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- 1.5 EFFECT OF ORIENTATION ON EFFECTIVE TOUGHNESS-TEMPERATURE CURVES IN V-4Cr-4Ti — E. Donahue, G. R. Odette, and G. E. Lucas (University of California, Santa Barbara) 33

Fracture tests were performed on fatigue precracked, 20% sidegrooved 0.26T compact tension specimens in LT and TL orientations under static loading conditions over temperatures ranging from -196 to -110°C . The effective toughness-temperature $K_{\text{e}}(T)$ curves were similar for both LT and TL orientations. The corresponding $100 \text{ MPa}\sqrt{\text{m}}$ transition temperature was estimated to be about -155°C . Additional tests to evaluate effects of specimen size, orientation, and material fabrication history on the K-T curves are under way.

- 1.6 STUDY OF IRRADIATION CREEP OF VANADIUM ALLOYS — H. Tsai, R. V. Strain, M. C. Billone, T. S. Bray, and D. L. Smith (Argonne National Laboratory) 36

Thin-wall tubing produced from the 832665 (500 kg) heat of V-4 wt.% Cr-4 wt.% Ti material was formed into pressurized tube specimens and irradiated in the HFIR RB-12J experiment to study irradiation creep. Irradiation and the required cool-down following irradiation have been completed and disassembly of the vehicle is under way. Calculated dose for the specimens ranged from 5.5 to 6.0 dpa and the calculated irradiation temperatures were 400 to 500°C .

- 1.7 FRACTOGRAPHY RESULTS FOR V-ALLOY TENSILE SPECIMENS IRRADIATED IN THE BOR-60 ATR, AND FFTF REACTORS — T. S. Bray, H. Tsai, R. V. Strain, M. C. Billone, and D. L. Smith (Argonne National Laboratory) 38

Fractography studies were conducted on numerous V-alloy specimens. These specimens had been irradiated in the ATR, FFTF, and BOR-60 reactors at temperatures ranging from 273 to 600°C and damage doses from 41 to 51 dpa. The results of the fractography studies show the medium dose (17 to 19 dpa), low irradiation temperature materials irradiated in BOR-60 to have mostly ductile fractures but with low areal reduction. The low dose (~ 4 dpa) ATR samples display a wide range of areal reductions with mostly ductile fractures. The fractography results for the FFTF samples with irradiation temperatures from 520 to 600°C and damage doses from 41 to 51 dpa show a wide range of reductions in area and all ductile fractures. Side-view observations revealed evidence of slip bands that are typically associated with dislocation channeling.

- 1.8 IMPURITY STUDIES OF GAS TUNGSTEN ARC WELDING OF VANADIUM ALLOYS — M. L. Grossbeck and J. F. King (Oak Ridge National Laboratory) 44

An improved getter system has been installed on the welding glove box since progress was last reported. Gas tungsten arc (GTA) welds using both oxygen and hydrogen getters resulted in very low oxygen levels but very high hydrogen levels in V-4Cr-4Ti. Charpy impact testing, nonetheless, determined a DBTT lower than previously achieved. The first weld with a DBTT at room temperature was made. Erratic results following post-weld heat treatments or low-temperature outgassing treatments were previously attributed to hydrogen cracking. It is now believed that this behavior is not so erratic and might result from precipitation. Transmission electron microscope studies have been initiated to study the unusual behavior.

- 1.9 IMPROVEMENT OF LASER WELD QUALITY OF V-Cr-Ti ALLOYS — Z. Xu,
C. B. Reed, K. Natesan, and D. L. Smith (Argonne National Laboratory) 49

During this report period, the use of a YAG laser to weld sheet materials of V-Cr-Ti alloys has focused on (a) development of optimal laser welding parameters to produce deep penetration and defect-free welds, (b) integration of a custom-designed environmental control box (ECB) into the laser system to control the oxygen uptake during the processing, (c) examination of the porosity on longitudinally sectioned welds, and (d) analysis for oxygen content of the welds. An innovative method has been developed to obtain deep penetration and oxygen contamination free welds.

