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This is the Extended Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

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M. Ando, T. Nozawa, T. Hirose, H. Tanigawa, E. Wakai (Japan Atomic Energy Agency), R. E. Stoller and Janie Myers (Oak Ridge National Laboratory)

The 34 pressurized tubes irradiated in MFE-RB15J capsule have been measured by a laser profilometer in hot cell. The irradiation creep of F82H IEA and ^{10}BN-F82H exhibited similar behavior below 573 K up to 5dpa. The irradiation creep strain in F82H irradiated at 573K and 673 K was almost linearly dependent on the Hoop stress level for stresses below 300 MPa and 200 MPa, respectively. The creep strain of ^{10}BN-F82H was similar to that of F82H IEA at each Hoop stress level except 340 MPa at 573 K irradiation.

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J. Ciston (National Center for Electron Microscopy, Lawrence Berkeley National Laboratory), Y. Wu and G. R. Odette (Materials Department, University of California Santa Barbara), P. Hosemann (Department of Nuclear Engineering, University of California, Berkeley)

Fusion energy will require developing new, high performance irradiation tolerant structural materials, like oxide dispersion strengthened nanostructured ferritic (ODS) alloys [1]. Fe-14Cr based NFA contain an ultrahigh density of Y-Ti-O enriched nanofeatures (NF) that provide both outstanding high temperature properties and remarkable tolerance to irradiation damage, including the transmutation product He. Understanding the detailed characteristics of the NF is critical to optimizing ODS alloys, but this remains an unresolved issue and a subject of continuing controversy.

2.2 Recent Progress on Understanding and Quantifying Atom Probe Tomography Artifacts for High Evaporation Rate nm-Scale Phases in Fe Based Alloys — 9
P. Wells, N. J. Cunningham, and G. R. Odette (University of California Santa Barbara)

Preferential undercounting and trajectory aberrations in APT measurements were investigated. The higher than physical atom densities observed in NFs are due to trajectory aberrations that are associated with local changes in the surface topology of the

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tip of the AP needle that focus both solute and matrix atoms into a smaller detector area. These topology changes are due to higher evaporation rates of the solutes and, in some cases, nearby matrix atoms that cause flattening or dimpling of the tip at the nano-oxides. The rapid evaporation rates are also accompanied by multiple hits and/or pre-evaporation events that can lead to undercounting of some solute species. These measurement artifacts are amplified in reconstructions that do not take them into account, for example, by placing atoms actually evaporated from a lower layer in a surface position. These phenomena are well known to APT practitioners, but their implications have not been widely recognized or well treated. However, atom probe data sets contain information that can provide insight on these phenomena, and perhaps eventually contribute to their resolution. A key piece of information is the spatially resolved sequence of atom emissions that are visualized in reconstruction software in color-coded detector hit maps. The hit maps show that the nano-oxides (and Cu rich precipitates in a ferrite matrix) evaporate much more rapidly than randomly located matrix atoms, and focus into the center of the solute rich region. Matrix atoms near the nano-oxides evaporate even more rapidly and focus more intensely than the solutes. Simple volume conservation considerations dictate that the higher evaporation rates lead to changes in the tip morphology resulting in the trajectory aberrations. Crude estimates of the degree of flattening-dimpling are possible, but more detailed understanding of the tip shape evolution will require additional observations and integration with field emission and atomic bond energy models. The hit maps also reveal that when the surface of a tip approaches a NF the thin layer of matrix atoms between the NF and the tip surface rapidly evaporates, forming a pre-dimple. Hit maps also show that un-ranged detector noise is concentrated at the nano-oxides, possibly partly due to DC pre-emission or unresolved multiple hit events. Solute specific multiple event frequencies are presented and other artifacts, like nano-oxide tops and bottoms, are described.

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D. T. Hoelzer, E. T. Manneschmidt, and M. A. Sokolov (Oak Ridge National Laboratory)

Three heats of the advanced ODS 14YWT-SM12 ferritic alloy were produced with different extrusion temperatures and plates of each heat were fabricated with two different rolling conditions. The 14YWT-SM12 was a “clean” heat that was produced with improved mechanical alloying conditions to achieve low C (128 wppm) and N (117 wppm) levels and elevated O (1184 wppm) level. Plates of three SM12 heats were obtained by extruding at 850ºC, 1000ºC and 1150ºC temperatures followed by rolling at 1000ºC to 50% reduction in thickness in either the parallel (PR) or cross (CR) directions with reference to the extrusion direction. Specimens were fabricated from four plates of the SM12 heat with different thermal-mechanical treatments (TMT) and supplied for assembly of the JP30/31 capsules. The reference characterization of the microstructure and mechanical properties of the three SM12 heats was initiated. Results obtained from tensile tests at 25ºC showed slightly lower strengths, but significantly higher uniform (>9%) and total elongations in all the 14YWT-SM12 heats compared to results obtained from previous 14YWT heats. The general microstructural characteristics observed by SEM analysis showed that slightly larger grains with less uniformity in grain size had formed in the SM12 heats compared to

