VANADIUM ALLOY IRRADIATION EXPERIMENT X530 IN EBR-II*

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OBJECTIVE

The objective of the X530 experiment in EBR-II was to obtain early irradiation performance data, particularly the fracture properties, on the new 500-kg production heat of V-4Cr-4Ti material before the scheduled reactor shutdown at the end of September 1994.

SUMMARY

To obtain early irradiation performance data on the new 500-kg production heat of the V-4Cr-4Ti material before the scheduled EBR-II shutdown, an experiment, X530, was expeditiously designed and assembled. Charpy, compact tension, tensile and TEM specimens with different thermal mechanical treatments (TMTs), were enclosed in two capsules and irradiated in the last run of EBR-II, Run 170, from August 9 through September 27. For comparison, specimens from some of the previous heats were also included in the test. The accrued exposure was 35 effective full power days, yielding a peak damage of ≈4 dpa in the specimens. The irradiation is now complete and the vehicle is awaiting to be discharged from EBR-II for postirradiation disassembly.

PROGRESS AND STATUS

Introduction

V-4 wt.%Cr-4 wt.%Ti has been identified as the most promising vanadium-based alloy for application in fusion reactor first wall and blanket structures. A 500-kg production heat of the V-4Cr-4Ti alloy was recently produced (see accompanying article in this report) as part of the developmental effort. It is important to confirm at an early date the performance of this new heat with irradiation in a fast flux environment. A decision was made in June 1994 to test this material in an irradiation experiment in EBR-II before the scheduled reactor shutdown at the end of September 1994.

In addition to the production heat V-4Cr-4Ti material, several earlier heats of ternary and binary vanadium alloys, and a Russian heat of V-4Cr-4Ti, were included in the experiment for comparison. A ^{10}B-doped V-4Cr-4Ti material was included to study the effect of helium generation on mechanical properties. The irradiation temperature for the test was ≈375-400°C, the lowest attainable in EBR-II, because of the importance of low-temperature data for ITER.

Thermal mechanical treatments are known to have significant effects on the mechanical properties of body-center-cubic metals, e.g., the vanadium alloys. One of the objectives of the experiment was to investigate these effects. The production heat and a V-5Cr-5Ti material were given different heat treatments before irradiation for this study.

Experiment Description

Hardware

The irradiation consisted of two Mark B7 (0.807-in. diameter) capsules with six subcapsules in each capsule. Near the top and bottom end of the capsules, holes were drilled through the capsule walls so that

* This work has been supported by the U.S. Department of Energy, Office of Fusion Energy Research, under Contract W-31-109-Eng-38.

reactor coolant sodium could flow between the capsule and the subcapsules to provide heat transfer. Lithium was used as a heat transfer medium for the specimens in the sealed subcapsules. All capsule and subcapsule components were fabricated from Type 316 stainless steel.

The specimens were machined from either sheets or plates of the specified heats of material. The as-machined specimens were polished and then given a heat treatment in a vacuum to remove any hydrogen that may have been adsorbed during these procedures.

An important aspect of the fabrication of the subcapsules was the handling, purification, and loading of the lithium. Primary operations were performed in an ultra-high-purity helium glovebox (oxygen level ≈30 ppb). Prior to introducing lithium into the helium glovebox, an initial purification step was removal of the outer rind from the lithium ingots that were stored in oil. This operation was performed in a small argon-atmosphere glovebox. The interstitial content of the lithium was reduced by heating it with SAES getter pellets at 650°C for about 22 h. During this process, the nitrogen content was reduced from ≈400 ppm to ≈10 ppm. After the purification, the lithium was poured into tantalum trays at a temperature of 250°C. The lithium was prepared for loading into the subcapsules by cutting 0.625-in.-diameter pellets from the 0.5-in.-thick sheets in the tantalum trays with a "cork borer." The Li pellets were cut to length and loaded into the bottom of the subcapsules. The specimens were then placed on top of the Li-pellet (a typical loading is shown in Fig. 1). The subcapsules were capped with a tight-fitting lid and transferred to another He-atmosphere glovebox for welding.

