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Technical Evaluation Study

TEV Title: Delayed Heatup Testing

TEV No.: TEV-1543

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1. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.
2. Concurrence of method or approach. See definition, LWP-10106.
3. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.
4. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10300.

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REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	05/08/2012	All	Newly issued document

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1. Quality Level (QL) No.	X	**Professional Engineer's Stamp** See LWP-10010 for requirements.
2. QL Determination No.	X	
3. Engineering Job (EJ) No.	X	
4. eCR No.	X	
5. Building	X	
6. Site Area	X	

7. Introduction:

Heatup testing for TRISO coated fuel traditionally has been conducted post-irradiation because core heatup in pressurized and depressurized loss of forced cooling accidents in High Temperature Gas Cooled Reactor (HTGRs) occurs post-reactor shutdown. Fuel temperatures drop quite quickly after reactor shutdown so that the microstructure in the fuel produced during irradiation is maintained. Considerable time is required to allow experiment cooldown, transport to hot cells, and disassembly prior to heatup testing. During this time, which can be up to several months, the fuel temperature is quite low so that the structure in the fuel is unchanged and atomic mobility within the structure is nil. At the start of heatup testing the temperature is raised to 1250°C and held for 12 hours to reestablish thermal conditions simulating normal operation prior to increasing the temperature to simulate core heatup under accident conditions.

The inventories of materials within fuel particles that may possibly affect the performance of the SiC layer, or that are radiologically significant, are dominated by stable or very long-lived isotopes. Thus, the chemistry that determines the mobility and interactions of these materials is constant both under irradiation conditions and under delayed heatup testing. During normal operation, palladium moves into the SiC and is observed as small nodules forming a front that penetrates into the SiC as a function of temperature. At high irradiation temperatures, up to 1% of the inventory of Pd has been measured to fully penetrate the SiC in AGR-1. Silver is generally not observed in the SiC, but it penetrates the layer at operating temperatures above 1000°C in varying degrees from fuel particle to fuel particle, up to values as high as 38% of the inventory beyond the fuel compact in a test capsule containing approximately 50,000 fuel particles. The possible effects of Pd and Ag on SiC integrity have been studied for many years without substantial conclusions to date. Europium is also mobile and small fractions, on the order of 1%, of the calculated inventory have been found to penetrate the SiC at high operating temperatures in AGR-1 UCO TRISO fuel. No effects of Eu on SiC integrity have been reported. Radioisotopes of iodine, cesium, tellurium, and strontium are of radiological importance for source terms used in reactor safety analyses. Results of calculations of the inventories of the isotopes of Pd, Ag, Eu, I, Cs, Te, and Sr during the final cycle in the AGR-1 test are presented below as a function of time both during and following irradiation.

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8. Conclusions/Recommendations:

For the seven elemental fission products considered (I, Cs, Te, Sr, Eu, Ag, Pd), it is shown that the compact concentration of these elements tends to buildup during the final ATR power cycle irradiation and then following the irradiation tend to remain relatively constant. This is due to the fact that the stable isotopes and relatively long-lived isotopes dominate these elemental concentrations at the end of the AGR-1 test. This may not be true for the early AGR-1 power cycles where the stable concentrations may be more or less equal to the short-lived isotopes. However, relative to the AGR-1 delayed heating tests, which are done post-irradiation and after the 13 ATR power cycle irradiation, the seven elemental concentrations should remain stable for years.

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INTRODUCTION

Heatup testing for TRISO coated fuel traditionally has been conducted post-irradiation because core heatup in pressurized and depressurized loss of forced cooling accidents in High Temperature Gas Cooled Reactor (HTGRs) occurs post-reactor shutdown. Fuel temperatures drop quite quickly after reactor shutdown so that the microstructure in the fuel produced during irradiation is maintained. Considerable time is required to allow experiment cooldown, transport to hot cells, and disassembly prior to heatup testing. During this time, which can be up to several months, the fuel temperature is quite low so that the structure in the fuel is unchanged and atomic mobility within the structure is nil. At the start of heatup testing the temperature is raised to 1250°C and held for 12 hours to reestablish thermal conditions simulating normal operation prior to increasing the temperature to simulate core heatup under accident conditions.

