VANADIUM ALLOY IRRADIATION EXPERIMENT ATR-A1 IN THE ADVANCED TEST REACTOR*

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OBJECTIVE

The objective of the ATR-A1 irradiation experiment is to obtain mechanical properties data, including fracture properties and irradiation creep, on vanadium alloys at low temperatures. Such data are presently lacking.

SUMMARY

A collaborative DOE/Monbusho irradiation experiment is being implemented to generate low-temperature mechanical properties data on vanadium alloys and low-activation ferritic steels. Monbusho is supplying the latter specimens. The experiment will be conducted in the Advanced Test Reactor at the Idaho National Engineering Laboratory and is designated ATR-A1. The core position selected, Channel A10, has relatively high fast neutron flux and fast-to-thermal flux ratio. These qualities are important for achieving a reasonable damage rate in the specimens and reducing the thickness requirements of thermal neutron filters. Filtering out the thermal neutron flux is necessary in the water-cooled ATR in order to avoid excessive V(n,γ)Cr transmutation.

The test vehicle will consist of four capsule segments containing a total of 15 subcapsules: 13 for vanadium alloy specimens and two for low-activation ferritic steel specimens. In all subcapsules the specimens will be lithium bonded to provide uniform specimen temperature, maximum heat transfer and, in the case of vanadium alloys specimens, impurity control. Two test temperatures are planned: 200 and 300°C. They will be achieved by filling the gas-gap between the subcapsules and capsule with different blends of He and Ar. The vanadium alloy test specimens will be biaxial creep (pressurized tubes), Charpy impact, compact tension, tensile, and transmission electron microscope (TEM) disks. For the ferritic steels, the specimens will be Charpy impact, tensile, and TEM disks. The goal fluence for the experiment is 5 dpa (in vanadium), which will be attained in ≈135 effective full power days (EFPDs) in the A10 position.

Most of the test vehicle design has been completed and fabrication of some of the components is underway. The irradiation is scheduled to begin in August 1995 and be completed in January 1996.

DESCRIPTION OF EXPERIMENT

ATR

The ATR is a light-water-moderated and -cooled reactor with highly enriched uranium in plate-type fuel. The core height is 1.22 m (4 ft). Forty fuel elements are arranged in a serpentine pattern that forms four corner lobes and one central lobe. The nominal operating power of the reactor is ≈120 MW and the lobes can be operated at significantly different power levels. A combination of hafnium control drums and shim rods is used to adjust power and minimize flux distortion. Cooling water enters the ATR core from the top at a nominal inlet temperature of ≈52°C. Typical ATR cycles are 5, 6 or 7 weeks at power followed by a 1 or 2 week refueling/maintenance outage.

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Compared to other available irradiation positions, the A-10 channel selected for the A1 experiment is among the highest fast neutron flux and lowest thermal flux locations in ATR. These are important attributes that led to this position being selected. These requirements stem from the need to filter out the thermal flux to minimize the V(n,γ)Cr transmutation. The low thermal flux in A-10 leads to a relatively thin filter being sufficient.

The axial profile for the fast flux in the A-10 channel is relatively flat over the middle ≈0.9 m of the core region. Based on data obtained in an earlier run, only the top and bottom ≈0.15m of the channel will have a fast flux that dips below ≈70% of the peak at the midplane. At the projected lobe power of 27 MW, preliminary analysis showed that 13.5 dpa can be attained in vanadium in one effective full power year.

With double encapsulation and other precautions, lithium can be used as the thermal bond for the specimens in the subcapsules. This is an important feature for the irradiation of vanadium alloy specimens in the ATR-A1 experiment.

Test Vehicle

The test vehicle will be a capsule made up of four segments joined by thread connections and spot welds. The 1.22-m core height will be fully utilized. One of the segments will contain three subcapsules and the other three will contain four subcapsules each. The space between the subcapsules and capsule wall will have different gas blends in each segment to attain the two target temperatures of 200 or 300°C. The capsule and subcapsules will be constructed of Type 304 stainless steel tubing, 0.381 mm thick. The diameter of the A-10 channel and the outside diameters for the capsule and subcapsules are 15.88, 13.46 and 12.40 mm, respectively.

The goal fluence for the ATR-A1 experiment is 5 dpa in the vanadium alloys. Extensive effort went into the selection of the thermal neutron filter material for the experiment. The principal criteria for the selection were maximizing the available test volume and good compatibility between the filter and the lithium bond. Among the candidates evaluated -- Hf, B_4C, Dy, Cd, Eu and Gd -- Eu and Gd were found to have the best overall attributes. Gd was finally selected over Eu because Gd can be more easily handled and machined, an important consideration in light of the tight fabrication schedule. (Eu is pyrophoric at ≈150°C and oxidizes rapidly in air, although it has the best neutronic characteristics.) Preliminary calculations indicated that for the 5 dpa exposure, a thickness of 1.7 mm of Gd would be required for the peak flux position.

