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# Oak Ridge National Laboratory Titanium Material Comparison for Second Target Station Moderators

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Second Target Station Project

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# 1 SUMMARY

Two titanium alloys, Ti 15-3-3-3 and Grade 5 Ti, have been analyzed for their neutronic differences after being exposed to neutron fluxes from a 5-year operational period in the Second Target Station (STS) moderators. There are several differences in the original composition of the two alloys where Ti 15-3-3-3 contains Cr and Sn and Grade 5 Ti does not. The differences in original composition propagate through the analysis to yield discrepancies in decay power density and decay gamma intensity density of more than a factor of 3.5 at some times during operation. Immediately after the 5-year operational period, Ti 15-3-3-3 has a factor of 3.59 higher intensity of high-energy decay gammas than Grade 5 Ti, and Ti 15-3-3-3 also has a factor of 3.53 higher decay power than Grade 5 Ti. After 1 year of shutdown, Ti 15-3-3-3 has a 48% higher intensity of high-energy decay gammas and a 86% greater decay power density when compared with Grade 5 Ti. The quantities-of-interest in this report are per unit volume and the overall volume of titanium should be considered when making engineering judgment on final titanium alloy selection.


# 2 INTRODUCTION

This report details the neutronic comparison between two titanium alloys for use as spacers in the STS moderators. The two alloys used in the analysis are Ti 15-3-3-3 and Grade 5 Ti, and equal volumes of both compounds are irradiated with the same neutron flux for the same operational period. Table 1 shows the material compositions of the two titanium alloys.

**Table 1. Titanium Alloy Compositions**

| Nuclide | Ti 15-3-3-3 Mass Percent | Grade 5 Ti Mass Percent |
|---|---|---|
| $^{27}$Al | 3.00 | 6.00 |
| $^{46}$Ti | 6.02 | 7.13 |
| $^{47}$Ti | 5.55 | 6.57 |
| $^{48}$Ti | 56.12 | 66.46 |
| $^{49}$Ti | 4.20 | 4.98 |
| $^{50}$Ti | 4.11 | 4.86 |
| $^{50}$V | 0.04 | 0.01 |
| $^{51}$V | 14.96 | 3.99 |
| $^{50}$Cr | 0.13 | - |
| $^{52}$Cr | 2.51 | - |
| $^{53}$Cr | 0.29 | - |
| $^{54}$Cr | 0.07 | - |
| $^{112}$Sn | 0.03 | - |
| $^{114}$Sn | 0.02 | - |
| $^{115}$Sn | 0.01 | - |
| $^{116}$Sn | 0.43 | - |
| $^{117}$Sn | 0.23 | - |
| $^{118}$Sn | 0.72 | - |
| $^{119}$Sn | 0.26 | - |
| $^{120}$Sn | 0.99 | - |
| $^{122}$Sn | 0.14 | - |
| $^{124}$Sn | 0.18 | - |

The neutron fluxes used in this comparison are tallied in the aluminum moderator vessel for a single proton pulse. The operational period where these fluxes are then incident on the titanium alloys is for 5000 hr of beam-on-target followed by 3760 hr of down time repeated for 5 years where the fifth year does not have the down time period. The operational period is followed by decay periods of 1 s, 7 days, 1 month, and 1 yr.

Several quantities-of-interest are evaluated in this report. The quantities-of-interest are per unit volume. The amount of high energy decay gammas is the intensity of decay gammas being emitted per second from the titanium alloy with energy greater than 0.5 MeV. The decay power is the amount of power being emitted from the titanium via various forms of decay radiation. CAT3 refers to the hazard categorization of a DOE facility as defined in DOE Standard 1027. The CAT3 quantity is calculated by summing over all of the radionuclides the ratio of the activity of a specific radionuclide divided by a preset threshold limit of activity for that nuclide. The CAT3 quantity gives insight into potential waste disposal aspects of an irradiated material. $\Sigma_A$ is the thermal macroscopic absorption cross section that indicates how well a material will absorb thermal energy neutrons.

