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Analysis of SNEAK-7A & 7B Critical Benchmarks using 3-D Deterministic Transport and Sensitivity Analysis Methods

S. J. Kim*[1], I. Kodeli[2], E. Sartori[2]
[1]*Korea Atomic Energy Research Institute, Yuseong-gu, Daejeon, 305-353, Korea*
[2]*OECD NEA Data Bank, 12 Boulevard des Iles, 92130 Issy-les-Moulineaux, France*

As the detailed information on critical experiments performed in the SNEAK facility became available in the framework of the International Reactor Physics Benchmark Experiments (IRPhE) project, SNEAK-7A & 7B critical benchmarks are re-evaluated. The realistic modeling of these assemblies was done using the DANTSYS code capability for X-Y-Z geometry. Predicted core eigenvalues, spectral indices, and central material worths with effective cross sections based on JEF-2.2 nuclear data file, have been compared with measured values. As a result, the capability of modern 3-D transport method featuring very small corrections to the raw calculated value is appreciated and the quality of basic library for the interested assemblies is assessed. In addition, the core eigenvalue sensitivity analysis to the basic cross section of each important nuclide is performed. By utilizing the deviation of calculated spectrum indices from the measurement, together with the sensitivity coefficient, it is shown how the sensitivity analysis can be usefully adopted to figure out a specific detail of basic cross section for improvement and investigate the quality of measured integral parameters.

KEYWORDS: SNEAK-7, THREEDANT, JEF-2.2, Eigenvalue, Spectrum Index, Material Worth, Sensitivity

1. Introduction

Computers with large core memories that are indispensable for minimising approximations with regard to neutronic modelling are becoming easily available these days. The evaluations carried out in the 70s, however, were featured as many critical facilities in operation but were based on the diffusion theory approximation and required various corrections that were deliberately determined to overcome modelling deficiencies. Sometimes, the result was an ambiguous core eigenvalue, therefore making it somewhat questionable to derive the accuracy of the computer code packages in use for the analysis of specific experiments.

The SNEAK core, information about which is now becoming available to the international community thanks to the IRPhE project under the auspices of the OECD/NEA Data Bank, is composed of square platelets which are stacked horizontally in vertical stainless steel tubes. The SNEAK-7A & 7B assemblies are characterised by Pu-fuelled fast critical assemblies in the Karlsruhe Fast Critical Facility for the purpose of testing cross-section data and calculational methods. They are simple one-zone cores fuelled with PuO_2-UO_2 and reflected by depleted uranium.

The purpose of this paper is to neutronically describe these experiments as closely as possible to the configuration as they existed in the critical facility. Without having to elaborate to discover the corrections, modern methods are likely to clearly reveal either the quality of basic cross-sections or the validity of the experiments. The re-analysis covers the predicted core

* Corresponding author, Tel. 82-42-868-2279, FAX 82-42-868-8256, E-mail: sjkim3@kaeri.re.kr

eigenvalue, plate heterogeneity effects, spectral indices and central material worth followed by the sensitivity analysis of core eigenvalue to effective cross-sections.

2. Description of the SNEAK-7 Assemblies and Analysis Methodology

2.1 Description of the SNEAK-7 Assemblies

The SNEAK facility is a fixed vertical assembly with fuel elements suspended from a grid plate. Each fuel element (lattice) is separated by 5.44 cm. Platelets of various thickness are stacked horizontally within square fuel element tubes. The cross-section of the platelets is 5.077x5.077 cm^2. The composition of each platelet in this study includes the steel of the fuel element tubes and has a reduced number density since platelets are stretched to have a surface area corresponding to the lattice pitch squared. This two-dimensional cell heterogeneity effect is not pursued.

In SNEAK-7A, the core unit cell consisted of one PuO_2-UO_2 platelet (26.6% PuO_2 and 73.4% UO_2) and one graphite platelet, the thicknesses of which are 0.626 cm and 0.3126 cm, respectively. The planar layout is given in Figure 1, where control rods are also displayed in their respective positions. Radial and axial blankets were loaded with depleted UO_2 plates. In SNEAK-7B (Figure 2), the graphite platelet in the cell of 7A was exchanged by a 0.6256 cm thick $U_{nat}O_2$ platelet resulting in an average Pu-enrichment of about 13%.

There was a shortage of special PuO_2-UO_2 platelets required to load control rod tubes with a composition identical to the core plates. This led to loading the control rods with an enriched uranium cell, and thus approximately 10% of the critical mass came from the contribution of ^{235}U in both assemblies. In the R-Z model of the assembly, the homogenisation of these control rods with the core became a tricky procedure. As Table 1 shows, the total corrections in the eigenvalue caused by cylinderisation and control rod homogenisation amount to –510 pcm and -290 pcm for SNEAK-7A and 7B, respectively.

