SUMMARY OF IEA WORKSHOP/WORKING GROUP MEETING ON FERRITIC/MARTENSITIC STEELS FOR FUSION—R. L. Klueh (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this report is to describe the working group meeting and workshop held to review planned and completed work that is being undertaken to prove the feasibility of using ferritic/martensitic steels for fusion applications.

SUMMARY

The International Energy Agency (IEA) Working Group on Ferritic/Martensitic Steels for Fusion held a workshop at ECN Nuclear Research, Petten, The Netherlands, 1-2 October 1998. The Working Group, consisting of researchers from Japan, the European Union, the United States, and Switzerland, met to review research that has been completed since the previous meeting and to continue planning and coordinating an international collaborative test program on reduced-activation ferritic/martensitic steels for fusion applications. At the workshop, data were presented from the continuing research on the IEA heats of steel that are being studied in the collaboration. Data on these and other reduced-activation steels in the irradiated and unirradiated condition were presented. Other subjects that were discussed included effects of a ferromagnetic steel in a fusion machine, the effect of helium on properties, and the development and application of oxide dispersion-strengthened steels for fusion. A Working Group status-review meeting is planned in conjunction with the International Conference on Fusion Reactor Materials (ICFRM-9) in Colorado Springs, Colorado, USA, 10-15 October 1999, at which time plans for a workshop to be held in 2000 will be finalized.

PROGRESS AND STATUS

Introduction

The IEA Working Group on Ferritic/Martensitic Steels for Fusion under the auspices of the IEA Executive Committee for the Implementing Agreement on Fusion Materials conducted a workshop at ECN Nuclear Research, Petten, The Netherlands, 1-2 October 1998. Researchers from Japan (4), the European Union (5), the United States (3), and Switzerland (1) participated. Russian Federation participation was invited, but no one from there attended the meeting. The objective of the Working Group is the establishment and coordination of an international collaborative test program to determine the feasibility of using ferritic/martensitic steels for fusion.

This workshop was the ninth meeting of the Working Group, which was formed as a result of a workshop on ferritic/martensitic steels in Tokyo in October 1992. At the first meeting following the Tokyo workshop, the Working Group developed specifications for large heats of reduced-activation steels and outlined a collaborative research program. Two 5-ton heats of the IEA-modified F82H steel and two 1-ton heats of JLF-1 steel were produced, fabricated into plates, and distributed to the participants of the collaboration. Subsequent meetings have been used to plan a test program and to coordinate the acquisition of the data needed to prove feasibility for the steels for fusion.

The Petten meeting was a follow up to the meeting at Tokyo, Japan, 3-4 November, 1997, in which information was presented that indicated helium has an embrittling effect on ferritic/ martensitic steels irradiated at 250-400°C. At the Tokyo meeting and at ICFRM-8 at Sendai, Japan, 27-31 October 1997, several investigators presented data on oxide dispersion-strengthened (ODS) steels as possible structural materials that will allow higher operating temperatures. At Petten, information was presented on both of these subjects, along with recently developed information on the properties of the IEA heats of reduced-activation steels and other reduced-activation steels. Information was also presented on work designed to determine the effects produced by ferritic/martensitic steels in the high magnetic fields of a magnetically confined fusion reactor.

Research and Development Activities

The following is a brief description of the information presented at the Petten workshop. Copies of viewgraphs and other information presented at the workshop are appended to this summary.

Ferromagnetic Effects

At one time it was believed that the expected strong interaction of a ferromagnetic material with the magnetic fields of a magnetically confined fusion system would make it impossible to use the ferritic/martensitic steels as structural materials. Calculations in the early 1980s indicated that the effect could be taken into account in the design of the reactor. Because these early studies were but cursory analyses of the problem, questions as to the magnitude of the effect persist, and detailed design studies as well as experimental investigations are required to eliminate this uncertainty.