Lithium Loading

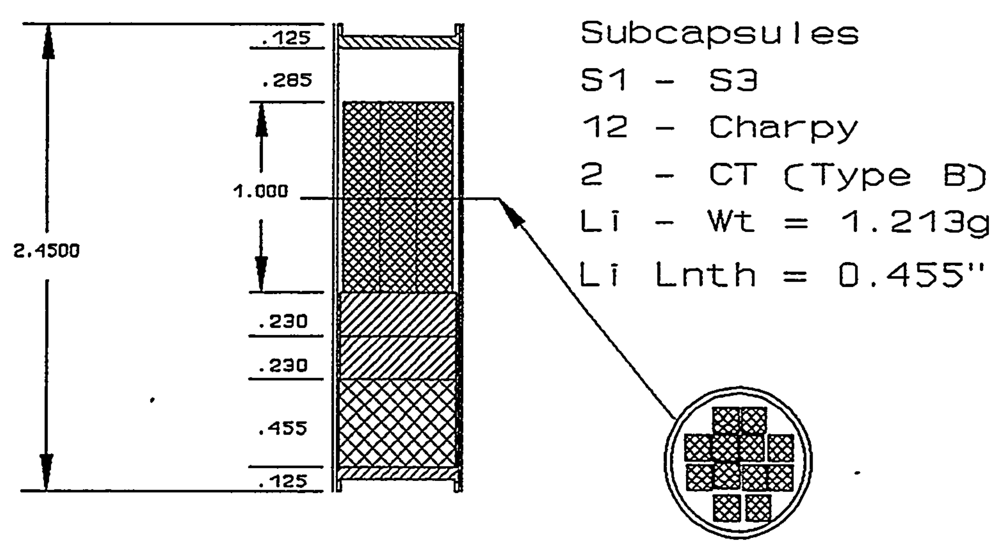

Fig. 1. Typical Subcapsule Loading for the X530 Irradiation.

The subcapsules and appropriate spacers and shields were then loaded into the capsules as shown in Figs. 2 and 3. These two capsules, four dummy rods, and a capsule containing samples of yttria (for the National Institute of Standards and Technology) were assembled in a Mark B7A subassembly and placed in Row 2 of EBR-II. The surface temperatures for the subcapsules were calculated using the HECTIC heat transfer code. Heat transfer from the adjacent subassemblies was important in this low-power, low-flow subassembly. The temperature calculations indicated that specimen temperatures differed with their axial positions in the subassembly (Fig. 4) and were between 370 and 410°C.