The criticality of SNEAK-7A and 7B were determined with all control rods in their most reactive position, i.e. with the fuelled portion of the rod in the core. The measurements were performed on critical eigenvalue, material buckling, spectral indices, neutron importance, central reactivity worths and delayed neutron fractions. An extensive description of experiments can be found in Ref. 1.

2.2 Analysis Methodology

As a fundamental analysis tool for this paper, the THREEDANT program included in the DANTSYS code package [2] was selected. Since SNEAK-7 consists of stacked plates in the square tube, this will allow to use 3-D discrete ordinates transport methods with minimal geometrical approximation. Where applicable, the TWODANT module was also utilised to analyse the whole assembly in R-Z geometry.

JEF-2.2 nuclear data files were processed into the KAFAX [3] 80-group library in the MATXS library format. The 80-group structure in the KAFAX was developed by LANL, and it appropriately treats the resonance behaviour of several materials such as ^{238}U, sodium and iron in the fast reactor analysis.

The library data were further processed by the TRANSX code [4] to produce the composition-dependent, region-wise macroscopic cross-section sets with the self-shielding effects arising from material and geometry taken into account. The effect of flux variation on the effective cross-section caused by the heterogeneous structure of a unit cell in the whole assembly is accounted for by R-Z full core heterogeneous calculations. In addition, correction factors for the mesh size effect on the evaluated core eigenvalue were generated.

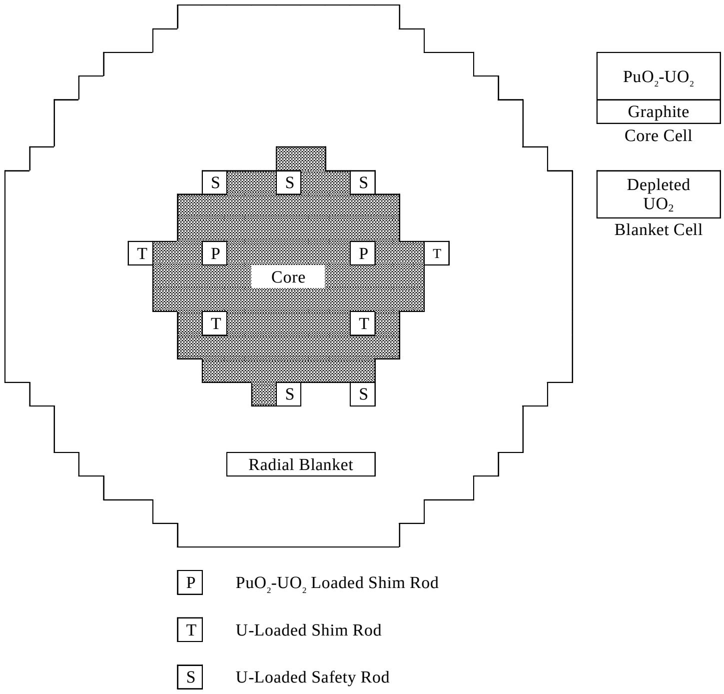

Fig.1 Horizontal cross-section and plate cells of SNEAK-7A

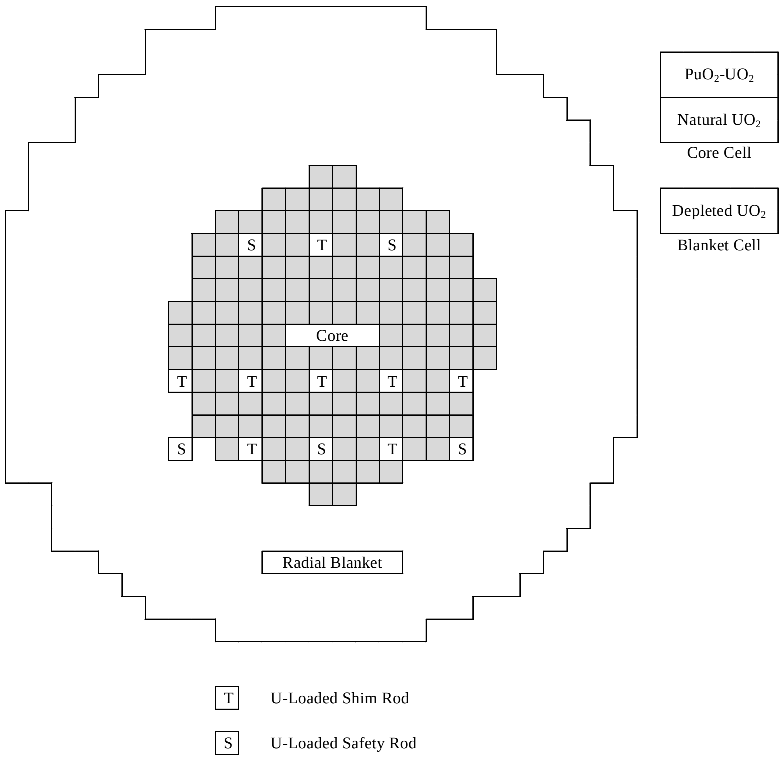

Fig.2 Horizontal cross-section and plate cells of SNEAK-7B

The first-order perturbation theory-based SUSD3D code [5] estimates the sensitivity of core eigenvalue with respect to the per cent change in the effective cross-sections, using the forward and adjoint fluxes from the THREEDANT runs.