P. Ruatto has been involved in a program at FZK Karlsruhe to study the transient eddy current problems and magnetic fields and forces that can develop with the use of ferritic/martensitic steels. Ruatto's presentation (given by E. Materna-Morris) discussed some of the information derived with the three-dimensional finite element method program AENEAS that was developed at FZK. Results were presented for calculations that examined the effect of plasma disruptions on the outboard blanket segment of the DEMO helium-cooled pebble bed outboard blanket segment and the European Helium cooled pebble bed test blanket module in ITER. A centered plasma disruption was considered for the DEMO, and the forces on the components were calculated and described for the MANET steel. The force calculations for a plasma disruption in ITER were also summarized. The conclusion was that for a correct mechanical design of a fusion power plant it is necessary to include an electromagnetic analysis, and the AENEAS is an appropriate tool for this task.

K. Shiba discussed the Japan Atomic Energy Research Institute (JAERI) research effort on the effect of a ferromagnetic material (ferritic/martensitic steel) on the operation of a fusion machine. (Note that this presentation was part of Shiba's presentation in the section on Steel Properties— Irradiated, and the viewgraphs on the ferromagnetic effects are included in his presentation in that section.) Three subject areas are being pursued by JAERI: (1) an experimental study of the use of a ferritic steel for plasma ripple reduction in ITER by the installation of a "ferritic board" on the JFT-2M tokamak, (2) an experimental study of the possibility of producing rippleless plasma operation with a reduced-activation martensitic steel as the vacuum vessel by the installation of a reduced-activation (F82H) ferritic steel liner in a small tokamak, and (3) using this lined tokamak to conduct research on possible undesirable effects due to ferritic/martensitic steels on plasma production and control. Work began on (1) this past year and involved a computer simulation and preliminary experiment using JFT-2M. The results indicated a reduction in ripple magnitude and a modification of the magnetic field over the whole plasma region due to the insertion of the ferritic board.

R. Klueh has attempted to determine what work has been conducted and what work is ongoing throughout the world on ferromagnetic effects, and the results of that have been summarized. A copy of that summary is included in the appended material following Ruatto's presentation.

Steel Properties—Unirradiated

The work of the Monbusho fatigue test program in Japan to develop mini-sized test techniques, study size effects, develop a strain-control test technique without contacting the specimen, and determine the fatigue behavior of JLF-1 steel was described by A. Kohyama. A hydraulic servo-controlled testing machine using laser measurements has been developed that should be applicable to hot-lab testing. Testing of full-sized hour-glass specimens (100 mm long, 9 mm at the center of the specimen) and miniature specimens (25.4 mm long, 1.25 mm at the center) measured comparable properties except under the condition of very low cycle fatigue. The machine was used to test JLF-1 base metal and TIG weldments, and the results indicated that fatigue strength (S-N curve) of the base metal was less than that of the weld metal. A correlation was developed between the fatigue limit and Vicker hardness that was related to the tensile strength, which was shown to provide good predictions for the fatigue limit.

A. Alamo presented data on the effect of thermal aging on the tensile and Charpy behavior of six European Union (EU) reduced-activation ferritic/martensitic steels and F82H and JLF-1. Aging was for up to 13400 hours at 250, 350, 400, 450, and 550°C. The EU steels included steels with high carbon and nitrogen (LA12Ta), low C with (LA12TaLC) and without (LA12LC) tantalum and low nitrogen (LA12TaLN). There was also high (11%) chromium (LA4Ta) and high (3%) tungsten (LA13Ta).

There was little effect of aging on the yield stress of the F82H after aging 13400 h, but the reduction of area was significantly reduced above 400°C. The Charpy results for the EU steels indicated that there were chemical composition effects. For example, aging the high-tungsten steel to 10000 h at 350, 400, 450, and 550°C, resulted in a reduction of upper-shelf energy (USE) and an increase of transition temperature for the higher temperatures, which was associated with Laves phase. There were also indications of chromium effects, especially at 400°C aging, which may be due to chromium-rich α' formation. The F82H and JLF-1 showed a reduction in USE and an increase in transition temperature after thermal aging 13400 h at 550°C, but little effect after aging at 250, 350, 400, and 450°C. Laves phase formation may play a role in this behavior. Tensile, creep, and Charpy tests were also made on thermally aged F82H weldments produced by the TIG and electron beam (EB) processes. TIG welds, which were post-weld heat treated (PWHT), displayed a similar strength but a slightly lower ductility and USE compared to the base metal. In particular, some degradation of impact properties was found after aging at 550°C. However, the results for EB welds without a post-weld heat treatment still need to be compared with steels that have a PWHT to fully evaluate the properties of the EB weldments.

