-02	1.44E-02
4.64E+03	1.31E-03	4.05E-02	1.11E-02	1.70E-02	1.74E-02
1.00E+04	1.70E-03	4.00E-02	1.13E-02	1.84E-02	1.80E-02
1.25E+04	1.93E-03	3.98E-02	1.14E-02	1.90E-02	1.79E-02
1.58E+04	2.18E-03	3.95E-02	1.15E-02	1.95E-02	1.74E-02
1.99E+04	2.47E-03	3.92E-02	1.16E-02	2.06E-02	2.03E-02
2.51E+04	2.80E-03	3.89E-02	1.18E-02	2.25E-02	2.12E-02
3.16E+04	3.16E-03	3.86E-02	1.20E-02	2.47E-02	2.27E-02
3.98E+04	3.59E-03	3.81E-02	1.22E-02	2.67E-02	2.57E-02
5.01E+04	4.06E-03	3.78E-02	1.25E-02	2.41E-02	2.91E-02
6.30E+04	4.61E-03	3.72E-02	1.28E-02	2.69E-02	2.97E-02
7.94E+04	5.21E-03	3.65E-02	1.31E-02	3.04E-02	3.38E-02
1.00E+05	5.92E-03	3.58E-02	1.33E-02	3.17E-02	3.76E-02
1.25E+05	6.69E-03	3.48E-02	1.37E-02	3.36E-02	3.77E-02
1.58E+05	7.54E-03	3.34E-02	1.40E-02	3.80E-02	4.26E-02
1.99E+05	8.59E-03	3.16E-02	1.44E-02	4.19E-02	4.86E-02
2.51E+05	9.71E-03	2.97E-02	1.47E-02	4.82E-02	5.01E-02
3.16E+05	1.09E-02	2.77E-02	1.51E-02	5.52E-02	5.84E-02
3.98E+05	1.23E-02	2.63E-02	1.58E-02	6.44E-02	5.97E-02
5.01E+05	1.37E-02	2.44E-02	1.64E-02	7.19E-02	6.57E-02
6.30E+05	1.53E-02	2.23E-02	1.71E-02	8.13E-02	6.95E-02
7.94E+05	1.70E-02	2.10E-02	1.81E-02	8.90E-02	7.30E-02
1.00E+06	1.89E-02	2.00E-02	1.93E-02	9.84E-02	7.79E-02
1.25E+06	2.09E-02	1.72E-02	2.00E-02	1.05E-01	8.22E-02
1.58E+06	2.31E-02	1.14E-02	2.02E-02	1.14E-01	8.39E-02
1.99E+06	2.54E-02	6.19E-03	2.07E-02	1.19E-01	8.81E-02
2.51E+06	2.83E-02	1.73E-03	2.17E-02	1.28E-01	8.96E-02
3.16E+06	3.13E-02	1.81E-03	2.34E-02	1.31E-01	8.97E-02
3.98E+06	3.62E-02	1.42E-03	2.77E-02	1.29E-01	9.18E-02
5.01E+06	4.78E-02	2.19E-03	3.66E-02	1.33E-01	9.39E-02
6.30E+06	6.75E-02	8.34E-04	5.12E-02	1.33E-01	9.41E-02
7.94E+06	7.93E-02	1.23E-03	6.03E-02	1.30E-01	9.48E-02
1.00E+07	8.66E-02	8.26E-04	6.54E-02	1.25E-01	8.30E-02
1.58E+07	1.55E-01	4.25E-03	1.17E-01	1.01E-01	4.86E-02
2.51E+07	2.79E-01	7.49E-03	2.12E-01	8.28E-02	1.64E-02
3.98E+07	3.23E-01	6.22E-04	2.43E-01	9.55E-02	1.19E-02
6.30E+07	1.06E+00	2.70E-02	8.01E-01	1.02E-01	5.86E-02
1.00E+08	0.00E+00	0.00E+00	0.00E+00	6.77E-02	1.51E-01
1.58E+08	0.00E+00	0.00E+00	0.00E+00	2.66E-02	1.73E-01
2.51E+08	0.00E+00	0.00E+00	0.00E+00	3.41E-04	1.02E-01
3.98E+08	0.00E+00	0.00E+00	0.00E+00	1.60E-04	8.64E-03