3. Analysis Results

3.1 Calculation in 2-D Geometry: priori

Due to the limited amount of PuO_2-UO_2 special platelets necessary to load all of the control rods with a composition identical to the core, control rods with enriched uranium were also used in SNEAK-7. Therefore, the uranium filled control rods were homogenized for SNEAK-7B over the whole core and for SNEAK-7A over an outer ring of the core. Ref. 1 lists recommended compositions for use in the homogenised core zone and also provides the R-Z geometry specifications that include the enriched uranium rods in the core zone. Since the homogenised number densities in each region are given, the cross-section generation for the R-Z model accounted for the material background alone in its resonance self-shielding evaluation.

The estimated core eigenvalues with P_3S_8 turn out to be 1.0000 for both SNEAK-7A and 7B. Applied correction factors [1] to this 2-D generated eigenvalues, as is seen in Table 1 are cylinderisation correction, the effect of control rod homogenisation into core zone and the heterogeneity effect of cell structure. Table 1 shows that core eigenvalues of either assembly are predicted with deviations less than 160 pcm from the measured values. Along with JEF-2.2 results, predictions with KFKINR library [1] are also provided, which required additional corrections such as large transport effect and small elastic removal correction.

It seems that JEFF-2.2 is well versed to analyze SNEAK-7 experiments. However, this is also related with the analysis method adopted. Excellent matches with the measurement may be originating from cross sections themselves (related with JEF-2.2 library or TRANSX procedure) or the R-Z model specification that requires significant corrections to cover modeling deficiencies. When this problem is run in a realistic 3-D geometry with transport theory adopted, the two largest correction factors at least will be no more needed and better understating for quality of these experiments or of basic cross section set can be made.

3.2 Calculation in 3-D Geometry: posterior

Realistic modeling of the SNEAK-7A assembly was performed using the DANTSYS code capability for X-Y-Z geometry in P_3S_8. Each unit cell consisting of square platelets of

Table 1 Criticality evaluation in 2-D

Assembly	SNEAK-7A		SNEAK-7B	
	JEF-2.2	KFKINR	JEF-2.2	KFKINR
k_{eff} – 2-D (RZ)	1.00451	1.0034	1.00210	1.0070
$\Delta k_{Cylinder}$	-0.0045		-0.0029	
$\Delta k_{Control\ Rods\ Homogenization}$	-0.0006		0.0	
$\Delta k_{Heterogeneous}$	0.0006		0.0008	
$\Delta k_{Other\ Corrections}$		0.0131		0.0039
Estimated k_{eff}	1.0000	1.0120	1.0000	1.0088
Measured k_{eff}	1.0010±0.0005		1.0016±0.00008	

PuO_2-UO_2 and graphite was divided into 2x2 meshes for plane, and thus computational mesh region of each plate is 2.72 cm x 2.72 cm wide. During the unit cell homogenization, the material background and geometrical heterogeneity effects affecting resonance escape probability were accounted for during the Bondarenko self-shielding factor evaluation process within the reflective slab cell. What is still missing is the effect of flux distribution within the cell on the cross-section finally at hand: heterogeneity effect due to flux redistribution.

In the axial direction, the 3-D model runs from mid-plane to the end of the axial blanket. An axial mesh size of 2.202 cm for SNEAK-7A is used. It is noted that the axial length of the given model for half core [1] is recommended to be 22.02 cm, while half of the core length is 22.0571 cm according to the detailed plate information available in SNEDAX [6]. This may be attributed to the fact that the mid-plane for the application of reflective boundary condition does not match with the geometrical halfway of the core zone along the axial direction. Heightened core and axial blanket consistent with SNEDAX data base would give rise to the core eigenvalue additive of about 40 pcm. SNEAK-7B adopts 2.1893 cm thick mesh size along axial direction.

The calculated core eigenvalues are 0.99748 for SNEAK-7A and 1.00139 for SNEAK-7B. After comparison between 2D and 3D core eigenvalues, we are inclined to conclude that the R-Z model suggested in the past was quite a legitimate specification to represent the 3-D geometry effect. The calculation itself took about 22 hours and 119 hours for SNEAK-7A and 7B, respectively on a SUN Sparc Ultra-5_10 Workstation that has 384 Mbyte core memory.