K. Shiba reported on the continued progress on the JAERI round robin tests that are generating a range of mechanical and physical properties data for the IEA heat of F82H. Mechanical property tests that have been made or that are in progress include hardness, tensile, Charpy impact, fatigue, fracture toughness, and creep. The range of physical properties include density, specific heat, thermal expansion, thermal and electrical conductivity, melting point, Young's modulus, Poisson's ratio, modulus of rigidity, and magnetic hysteresis. Other measurements include the determination of a continuous-cooling-transformation diagram, water corrosion, hydrogen permeability, and hydrogen cracking. Some of the mechanical property tests have also been conducted on aged steel and on weldments. Shiba presented recent tensile, Charpy, fatigue, and fracture toughness results on thermally aged and unaged F82H steel. Analysis of the extracted precipitates from the aged steel indicated a tendency toward the production of Laves phase for steel aged at 550, 600, and 650°C. Mechanical properties of the weldments were generally comparable to the base metal.

Fabrication of the blanket structure of a fusion power plant presents many difficulties, especially welding and joining, and A. Hishinuma presented information on a potential joining technique. Hot Isostatic Pressing (HIP) bonding is a potential technique for certain geometries. However, the optimum conditions for HIP bonding are 150 MPa at 1040°C for 2 h followed by tempering. Such a high temperature and long hold time can have negative effects on the properties due to austenite grain growth. Spark plasma sintering (SPS) bonding, which involves the formation of a plasma between the parts being joined, is being studied by JAERI as an alternative to HIP bonding. SPS conditions are 20-50 MPa at 800-900°C with hold times of 0.08-1 h. Excellent joints have been obtained with this technique; the joints are improvements over HIP-bonded material in metallographic appearance and strength.

Steel Properties—Irradiated

The status of the JAERI irradiation program on F82H was reviewed by K. Shiba. Irradiations are being carried out in the High Flux Isotope Reactor (HFIR) in the U.S./JAERI collaboration and in the Japan Materials Test Reactor (JMTR) and the Japan Research Reactor (JRR-2/JRR-3/JRR-4). Accelerator (dual/triple beam) irradiations are also being conducted. The program involves tensile, Charpy, and fracture toughness measurements and microstructural studies of the irradiated steel.

E. V. van Osch reported on results of work at ECN at Petten on post-irradiation properties of the IEA F82H plate and welds. Irradiation was in the High Flux Reactor (HFR) to 2-3 dpa and the testing (tensile, impact, and static fracture toughness) is in progress. A 65 kg heat of steel (ECN-BS) was obtained and irradiated with F82H. ECN-BS contained somewhat more Cr, C, and Ta and less B than the F82H. The ECN-BS steel showed improved Charpy properties over the F82H after irradiation to 2.5 dpa at 300°C. Comparison was made between EB and TIG weldments of the IEA F82H. Before irradiation, the EB welds had a higher strength and ductility; testing of the irradiated welds is in progress. Irradiations to 10 dpa at 300°C are in progress, with the testing to be performed under the next EU Framework Program (1999-2002). The F82H is included in this experiment, but emphasis of this framework program will be on the new EUROFER steels. This experiment will also include work on B-doped steels to investigate the effect of helium on properties, to investigate the distribution of the boron in the steel, and to measure the helium content.

The Japanese universities (Monbusho) program on the properties of irradiated reduced-activation ferritic steels for fusion reactors was reviewed by A. Kohyama. Most of this work was on the JLF-1. The first irradiations were carried out in FFTF. The results included: tensile studies conducted on steels irradiated to 60 dpa at 365-600°C, swelling data obtained after irradiation to 70 dpa at 420°C, ΔDBTT (change in ductile-brittle transition temperature) data obtained from irradiations to 50°C at ≈400°C, and pressurized-tube irradiation creep tests for specimens irradiated to 35 dpa at 520°C. Current work involves experiments in HFIR, JOYO, and JMTR. At present a dual-beam ion-irradiation facility (DuET) is being constructed at Kyoto University that will be used for future in-beam studies. The facility is expected to begin operation in FY 1999.