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ADDITIONAL INFORMATION

Time Dependence of Elemental Fission Product Concentrations

Elemental fission product concentrations (moles) are calculated as a function of irradiation and decay time. For the calculation, it is assumed that time (t=0) corresponds to the beginning of the last ATR power (cycle 145A) which is the last or final cycle of the thirteen ATR power cycles for the AGR-1 test. The decay time following the cycle 145A irradiation is assumed to extend out to one-year (365 days).

Cycle 145A had duration of 62.167 days and included 2 reactor scrams where ATR core power went to zero for a period of time of approximately 7 days. During the power cycle, the fission product concentrations buildup; and then post-irradiation they tend to decay slightly or remain nearly constant. The calculated elemental concentrations are for one-half of a TRISO fuel compact in Capsule 4 (Stack 1) near the ATR core midplane. For this calculation the starting isotope concentrations are the same as the concentrations at the beginning of cycle 145A and represent the buildup of these isotopes over the previous 12 ATR power cycles in the AGR-1 test. The trend results here should be typical for all the compacts.

Seven fission product elements were chosen for this analysis, namely, (1) iodine, (2) cesium, (3) tellurium, (4) strontium, (5) europium, (6) silver, and (7) palladium. Table 1 shows the important isotopes (radioactive and stable) that were included in each elemental fission product concentration summation.

Table 1. List of stable and radioactive isotopes included in each of the elemental concentrations.

Iodine	Cesium	Tellerium	Strontium	Europium	Silver	Palladium
*I-127	Cs-132	Te-124	Sr-86	Eu-150	Ag-106	*Pd-104
I-128	*Cs-133	Te-125	Sr-87	Eu-151	Ag-107	*Pd-105
*I-129	Cs-134	Te-125m	Sr-87m	Eu-152	Ag-108	*Pd-106
I-130	Cs-134m	Te-126	*Sr-88	Eu-152m	Ag-108m	Pd-107
I-131	Cs-135	Te-127	Sr-89	*Eu-153	*Ag-109	*Pd-107m
I-132	Cs-135m	Te-127m	*Sr-90	*Eu-154	Ag-109m	*Pd-108
I-132m	Cs-136	*Te-128	Sr-91	Eu-155	Ag-110	Pd-109
	Cs-136m	Te-129	Sr-92	Eu-156	Ag-110m	Pd-109m
	*Cs-137	Te-129m	Sr-93	Eu-157	Ag-111	Pd-110
	Cs-138	Te-130		Eu-158	Ag-111m	Pd-111
	Cs-138m	Te-131		Eu-159	Ag-112	Pd-111m
	Cs-139	Te-131m			Ag-113	Pd-112
	Cs-140	Te-132			Ag-113m	
	Cs-141	Te-133			Ag-114	

	Te-133m
	Te-134
	Te-135

RED = stable isotope
BLUE = relatively long-lived radioisotope
* = major contributor to the elemental concentration

Table 1 shows that the major contributors (*) to each of the respective elemental concentrations are dominated by stable (**red**) and very long-lived (**blue**) isotopes. Hence, one would expect the elemental concentrations to remain relatively constant in the decay period following irradiation, and this is the case as discussed further below.

The seven fission product elements buildup during the cycle 145A irradiation and then decay very slowly post-irradiation. The post-irradiation decay time extends from end-of-cycle out to one-year (365 days). The following two figures (1a and 1b) are the same, except for the time span on the x-axis. Figure 1a shows the elemental concentrations buildup gradually over the 62-day burnup (cycle 145A) and then begin to decay at end-of-cycle. The observed buildup on the semi-log plot here is relatively smooth, but some wiggle is observed on some of the curves due to core power fluctuations and reactor scrams. Figure 1b expands the x-axis or decay time. It is noted that all of the seven selected elemental concentrations decay very slowly in time (almost imperceptibly) with the exception of palladium which tends to increase slightly in concentration but also at a very slow rate. In conclusion, the selected fission product elemental concentrations essentially do not change significantly for up to one year following the end of irradiation. This is due to the continuous buildup of the stable and very long-lived isotopes over the 13 ATR power cycles, and it is these stable isotopes that dominate the end-of-life elemental concentrations (relative to the radioactive isotopes).

