ORNL/FTR--3782

DE91 002724

OAK RIDGE NATIONAL LABORATORY

OPERATED BY MARTIN MARIETTA ENERGY SYSTEMS INC
POST OFFICE BOX 2008, OAK RIDGE, TENNESSEE 37831-6285

ORNL

FOREIGN TRIP REPORT

ORNL/FTR-3782

DATE: November 1, 1990

SUBJECT: Team Trip Report of Foreign Travel of R. H. Jones, Pacific Northwest Laboratories; R. L. Klueh, Metals and Ceramics Division; B. A. Loomis, Argonne National Laboratory; A. F. Rowcliffe, Metals and Ceramics Division; and F. W. Wiffen, Office of Fusion Energy, DOE (on assignment from M&C Division, ORNL)

TO: Alvin W. Trivelpiece

FROM: A. F. Rowcliffe (Coordinator)

PURPOSE: To visit the Kernforschungszentrum (KfK) Karlsruhe and to participate in the International Energy Agency (IEA) Fusion Materials program review meetings; to present invited papers at the Leningrad Fusion Materials conference, and to conduct the U.S./USSR 1.5 Fusion Exchange meeting on the collaborative materials program.

SITES VISITED: In addition to the discussions noted above, visits were made by team members to institutes in the USSR and to the Harwell Laboratory in England. Individual itineraries are in Appendix A.

ABSTRACT: During his visit to the KfK, Karlsruhe, F. W. Wiffen attended the IEA 12th Working Group Meeting on Fusion Reactor Materials. Plans were made for a low-activation materials workshop at Culham, UK, for April 1991, a data base workshop in Europe for June 1991, and a molecular dynamics workshop in the United States in 1991. At the 11th IEA Executive Committee on Fusion Materials, discussions centered on the recent FPAC and Colombo panel review in the United States and EC, respectively. The Committee also reviewed recent progress toward a neutron source in the United States (CWDD) and in Japan (ESNIT). A meeting with D. R. Harries (consultant to J. Darvas) yielded a useful overview of the EC technology program for fusion. Of particular interest to the U.S. program is a strong effort on a conventional ferritic/martensitic steel for first wall/blanket operation beyond NET/ITER. Following

these discussions, a comprehensive review of the KfK fusion technology program was provided by KfK staff members.

The International Conference on Effects of Irradiation on Materials for Fusion Reactor Materials was attended by 320 participants from the USSR and 14 participants from other countries, including the U.S. team members. This meeting provided a comprehensive view of the breadth of the Soviet program, the complexity of its organization, and the internal competition between its various branches. Following these meetings, visits were made to various laboratory sites and major institutes in both the Leningrad and Moscow areas. There is a very strong commitment to the ITER project and in every Soviet organization there is a desire to work closely with Western countries coupled with a willingness to discuss fully and openly any aspects of their fusion materials program. Soviet capabilities and experience which are of interest to the U.S. materials program include: (a) in situ reactor measurements; (b) low-temperature (100 to 300°C) irradiation space in mixed-spectrum reactors; (c) in-reactor cryogenic testing at 77 K; (d) hydrogen permeation and embrittlement studies, including in-reactor measurements; (e) irradiation-enhanced corrosion and stress corrosion testing of irradiated materials; (f) development of copper alloys and Mo-Re alloys for divertor structures; (g) development of hydrogen and tritium barrier coatings; (h) development of barriers to inhibit liquid metal corrosion. Particularly impressive was the capability, within a single institute, of performing materials research and development, irradiation testing; commercial-scale alloy production/fabrication; and component design, testing and manufacture. In meetings at the Kurchatov Institute and the Baikov Institute in Moscow, details of the next phase of a collaborative U.S./USSR materials program were worked out and the text of a final document agreed upon. During the visit to the Harwell Laboratories (UK), it was learned that the Variable Energy Cyclotron materials irradiation facility is being permanently shut down for economic reasons.

COMPREHENSIVE TRIP REPORT

Purpose

This trip fulfilled several objectives related to the U.S. Fusion Materials program.

(a) Participation in the IEA Fusion Materials collaboration planning meeting at KfK Karlsruhe and discussions with senior European Community (EC) staff on the current status and future of the EC materials program (F. W. Wiffen).

(b) Presentation of papers at the First Leningrad International Conference on "Effects of Irradiation on Materials for Fusion Reactors" (R. H. Jones, R. L. Klueh, B. A. Loomis, A. F. Rowcliffe, and F. W. Wiffen).

(c) Visits in the USSR to gain information on materials programs at five different institutes.

(d) Participation in U.S./USSR Exchange meeting 1.5 to review progress and to redefine the collaborative materials research program.