Another Monbusho effort is the Ferritic Isotopic Tailoring (FIST) experiment in which isotopic-tailored F82H disks were irradiated in HFIR to simulate the fusion environment effects of producing hydrogen and helium in the steel. Preliminary results from TEM and shear-punch tests have been obtained and are being evaluated.

The effect of tantalum in the ORNL 9Cr-2WVTa steel on Charpy and tensile properties after irradiation was discussed by R. L. Klueh. The steel has excellent strength and impact toughness before and after irradiation in the Fast Flux Test Facility (FFTF) and the High Flux Reactor (HFR). The ductile-brittle transition temperature (DBTT) increased only 32°C after 28 dpa at 365°C in FFTF, compared to a shift of ≈60°C for a 9Cr-2WV steel—the same as the 9Cr-2WVTa steel but without tantalum. This difference occurred despite the two steels having similar tensile properties before and after irradiation. The 9Cr-2WVTa steel has a smaller prior-austenite grain size, but otherwise microstructures are similar before irradiation and show similar changes during irradiation. The irradiation behavior of the 9Cr-2WVTa steel differs from the 9Cr-2WV steel and other similar steels in two ways: (1) the shift in DBTT of the 9Cr-2WVTa steel irradiated in FFTF does not saturate with fluence by ≈28 dpa, whereas for the 9Cr-2WV steel and most similar steels, saturation occurs by <10 dpa, and (2) the shift in DBTT for 9Cr-2WVTa steel irradiated in FFTF and HFR increased with irradiation temperature, whereas it decreased for the 9Cr-2WV steel, as it does for most similar steels. The improved properties of the 9Cr-2WVTa steel and the differences with other steels were attributed to tantalum in solution and the loss of that tantalum during irradiation by precipitation. The precipitation still needs to be confirmed.

ODS Steels and Alloy Development

B. van der Schaaf reviewed the possibility of oxide dispersion-strengthened (ODS) steels for fusion applications. These steels contain a high number density of (TiO_2 or Y_2O_3) oxide particles that provide enhanced creep strength. One problem with the conventional and reduced-activation ferritic/martensitic steels being investigated for fusion is that the upper operating temperature will be limited to ≈550°C, and this limits the systems in which they can be used (e.g. water-cooled system). ODS steels with their improved creep properties offer the possibility of extending that temperature to 600°C and higher. Because they are strengthened by a high number density of small oxide particles, the oxide particles could provide sites for defect recombination and helium trapping and thus reduce swelling and suppress helium bubble effects. Most of the prior work on these materials for nuclear applications were for fuel canning for fast breeder reactors. The results for that application indicated significant improvement in creep strength over conventional steels with the helium effects suppressed. The major problems involved the anisotropy due to the powder metallurgy fabrication techniques used to make the tubes. There is limited experience on thick-wall parts, and although reduced-activation ODS steels are being developed, there is as yet no literature information available on them.

Van der Schaaf concluded that the ODS reduced-activation steels being developed show considerable promise that indicates they could, if developed, extend operating temperatures above 600°C (assuming creep controls and not corrosion) and reduce helium effects. However, the fabrication route needs to be developed for the larger sections needed in a fusion reactor blanket. Joining may present some difficulty and should be addressed early in the development stage.

Work on the development of ODS steels was described by A. Alamo. The high-chromium ferritic steels (MA 956 and MA 957) had elongated grains (recrystallized grain size d>1 mm, recrystallization temperature >1300°C) with a high texture, anisotropic properties, and low ductility. The creep and aging behavior of these steels was studied. The MA 957 with an optimized grain size showed excellent creep resistance at 650°C relative to a 15-15 austenitic stainless steel, especially for longer rupture times (>10^4). Precipitation of intermetallic phases (χ, Laves, and α' phases) was detected in the thermal aging studies and irradiation experiments.