## 3 RESULTS

Table 2 shows the total of the quantities of interest 1 s after shutdown of the 5-year operational period for the two titanium alloys. Ti 15-3-3-3 produces significantly more high-energy decay gammas and decay power than Grade 5 Ti. $^{52}$V is the main contributor to the decay power discrepancy where Ti-15-3-3-3 produces 4 times more $^{52}$V than Grade 5 Ti after the operational period. The CAT3 quantity differs by 44% between Ti 15-3-3-3 and Grade 5 Ti. Ti 15-3-3-3 absorbs 6% more thermal neutrons than Grade 5 Ti as shown by the 6% higher thermal macroscopic cross section, $\Sigma_A$.

**Table 2. Totals Comparison 1 second After Shutdown**

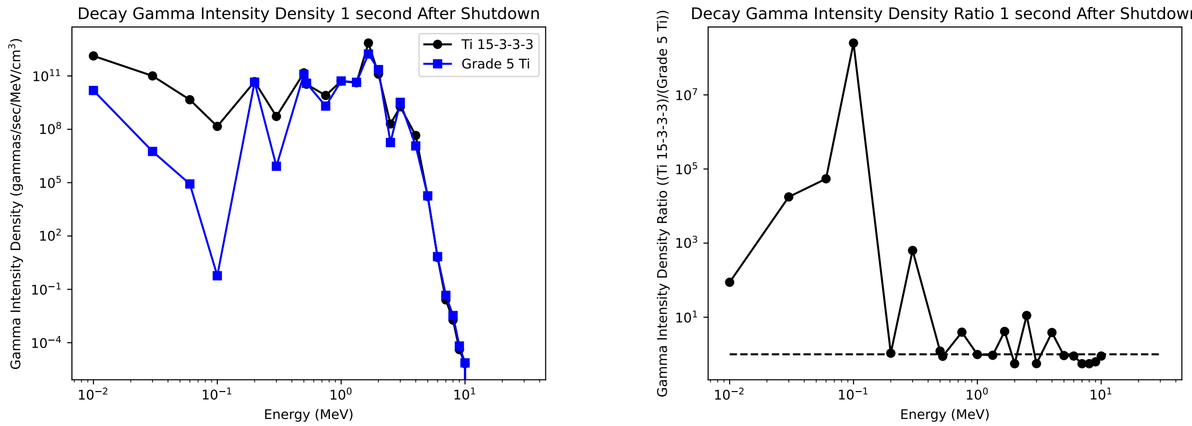
| Attribute | Ti-15-3-3-3 | Grade 5 Ti | Ratio $\left(\frac{\text{Ti 15-3-3-3}}{\text{Grade 5 Ti}}\right)$ |
|---|---|---|---|
| Decay Gammas > 0.5 MeV ($\gamma$/sec/cm$^3$) | 2.4090E+12 | 6.7166E+11 | 3.59 |
| Decay Power Density (W/cm$^3$) | 9.6610E-01 | 2.7390E-01 | 3.53 |
| CAT3 Density (1/cm$^3$) | 1.6678E-03 | 1.1617E-03 | 1.44 |
| $\Sigma_A$ (cm$^{-1}$) | 8.275E-02 | 7.823E-02 | 1.06 |

Table 3 shows the total of the quantities-of-interest 1 yr after shutdown. Overall, Ti 15-3-3-3 is more radioactive than Grade 5 Ti after a year of shutdown, and has 48% more high-energy gammas, 86% more decay power, and a factor of 2.38 higher CAT3 ratio when compared with Grade 5 Ti. The macroscopic cross sections for the two alloys are the same as in Table 2.

**Table 3. Totals Comparison 1 year After Shutdown**

| Attribute | Ti 15-3-3-3 | Grade 5 Ti | Ratio $\left(\frac{\text{Ti 15-3-3-3}}{\text{Grade 5 Ti}}\right)$ |
|---|---|---|---|
| Decay Gammas > 0.5 MeV ($\gamma$/sec/cm$^3$) | 6.9990E+08 | 4.7292E+08 | 1.48 |
| Decay Power Density (W/cm$^3$) | 1.5680E-04 | 8.4160E-05 | 1.86 |
| CAT3 Density (1/cm$^3$) | 6.1327E-05 | 2.5764E-05 | 2.38 |
| $\Sigma_A$ (cm$^{-1}$) | 8.275E-02 | 7.823E-02 | 1.06 |