CONCLUSIONS/RECOMMENDATIONS

For the seven elemental fission products considered (I, Cs, Te, Sr, Eu, Ag, Pd), it is shown that the compact concentration of these elements tends to buildup during the final ATR power cycle irradiation and then following the irradiation tend to remain relatively constant. This is due to the fact that the stable isotopes and relatively long-lived isotopes dominate these elemental concentrations at the end of the AGR-1 test. This may not be true for the early AGR-1 power cycles where the stable concentrations may be more or less equal to the short-lived isotopes. However, relative to the AGR-1 delayed heating tests, which are done post-irradiation and after the 13 ATR power cycle irradiation, the seven elemental concentrations should remain stable for years.

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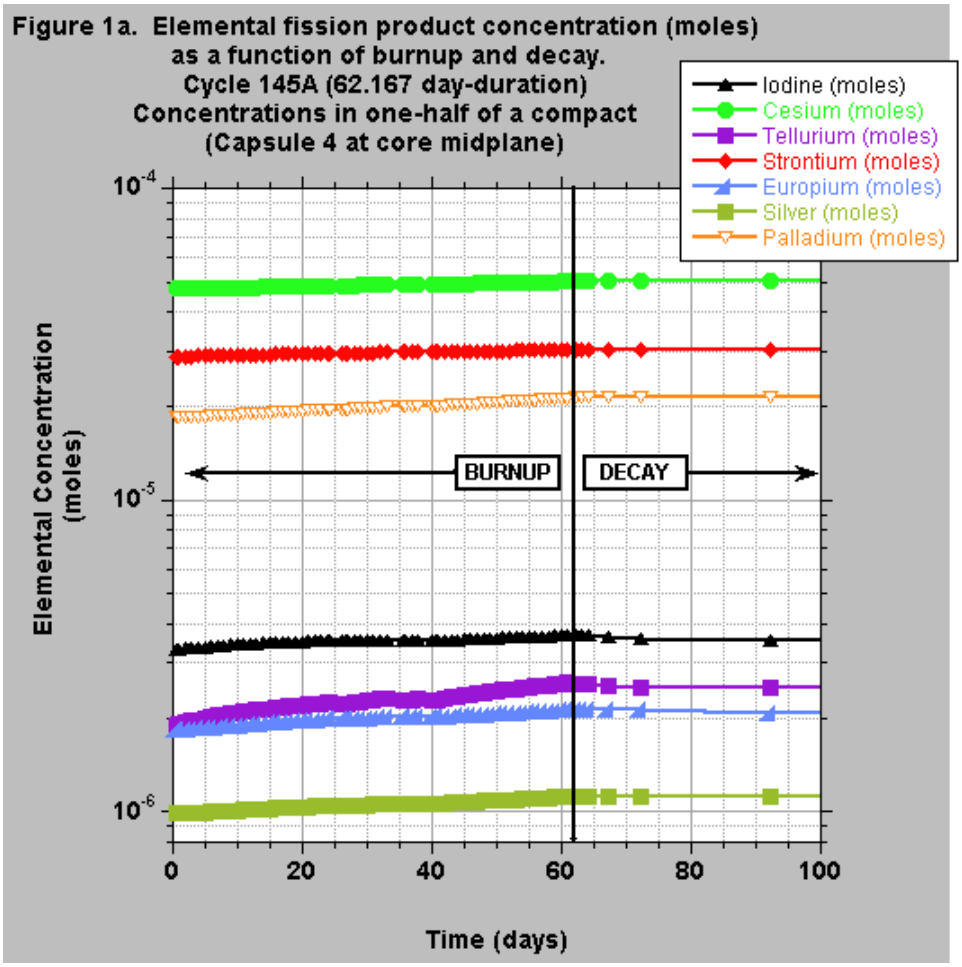

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