3.2.1 Heterogeneity Effect in the Whole Assembly

Since core volumes of both assemblies only occupies about 10% of the whole assembly and the exterior blankets are already of homogeneous composition, evaluating heterogeneity effect of core unit cell in the infinite array of heterogeneous platelets is expected not to be a legitimate approach. Therefore, the R-Z model is constructed to calculate the core zone heterogeneity effect over the whole assembly. In the heterogeneous model, each platelet in the axial direction is identifiable. Since the fuel and graphite platelets in SNEAK-7A are placed alternatively, there is no mid-plane in the material distribution sense to enable the application of the reflective boundary condition that has been applied in the homogeneous model. Depending on where the mid-plane is defined in the heterogeneous model, the resulting heterogeneity effect is found not to make sense in certain cases. In order to completely remove this problem, every platelet in the core zone is modeled along the full axial direction, and the vacuum boundary condition is applied at both ends of the axial blankets. In the core zone of the R-Z model for SNEAK-7A, there are two meshes of 0.313 cm for the driver fuel and one mesh of 0.3126 cm for the graphite. Although there are PuO_2-UO2 loaded shim rods, U-loaded shim rods and U-loaded safety rods in the planar direction, they are neglected. Due to the reduced neutron leakage in the cylindrical geometry, the current R-Z models resulted in greater eigenvalues than that of the THREEDANT simulation.

Table 2 Heterogeneity effect (pcm) of SNEAK-7 by the R-Z model

	SNEAK-7A	SNEAK-7B
Volume-homogenisation	178	18
Self-shielded* Homogenisation	10	22
Heterogeneous calculation	-	-

*) Material and geometry effects are only accounted for during resonance self-shielding.

According to Table 2, the heterogeneity correction for the volume-homogenized TWODANT result is 178 pcm for SNEAK-7A and just 18 pcm for SNEAK-7B. This is in accordance with the prediction that the region of heterogeneity comprises only 10% of the assembly, and thus the amount of heterogeneity correction would be small. With the same reason, the self-shielded homogenisation that was adopted in the THREEDANT simulation requires a reduced heterogeneity correction of 10 pcm for SNEAK-7A. This fact effectively eliminates any necessity for heterogeneity correction.

3.2.2 Mesh Size Effect in the Whole Assembly

The THREEDANT simulation of SNEAK-7A was performed with each plate divided into 2x2 nodes (2.72 cm x 2.72 cm per node) and axially 2.202 cm per grid. The axial grid thickness of SNEAK-7B was 2.19 cm for core and 2.5 cm for reflector. The 4x4 model of each plate in the SNEAK-assembly can not run due to shortage of core memory. Therefore, mesh size effects are investigated in the R-Z geometry.

The reference mesh sizes for correction factor estimation were 2.60/2.70 cm in radial direction and 2.20/2.19 cm in axial direction for SNEAK-7A and 7B, respectively. Then, the number of meshes were doubled and tripled to find out asymptotic behavior of correction factors. The existing THREEDANT models are determined to be subject to very small corrections for the finite mesh size, which sum up to 20 pcm for SNEAK-7A and 8 pcm for SNEAK-7B.

3.2.3 State-of-art Prediction of the SNEAK-7 Eigenvalue

With studies on the heterogeneity effects of plates and mesh size effects, we propose the core eigenvalues of 0.99778 for SNEAK-7A and 1.00169 as best-estimate eigenvalues that became available by the usage of JEF-2.2-based library and the THREEDANT X-Y-Z simulation. These values are quite close to the measured eigenvalues than the old evaluation of the KFKINR library and the R-Z diffusion model [1] that gave core eigenvalues of 1.0120 (7A) and 1.0088 (7B) after corrections for cylinderisation, control rod homogenisation, heterogeneity effect, elastic removal and transport effect were applied.

One of underlying major approximations to these values is that the steel tube outside the plate is volume-homogenized when input for TRANSX was being prepared. Increasing discrete angles from S_8 to S_{16} only resulted in a core eigenvalue difference of 3 pcm for SNEAK-7A. Although we do not pursuit here, the corrections needed further for the state-of-art eigenvalue can be energy group effect (> 30 pcm), angle discretization (< 10 pcm), interface heterogeneity effect (~10 pcm), etc.

The new evaluation is characterized with very small corrections to raw calculated values. However, there still remain discrepancies in core eigenvalues between evaluation and measurement. Spectrum indices and central material worths will be utilized to figure out the cause of identified discrepancy.