The development of a 9Cr ODS steel which can transform to martensite is being pursued. The objective is to avoid intermetallic phase precipitation and reduce the anisotropy of the properties compared to the fully ferritic materials. 9Cr-Mo and 9Cr-W steels containing Y_2O_3 are being examined. These steels developed an eqiaxed grain structure when normalized and tempered, and there was no grain growth in the range 1000-1250°C. The yield stress for each of these steels was higher than that for MA 957 with a somewhat reduced, but still high, reduction of area. This development study is continuing.

A. Hishinuma reported on the JAERI efforts to produce an ODS reduced-activation ferritic/ martensitic steel. The compositions that have been investigated were variations on the F82H with 8% Cr, 0-1.75% W, 0.1-0.28% Ti, 0.15% O, 0.1-0.23% Y, 0.12% C. The manufacturing process involved mechanical alloying the powders followed by hot extrusion at 1050°C to fabricate the steel, after which it was normalized and tempered. Microstructures have been produced that have a fine-grain structure that appears relatively equiaxed. Excellent Charpy and tensile properties were obtained from several of the experimental steels. The compositional variations indicated that the tensile properties depended on the Y_2O_3 and tungsten content, but much less on the titanium content.

G. R. Odette discussed the recent review of the fusion materials program in the U.S. by The Fusion Energy Systems Advisory Committee of which Odette was a member. They recommended that the fusion materials program seek to integrate modeling, experiment, and data-base development to develop advanced materials for fusion. This means bringing more modeling into the materials program, as the committee viewed the program as being deficient in this area. Odette feels that one area where such an approach can be applied is the study of fracture of fusion reactor components. Since fracture behavior of irradiated materials is of critical importance for fusion, micromechanical-based local fracture models need to be applied with small specimen measurement of fracture resistance on unirradiated and irradiated material to provide the resultant properties necessary to predict limits for fusion structures. These results need to be further combined with microstructure-property models that reflect the effect of alloy composition, processing variables, and irradiation. The implementation of such an integrated approach was discussed in terms of work being conducted at the University of California at Santa Barbara. As one example, work on reactor pressure vessel embrittlement was cited and discussed.

Helium Effects Studies

Electron microscopy studies of the reduced-activation ferritic/martensitic steels IEA F82H and OPTIMAX A were discussed by R. Schaüblin. The F82H was irradiated to 0.5 and 1.7 dpa with 590 MeV protons at PSI in Switzerland, and F82H and OPTIMAX A were irradiated to 2.5 dpa at 250°C in HFR in Petten. The dislocation structure, carbide composition and size distribution, and grain/lath boundary chemistry of the F82H irradiated with protons were determined for the unirradiated (before and after tensile deformation) and irradiated steels. The results for the proton irradiation of the IEA F82H generally indicated that there was essentially no difference in the microstructural defects in the as-received (unirradiated), deformed (material taken outside the necked region), and irradiated conditions. The $M_{23}C_6$ particles, which constituted the majority of the precipitate, were found to be coherent with the matrix. Chromium enrichment at prior austenite grain boundaries was detected for the normalized-and-tempered steel, but after irradiation, chromium depletion was observed.

Neutron irradiation of OPTIMAX A at 250°C produced no defects, but faceted cavities were observed. For the F82H, on the other hand, no cavities were present, but black dot (loops) damage was observed.