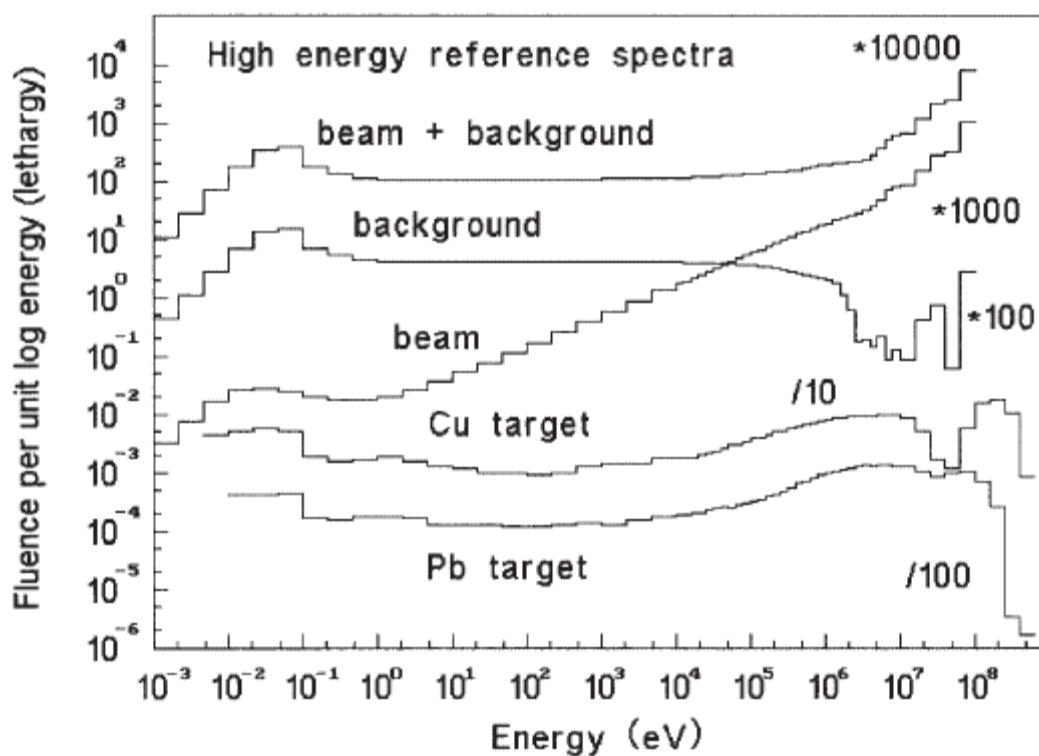


Figure B17. HIGH ENERGY REFERENCE SPECTRA (PSI AND CERN)

Table B19. HIGH ENERGY REFERENCE SPECTRA (CERN)

Energy in eV	Concrete, top	Concrete, side	Fe, top	Fe, side
1.00E-03	1.69E-03	1.45E-03	2.32E-04	6.53E-03
2.15E-03	4.27E-03	4.15E-03	5.00E-04	1.35E-02
4.64E-03	1.10E-02	1.22E-02	1.01E-03	2.63E-02
1.00E-02	2.78E-02	3.47E-02	1.73E-03	4.40E-02
2.15E-02	5.66E-02	7.81E-02	2.15E-03	5.45E-02
4.64E-02	6.48E-02	9.35E-02	2.41E-03	5.58E-02
1.00E-01	2.77E-02	3.74E-02	2.71E-03	4.77E-02
2.15E-01	2.03E-02	2.51E-02	3.07E-03	4.51E-02
4.64E-01	1.69E-02	1.97E-02	3.56E-03	4.29E-02
1.00E+00	1.69E-02	1.89E-02	4.24E-03	4.11E-02
2.15E+00	1.68E-02	1.79E-02	5.18E-03	3.94E-02
4.64E+00	1.67E-02	1.69E-02	6.44E-03	3.78E-02
1.00E+01	1.67E-02	1.60E-02	8.11E-03	3.63E-02
2.15E+01	1.67E-02	1.52E-02	1.02E-02	3.49E-02
4.64E+01	1.67E-02	1.46E-02	1.30E-02	3.36E-02
1.00E+02	1.68E-02	1.40E-02	1.67E-02	3.22E-02
2.15E+02	1.69E-02	1.35E-02	2.14E-02	3.11E-02
4.64E+02	1.70E-02	1.33E-02	2.75E-02	3.00E-02
1.00E+03	1.72E-02	2.22E-02	3.53E-02	2.90E-02
2.15E+03	1.74E-02	2.01E-02	4.50E-02	2.81E-02
4.64E+03	1.78E-02	2.32E-02	5.80E-02	2.73E-02
1.00E+04	1.81E-02	1.90E-02	6.85E-02	2.70E-02