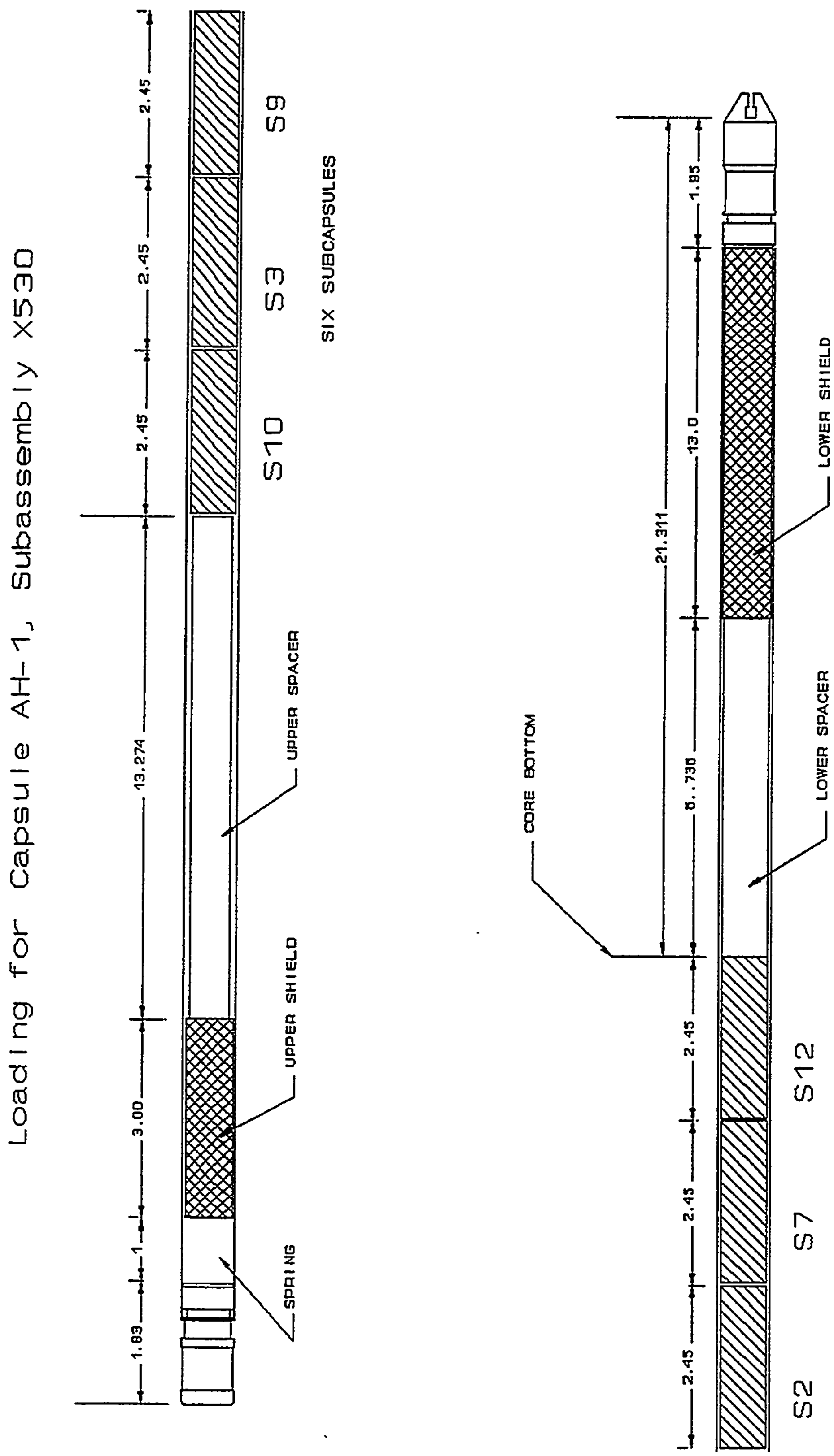

Fig. 2. Loading of Capsule AH-1 for X530.