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D. T. Hoelzer, M. A. Sokolov, and Z. Feng, (Oak Ridge National Laboratory)

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T. Nozawa and H. Tanigawa (Japan Atomic Energy Agency), P. Dou, H. Bei, Y. Katoh, L. L. Snead, and R. E. Stoller (Oak Ridge National Laboratory)

To investigate the irradiation effects on interfacial shear properties such as an interfacial debond shear strength (IDSS) and an interfacial friction stress (IFS), the single fiber push-out tests were applied to Hi-Nicalon Type-S fiber reinforced chemical-vapor-infiltration (CVI) SiC matrix composites neutron irradiated up to 70 dpa at 300~800 ºC. Test results demonstrated no significant irradiation-enhanced degradation of interfacial shear properties expected at any doses (i.e., a slight decrease at lower doses <10 dpa and apparent improvement at higher doses >10 dpa). The irradiation-induced stress is a primary source to affect the F/M interfacial stresses. At higher doses ~70dpa, volume expansion by disordering of PyC possibly induced a residual clamping stress, eventually improving interfacial shear properties. A good correlation between the F/M interfacial strength and the macro strength for certain irradiation conditions was obtained. Interfacial functions sustained but fiber (Hi-Nicalon Type-S) deterioration was implied by irradiation at 70dpa. In the future we must clearly define the irradiation-induced change in thermal expansivity. The differential swelling between the fiber and matrix and irradiation creep are also critically important.

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G. E. Youngblood*, E. C. Thomsen and C. H. Henager, Jr. (Pacific Northwest National Laboratory

This is the Extended Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

3.3 Contact Resistance at a CVD-SiC/Ni Interface — 41
G. E. Youngblood and E. C. Thomsen (Pacific Northwest National Laboratory)

In a previous report, a fairly substantial correction due to contact resistance at a silicon carbide composite-metal (either gold or porous nickel) electrode interface was required to

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arrive at reliable transverse electrical conductivity values for the composite. A semi-logarithmic plot of the inverse specific contact resistance vs. 1000/K was nearly linear over a temperature range ~100-700°C, with an effective thermal activation energy of ~0.3 eV, which suggested that the contact resistance was due to electron tunneling through a Schottky-type barrier at the composite SiC seal coat/metallic interface. For the FCI-application, additional contact resistance at SiC composite wall/liquid Pb-Li interfaces could potentially and beneficially reduce the transverse electrical conductivity.

In this report, we further examine the behavior of the contact resistance; in particular, by examining contact resistance for a single pure, monolithic but polycrystalline CVD-SiC disc sample with nickel electrodes applied by physical vapor deposition (PVD). After making contact resistance measurements with the as-applied Ni electrodes, a heat treatment at 900°C was performed to lower the contact resistance, presumably by the formation of nickel silicide (NiSi) at the SiC-electrode interface. Using a 2/4-probe dc electric set up, we were able to simultaneously measure the total resistance across the sample disc with and without contact resistance from ambient up to 700ºC, with the difference representing the temperature dependent behavior of the contact resistance alone. Surprisingly, the specific contact resistance values for each electrode type at all temperatures were almost identical (~1000 Ω-cm^2 at RT decreasing continuously to <2 Ω-cm^2 at 700°C). The temperature dependence indicated a thermally activated interfacial conductance with effective activation energy of ~0.24 eV, a value slightly greater than that for ultra high-purity CVD-SiC (0.21eV). Apparently, the electrical conductance of the CVD-SiC/metal (Ni or NiSi) interface depends mostly on the near surface SiC electrical conductivity properties rather than the type of metallic conductor.