- 1.10 DIFFUSION BONDING OF VANADIUM ALLOYS — Z. Xu, D. L. Smith, and C. B. Reed
(Argonne National Laboratory) 54

Preliminary investigations are in progress to evaluate the potential of diffusion bonding processes for joining vanadium-base alloys. Diffusion bonds were prepared on 3.8 mm thick V-4Cr-4Ti alloy plate on a 50 KVA welder with a range of process parameters. Preliminary microstructural analyses conducted on the test samples indicated that bonding was achieved for a range of process parameters.

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K. Natesan, M. Uz, and S. Wieder (Argonne National Laboratory) 57

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T. Shibayama (Center for Advanced Research of Energy Technology, Hokkaido
University), T. Hinoki, M. Ando, Y. Katoh, and A. Kohyama (Institute of Advanced
Energy, Kyoto University) 65

Joining methods are required to allow affordable fabrication of large or complex SiC/SiC components for fusion energy systems. Previous analysis of the criteria for successful and functional joints indicates that reactor-formed and polymer-derived silicon carbide should be considered as candidate joint materials. This report summarizes preliminary mechanical properties of silicon carbide joints formed by a reaction-based approach. Both the test methods and materials are preliminary in design and require further optimization. The values of the room temperature strength of the joints, tested in flexure, are one-third to one-quarter the expected

value. It is believed that the material evaluated was not fully reacted during fabrication. Further annealing, in vacuum, also decreased the strength of the joints.

3.0 FERRITIC/MARTENSITIC STEELS 73

3.1 IMPURITY CONTENT OF REDUCED-ACTIVATION FERRITIC STEELS AND THE EFFECT ON THE REDUCED-ACTIVATION CHARACTERISTICS — R. L. Klueh (Oak Ridge National Laboratory), E. T. Cheng (TSI Research, Inc.), M. L. Grossbeck and E. E. Bloom (ORNL) 75

Three heats of reduced-activation martensitic steel were analyzed by inductively coupled plasma mass spectrometry for low-level impurities that compromise the reduced-activation characteristics: a 5-ton heat of modified F82H for which an effort was made during production to reduce detrimental impurities, a 1-ton heat of JLF-1, and an 18-kg heat of ORNL 9Cr-2WVTa. Specimens from commercial heats of modified 9Cr-1Mo and Sandvik HT9 were also analyzed. The objective was to determine the difference in the impurity levels in the F82H and steels for which less effort was used to insure purity. Silver, molybdenum, and niobium were found to be the tramp impurities of most importance. The modified F82H had the lowest levels, but in some cases the levels were not much different from the other heats. The impurity levels in the F82H produced with present technology did not achieve the limits for low activation for either shallow land burial or recycling. The results indicate the progress that has been made and what still must be done before the reduced-activation criteria can be achieved.

3.2 CONSTITUTIVE AND FRACTURE TOUGHNESS PROPERTIES OF AN ADVANCED FERRITIC/MARTENSITIC STEEL — P. Spätig, G. R. Odette, G. E. Lucas, and M. Victoria (University of California, Santa Barbara); M. Victoria (Technologie de la Fusion-Centre de Recherches en Physique des Plasmas, Ecole Polytechnique Fédérale de Lausanne) 83

A detailed investigation of the strain-hardening rate of the International Energy Agency (IEA) program heat of 8 Cr unirradiated F82H ferritic-martensitic steel has been undertaken in the temperature range [80K-723K]. The overall tensile flow stress is decomposed into an athermal/thermal yield stress contribution plus a mildly temperature-dependent strain-hardening component. The latter is based on a phenomenological dislocation mechanics model. Compared to simple power law treatments, this formulation provides a more accurate and physically based representation of the flow stress as a function of the key variables of test temperature, strain, and strain rate. Fracture toughness measurements from small 0.18 CT specimens are also reported and analyzed using a constraint correction model to estimate a small scale yielding $K_{Ic}(T)$ toughness curve. Finally, the status of the MACE collaboration is briefly summarized. The first irradiation at 250°C to 0.5 dpa has been tentatively completed, and is awaiting confirmation of the preliminary dosimetry. Near term plans for higher doses and other temperatures are described.