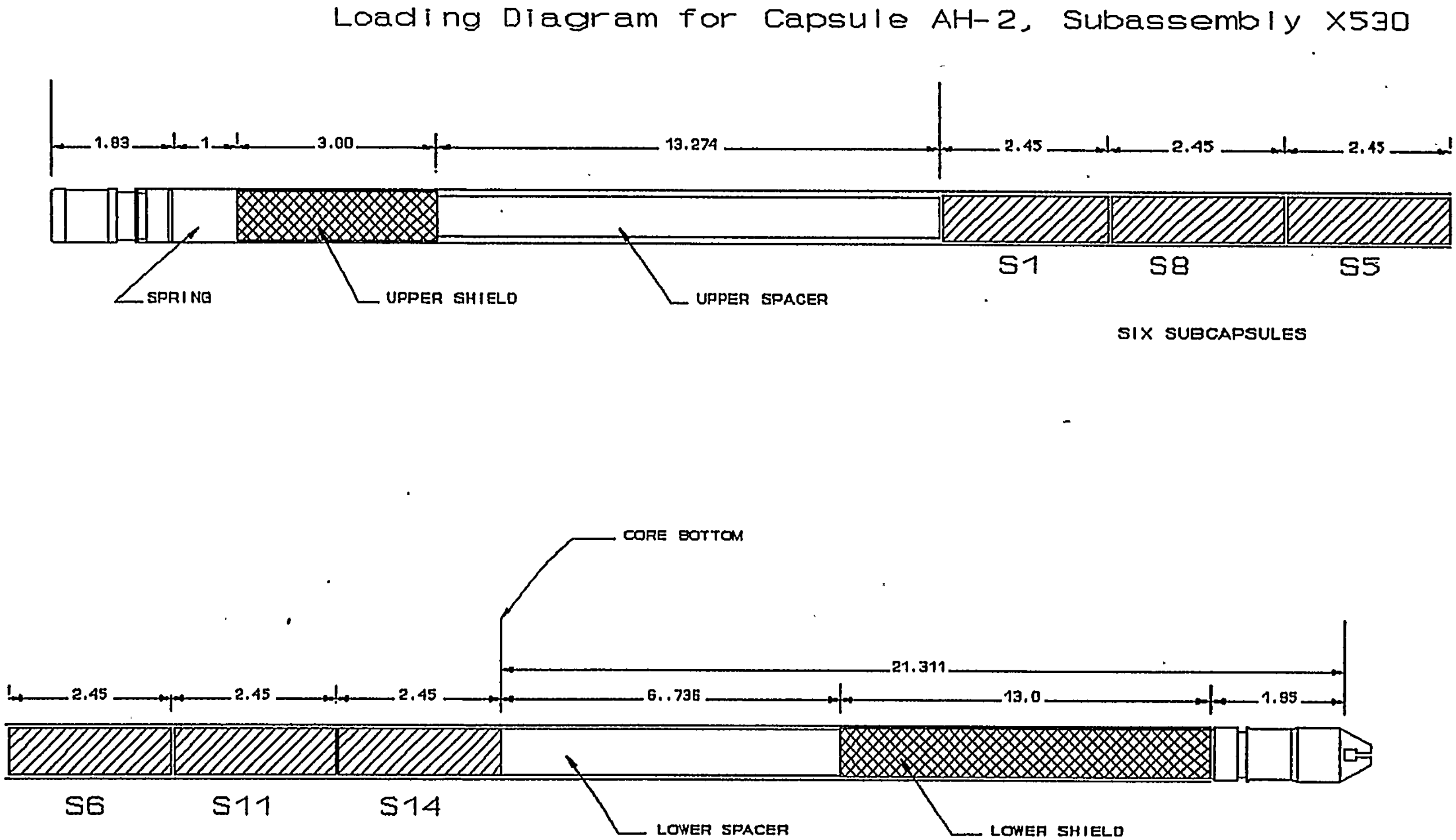

Fig. 3. Loading of Capsule AH-2 for X530.

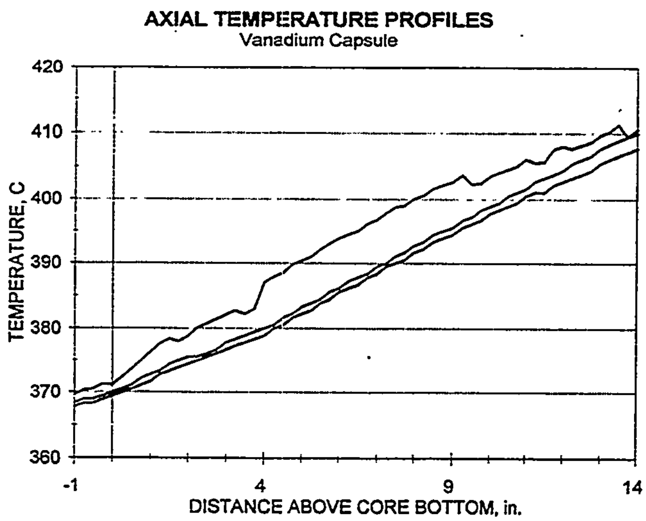

Fig. 4. Calculated Axial Temperature Profile for Capsule AH–1.

Test Matrix

The list of specimens included in the X530 experiment is shown in Table 1, and specimen loadings in the subcapsules are summarized in Table 2.