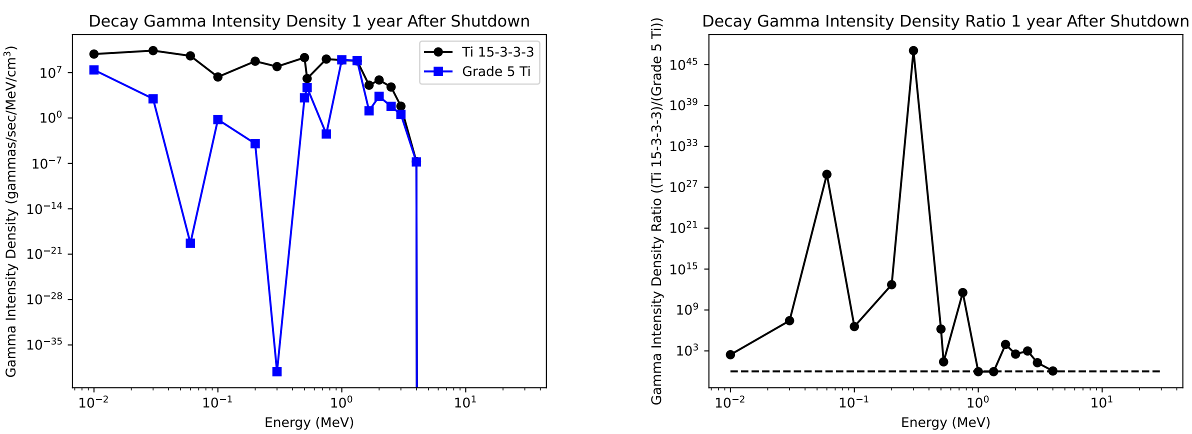
Figure 1 shows the decay gamma intensity density spectra as a function of energy at 1 second. There are major discrepancies between Ti 15-3-3-3 and Grade 5 Ti at lower energies as shown by Figure 1b. These discrepancies are largely due to the Sn in Ti 15-3-3-3.




**(a) Decay Gamma Energy Spectra** **(b) Decay Gamma Energy Ratio**

**Figure 1. Decay gamma intensity density as a function of energy for Ti 15-3-3-3 and Grade 5 Ti at 1 second after shutdown**

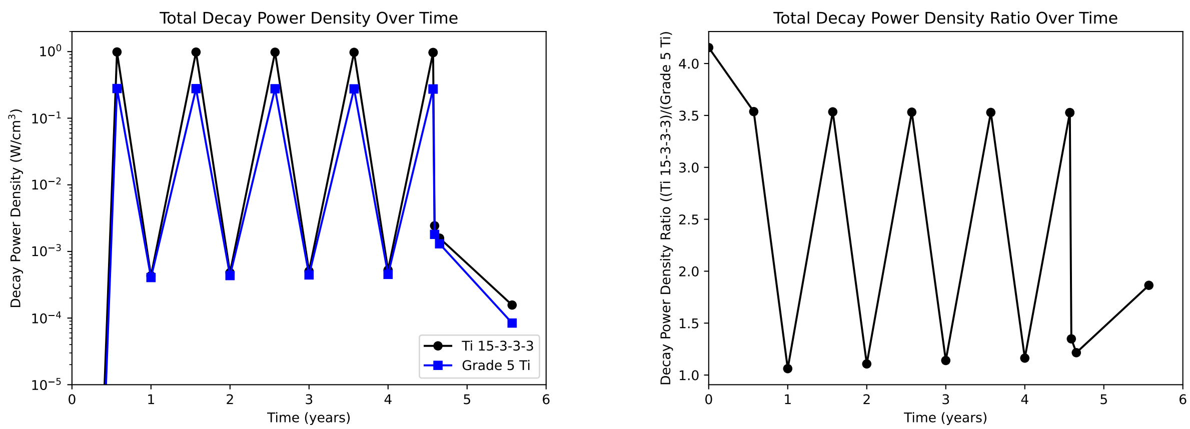
Figure 2 shows the decay gamma intensity density as a function of energy at 1 year after shutdown. There are major discrepancies of more than a factor of 1000 in the upper energies. These discrepancies are due to Sn in Ti 15-3-3-2.