Table 3 State-of-art criticality evaluation

	SNEAK-7A	SNEAK-7B
k_{eff} – 3D transport (XYZ)	0.99748	1.00139
$\Delta k_{heterogeneous}$	0.00010	0.00022
$\Delta k_{mesh\ size}$	0.00020	0.00008
Estimated k_{eff}	0.99778	1.00169
Measured k_{eff}	1.0010±0.0005	1.0016±0.00008

3.3 Spectral Indices

In SNEAK-7A, the activation foils were placed at the core centre between the fuel and graphite platelet. The average cell values

Table 4 Spectral index ratios in the SNEAK-7 assemblies

Spectrum Index	SNEAK-7A			SNEAK-7B		
	Experiment	Cal./Experiment		Experiment	Cal./Experiment	
		KFKINR	JEF-2.2		KFKINR	JEF-2.2
σ_{f8}/σ_{f5}	0.0449±3%	0.900	0.927	0.0328±2%	0.955	0.998
σ_{f9}/σ_{f5}	0.984±3%	0.985	0.997	0.975±2%	1.014	1.027
σ_{c8}/σ_{f5}	0.138±3%	0.985	0.947	0.132±3%	1.025	0.999

were obtained by correcting the measurements with the calculated results of the KAPER code [1]. Therefore, the spectral indices from the calculations can be directly compared with the measurement values cited in Table 4. In SNEAK-7B, special half platelets were employed so that the foils could be positioned between the platelets perpendicular to their surfaces. In this manner cell integrated values were measured directly.

The up-to-date library JEF-2.2 for SNEAK-7A shows the smaller activation rates for ^{238}U fissions and captures, assuming ^{235}U fission cross-sections are correct. The under-prediction of ^{238}U fissions would have played the role of making the predicted core eigenvalue smaller than that obtained from the measurement. Knowing that the predicted eigenvalue is rather significantly smaller than the measured k_{eff}, an increase of ^{238}U fission cross-sections will make the prediction better. According to Table 7, in which the integral sensitivities are listed, this leads to adding ~700 pcm to the current evaluation.

For SNEAK-7A, there also appears to be an appreciable underestimation of ^{238}U capture cross-sections. This may have contributed to increase the predicted eigenvalue. From Table 4, it appears that the ^{238}U capture cross-section may have been underestimated by 5.6%. From Table 7, we read the eigenvalue sensitivity of –0.195%$\Delta\rho$ per one per cent change in ^{238}U capture cross-section. When a 5.6% increase in the ^{238}U capture cross-section is assumed, this causes the decrease of core eigenvalue by nearly 1100 pcm, which then results in a corrected core eigenvalue (~ 0.99378) that further deviates from the measured value of 1.0010.

As for SNEAK-7B, the calculated spectral indices are within the measurement uncertainties for fission and capture reactions of ^{238}U, while fission reaction of ^{239}Pu is over-estimated, but still within 2σ of the measurement uncertainty. With 1.027 for σ_{f9}/σ_{f5} synthesized with sensitivities in Table 7, the correction amounts to -1340 pcm. Augmenting this with the best estimate core eigenvalue would make the prediction deviates by -1280 pcm from the measured eigenvalue, while the prediction was excellent in the beginning. In order for a successful synthesis of spectral index and sensitivity profile, higher quality of measurement is mandatory.

3.4 Central Reactivity Worth of U-238 Sample

In the last section, ^{238}U fission and capture cross-sections are postulated to be under-estimated for SNEAK-7A. Combined with the eigenvalue sensitivity to cross section, this has led to further reducing the predicted core eigenvalue, implying that the negative material worth of ^{238}U is underestimated. The central reactivity worth of ^{238}U can contribute to confirming this finding.

The first-order perturbation theory code working on DANTSYS to evaluate a small reactivity change arising from the material substitution at the core centre is not publicly available at present. Therefore, the reactivities arising from placing a 124 gm ^{238}U specimen at the core centre in the pneumatic oscillator experiment at both assemblies were simulated by two forward calculations in THREEDANT in which the oscillator channel is described as a vacuum along the axial direction. Since the samples had a cross section of 4.6x4.6 cm^2, the number density of ^{238}U was smeared into a cross section of 5.44x5.44 cm^2. Sufficient convergence has been reached such that core eigenvalue change is less than $1.0x10^{-8}$ and local flux change is less than $1.0x10^{-5}$. According to Ref. 1, smearing of sample led to correction factors of 1.0723 and 1.004 for SNEAK-7A and 7B, respectively. The corrected material worths are shown in Table 5.