1.25E+04	1.83E-02	1.80E-02	7.39E-02	2.69E-02
1.58E+04	1.86E-02	2.10E-02	8.03E-02	2.69E-02
1.99E+04	1.90E-02	2.26E-02	8.71E-02	2.71E-02
2.51E+04	1.91E-02	2.41E-02	9.06E-02	2.68E-02
3.16E+04	1.75E-02	2.28E-02	7.12E-02	2.41E-02
3.98E+04	1.44E-02	1.77E-02	2.65E-02	1.91E-02
5.01E+04	1.73E-02	2.08E-02	2.42E-02	2.28E-02
6.30E+04	2.82E-02	3.42E-02	8.66E-02	3.83E-02
7.94E+04	3.02E-02	3.83E-02	1.23E-01	4.73E-02
1.00E+05	2.17E-02	3.16E-02	1.42E-01	4.75E-02
1.25E+05	2.27E-02	3.28E-02	1.82E-01	4.97E-02
1.58E+05	3.26E-02	3.96E-02	2.17E-01	4.83E-02
1.99E+05	3.65E-02	4.06E-02	2.46E-01	5.28E-02
2.51E+05	3.57E-02	3.74E-02	2.56E-01	6.45E-02
3.16E+05	3.64E-02	3.60E-02	2.88E-01	5.68E-02
3.98E+05	3.81E-02	3.85E-02	3.41E-01	3.00E-02
5.01E+05	5.20E-02	4.95E-02	3.02E-01	3.24E-02
6.30E+05	8.04E-02	7.19E-02	1.60E-01	7.14E-02
7.94E+05	8.24E-02	7.33E-02	6.82E-02	7.16E-02
1.00E+06	5.04E-02	4.67E-02	6.30E-02	3.07E-02
1.25E+06	5.22E-02	4.92E-02	3.45E-02	2.23E-02
1.58E+06	9.26E-02	8.52E-02	4.97E-02	4.43E-02
1.99E+06	1.07E-01	1.02E-01	5.21E-02	5.39E-02
2.51E+06	9.99E-02	1.01E-01	2.26E-02	5.90E-02
3.16E+06	8.31E-02	8.46E-02	2.08E-02	5.34E-02
3.98E+06	4.48E-02	3.90E-02	1.18E-02	2.49E-02
5.01E+06	3.38E-02	2.21E-02	1.19E-02	1.74E-02
6.30E+06	6.78E-02	5.14E-02	9.97E-03	3.60E-02
7.94E+06	6.68E-02	5.13E-02	1.08E-02	3.55E-02
1.00E+07	3.32E-02	3.27E-02	9.01E-03	1.96E-02
1.58E+07	5.42E-02	4.46E-02	9.74E-03	2.63E-02
2.51E+07	7.33E-02	6.57E-02	1.37E-02	3.08E-02
3.98E+07	1.32E-01	1.16E-01	1.70E-02	6.79E-02
6.30E+07	1.90E-01	1.49E-01	2.58E-02	6.76E-02
1.00E+08	1.69E-01	1.49E-01	2.09E-02	8.67E-02
1.58E+08	1.01E-01	7.48E-02	1.24E-02	3.46E-02
2.51E+08	8.70E-03	1.21E-02	2.79E-03	1.18E-02
3.98E+08	1.62E-02	1.22E-02	1.33E-03	2.86E-03

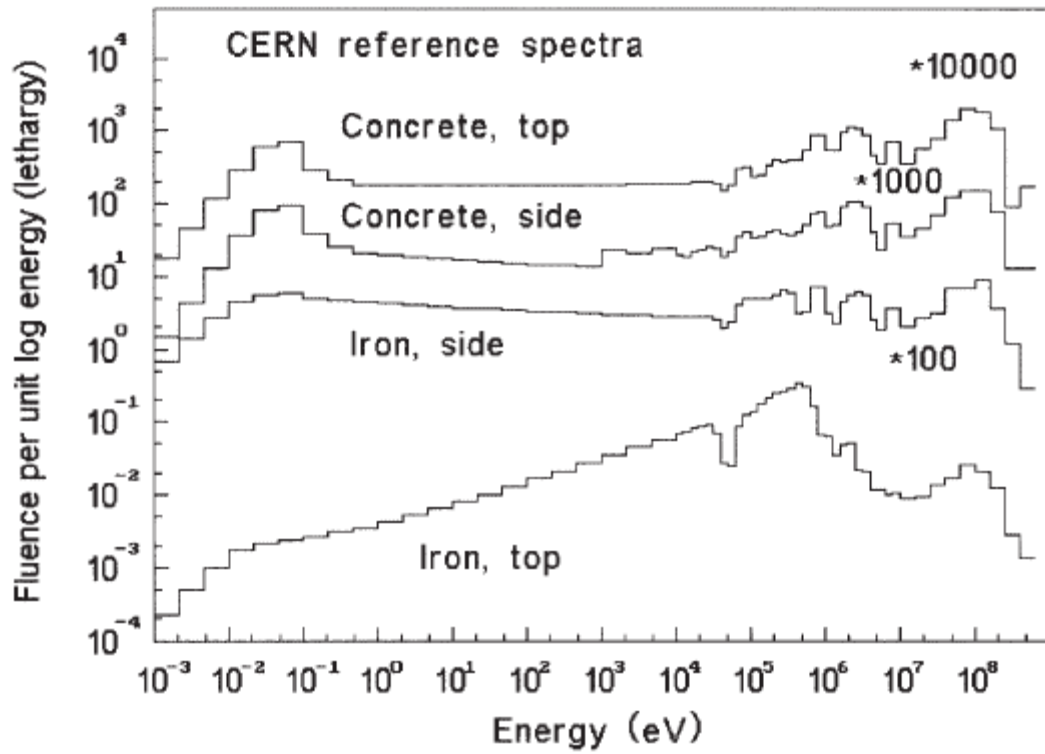


Figure B19. HIGH ENERGY REFERENCE SPECTRA (CERN)