- 3.3 MICROSTRUCTURE OF ISOTOPICALLY-TAILORED MARTENSITIC STEEL HT9 IRRADIATED AT 400°C — N. Hashimoto, J. P. Robertson (Oak Ridge National Laboratory), and K. Shiba (Japan Atomic Energy Research Institute) 96
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- 3.4 TENSILE PROPERTIES OF LOW ACTIVATION FERRITIC STEELS FOLLOWING IRRADIATION IN ORR — M. L. Hamilton and D. S. Gelles (Pacific Northwest National Laboratory) 102
- Post-irradiation tensile test results are reported for a series of low activation steels containing Mn following irradiation in the Oak Ridge Reactor at 60, 200, 330, and 400°C to 10 dpa. Alloy compositions included 2Cr, 9Cr, and 12Cr steels with V to 1.5% and W to 1.0%.
- Strength increases were higher in all alloys for irradiation conditions below 400°C, with peak hardening occurring following irradiation at 200°C, corresponding to a minimum of 4% total elongation. The 9Cr alloy class exhibited the smallest increases in hardening. Test results are provided and compared with behavior following irradiation in FFTF.
- 3.5 EFFECT OF HEAT TREATMENT AND IRRADIATION TEMPERATURE ON IMPACT PROPERTIES OF Cr-W-V FERRITIC STEELS — R. L. Klueh (Oak Ridge National Laboratory) and D. J. Alexander (Los Alamos National Laboratory) 117
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- 4.2 MICROSTRUCTURES OF Ti-Al INTERMETALLIC COMPOUNDS IRRADIATED AT 674 K IN HFIR — Y. Miwa, T. Sawai (Japan Atomic Energy Research Institute) D. T. Hoelzer (Oak Ridge National Laboratory), and A. Hishinuma (JAERI) 126

Four kinds of Ti-Al intermetallic compounds were irradiated at 673 K to the fluence of 5.16×10^{25} n/m² ($E > 1$ MeV) in HFIR. One consists of α_2 -Ti₃Al single phase, and others consist of α_2 -Ti₃Al and γ -TiAl duplex phases. After irradiation, transmission electron microscopy was carried out. In both α_2 -Ti₃Al and γ -TiAl phases of the specimens, loop-shaped and dot-like clusters were observed. However, the nucleation behavior of cavities in α_2 -Ti₃Al and γ -TiAl phases has been influenced by chemical compositions and fabrication processes.

- 5.0 AUSTENITIC STAINLESS STEELS 149

No contributions.

- 6.0 INSULATING CERAMICS AND OPTICAL MATERIALS 151

No contributions

- 7.0 SOLID BREEDING MATERIALS 153

No contributions.

- 8.0 RADIATION EFFECTS, MECHANISTIC STUDIES, AND EXPERIMENTAL METHODS 155

- 8.1 AN INTEGRATED THEORY, MODELING, EXPERIMENTAL, AND DATABASE PROGRAM FOR THE DEVELOPMENT OF ADVANCED FUSION MATERIALS — R. E. Stoller (Oak Ridge National Laboratory), G. R. Odette (University of California-Santa Barbara), and H. L. Heinisch (Pacific Northwest National Laboratory) 157

A White paper on an Integrated Theory, Modeling, Experimental, and Database Program has been prepared as part of the overall AMP planning process. A review of the current program status has lead to the following primary recommendations: (a) an ambitious integrated modeling program should be initiated and closely linked to the entire AMP program, (b) program planning should consider the items identified by the workshop participants described in Appendix A and those listed in Table 4.1, (c) the program should encourage inter-institutional collaborations, i. e. between national laboratories and universities as well as between national laboratories, (d) regular program exchanges and reviews should be an integral part of the program, (e) both new and ongoing research should demonstrate relevance to the issues described in this document and the overall AMP White paper.