The most important, and hence most extensively tested, material in the X530 experiment was the 500-kg production heat V-4Cr-4Ti material (Heat No. 832665, also designated BL-71). The test specimens consisted of disk compact tension, 1/3-size Charpy, SS-3 tensile, and transmission electron microscopy disks. These specimens were prepared from sheets/plates that were hot rolled at ≈400°C, followed by a vacuum annealing at 950, 1050, or 1125°C. The purpose of the different annealing temperatures was to yield data on the effects of TMT on mechanical properties.

The other materials included in the X530 test were

- A 250 ppm-^{10}B-doped V-4Cr-4Ti material (BL-70) to study the effect of helium generation,
- A Russian Federation heat of V-4Cr-4Ti material (BL-69),
- A V-5Cr-5Ti material (BL-63) whose original fracture properties were marginal and that was modified for this test by additional TMTs, i.e., either cold rolling or warm rolling at 400°C, then annealing at 950 or 1050°C, and
- Several other earlier heats of materials with different binary or ternary compositions.

Depending on emphasis and material availability, as shown in Table 1, not all forms of specimens were prepared for all materials.

Irradiation History

Subassembly X530 was loaded into EBR-II core position 2F1 (with a fast flux of 2.4×10^{15} n·cm^{-2}·s^{-1}, E>0.11 MeV) and irradiated for the entire 170A run from August 19 until the final reactor shutdown on September 27. The accrued exposure was 35 effective full power days, yielding a peak damage of ≈4 dpa in the vanadium specimens.

For Run 170A, the reactor inlet temperature was lowered from the nominal 371 to 366°C. The flow rate for the subassembly was 13.3 gpm, within the requested range.

Table 1. Types and Numbers of Specimens Irradiated in the X530 Experiment

Composition, wt.%	ANL ID Number	DCT-A, 0.140 in.	DCT-B, 0.230 in.	1/3-size Charpy	SS-3 Tensile	TEM
V-3Ti-1Si	BL-45	-	-	5	2	-
V-5Ti	BL-46	3	-	5	2	5
V-4Cr-4Ti	BL-74	-	4	6	-	-
V-7Cr-5Ti	BL-49	3	-	5	2	5
V-5Cr-3Ti	BL-54	-	-	5	-	-
V-3Ti	BL-62	3	-	5	2	4
V-5Cr-5Ti	BL-63	-	2	5	2	-
V-5Cr-5Ti	BL-63-CR950	1	-	5	2	3
V-5Cr-5Ti	BL-63-CR1050	1	-	5	2	3
V-5Cr-5Ti	BL-63-WR950	1	-	5	2	3
V-5Cr-5Ti	BL-63-WR1050	1	-	5	2	3
V-4Cr-4Ti-RF	BL-69	-	-	-	5	5
V-4Cr-4Ti-B	BL-70	4	4	6	5	5
V-4Cr-4Ti	BL-71-WR950	4	-	6	5	5
V-4Cr-4Ti	BL-71-WR1050	4	-	6	5	5
V-4Cr-4Ti	BL-71-WR1125	3	-	6	5	5
SUBTOTAL		28	10	80	43	51

B = Boron doped (250 appm ^{10}B)
RF = Russian Federation
CR950 = Cold roll and final anneal at 950°C
CR1050 = Cold roll and final anneal at 1050°C
WR950 = Warm roll and final anneal at 950°C
WR1050 = Warm roll and final anneal at 1050°C
WR1125 = Warm roll and final anneal at 1125°C

FUTURE ACTIVITIES

X530 has successfully completed the planned irradiation in EBR-II Run 170. Instructions have been given to EBR-II personnel to discharge and disassemble the test vehicle. Nondestructive examination, including neutron radiography, is scheduled for the two capsules before their return to ANL-East for disassembly and specimen retrieval. Initial results on specimen examination and testing are expected to be available in the next reporting period.