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C. H. Henager, Jr., R. J. Kurtz (Pacific Northwest National Laboratory), A. Ventrella and M. Ferraris (Politecnico di Torino)

The use of SiC composites in fusion environments likely requires joining of plates using reactive joining or brazing. One promising reactive joining method uses solid-state displacement reactions between Si and TiC to produce Ti_3SiC_2 + SiC. We continue to explore the processing envelope for this joint for the TITAN collaboration in order to produce optimal joints to undergo irradiation studies in HFIR. The TITAN collaboration has designed miniature torsion joints for preparation, testing, and irradiation in HFIR. PNNL synthesized 40 miniature torsion joints and several were tested for shear strength prior to irradiation testing in HFIR. The resulting tests indicated that 1) joint fixture alignment problems cause joint strengths to be lower than optimal, 2) that non-planar torsion test failures limit the effectiveness of the miniature specimen design, and 3) that several joints that were well aligned had high shear strengths and promising mechanical properties. In summary, we now show conclusively that high joint strengths cause non-planar shear fracture and complicate strength analysis for miniature torsion specimens.

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S. Sharafat[1], A. Aoyama[1], B. Williams[2], N. Ghoniem[1], [1]University of California Los Angles, Los Angeles, California, USA, [2]Ultramet Inc., Pacoima California, USA

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Tamer Crosby (University of California, Los Angeles), Nasr M. Ghoniem (University of California, Los Angeles)

This is the Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

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W. Setyawan and R. J. Kurtz (Pacific Northwest National Laboratory)

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K. J. Leonard and L. L. Snead (Oak Ridge National Laboratory)

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This is the Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

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B. A. Pint and K. A. Unocic (Oak Ridge National Laboratory)

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This is the Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

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B. A. Pint and K. A. Unocic (Oak Ridge National Laboratory)

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G. Po (University of California, Los Angeles) N. M. Ghoniem (University of California, Los Angeles)

This is the Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

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T. Yamamoto, G. R. Odette, Y. Wu (University of California, Santa Barbara)

Standard uniaxial tensile tests cannot provide generally transferable post-yield information on deformation and ductile failure for materials with low uniform strain limits. Deformation mediated failure is not only controlled by the intrinsic constitutive properties, but also extrinsic factors, especially the loading-specimen geometry. A self-consistent approach is used to derive true stress-stain constitutive [s(e)] laws, for candidate fusion reactor structural materials encompassing a range of unirradiated and irradiated conditions. In this report, unirradiated F82H with 0 to 80% of cold-work and neutron and spallation proton irradiated F82H were evaluated. The approach is based on simultaneous measurements and finite element method (FEM) simulations of engineering stress-strain s(e) curves, that are consistent only for a unique s(e) law. TEM observations of the selected deformed specimens were also performed to obtain microstructural insight. The most important and surprising result is that the s(e) of the irradiated alloys are consistently higher that for unirradiated condition over a wide range of strain. The s(e) after neutron irradiation are higher than in the 80% cold worked unirradiated condition at high strains. For deformation conditions that do not lead to plastic flow instabilities the higher strength levels are an asset even if accompanied by the low initial stain hardening rates following neutron irradiations. Further, there is evidence that high levels of He may suppress the initial loss strain hardening. If verified by additional experiment and modeling, these conclusions will have a tremendous impact on assessing the effects of irradiation service on the failure limits of fusion structures.

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B. Yao, D. J. Edwards, R. J. Kurtz (Pacific Northwest National Laboratory), G. R. Odette, T. Yamamoto (university of California, Santa Barbara)

The results of this simulation study show that the size of TEM imaged He bubbles, represented by the inner diameter of the first dark Fresnel ring under defocused condition (D_{in}), deviated from the actual bubble size (D_o). D_{in} was found to be larger than D_o when imaged with a highly incoherent electron beam, but smaller than D_o if the beam is coherent. The deviation of D_{in} from D_o increases with increasing defocus. On the other hand, the electron beam accelerating voltage, bubble size, bubble position, and TEM sample thickness do not significantly affect the value of D_0/D_o. This study also suggests that He bubbles can be differentiated from argon (Ar) bubbles by differences in Fresnel contrast.

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G. R. Odette, T. Yamamoto, Y. Wu, E. Stergar and N. J. Cunningham (University of California Santa Barbara), R. J. Kurtz and D. J. Edwards (Pacific Northwest National Laboratory)

The feasibility of fusion energy depends on developing advanced structural materials that can sustain extended component lifetimes in an ultra-severe environment, including up to 200 displacements per atom (dpa) and 2000 appm He. Helium and displacement defects individually and synergistically drive complex microstructural evolutions that degrade many performance-sustaining properties. Managing helium is perhaps the greatest challenge facing fusion structural materials. Here we show that an in situ helium injection fission reactor irradiation at 500°C to ≈ 25 dpa and 1450 appm helium produced populations of both bubbles and growing voids in a leading candidate tempered martensitic steel Eurofer97. The voids, which would be absent at low helium contents, are precursors to rapid swelling, suggesting that tempered martensitic steels may not tolerate extended service in the fusion environment. In contrast, only an ultrahigh density of tiny bubbles form in a companion nano-dispersion strengthened ferritic alloy, MA957. It is expected that the bubbles will inhibit swelling and other deleterious manifestations of irradiation effects at much higher dpa in materials with a high density of stable nano-dispersoids.