(e) Discussions at AEA Harwell Laboratory on the utilization of the Variable Energy Cyclotron (VEC) facility for U.S. irradiation experiments on SiC composites (A. F. Rowcliffe).

Twelfth Working Group Meeting, IEA Fusion Materials Annex II, KfK, Karlsruhe, Germany

Attendee: F. W. Wiffen

This group met September 10 at KfK with the attendees and agenda shown in Appendix B. Past activities and recent workshops were reviewed. The group asked that action be taken to assure final reports on the Oak Ridge test matrix and on the BEATRIX-I program. Wiffen was asked to coordinate U.S. action to complete these two activities.

Brief reports were given on the June 1990 workshop on Radiation Effects in Ceramic Insulators, and on activities on neutron sources and on the data base; discussions on including the USSR in the data base activity were not conclusive.

Future activities include a workshop on low-activation materials (Culham, UK, April 8–12, 1991), a data base workshop (Europe, June 1991), and a molecular dynamics workshop in the United States in the first half of 1991. A workshop on small specimen test techniques was proposed by A. Hishinuma (JAERI), who will develop a detailed proposal for a 1991 meeting in Japan.

Wiffen was elected the new chairman of the Working Group. The group will next meet at Culham in April and/or Florida in November 1991.

Detailed minutes of this meeting will be issued by Hishinuma.

Eleventh Executive Committee Meeting on IEA Fusion Materials, KfK, Karlsruhe, Germany

Attendee: F. W. Wiffen

The Executive Committee and observers met September 11 at KfK; the attendees and the agenda are shown in Appendix C.

Discussions at this meeting centered on the recent program reviews in the United States (FPAC) and EC (Colombo panel) on progress toward an intense neutron source in the United States (CWDD) and Japan (ESNIT), and on inclusion of USSR representatives in various workshops and activities sponsored by this committee. Most discussions were for information, without conclusions being reached.

K. Ehrlich of KfK was elected the new chairman of the Executive Committee, and the next meeting will be in Florida in November 1991. Meeting minutes will be prepared by H. H. Yoshikawa of Westinghouse Hanford Company.

Discussions with Dr. D. R. Harries on the EC Fusion Program

Attendee: F. W. Wiffen

Don Harries serves as a part-time consultant to J. Darvas to coordinate parts of the EC Fusion program. He spent some time outlining the elements of the program he currently is involved with. There are three elements of the technology program.

1. NET Study ($120M for 1989–91) — Harries is not currently involved with this element, but served previously as manager of the technology unit. At that time (1984–1986), there was a specific focus on materials. The NET program organization has now shifted to providing coverage of materials issues mainly by the separate component development units, in part because of the shift of NET goals to short lifetime and low operating fluences. The reference structural material continues to be an austenitic stainless steel.

2. Blanket Study ($60M for 1989–91) — Harries has a separate role here, as a consultant to KfK. The program is described under KfK discussions. The structural material is restricted to martensitic steel.

3. <u>Long-Range Technology ($30M for 1989–91)</u> — There are four major items: (a) safety and environment ($4M); (b) 14-MeV neutron source ($5M); (c) martensitic steels ($15M), and (d) low-activation materials ($6M). Dr. Harries coordinates areas (c) and (d), but has no role in items (a) and (b). The work on martensitic steels focuses on the DIN 1.4914 steel (12 CrMoVNb) referred to as MANET. It involves a number of the EC laboratories and includes: (1) characterization of large heats and development of heat treatments; (2) advanced fabrication, especially welding technology; (3) corrosion, especially in water systems; (4) reactor irradiation and postirradiation examination — tensile, fracture toughness, fatigue, and fatigue crack growth work is included; (5) irradiation simulation using dual-ion beam bombardments; study of helium effects, tensile, creep and fatigue measurements; three laboratories participate, including KfK and KfA; (6) structural stability of welds, done at HMI; and (7) review areas, without experimental work, which include reweld of irradiated steel, corrosion in H_2O and other liquids, hydrogen effects, fabrication, and current status of cold work on high-chromium steels (to 15% Cr).

Studies in the blanket program on compatibility with Pb-17Li and development of tritium barriers are related.

Harries sees the critical issue as the increase in ductile-brittle transition temperature (DBTT) by irradiation, and potential control of this. He is interested in the Farrell-Mansur work interpreting the results on High Flux Isotope Reactor (HFIR) vessel steel embrittlement. He mentioned pursuing control of DBTT through inclusion shape control, and suggested the need for postirradiation annealing studies to evaluate the use of periodic in situ annealing of reactor components.