Table B20. HIGH ENERGY REFERENCE SPECTRA (CERN, FFTF, SSRL)

Energy in eV	CERN, Fe shield	CERN, concrete shield	FFTP facility	SSRL linac, diagnostic room	SSRL SPEAR, on the roof
1.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.64E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.15E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-01	3.09E-03	3.13E-02	3.60E-02	1.09E-01	1.72E-01
2.15E-01	3.09E-03	2.97E-02	4.24E-02	1.09E-01	1.76E-01
4.64E-01	3.36E-03	2.66E-02	2.34E-02	9.18E-02	1.32E-01
1.00E+00	3.41E-03	2.54E-02	1.82E-02	7.41E-02	9.09E-02
2.15E+00	3.69E-03	2.36E-02	1.62E-02	5.95E-02	6.34E-02
4.64E+00	4.15E-03	2.16E-02	1.53E-02	4.67E-02	4.77E-02
1.00E+01	4.53E-03	2.21E-02	1.48E-02	3.96E-02	3.73E-02
2.15E+01	5.28E-03	1.99E-02	1.42E-02	3.29E-02	2.92E-02
4.64E+01	6.77E-03	1.92E-02	1.47E-02	2.84E-02	2.57E-02
1.00E+02	8.35E-03	1.97E-02	1.50E-02	2.65E-02	2.21E-02
2.15E+02	1.06E-02	1.94E-02	1.64E-02	2.39E-02	1.88E-02
4.64E+02	1.47E-02	1.83E-02	1.71E-02	2.42E-02	1.76E-02
1.00E+03	2.09E-02	1.93E-02	1.94E-02	2.37E-02	1.70E-02

2.15E+03	2.98E-02	1.97E-02	2.18E-02	2.43E-02	1.67E-02
4.64E+03	4.47E-02	2.05E-02	2.43E-02	2.68E-02	1.67E-02
1.00E+04	5.31E-02	2.04E-02	2.62E-02	2.81E-02	1.75E-02
1.25E+04	5.83E-02	2.14E-02	2.69E-02	2.92E-02	1.74E-02
1.58E+04	6.94E-02	2.16E-02	2.77E-02	3.03E-02	1.76E-02
1.99E+04	7.94E-02	2.18E-02	2.90E-02	3.24E-02	1.98E-02
2.51E+04	9.21E-02	2.37E-02	3.03E-02	3.34E-02	2.18E-02
3.16E+04	1.04E-01	2.39E-02	3.24E-02	3.45E-02	2.12E-02
3.98E+04	1.25E-01	2.42E-02	3.50E-02	3.61E-02	2.11E-02
5.01E+04	1.44E-01	2.51E-02	3.76E-02	3.96E-02	2.18E-02
6.30E+04	1.66E-01	2.68E-02	4.05E-02	4.51E-02	2.58E-02
7.94E+04	1.92E-01	2.87E-02	4.30E-02	4.67E-02	2.69E-02
1.00E+05	2.17E-01	3.04E-02	4.75E-02	5.15E-02	2.99E-02
1.25E+05	2.39E-01	3.22E-02	4.98E-02	6.08E-02	3.24E-02
1.58E+05	2.51E-01	3.57E-02	5.33E-02	6.11E-02	3.75E-02
1.99E+05	2.50E-01	4.15E-02	6.36E-02	6.64E-02	4.73E-02
2.51E+05	2.63E-01	4.44E-02	6.84E-02	7.99E-02	4.94E-02
3.16E+05	2.55E-01	5.15E-02	7.32E-02	9.05E-02	5.39E-02
3.98E+05	2.21E-01	6.34E-02	7.71E-02	9.00E-02	5.80E-02
5.01E+05	1.75E-01	7.08E-02	9.54E-02	9.32E-02	6.34E-02
6.30E+05	1.57E-01	7.50E-02	8.93E-02	9.53E-02	6.66E-02
7.94E+05	1.34E-01	8.24E-02	9.86E-02	9.66E-02	7.04E-02
1.00E+06	1.26E-01	8.21E-02	1.09E-01	1.00E-01	7.45E-02
1.25E+06	7.34E-02	8.44E-02	1.15E-01	1.07E-01	7.78E-02
1.58E+06	5.20E-02	8.82E-02	1.14E-01	1.16E-01	7.78E-02
1.99E+06	4.23E-02	9.21E-02	1.12E-01	1.01E-01	7.16E-02
2.51E+06	3.06E-02	9.18E-02	1.10E-01	6.45E-02	5.51E-02
3.16E+06	1.94E-02	8.95E-02	1.03E-01	6.05E-02	5.10E-02
3.98E+06	1.44E-02	9.31E-02	1.01E-01	5.04E-02	4.28E-02
5.01E+06	1.45E-02	9.37E-02	9.86E-02	2.89E-02	4.04E-02
6.30E+06	1.12E-02	8.18E-02	9.76E-02	2.97E-02	3.93E-02
7.94E+06	9.48E-03	7.99E-02	8.80E-02	2.11E-02	3.32E-02
1.00E+07	1.09E-02	9.05E-02	9.44E-02	2.19E-02	2.91E-02
1.58E+07	1.14E-02	1.29E-01	8.90E-02	4.22E-03	2.18E-02
2.51E+07	1.62E-02	1.50E-01	1.21E-01	4.06E-04	8.27E-03
3.98E+07	1.42E-02	1.33E-01	1.24E-01	5.28E-04	5.39E-04
6.30E+07	1.34E-02	1.21E-01	1.17E-01	7.38E-06	2.52E-04
1.00E+08	6.15E-03	1.06E-01	5.33E-02	0.00E+00	0.00E+00
1.58E+08	1.42E-03	5.22E-02	1.02E-02	0.00E+00	0.00E+00
2.51E+08	8.75E-04	7.25E-03	0.00E+00	0.00E+00	0.00E+00
3.98E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