With the current vehicle design, each subcapsule is 76.20 mm long, including the end caps. The gadolinium filter, in the form of a 1.70-mm-thick cylindrical shell with end disks, is located in the inner periphery of the subcapsule. Because of the reduced thermal flux towards the ends of the core, a thinner filter (1.30 mm) will be used in the top and bottom subcapsules. These two end capsules will be used exclusively for the 9.6-mm-dia. compact tension specimens, which will not fit inside a 1.7-mm-thick filter body. Thermodynamic data suggest that Gd in the lithium bond will act as a getter for oxygen and hydrogen impurities during the irradiation. A plenum in the subcapsule above the lithium level provides room to accommodate the gas released from the pressurized creep capsule in case of a specimen rupture.

The relatively small diameter of the A-10 channel and the lack of an instrument lead in the reactor preclude the incorporation of a thermocouple in the test vehicle. In order to obtain postmortem indications of the peak temperatures attained, metals and alloys with melting temperatures in the range of ≈200-400°C will be included in selected subcapsules. These indicator materials will be in the forms of shavings and contained in separately sealed holders. Radiography before and after the irradiation will be conducted to determine whether the shavings have melted into a solid mass. A tentative selection of the indicator materials includes: Sn/Pb eutectic (183°C), Se (221°C), Sn (232°C), Bi (271°C), Pb (327°C), and Zn (420°C).

Flux monitor wires will be included in selected subcapsules to provide data on the neutron spectrum and the axial distribution of the neutron flux. For the spectral data, wires of Fe, 0.1%Co-Al, Ti, Nb, Cu and 80%Mn-Cu will be used. The wire sets will be incorporated at the midplane and bottom-of-core locations. Iron and 0.1%Co-Al wires will be used for the flux gradient determination and will be placed at five nearly evenly spaced locations along the length of the vehicle.

Test Specimens

The collaborative agreement with Monbusho stipulates approximately 1/3 of the ATR-A1 test volume be used for Monbusho specimens and the remaining 2/3 for DOE specimens. Vanadium alloy test specimens for both Monbusho and DOE will consist of miniature biaxial creep (pressurized tubes), Charpy impact, compact tension, tensile, and TEM disks. Table 1 shows the dimensions of the Monbusho and DOE specimens and the number of specimens that can be accommodated in the vehicle based on a mixed loading of Monbusho and DOE specimens. (Because of differences in sizes in US and Monbusho Charpy and tensile specimens, a mixed loading can significantly improve the overall loading efficiency.)

Table 1. Specimen Types and Loading Capacities for the ATR-A1 Experiment

	Specimen Type	Quantity
US	Creep capsules (4.6 mm dia. x 22.9 mm)	8
	Compact tension (9.6 mm dia. x 3.6 mm)	18
	Charpy (3.3 mm x 3.3 mm x 25.4 mm)	33
	Tensile (0.8 mm x 5.0 mm x 25.4 mm)	31
	TEM disks	≈160
JP	Creep capsules (4.6 mm dia. x 22.9 mm)	2
	Compact tension (9.6 mm dia. x 3.6 mm)	10
	Charpy (1.5 mm x 1.5 mm x 20.0 mm)	60
	Tensile (0.25 mm x 4.0 mm x 16.0 mm)	70
	TEM disks	≈128

The principal vanadium material to be tested by the US will be the reference 500-kg heat of V-4%Cr-4%Ti alloy and its weldment. Limited specimens from several laboratory-size alloy heats will be included to study the effects of compositional variations. For Monbusho, several different heats of V-Cr(Fe)-Ti alloys with and without Si-Al-Y additions will be studied.

Biaxial creep capsules will be irradiated for the first time in the US vanadium alloy development program. Thin-wall tubing, 4.57 mm OD, 0.25 mm wall, for making the pressurized creep capsules is being produced by drawing and sinking of a bored bar stock from the 500-kg V-4%Cr-4%Ti heat. Thus far, the process has progressed well. More details on tubing fabrication and creep specimen production will be presented in the next report.

The ferritic steel specimens will be submitted by Monbusho and will include F82H and several other low-activation heats. The specimens will consist of miniature tensile, Charpy and TEM disks. These specimens will be in two dedicated subcapsules containing no vanadium alloy specimens.

FUTURE ACTIVITIES

The final design and fabrication of the ATR-A1 experiment are expected to be completed in the next reporting period. Irradiation is expect to begin in ATR cycle 107A, starting in August 1995. The irradiation is scheduled to last three cycles, 107A, 107B and 108A, ending in January 1996. In the three cycles, the experiment is expected to accrue 133 EFPDs, which is consistent with the target exposure of 135 EFPDs. Following the irradiation, the capsule will be opened in the ATR canal tray. The subcapsules will be returned to ANL for disassembly, lithium removal and specimen retrieval. The cleaned specimens will be disseminated to DOE and Monbusho laboratories for postirradiation examination and testing.