ASSESSMENT OF TITANIUM CROSS SECTIONS AND UNCERTAINTIES FOR APPLICATION IN CRITICALITY SAFETY

L. Leal and R. Westfall
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831 USA

D. Eghbali and F. Trumble
Washington Safety Management Solutions
2131 South Centennial Drive
Aiken, South Carolina 29803 USA

Data and Uncertainties for Titanium Isotopes

As a neutron absorber titanium has not been commonly considered in nuclear applications such as reactor design and analysis. Rather, titanium appears as a structural material that may be present in fuel cycle facilities or as canisters for transport and disposition of nuclear waste. Criticality safety evaluations of systems in which titanium is present require an understanding of the titanium nuclear data and uncertainties. Natural titanium consists of five isotopes, with thermal capture cross sections ranging from about 0.18 to 8.3 barns. The isotopic abundances and thermal capture cross sections for titanium are shown in Table 1. As shown in the table, ^{48}Ti is the most abundant isotope and also has the largest thermal capture cross section.

Table 1. Thermal capture cross sections and abundances for titanium isotopes

Isotope Name	Abundance %	Thermal Capture Cross Section (barns)
^{46}Ti	8.25	0.59 ± 0.18
^{47}Ti	7.44	1.63 ± 0.04
^{48}Ti	73.72	8.32 ± 0.16
^{49}Ti	5.41	1.87 ± 0.04
^{50}Ti	5.18	0.179 ± 0.03

The most recent cross-section evaluations for the titanium isotopes are available in the U.S. Evaluated Nuclear Data Files, version 7[1] (ENDF/B-VII), with covariance information only for the ^{48}Ti isotope. Total and capture ENDF/B-VII cross sections for ^{48}Ti are shown in Fig. 1.

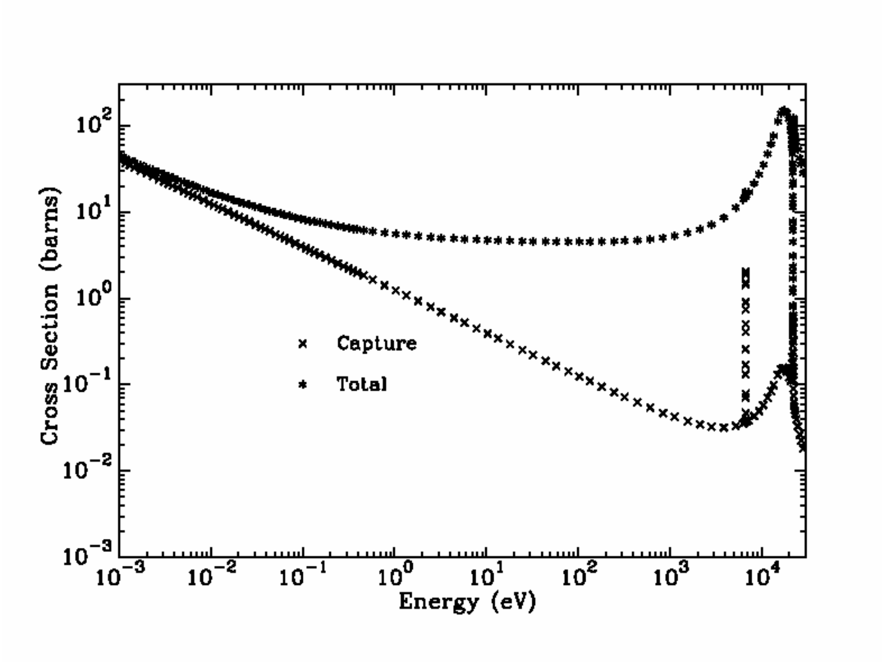

Fig. 1. Total and capture ENDF/B-VII cross sections for ^{48}Ti from 10^{-3} eV to 30 keV.