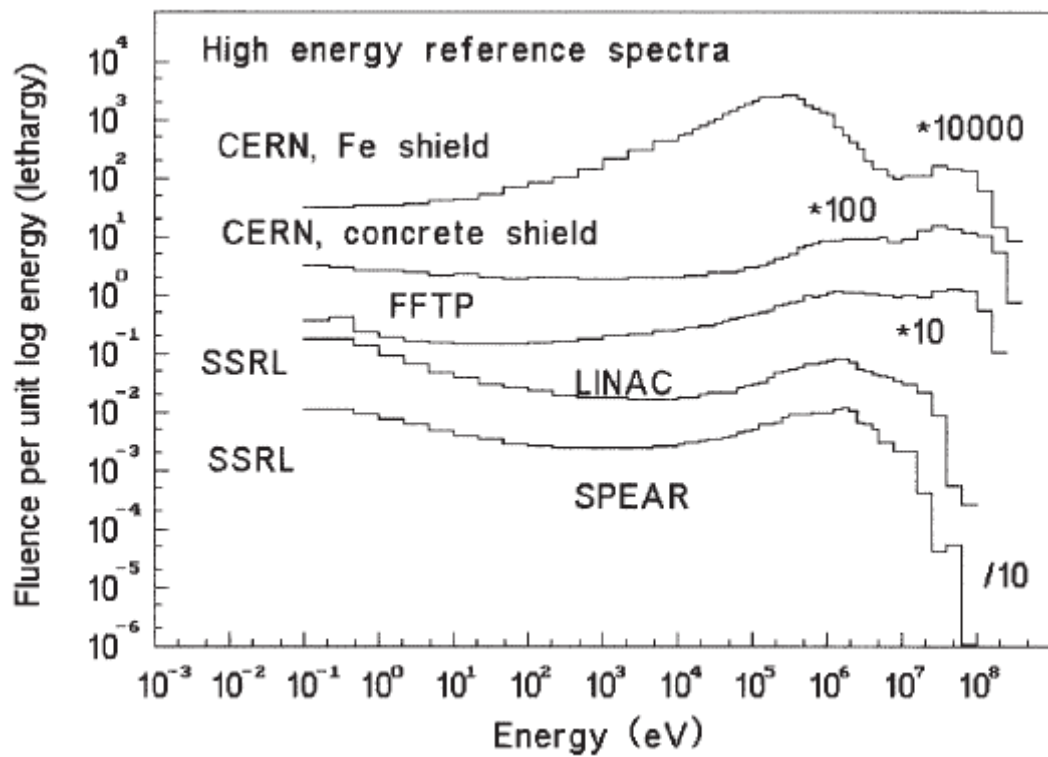


Figure B20. HIGH ENERGY REFERENCE SPECTRA (CERN, FFTP, SSRL)

Table B21. HIGH ENERGY REFERENCE SPECTRA (JINR AND IHEP)