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This is the Extended Abstract for a paper in preparation for journal submission.

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R. E. Stoller (Oak Ridge National Laboratory)

Helium generation and accumulation is important under DT fusion irradiation conditions. Ballistic resolutioning of He from bubbles could limit bubble growth by ejecting gas atoms back into the metal matrix. Molecular dynamics simulation has been used to study this process in iron as a surrogate for structural materials. A newly-developed Fe-He interatomic potential was employed. The primary variables examined were: irradiation temperature (100 and 600K), iron knock-on atom energy (5 and 20 keV), bubble radius (~0.5 and 1.0 nm), and He-to-vacancy ratio in the bubble (0.25, 0.5 and 1.0). Helium ejection by high-energy iron recoils was clearly observed on a time scale consistent with a ballistic mechanism. The results are summarized.

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This is the Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

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V. I. Dubinko (NSC Kharkov Institute of Physics and Technology, Kharkov 61108, Ukraine), S. Y. Hu, Y. L. Li, C. H. Henager and R. J. Kurtz (Pacific Northwest National Laboratory)

This is the Extended Abstract of a manuscript submitted for publication in Philosophical Magazine & Philosophical Magazine Letters.

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H. L. Heinisch, R. J. Kurtz, and F. Gao, Pacific Northwest National Laboratory, Richland, WA USA

This is the Extended Abstract for an ICFRM-15 paper submitted for publication in the Proceedings.

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Y. N. Osetskiy and R. E. Stoller (Oak Ridge National Laboratory)

This extensive simulation program is design to investigate the basic mechanisms of strengthening and hardening during irradiation of fusion materials. Strength of spherical obstacles of different types and sizes is discussed for comparison. An interesting observation is that the relative strength of rigid particles (a model for oxide particles) depends on their size: small particles, 2 nm in diameter, are relatively weak compared to voids or equilibrium He-filled bubbles, while large particles are the strongest obstacle. The explanation is related to the atomic scale features of dislocation-obstacle interactions, particularly to cross-slip and climb mechanisms.

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Jaime Marian and Wayne Meier (Lawrence Livermore National Laboratory)

The high-temperature strength of structural ferritic alloys (ferritic/martensitic steels, ODS steels, bcc refractory alloys) hinges on the thermal stability of second phase particles and their interactions with dislocations. Irradiation damage can modify the structure and stability of both the particles and dislocations, particularly by the introduction of gas atoms,

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point defects and point defect clusters. The three aspects of materials strength that we are studying are:

a) Computation of dislocation mobility functions (stress-velocity relations) as a function of temperature and dislocation character. This will be done via molecular dynamics (MD) simulations of single dislocation motion under applied shear stress. This is a fundamental input to dislocation dynamics (DD) simulations and also provides fundamental insights into the high-temperature plastic behavior of ferritic materials.

b) Simulations of dislocation-obstacle interactions using MD and DD. This subtask includes simulating the effect on dislocation glide of precipitates (e.g., α' Cr precipitates), ODS particles, and irradiation induced defect clusters (e.g. voids, dislocation loops, etc.).

c) Implementation of this information (dislocation mobilities and dislocation-defect interaction rules) into DD codes that will allow us to study plasticity of single crystals Fe alloys under relevant irradiation conditions.

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T. Nozawa, T. Hirose, H. Tanigawa, M. Ando (Japan Atomic Energy Agency), J. L. McDuffee, D. W. Heatherly, R. G. Sitterson, M. A. Sokolov, L. Tan, D. T. Hoelzer, R. E. Stoller, and L. L. Snead (Oak Ridge National Laboratory), and T. Yamamoto (University of California, Santa Barbara)

Assembly of the JP-30 and JP-31 capsules was completed in November, 2011 and installed in HFIR. Irradiation began with cycle 439, starting November 21, 2011. A detailed specimen-loading list for the capsules is provided in this report.

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Y. Katoh and J. McDuffee (Oak Ridge National Laboratory)

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