The 1/*v* behavior of the ^{48}Ti capture cross section extends up to 2 keV. The first important resonance is seen in the capture cross section at about 8 keV. The shape of the cross section in the thermal energy region is very important for applications with thermal neutron spectra. Likewise, the uncertainty in the cross sections is important in assessing the uncertainty in the calculated neutron capture. The ENDF/B-VII uncertainties in the capture cross section for ^{48}Ti are shown in Fig. 2. The covariance data were processed with the PUFF[2] and ERRORJ[3] codes in the 44-neutron group structure of the SCALE system.[4]

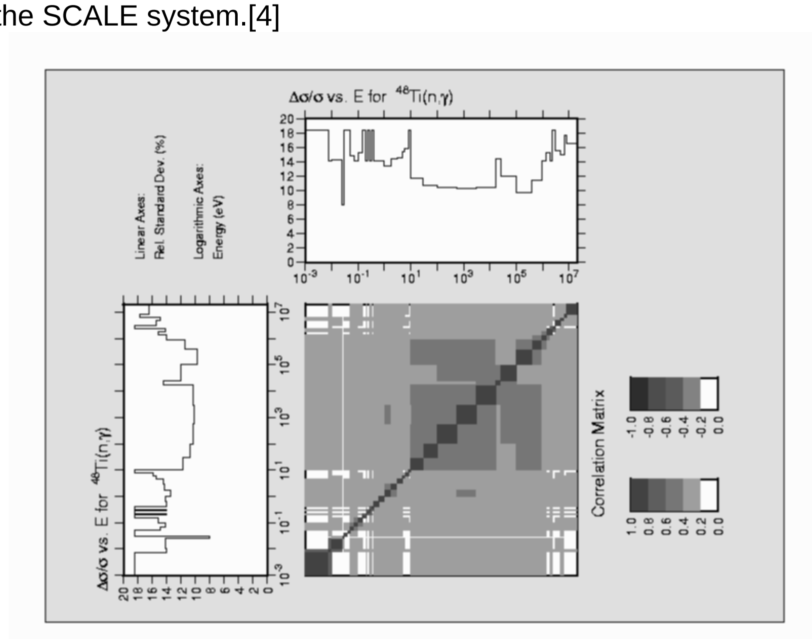

Fig. 2. ENDF/B-VII covariance data for the capture cross section of ^{48}Ti processed with the PUFF and ERRORJ codes in the SCALE 44-neutron energy group structure.

The relative uncertainty in the capture cross section for ^{48}Ti, as given in the ENDF/B-VII evaluation, can be as high as 18% in the thermal region. A concern has been raised as to whether this uncertainty is legitimate. There is no obvious reason for the trend in the capture cross-section uncertainty in the thermal neutron energy range. Table 1 indicates that the experimental uncertainty in the thermal capture cross section for ^{48}Ti is about 2%. In addition, since the capture cross section for ^{48}Ti has a 1/*v* shape and the first important resonance is at approximately 8 keV, one expects that the 2% uncertainty should extend at least to 8 keV. A revision of the ^{48}Ti uncertainties has been performed to address these concerns. The retroactive method of the code SAMMY[5] was used to generate resolved-resonance parameter covariance data for ^{48}Ti in the resonance region from 10^{-5} eV to 300 keV. The revised covariance results for the capture cross section are shown in Fig. 3. The percentage uncertainty in the capture cross section as shown in Fig. 3 is about 2% up to the first important resonance at 8 keV, in agreement with the values indicated in Table 1. Figure 3 also indicates that above 8 keV up to 300 keV, the shape of the uncertainty changes due to the presence of resonances. The covariance data in the energy above 300 keV is identical to those in the ENDF/B-VII evaluation.

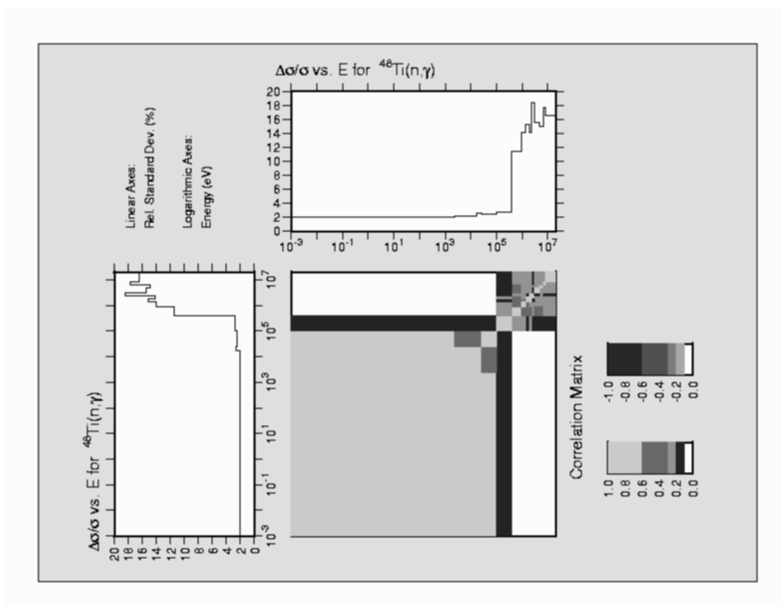

Fig. 3. Revised ENDF/B-VII covariance data for the capture cross section of ^{48}Ti processed with the PUFF and ERRORJ codes in the SCALE 44-neutron energy group structure.