Energy in eV	Phasotron, soft field	Phasotron, hard field	IHEP, filtered by 220 cm concrete
1.00E-03	0.00E+00	0.00E+00	0.00E+00
2.15E-03	0.00E+00	0.00E+00	0.00E+00
4.64E-03	1.74E-01	7.60E-02	0.00E+00
1.00E-02	1.56E-01	7.18E-02	0.00E+00
2.15E-02	1.36E-01	6.72E-02	6.23E-02
4.64E-02	1.16E-01	6.26E-02	6.36E-02
1.00E-01	9.65E-02	5.73E-02	7.15E-02
2.15E-01	7.86E-02	5.17E-02	2.66E-02
4.64E-01	6.13E-02	4.47E-02	9.21E-03
1.00E+00	4.61E-02	3.66E-02	1.38E-02
2.15E+00	3.42E-02	2.87E-02	1.33E-02
4.64E+00	2.43E-02	2.09E-02	1.32E-02
1.00E+01	1.76E-02	1.46E-02	1.41E-02
2.15E+01	1.43E-02	1.12E-02	1.37E-02
4.64E+01	1.30E-02	1.00E-02	1.46E-02
1.00E+02	1.41E-02	1.20E-02	1.45E-02
2.15E+02	1.69E-02	1.67E-02	1.46E-02
4.64E+02	2.07E-02	2.34E-02	1.49E-02
1.00E+03	2.49E-02	3.15E-02	1.51E-02

2.15E+03	2.87E-02	3.94E-02	1.55E-02
4.64E+03	3.19E-02	4.75E-02	1.62E-02
1.00E+04	3.32E-02	5.17E-02	1.64E-02
1.25E+04	3.36E-02	5.31E-02	1.65E-02
1.58E+04	3.40E-02	5.49E-02	1.70E-02
1.99E+04	3.40E-02	5.59E-02	1.74E-02
2.51E+04	3.40E-02	5.70E-02	1.79E-02
3.16E+04	3.38E-02	5.73E-02	1.84E-02
3.98E+04	3.34E-02	5.80E-02	1.93E-02
5.01E+04	3.28E-02	5.77E-02	2.00E-02
6.30E+04	3.23E-02	5.77E-02	2.28E-02
7.94E+04	3.15E-02	5.70E-02	2.62E-02
1.00E+05	3.06E-02	5.63E-02	2.58E-02
1.25E+05	2.92E-02	5.52E-02	2.90E-02
1.58E+05	2.79E-02	5.38E-02	3.16E-02
1.99E+05	2.66E-02	5.21E-02	3.12E-02
2.51E+05	2.51E-02	5.03E-02	3.31E-02
3.16E+05	2.35E-02	4.82E-02	3.49E-02
3.98E+05	2.18E-02	4.61E-02	3.47E-02
5.01E+05	1.99E-02	4.36E-02	3.82E-02
6.30E+05	1.83E-02	4.12E-02	4.41E-02
7.94E+05	1.65E-02	3.90E-02	4.95E-02
1.00E+06	1.46E-02	3.66E-02	6.20E-02
1.25E+06	1.28E-02	3.48E-02	6.70E-02
1.58E+06	1.10E-02	3.29E-02	7.15E-02
1.99E+06	9.46E-03	3.14E-02	8.03E-02
2.51E+06	7.84E-03	3.01E-02	1.11E-01
3.16E+06	6.49E-03	2.95E-02	1.94E-01
3.98E+06	5.07E-03	2.90E-02	8.88E-02
5.01E+06	4.03E-03	2.93E-02	7.89E-02
6.30E+06	2.92E-03	2.97E-02	1.62E-01
7.94E+06	2.18E-03	3.09E-02	7.31E-02
1.00E+07	1.20E-03	3.30E-02	5.94E-02
1.58E+07	4.20E-04	3.62E-02	4.88E-02
2.51E+07	3.02E-04	3.98E-02	4.25E-02
3.98E+07	1.42E-04	4.26E-02	8.83E-02
6.30E+07	5.16E-04	4.26E-02	1.18E-01
1.00E+08	7.03E-04	3.80E-02	1.32E-01
1.58E+08	1.04E-03	2.82E-02	9.75E-02
2.51E+08	1.42E-03	1.54E-02	9.23E-02
3.98E+08	0.00E+00	9.36E-03	4.88E-02