While the vacuum channel can be one extreme model for describing the environment of the pneumatic oscillator, this may tend to reduce the worth of each specimen as a result of the strong neutron streaming from the sample through the vacuum channel above and below the sample. An opposite extreme is the case when the sample is placed at the core centre where it was vacant but no axial vacuum channel is provided, thereby minimizing the leakage. If the worth obtained from this calculation is less than the measurement, this confirms the postulation regarding the ^{238}U capture cross-section. The predicted sample worth based on the realistic arrangement would fall between -4.7 pcm and -5.0 pcm, and be nearer to -5.0 pcm for SNEAK-7A since the oscillator element was filled so that the regular core lattice was not disturbed at both end positions of the oscillator stroke. This implies that the negative worth of the sample is being over-estimated, and thus this conclusion is contradictory to previous postulation derived from the synthesis of both measured spectral indices and eigenvalue sensitivity. In other words, the measured σ_{f8}/σ_{f5} could have been larger or σ_{c8}/σ_{f5} could have been smaller if we give credit to material worth measurement. Since increasing the measured σ_{f8}/σ_{f5} makes the deviation of spectrum index larger from the prediction, there is only one possibility.

Remembering that the spectral indices of SNEAK-7A are not the results of direct measurement, Table 4 was examined and reformatted in Table 6. The σ_{f8}/σ_{f5} ratio shows that SNEAK-7A has a lot harder spectrum than SNEAK-7B. It is typically observed that σ_{c8}/σ_{f5} increases due to increased resonance capture of ^{238}U in the interested energy range of fast reactor when the spectrum is softened. This is not observed between SNEAK-7A and 7B, of

Table 5 Material worth (pcm) in the SNEAK-7 assemblies

Oscillator Channel Described by	SNEAK-7A		SNEAK-7B	
	JEF-2.2	Measurement	JEF-2.2	Measurement
Vacuum	-4.7	-4.8	-3.1	-3.3
Driver Fuel	-5.0		-3.4	

Table 6 Spectral indices in the SNEAK-7 assemblies

	SNEAK-7A		SNEAK-7B	
Spectrum Index	Experiment	Calculation	Experiment	Calculation
σ_{f8}/σ_{f5}	0.0449±3%	0.0416	0.0328±2%	0.0327
σ_{f9}/σ_{f5}	0.984±3%	0.9807	0.975±2%	1.0010
σ_{c8}/σ_{f5}	0.138±3%	0.1307	0.132±3%	0.1318

which reason is partially explained by the fact that SNEAK-7A flux levels (Figure 3) in the energy ranges greater than 821 KeV and lower than 13.3 KeV are higher than those of SNEAK-7B. However, in overall it seems that the measured σ_{c8}/σ_{f5} for SNEAK-7A was slightly larger than the true for SNEAK-7A.

3.5 Sensitivity analysis of core eigenvalue on cross-section

The sensitivity profiles provide some details on the phenomenal features owing to physical mechanism, like the preponderant reaction types and energy ranges that govern particle transport in a particular experiment. Furthermore, comparing both the C/E results of k_{eff} as well as the sensitivities between different experiments substantially enlarges the amount of information which can be deduced from the benchmark experiments, rather than simply comparing the k_{eff} values.

The cross-section sensitivity analysis of SNEAK-7A and 7B were performed using the SUSD3D [5] sensitivity and uncertainty code. The sensitivity profiles were calculated from the direct and adjoint flux moments produced by the THREEDANT code, and the partial cross-sections. The partial cross-sections were taken from the JEF-2.2 evaluation and processed by the NJOY/GROUPR code [7] using the (thermal-1/e-fission+fusion) weighting. The data at several self-shielding factors were calculated, permitting us to use in the SUSD3D sensitivity calculations the self-shielded cross-sections close to those actually used in the transport calculation(the sigma-0 values calculated by the TRANSX-2 code were input to the SUSD3D code). All calculations were done in 80 neutron energy groups.

Some results are presented in Table 7 and Figure 4 for SNEAK-7. Figure 4 shows energy-dependent sensitivity of k_{eff} to fission cross-sections of heavy metals for SNEAK-7. The energy-dependent sensitivity of each nuclide in Figure 4 reflects the differences in the spectra (see Figure 3) and in the material compositions. When energy-dependent spectrum index is measured, the whole information from this figure can be utilized. In Table 7, the greatest integral sensitivities for SNEAK-7 per partial reaction change are in the order ^{239}Pu fission and ^{238}U capture. In turn, this means that the spectral index measurement involving ^{239}Pu fission needs extreme caution in order to reduce measurement uncertainty, and to perform valid investigation of benchmark experiments by the syntheses of integral sensitivity and spectrum index.