Impact of the Titanium Cross Sections and Uncertainties in Benchmark Calculation

In an earlier study,[6] the impact of the titanium cross sections and uncertainties on the criticality safety of the Actinide Removal Process (ARP) facility at the Savannah River Site (SRS) was evaluated. Here, the revised titanium data are utilized for the same application. The ARP receives batches of alkaline salt solution containing radionuclides, including small amounts of uranium and plutonium, from a feed tank into one of two strike tanks. In the strike tank the salt solution is diluted with inhibited water (low-molarity sodium hydroxide solution) to yield a solution that is ~5.5 M in sodium ion concentration. Monosodium titanate (MST,$NaHTi_2O_5$) at a concentration of 0.4 g/L is added to the diluted salt solution to adsorb soluble radionuclides, including uranium and plutonium. The salt solution with MST/sludge solids from the 8000-gal strike tank is transferred to a 1600-gal precipitate tank, where the MST/sludge solids from processing several salt solution batches will be accumulated and concentrated to approximately 5 wt% solids. Concentration is performed by circulating the salt solution with MST/sludge solids through a cross-flow filter and allowing the filtrate to collect in a filtrate hold tank. In the absence of sufficient neutron poison (e.g., titanium), accumulation of MST/sludge solids in the precipitate tank is a criticality concern.

This study analyzes the criticality safety of the precipitate tank, where MST/sludge with the solids entrained in a slurry containing fissile material is accumulated. The precipitate tank model consists of a water-reflected 304 stainless steel cylinder filled with a mixture of water, ^{235}U, and MST. Because the solubility of plutonium is much lower than that of uranium in an alkaline salt solution, the plutonium is included in the model as equivalent ^{235}U.

The ENDF/B-VII titanium cross sections have been processed with the AMPX code system[7] with the resonance treatment based on CENTRM methodology[8] in the SCALE 238-neutron group structure. Cross sections for water and ^{235}U are from the ENDF/B-V SCALE 238-neutron library. The PUFF code has been used to generate the 44-group covariance in the COVERX format.[9] The uncertainty analysis was performed using the SCALE sensitivity sequence TSUNAMI.[10] The sensitivity of the effective multiplication factor for the application to the capture cross section of ^{48}Ti is displayed in Fig. 4. For comparison, the sensitivity to the capture cross section of ^{235}U is also shown and indicates that the system is quite sensitive to the ^{48}Ti cross sections.