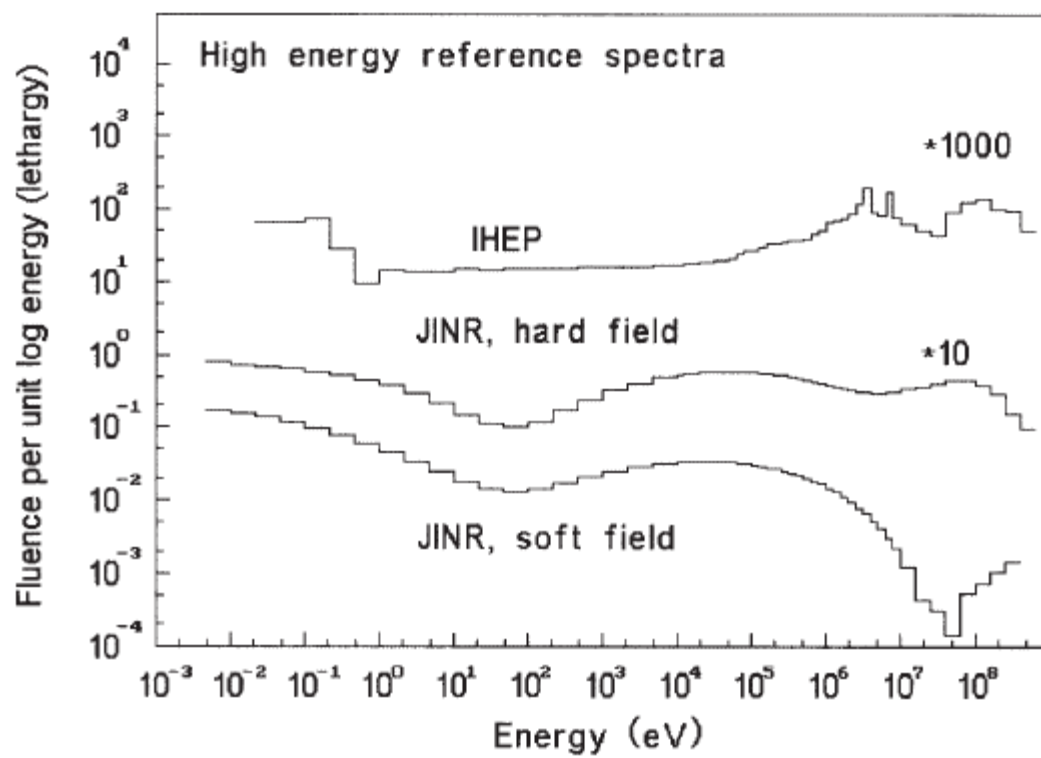


Figure B21. HIGH ENERGY REFERENCE SPECTRA (JINR AND IHEP)

APPENDIX C

MATLAB Code

The MATLAB embedded Neural Network Toolbox 5.1 was implemented to conduct this research. [22] The Neural Network Toolbox extends MATLAB with tools for designing, implementing, visualizing, and simulating neural networks. The Neural Network Toolbox supports the most commonly used supervised and unsupervised network architectures, as well as comprehensive set of training and learning functions.

It also provides comprehensive support for many proven network paradigms, as well as graphical user interfaces (GUIs) that enable users to design and manage their networks. The modular, open, and extensible design of the toolbox simplifies the creation of customized functions and networks.

Once the Neural Network Toolbox 5.1 is installed with MATLAB, all the functions used in the programs listed below will be available. The input and output files are available in the CD coming along with the hardcopy version of this thesis.

1. Calculation of the optimal spread constant

```
% bestsc.m
% Calculate the optimal spread constant value giving the minimum SSE

% Jia Hou
% Department of Nuclear Engineering
% The University of Tennessee, 10/17/2007

clear

% Data loading
load egy_new; %Load energy bin data
load rfs; %Load response matrix

% Load and form the neutron spectrum data
load spe_data1; load spe_data2; load spe_data3; load spe_data4;
spe_data = [spe_data1 spe_data2 spe_data3 spe_data4];
```

```

% Number of Observations: obs = # of column of matrix
obs = size(spe_data,2);

% Convert unit from #(neutron)/cm2/sec/lethargy into #(neutron)/cm2/sec
spe_data_temp=zeros(size(spe_data));
for i=1:obs
    for j=1:43
        spe_data_temp(j,i)=spe_data(j,i)/log(25/egy_new(j));
    end
end

% Calculate the count rates for Bonner Spheres
cr_data = (spe_data_temp'*rfs)'; %

% Add uncertainty info to input matrix
cr_temp = zeros(16,obs);
cr_temp(1:8,:)=cr_data;
cr_temp(9:16,:)=(cr_data).^5;
cr_data=cr_temp;

%Standardize the input and output data with zscore1
cr_data=cr_data';
[cr_datas,xm,xs]=zscore1(cr_data);
cr_datas=cr_datas'; %standardized input data
spe_data=spe_data';
[spe_datas,ym,ys]=zscore1(spe_data);
spe_datas=spe_datas'; %%standardized output data

% Calculate the optimal spread constant
h=0.01:0.01:2; % Spread constant range
MSSE=zeros(size(h));
SSE=zeros(1,obs);
outp=zeros(43,obs); %Output matrix
for j=1:length(h);
    for i=1:obs;
        xtests=cr_datas(:,i); %Choose the i-th input vector
        ytests=spe_datas(:,i); %Choose the i-th output vector
        if i==1
            xtrns=cr_datas(:,2:obs);
            ytrns=spe_datas(:,2:obs);
        elseif i==obs
            xtrns=cr_datas(:,1:obs-1);