Table 2. Subcapsule Specimen Loading for X530

Capsule	Specimen Type	Material Composition	Quantity	Capsule	Specimen Type	Material Composition	Quantity
S1	DCT-B	V-4Cr-4Ti (BL-74)	2	S8	Tensile	V-3Ti (BL-62)	2
	Charpy	V-3Ti-1Si (BL-45)	5		Tensile	V-5Ti (BL-46)	2
	Charpy	V-5Ti (BL-46)	5		Tensile	V-7Cr-5Ti (BL-49)	2
	Charpy	V-7Cr-5Ti (BL-49)	2		Tensile	V-3Ti (BL-62)	2
					Tensile	V-5Cr-5Ti (BL-63	2
S2	DCT-B	V-4Cr-4Ti (BL-74)	2		Tensile	V-5Cr-5Ti (BL-63)	2
	Charpy	V-4Cr-4Ti (BL-74)	6		Tensile	V-5Cr-5Ti (BL-63)	2
	Charpy	V-7Cr-5Ti (BL-49)	1		Tensile	V-5Cr-5Ti (BL-63)	2
	Charpy	V-5Cr-3Ti (BL-54)	5		Tensile	V-5Cr-5Ti (BL-63)	2
					Tensile	V-4Cr-4Ti (RF)	3
S3	DCT-B	V-5Cr-5Ti (BL-63)	2		TE	V-5Ti (BL-46)	5
	Charpy	V-7Cr-5Ti (BL-49)	2		TE	V-7Cr-5Ti (BL-49)	5
	Charpy	V-3Ti (BL-62)	5		TE	V-3Ti (BL-62)	4
	Charpy	V-5Cr-5Ti (BL-63)	5		TE	V-5Cr-5Ti (BL-63)	3
					TE	V-5Cr-5Ti (BL-63)	3
S14	DCT-B	V-4Cr-4Ti-B (BL-70)	2		TE	V-5Cr-5Ti (BL-63)	3
	Charpy	V-5Cr-5Ti (BL-63)	5		TE	V-5Cr-5Ti (BL-63)	3
	Charpy	V-4Cr-4Ti-B (BL-70)	6				
				S9	Tensile	V-4Cr-4Ti (RF)	2
S4	DCT-B	V-4Cr-4Ti-B (BL-70)	2		Tensile	V-4Cr-4Ti-B (BL-70)	5
	Charpy	V-5Cr-5Ti (BL-63)	5		Tensile	V-4Cr-4Ti (BL-71)	5
	Charpy	V-4Cr-4Ti (BL-71)	6		Tensile	V-4Cr-4Ti (BL-71)	5
					Tensile	V-4Cr-4Ti (BL-71)	5
S6	DCT-A	V-5Ti (BL-46)	2		TE	V-4Cr-4Ti (RF)	5
	Charpy	V-5Cr-5Ti (BL-63)	5		TE	V-4Cr-4Ti-B (BL-70)	5
	Charpy	V-4Cr-4Ti (BL-71)	6		TE	V-4Cr-4Ti (BL-71)	5
					TE	V-4Cr-4Ti (BL-71)	5
S7	DCT-A	V-5Ti (BL-46)	1		TE	V-4Cr-4Ti (BL-71)	5
	DCT-A	V-7Cr-5Ti (BL-49)	1				
	Charpy	V-5Cr-5Ti (BL-63)	5	S10	DCT-A	V-7Cr-5Ti (BL-49)	2
	Charpy	V-4Cr-4Ti (BL-71)	6		DCT-A	V-3Ti (BL-62)	3
					DCT-A	V-4Cr-4Ti (BL-71)	3
				S11	DCT-A	V-5Cr-5Ti (BL-63)	1
					DCT-A	V-5Cr-5Ti (BL-63)	1
					DCT-A	V-5Cr-5Ti (BL-63)	1
					DCT-A	V-5Cr-5Ti (BL-63)	1
					DCT-A	V-4Cr-4Ti-B (BL-70)	4
				S12	DCT-A	V-4Cr-4Ti (BL-71)	4
					DCT-A	V-4Cr-4Ti (BL-71)	4

2.0 DOSIMETRY, DAMAGE PARAMETERS, AND ACTIVATION CALCULATIONS