As expected from ^{238}U number density ratio (~1.83) of SNEAK-7B over SNEAK-7A, SNEAK-7B is more sensitive to uranium cross-sections for fission and capture reactions. However, sensitivity to (n, 2n) reaction of which threshold energy is 6.2 MeV is smaller for SNEAK-7B, since high energy portion (>821 KeV) is small in SNEAK-7B due to

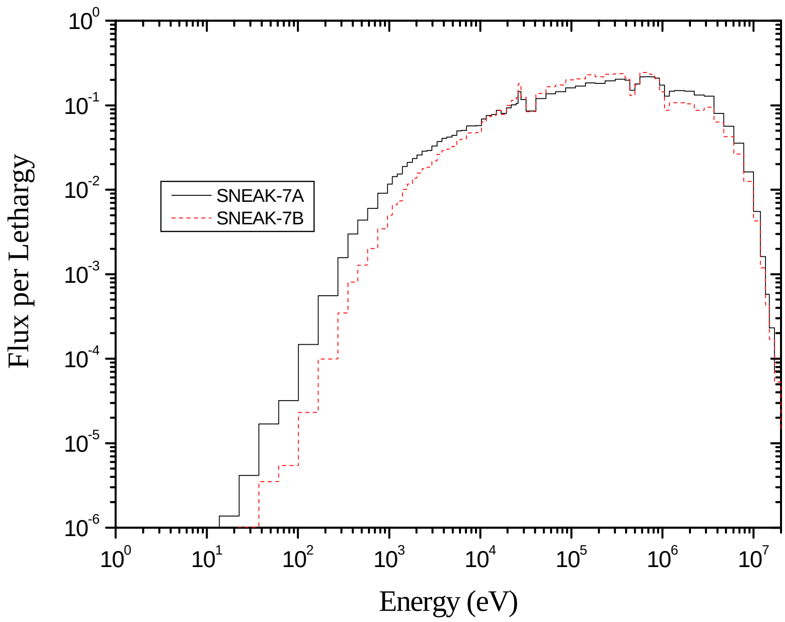

Fig.3 Spectrum at core center of SNEAK-7

large inelastic scattering contribution of ^{238}U.

4. Conclusion

From the analyses of the SNEAK-7 critical assemblies it is shown how full-scale complex 3-D problems can be solved with today's performing computers within acceptable computing times. The calculated core eigenvalues from the THREEDANT in X-Y-Z geometry are 0.99748 and 1.00139 for SNEAK-7A and 7B, respectively.