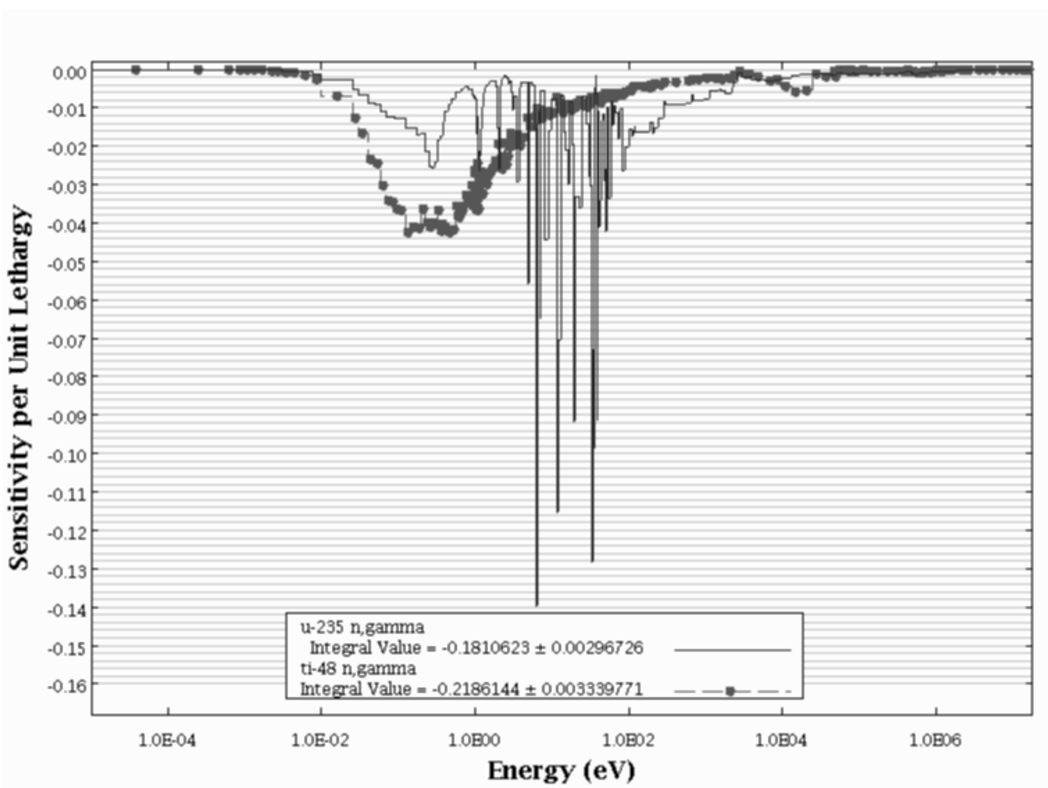

Fig. 4. Sensitivity of the system effective multiplication factor to the ^{48}Ti and ^{235}U capture cross sections.

Calculations with TSUNAMI were performed using the ENDF/B-VII titanium cross sections and ^{48}Ti covariance and with the revised ^{48}Ti covariance. Table 2 shows the relative standard deviation for the effective multiplication factor (k_{eff}) in percentage of $\delta k/k$ due to cross-section covariance data for ^{48}Ti. The contributions to the uncertainty in k_{eff} for nuclide reactions, (n,γ), (n,n), (n,n'), (n,2n), (n,p), and (n,α) are also given. Similarly, Table 3 shows the results of calculations using the revised covariance data for ^{48}Ti.

Table 2. Relative standard deviation of k_{eff} due to ^{48}Ti uncertainty data in ENDF/B-VII

	(n,γ)	(n,n)	(n,n')	(n,2n)	(n,p)	(n,α)
(n,γ)	1.7474 ± 1.4397×10^{-2}					
(n,n)						
(n,n')			3.6275×10^{-2} ± 1.9952×10^{-2}			
(n,2n)				7.1547×10^{-5} ± 2.6364×10^{-5}		
(n,p)					6.5078×10^{-5} ± 1.0821×10^{-5}	
(n,α)					5.6918×10^{-6} ± 7.5055×10^{-9}	
Relative standard deviation in k_{eff} computed from individual values by adding the square of the values and taking the square root.						
1.7478 ± 0.0503						

Table 3. Relative standard deviation of k_{eff} due to ^{48}Ti uncertainty data with a revised covariance

	(n,γ)	(n,n)	(n,n')	(n,2n)	(n,p)	(n,α)
(n,γ)	0.445440 ± 3.5007×10^{-3}					
(n,n)	-4.5693×10^{-2} ± 2.2033×10^{-2}	2.2027×10^{-2} ± 3.9200×10^{-2}				
(n,n')			3.6275×10^{-2} ± 1.9952×10^{-2}			
(n,2n)				7.1547×10^{-5} ± 2.6364×10^{-5}		
(n,p)					6.5078×10^{-5} ± 1.0821×10^{-5}	
(n,α)					5.6918×10^{-6} ± 7.5055×10^{-9}	
Relative standard deviation in k_{eff} computed from individual values by adding the square of the values and taking the square root.						
0.4451 ± 0.0043						

Conclusions

Titanium cross sections and uncertainties have been revised for application in criticality safety analysis of the SRS ARP facility. Of the five-existing titanium isotopes, ^{48}Ti has the largest cross sections and greatest abundance. ENDF/B-VII has an updated-cross section evaluation for ^{48}Ti that includes cross-section uncertainties. The ENDF/B cross-section uncertainties for ^{48}Ti below 300 keV seem too high in comparison with the experimental uncertainty. A revised uncertainty file has been generated for ^{48}Ti resonance parameters using the retroactive methodology of the code SAMMY. The resulting uncertainties are in good agreement with experimental uncertainties. The revised uncertainties were used in analyzing the criticality safety of the precipitate tank at the SRS ARP facility. The results indicate that the uncertainty calculated with the revised data is a factor of 4 smaller than that obtained with the ENDF/B-VII data.

References

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