- 8.2 A KINETIC MONTE CARLO STUDY OF MIXED 1-D/3-D DEFECT MIGRATION — H. L. Heinisch (Pacific Northwest National Laboratory), B. N. Singh (Risø National Laboratory), S. I. Golubov (Institute of Physics and Power Engineering) 179

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9.1 RADIATION DAMAGE CALCULATIONS FOR THE FUBR AND BEATRIX IRRADIATIONS OF LITHIUM COMPOUNDS IN EBR-II AND FFTF — L. R. Greenwood (Pacific Northwest National Laboratory) 187

The Fusion Breeder Reactor (FUBR) and Breeder Exchange Matrix (BEATRIX) experiments were cooperative efforts by members of the International Energy Agency to investigate the irradiation behavior of solid breeder reactor materials for tritium production to support future fusion reactors. Lithium ceramic materials including Li_2O , LiAlO_2 , Li_4SiO_4 , and Li_2ZrO_3 with varying ^6Li enrichments from 0 to 95% were irradiated in a series of experiments in the Experimental Breeder Reactor (EBR II) and in the Fast Flux Test Facility (FFTF) over a period of about 10 years from 1982 to 1992. These experiments were characterized in terms of the nominal fast neutron fluences and measured ^6Li burnup factors, as determined by either mass spectrometry or helium measurements. Displacement per atom (dpa) values have been calculated for each type of material and irradiation. Values up to 11% ^6Li -burnup and 130 dpa are predicted for the longest irradiations. Using these new calculations, previously measured radiation damage effects in these lithium compounds can be compared or correlated with other irradiation data on the basis of the dpa factor as well as ^6Li -burnup.

9.2 NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE TRIST ER-1 EXPERIMENT IN HFIR — L. R. Greenwood (Pacific Northwest National Laboratory) and C. A. Baldwin (Oak Ridge National Laboratory) 194

Neutron fluence measurements and radiation damage calculations are reported for the TRIST ER-1 experiment, which was conducted in the removable beryllium position in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). The maximum neutron fluence at midplane varied from 1.38 to 1.57×10^{22} n/cm² resulting in about 2.4 to 2.8 dpa in Al_2O_3 .

9.3 NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE HFIR-CTR-62 AND 63 IRRADIATIONS — L. R. Greenwood (Pacific Northwest National Laboratory) and C. A. Baldwin (Oak Ridge National Laboratory) 199

Neutron fluence measurements and radiation damage calculations are reported for the CTR-62 and -63 experiments, which were conducted in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). The maximum neutron fluence at midplane was $6.9\text{E}+22$ n/cm² resulting in about 14 dpa in the 316 stainless steel.

10.0 MATERIALS ENGINEERING AND DESIGN REQUIREMENTS

No contributions.

11.0 IRRADIATION FACILITIES, TEST MATRICES, AND EXPERIMENTAL METHODS 205

- 11.1 CONCEPTUAL DEVELOPMENT OF FUSION-2 EXPERIMENT FOR IRRADIATION TESTING OF VANADIUM ALLOYS IN A LITHIUM ENVIRONMENT AT ≈ 500 - 750°C IN THE BOR-60 REACTOR — V. Kazakov, V. Chakin, V. Efimov, V. Petukhov, A. Tuktabiev, P. Gabiev (Research Institute of Atomic Reactors), H. Tsai, T. S. Bray, D. L. Smith (Argonne National Laboratory), and A. F. Rowcliffe (Oak Ridge National Laboratory) 207

The requirements of this task are to complete the conceptual designs of irradiation capsules to be exposed to a neutron dose of ≈ 20 dpa in BOR-60. The specimen matrix will include sheet tensile specimens, compact tension specimens, bend bars, TEM disks, and pressurized creep tubes. To better utilize the test volume and provide additional temperature options, it was decided to modify the experiment from a two-capsule to a three-capsule design. All capsules will be liquid-metal-bonded for temperature uniformity. Goal temperatures for the three capsules will be 450, 600, and 700- 750°C , with an emphasis on 600°C . A key objective of the experiment will be to generate irradiation creep data for vanadium-base alloys, especially at the emphasized temperature of 600°C , where thermal creep may not be dominant.

- 11.2 SCHEDULE AND STATUS OF IRRADIATION EXPERIMENTS — A. F. Rowcliffe (Oak Ridge National Laboratory) 210

The current status of reactor irradiation experiments is presented in tables summarizing the experimental objectives, conditions, and schedule.