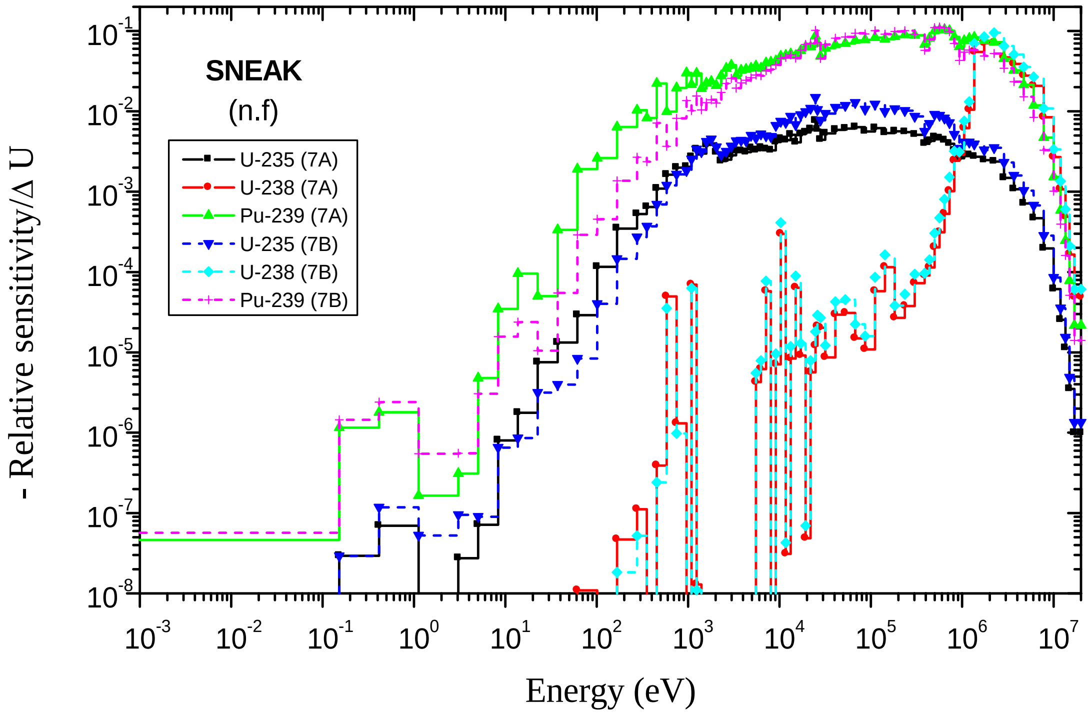

Fig.4 Sensitivity to the (n,f) reactions of U and Pu isotopes of SNEAK-7

Table 7 Integrated Sensitivity in (%Δρ/%) to Various Cross-sections for SNEAK-7

Nuclide	Reaction	Sensitivity	
		7A	7B
U-235	Total	3.15E-2	5.23E-2
	(n,f)	3.69E-2	5.98E-2
	(n,γ)	-5.39E-3	-7.30E-3
	ν	5.61E-2	8.79E-2
U-238	Total	-1.43E-2	-1.10E-1
	Elastic	1.06E-1	7.34E-2
	Inelast.	-1.47E-2	-6.31E-2
	(n,2n)	7.47E-4	6.21E-4
	(n,f)	8.87E-2	1.15E-1
	(n,γ)	-1.95E-1	-2.35E-1
	ν	1.39E-1	1.86E-1

Nuclide	Reaction	Sensitivity	
		7A	7B
Pu-239	Total	4.84E-1	4.66E-1
	(n,f)	5.50E-1	5.08E-1
	(n,γ)	-6.58E-2	-4.20E-2
	ν	7.94E-1	6.99E-1
Pu-240	Total	6.83E-3	6.44E-3
	(n,f)	1.35E-2	1.08E-2
	(n,γ)	-6.67E-3	-4.36E-3
	ν	1.97E-2	1.57E-2
Pu-241	Total	5.55E-3	4.98E-3
	(n,f)	6.11E-3	5.40E-3
	(n,γ)	-5.65E-4	-4.19E-4
	ν	8.60E-3	7.43E-3

The corrections for these eigenvalues were identified. With some of these corrections like core plate cell heterogeneity and mesh size effects applied, the best-estimate core criticality with JEF-2.2-based cross-sections is estimated to be 0.99778 (7A) and 1.00169 (7B). This is a significant improvement over the old evaluation by diffusion theory method and KFKINR library in 70s. Especially for SNEAK-7B that more resembles typical fast reactor spectrum, the predicted eigenvalue misses the measured eigenvalue by as small as 9 pcm.

Spectral indices and central material worths are also compared between prediction and measurement. In SNEAK-7A, there are still large deviations in ^{238}U spectral indices, while SNEAK-7B shows excellent matches. Material worth comparison of ^{238}U sample indicated that there is no under-estimation of fission or capture worth of this sample for SNEAK-7A. However, the spectral index deviation combined with integral sensitivity to cross section leads to the postulation that measured nominal σ_{c8}/σ_{f5} for SNEAK-7A was over-estimated and the desired index ratio falls nearly at the end of measurement uncertainty limit. This projection is based on the fact that the current estimation relied on robust 3-D transport methods, and thus we were able to give much credit to the calculation than ever.

The integral sensitivities of both experiments over effective cross section were calculated, and they are synthesized with spectral index information to facilitate interpretation of experiments.

Once the details in the old critical experiments are available, they can be valuable resources for verifying the quality of modern neutronic calculation capability. With minimal approximations involved, the results from the re-evaluations allow to draw firm conclusions with regard to the overall quality of experiments or calculations as was demonstrated herein. The only minor problem would be the fact that old measurements are subject to larger measurement uncertainties than those of recent measurements. Another encouraging fact is that the analyses in this paper are based on the publicly available data and methodologies: sharing of information within nuclear physics society is becoming rich in these days.

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References

1) E.A. Fischer and P.E. McGrath, "Physics Investigations of Two Pu-Fuled Fast Critical Assemblies: SNEAK-7A and 7B", KFK-1939, Karlsruhe Research Center (1974).
2) R. E. Alcouffe, R. S. Baker, F. W. Brinkley, D. R. Marr, R. D. O'Dell, and W. F. Walters, "DANTSYS: A Diffusion Accelerated Neutral Particle Transport Code System,"LA-12969-M, LANL (1995).
3) J. D. Kim and C. S. Gil, "KAFAX-F22: A Multi-group Library for Fast Reactor Based on JEF-2.2," KAERI/TR-888, KAERI (1997).
4) R. E. MacFarlane, "TRANSX 2: A Code for Interfacing MATXS Cross-Section Libraries to Nuclear Transport Codes,"LA-12312-MS, LANL (1992).
5) I. Kodeli, "Multidimensional Deterministic Nuclear Data Sensitivity and Uncertainty Code System, Method and Application," *Nucl. Sci. Eng.*, **138**, 45-66 (2001).
6) F. Helm, "The SNEDAX Data Base General Description and Users' Instructions," INR 1950, Karlsruhe Research Center (1996).
7) R. E. MacFarlane and D. W. Muir, "The NJOY Nuclear Data Processing System Version 91,"LA-12740-M, LANL (1994).