Helium effects studies using boron-doped F82H steel irradiated in HFIR and JMTR were reported by K. Shiba. Standard F82H, which contains a small amount of natural boron, F82H to which natural boron was added, and F82H to which ^{10}B was added were compared. The ^{10}B is transmuted to helium; natural boron contains ≈20% ^{10}B. Irradiation in HFIR at 300-500°C up to ≈30 dpa produced very little effect on the tensile properties (yield stress and total elongation). Tensile specimens irradiated in JMTR to 0.7 dpa and 120 appm He for the ^{10}B-doped steel had little effect on the yield stress, but there was an indication of a slight reduction in total elongation and reduction of area. Although the standard F82H and the F82H containing the ^{10}B addition had similar Charpy impact properties in the unirradiated condition, irradiation to 0.2-0.6 dpa at 250-350°C in JMTR produced a much larger shift in the Charpy transition temperature for the ^{10}B-doped (≈100 appm He) steel. At temperatures above ≈400°C, there was only a small difference in the Charpy behavior of the steels with and without ^{10}B. Microstructural examination of steels irradiated to 57 dpa in HFIR indicated 2 x 10^{21} m^{-3} (3 nm) cavities present in the ^{10}B-doped steel but none in the non-doped steel.

E. Matera-Morris reported on the effect of helium on steels after dual-beam irradiation and neutron irradiation in the HFR. MANET I hardened more than the F82H did during dual-beam irradiation to 0.3 dpa and 500 appm He. For irradiations in HFR at 300°C, a larger shift in Charpy transition temperature was observed for MANET I and OPTIFER II than for the ORNL 9Cr-2WVTa and F82H. Dual-beam irradiation of the F82H to 0.8 dpa and 300 appm He at 250°C produced a larger shift in the transition temperature than for a similar irradiation in HFR. The excess shift was attributed to helium. Likewise, to explain the relative Charpy transition temperature behavior of MANET I, OPTIFER II, F82H, and 9Cr-2WVTa (listed in order of decreasing transition temperature shift) after irradiation in HFR, the results were correlated with ^{10}B content, which transmuted to helium, although it was stated that the helium contribution to the shift in transition temperature cannot be determined quantitatively because it is not possible to separate helium and alloying effects. Scanning electron microscopy observations of relative amounts of cleavage and intergranular fracture on the fracture surfaces were correlated with the Charpy results (change in transition temperature).

A. Kimura discussed a small punch test procedure used to evaluate the effect of helium on the DBTT of 9Cr-2W steels. Disk specimens 3-mm in diameter and 0.22-mm thick were irradiated in a 36 MeV α-particle beam from a cyclotron. An energy degrader was used to uniformly implant 120 and 580 appm He (0.048 and 0.23 dpa) in the disk. Irradiation was at <150°C. Hardness data were used to estimate a yield stress and yield stress increase ($\Delta\sigma_y$) during irradiation. Data from JMTR irradiations where no helium was present indicated that the shift in yield stress fit a $dpa^{1/4}$ law, which agreed with the results for the cyclotron-irradiated specimens, indicating no helium effect on hardening (just the effect of displacement damage). The data for the cyclotron-irradiated material fit the linear correlation between $\Delta\sigma_y$ and ΔDBTT obtained from the JMTR data, indicating that helium did not affect the shift in DBTT. From hardening changes during annealing, it was found that helium reduced the rate of recovery of the irradiation hardening, suggesting that helium stabilizes the defect clusters. TEM indicated that helium decreased the size of the clusters but increased the number density. In this experiment, irradiation to 0.23 dpa and 580 appm He at <150°C did not affect irradiation hardening and embrittlement.

E. V. van Osch reported on work being started to study the post-irradiation welding of helium-containing steel at ECN in Petten. Neutron irradiated F82H plates of 1, 3, and 5 mm thickness that were irradiated in HFR to 2 dpa (≈5 appm He) and some 1 mm plates that were irradiated to 2.5 dpa were available for the study. The irradiated 1, 3, and 5 mm plates were successfully TIG welded to unirradiated plates with no external defects detected by SEM. The 1 and 3 mm plates were welded in a single pass with no filler metal, and the 5 mm plate contained a Y-groove and was welded with 4-6 passes. Further inspection of the welds is planned. Heats of steel have been ordered with ^{10}B, ^{11}B, and natural boron, so that it will be possible to generate various amounts of helium up to 250 appm He and higher.