```

```

        ytrns=spe_datas(:,1:obs-1);
    else
        xtrns=cr_datas(:,[1:i-1,i+1:obs]);
        ytrns=spe_datas(:,[1:i-1,i+1:obs]);
    end
    % GRNN Calculation
    net = newgrnn(xtrns,ytrns,.01*j);
    outp(:,i) = sim(net,xtests);
    serror=ytests-outp(:,i);
    SSE(i)=sse(serror);
end
MSSE(j)=mean(SSE);
end
ind=find(min(MSSE)==MSSE); %Find the index associated with the min SSE
h_ind=h(ind); %Store the optimal spread constant

plot(h,MSSE); %Plot the tradeoff between SSE and spread constant
title('Optimization of kernel spread constant');
xlabel('Spread Constant');
ylabel('Mean SSE');
hold on
plot(h(ind),MSSE(ind),'--rs','LineWidth',1,'MarkerEdgeColor','k',...
'MarkerFaceColor','r','MarkerSize',3); %Plot the global minimum
hold off;
save sc h_ind; %Save the optimal spread constant value to sc.mat
%Save the mean and standard deviation of input data respectively
save xm xm; save xs xs;
%Save the mean and standard deviation of output data respectively
save ym ym; save ys ys;

```

2. Neutron Spectrum Unfolding with GRNN

```
% ufd8.m
% Neutron spectrum unfolding using GRNN

% Jia Hou
% Department of Nuclear Engineering
% The University of Tennessee, 10/17/2007

clear

load egy_new; %Load energy bin data
load rfs; %Load the response matrix
%Load previous stored mean and standard deviation for input and output
load xm; load xs; load ym; load ys;
load sc; %Load previous stored optimal spread constant value

% Load and form the neutron spectrum data
load spe_data1; load spe_data2; load spe_data3; load spe_data4;
spe_data=[spe_data1 spe_data2 spe_data3 spe_data4];

% Number of Observations: obs = # of column of matrix
obs=size(spe_data,2);

% Convert unit from #(neutron)/cm2/sec/lethargy into #(neutron)/cm2/sec
spe_data_temp=zeros(size(spe_data));
for i=1:obs
    for j=1:43
        spe_data_temp(j,i)=spe_data(j,i)/log(25/egy_new(j));
    end
end

% Calculate the count rates for Bonner Spheres
cr_data = (spe_data_temp'*rfs)';

% Add uncertainty info to input matrix
cr_temp = zeros(16,obs);
cr_temp(1:8,:)=cr_data;
cr_temp(9:16,:)=(cr_data).^0.5;
cr_data=cr_temp;

% Standardization of the data
cr_data=cr_data';
spe_data=spe_data';
```

```

% Standardize input data with previous criterion
[cr_datas]=zscore1(cr_data,xm,xs);
% Standardize input data with previous criterion
[spe_datas]=zscore1(spe_data,ym,ys);
cr_datas=cr_datas';
spe_datas=spe_datas';

% Data Set Division (Odd-and-Even)
train_ind=find(rem([1:obs],2)==1);
test_ind=find(rem([1:obs],2)~=1);
xtrns=cr_datas(:,train_ind);
xtests=cr_datas(:,test_ind);
ytrns=spe_datas(:,train_ind);
ytests=spe_datas(:,test_ind);

% Set up the error matrix
SSE=zeros(1,obs);

% GRNN Calculation
net = newgrnn(xtrns,ytrns,h_ind);
outp = sim(net,xtests); %Output matrix from GRNN

% Unscore the output
outp=outp';
output=unscore(outp,ym,ys); %Unscore the output data
output=output';

% Unscore the ytest data
ytests=ytests';
ytest=unscore(ytests,ym,ys); %%Unscore the testing output data
ytest=ytest';

% Calculate the Mean SSE
e=abs(ytest-output).^2;
perf=sum(e)/size(ytest,1);

% Plot the error information
bar(perf);
xlabel('Test data');
ylabel('Mean SSE');
title('GRNN Prediction error');

```

3. Code for Standardization

```
function [y,meanval,stdval] = zscore1(x, mvin,stdin)
%
% [y,meanval,stdval] = zscore1(x, mvin,stdin)
%
% Mean center the data and scale to unit variance.
% If number of inputs is one, calculate the mean and standard deviation.
% If the number of inputs is three, use the given mean and SD.

% J. Wesley Hines, The University of Tennessee, 1998
% 6-10-98
% Copyright (c)
%

[nrows,ncols]=size(x);

if nargin == 1
    meanval = mean(x); % calculate mean values
else
    meanval = mvin; % use previously calculated value
end

y = x - ones(nrows,1)*meanval; % subtract off mean

if nargin == 1
    stdval = std(y); % calculate the SD
else
    stdval = stdin; % use previously calculated value
end

y = y ./ (ones(nrows,1)*stdval); % normalize to unit variance
```

VITA

Jia Hou was born in Xi'an, Shaanxi, the People's Republic of China on November 12, 1982. He is the son of Tongrui Hou and Lai Zhang. In 2001, He entered Tsinghua University in Beijing where he received his Bachelor of Science degree in Engineering Physics in July 2005. Starting in August 2006, he entered graduate school at the University of Tennessee at Knoxville and received a Master of Science degree in Nuclear Engineering in December 2007.