**(a) Decay Gamma Energy Spectra** **(b) Decay Gamma Energy Ratio**

**Figure 2. Decay gamma intensity density as a function of energy for Ti 15-3-3-3 and Grade 5 Ti at 1 year after shutdown**

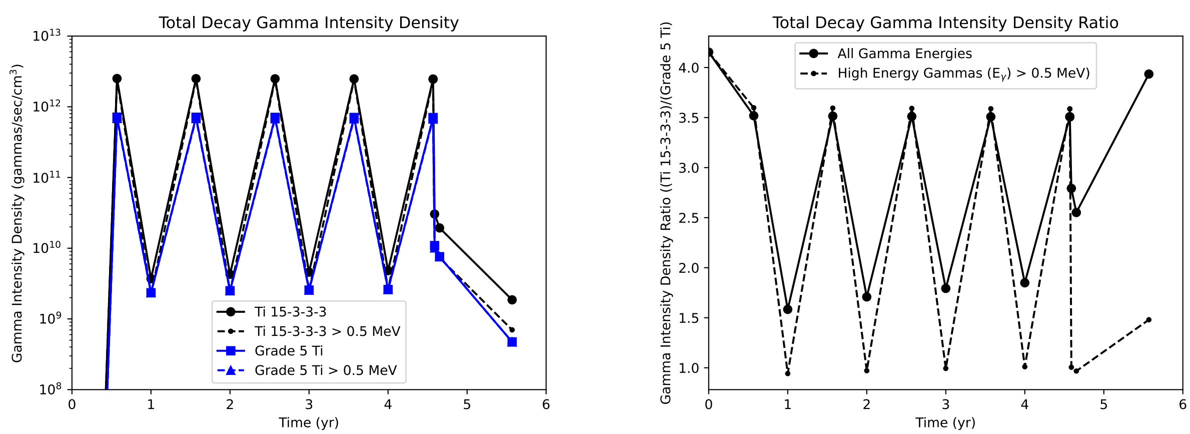
Figure 3a shows the total decay power over time for Ti 15-3-3-3 and Grade 5 Ti, and Figure 3b shows the ratio of Ti 15-3-3-3 decay power over Grade 5 Ti decay power. The two alloys differ by more than a factor of 3.5 immediately after the 5000 hr of beam-on-target periods but that factor falls to 1.22 during the 3760 hr of down time. During the final shutdown period, the two alloys differ by more than a factor of 1.5 by 1 yr of shutdown.




**(a) Total decay power over time** **(b) Ratio of total decay power over time**

**Figure 3. Total decay power over time for Ti 15-3-3-3 and Grade 5 Ti**

Figure 4a shows the decay gamma intensity density over time for Ti 15-3-3-3 and Grade 5 Ti for the integral over all gamma energies and the integral over gamma energies greater than 0.5 MeV. Figure 4b shows the ratio of Ti 15-3-3-3 over Grade 5 Ti for the decay gamma intensity density of all gamma energies and the high-energy component. The two alloys have greater differences in the total decay gamma intensity density than in the high-energy component. These differences follow the same pattern set by the decay power in Figure 3b where the differences are greater in the beam-on-target periods, and less in the decay periods. The total decay gamma intensity density differs by more than 3.5 after 1 yr of shutdown whereas the high-energy component differ by 1.5.




**(a) Decay gamma intensity density over time** **(b) Ratio of decay gamma intensity density over time**

**Figure 4. Decay gamma intensity density over time for Ti 15-3-3-3 and Grade 5 Ti**

# 4 CONCLUSIONS

Two titanium alloys were analyzed for their neutronic differences after a 5-year operational period in the STS moderators. Overall, Ti 15-3-3-3 is more radioactive than Grade 5 Ti during beam-on-target and decay periods resulting in higher decay power, CAT3 ratio, and decay gamma intensity density. Ti-15-3-3-3 also absorbs more thermal neutrons when compared with Grade 5 Ti. All of the quantities-of-interest are per unit volume and the overall amount of material should be considered when choosing between the two materials. From the neutronics perspective the Grade 5 Ti is the preferred material; however, given the small quantity of the material the overall impact on the moderator performance will be small and the final choice of the material may be based on engineering considerations rather than neutronics properties.