Strategy for the Development of Ferritic/Martensitic Steels for Fusion

Presentations were made on the strategy for the development of ferritic/martensitic steels in Japan, EU, and the U.S. by A. Hishinuma, B. van der Schaaf, and F. W. Wiffen, respectively. The stated goal of this session was the development of a united strategy that could be presented by representatives from the Working Group (van der Schaaf and Hishinuma) to an IEA panel that was meeting in Copenhagen the following week, 5-9 October 1998, to consider a coordinated strategy for fusion materials development.

The strategies for Japan and the EU are pointed toward a DEMO using a martensitic steel, and this gives rise to dates for selecting a given material for the construction of the plant. Japan has a potential date of 2015 for selecting a material for DEMO, and the EU has a date for a DEMO-relevant design by 2009 based on conventional-type ferritic/martensitic steels. Should ODS steels be successfully developed, the date for a DEMO-relevant design for this material would be 2015.

In contrast to Japan and the EU, the U.S. has no plans for a DEMO and instead is involved in a science-based approach in which the technical program will emphasize, "enabling technologies for plasma experiments, domestic and internationally." The materials work will be targeted at developing materials that will support economically attractive, environmentally attractive, and safe fusion energy source designs.

A. Kohyama presented some further views on the Japanese strategy. He expressed concern about what should be done beyond the work presently being carried on the large heats of the IEA F82H and JLF-1 that are being studied in the IEA collaboration. He emphasized the need for a clear strategy for ferritic/martensitic steel development to be presented to the fusion community.

The discussion on the strategies of the various programs indicated that at present it appears there are common features in the strategies of the three programs, starting with the need to coordinate the materials development with the design and engineering community. The question of whether ferromagnetic structural materials are acceptable for magnetically confined fusion still needs to be answered, as do questions on the effect of the simultaneous helium and displacement damage on properties (embrittlement). An expansion of the design window for ferritic/martensitic steels is desirable, and it is agreed that the ODS steels offer the best approach to achieve that goal by raising the operating temperature. This development needs to be pursued.

Other questions vital to the application of ferritic/martensitic steels to fusion include nuclear transmutations that will burn out elements of the steel (e.g., W, Ta, etc.), the effect of tungsten on the breeding ratio, compatibility issues and the need for barriers or other coatings for the steel. The urgent need for a 14 MeV neutron source was again emphasized.

Despite different objectives of the European Union, Japan, and the United States and given the time and financial constraints on the programs, the complexity of the common problems standing in the way of the three programs meeting their respective goals makes a coordinated effort of international collaboration by the three programs essential if their goals are to be achieved.

Action Items

No formal action items were set forth at this meeting. However, the following action item from the Tokyo meeting has not yet been completed:

Considerable work has now been completed on the IEA heats of ferritic/ martensitic steels. Compilations of the work on the IEA heat of F82H by the Japanese and European Union are being prepared by K. Shiba and R. Lindau, respectively, who will consult on an exchange of reports and a distribution of the reports to other members involved in the IEA collaboration. In the future, a report summarizing the work being carried out in the European Union, Japan, and the United States will be prepared.

K. Shiba has agreed to continue this cooperative effort with R. Lindau. In addition, E. van Osch has expressed his interest to Shiba in participating in the effort.

On an informal basis, the EU approached Shiba requesting the JAERI irradiation matrix for F82H, so they can avoid duplication in their program. Shiba has this information in his data base, but he also agreed to prepare a hard copy and distribute it.

Other Information

Although it was not discussed formally in the meeting, the EU has ordered a 4000 kg heat of EUROFER 97, the EU reduced-activation reference steel for DEMO. Delivery is expected in the spring of 1999. Most of the ingot will be processed into plate to be used for the EU testing program for wrought and weld products. Tens of meters of tubes will be produced that will be used for welding trials and component mock-ups. Welds for testing will be made by fusion and HIP processes. There will be a limited number of forged bars, some of which will be atomized for powder products that will be made by the HIP process for qualification of the process. There are plans to offer material to participants in the IEA program for evaluation.

Next Meeting

The next meeting of the Working Group will occur on one evening of the ICFRM-9 Conference in Colorado Springs, Colorado, USA, during the week of 10-15 October 1999. This meeting will serve as the planning meeting for the next workshop, which will be held in the fall of 2000.