The major elements of the low activation materials ($6M for 1989–91) are: (1) criteria, (2) nuclear data base, (3) martensitic steels, (4) austenitic steels, (5) nonferrous alloys (vanadium base alloys), (6) advanced materials (SiC), and (7) high-purity material production.

The details will be presented in the IEA workshop on low activation materials next April. Many of these areas contain little work. Harries is pushing to set goals for any work planned, with carefully staged programs. He does not want to start irradiation tasks until adequate unirradiated work has been completed to justify continuation with the approach/material. Furthermore, he insists on irradiating only commercial or commercial-practice produced materials, not laboratory melts.

<u>The KfK Fusion Technology Program</u>

Attendee: F. W. Wiffen

Bob Price (DOE Washington) and Wiffen were given a presentation on the KfK Fusion Technology program that took most of September 12.

As part of the informal agenda, the U.S. Fusion Materials program was discussed by F. W. Wiffen. The KfK attendees are listed in Appendix D. Also included was a brief tour of the dual ion irradiation laboratory on Monday, September 10.

This program is run by a matrix management system, with Dr. J. E. Vetter in charge. Technical work is performed in the institutes with the appropriate equipment and experience.

The impression was obtained that the tasks are attacked thoroughly and in depth. The technical people do not have a view of a "big picture," or any evaluation of how fusion reactor design parameters may change in the future. Two examples illustrate this: For the martensitic steels they showed no interest in increasing creep strength and thus raising the upper temperature limit for use. For the vanadium alloys they have little interest in helium embrittlement, because they do not envision high-temperature use. In both cases, their argument is based on the temperature range of <u>today's</u> designs at KfK for NET/ITER test blanket modules.

Five elements of the KfK program were described to us. Additional details are available from F. W. Wiffen. The program elements are:

(a) Support of NET/ITER. Support is provided in magnetics (Nb_3Sn magnets), robotics and remote maintenance, fuel cycle (especially cryopumping), first wall (testing of prototype elements, including thermal cycling of graphite or other tiles on 316L prototype), divertor element (graphite/TZM/copper alloy test segments), and safety/environment. The KfK fraction of the total EC program ranges from about 50% of the EC magnet program down to about 10% of the safety/environment program.

(b) Blanket Program. This program in 1990 is funded at DM 20M (approximately $13M) and staffed by 56 scientists and engineers plus 20 technicians (this is about 35% of the EC Test Blanket program). The program goals are to design, construct, test, and deliver test blanket modules to ITER (or NET) for the engineering phase of ITER. They also mentioned blankets for "long term," but there seems to be no effort directed beyond ITER.

Two parallel efforts are included, equally funded. The solid breeder design uses Li_4SiO_4 (backup is Li_2ZrO_3) pellets (0.5 mm diam) in a pebble-bed system. Large beryllium slabs provide neutron multiplication, and all structures are martensitic steel. Helium coolant flows through the first wall, then back through the pebble bed. Neutron wall loadings of 2 MW/m^2 can be accommodated. Helium at 80 bars enters at 250°C and exits at 400°C. The liquid-metal, self-cooled blanket design uses the Pb-17Li eutectic. It can operate without beryllium if both inboard and outboard blankets are included, or use a multiplier with only an outboard blanket. A NaK circuit is also used for a batch process to recover tritium in a cold trap getter. The structure of this blanket design is also martensitic steel.

A number of planned or ongoing experiments support these design efforts. Materials questions under study include the irradiation effects on the properties of beryllium, properties of the ceramic breeders (including irradiation experiments), and the development of insulators for reduction of magnetohydrodynamics (MHD) effects.

(c) Tritium Technology. A range of subjects are under study, including recovery of tritium from Li_4SiO_4, study of tritium handling/processing systems for NET/ITER, alternate storage/getter bed materials (interest in a ZrCo alloy), and tritium and impurity analysis techniques.

(d) 14-MeV Neutron Source. S. Cierjacks is studying a potential neutron source for an irradiation effects facility. A tritium beam on a water jet would produce neutrons without a high-energy tail and with less beam energy to dissipate than the d-Li source commonly proposed. He proposes a 21-MeV, 250-mA beam to drive the reaction $^1H(^3T,n)^3He$ for 14-MeV neutrons with few or no neutrons at higher energies. A 10-L volume of usable space with flux above 1×10^{14} neutrons/$cm^2 \cdot s$ and usable volume at 1×10^{15} neutrons/$cm^2 \cdot s$ is claimed.

The accelerator parameters are simply lifted from other concepts. An obvious drawback is the tritium accelerator and tritium-contaminated system.

(e) Materials Program. Work is on martensitic steels and low activation alloys. The martensitic steel work is directed at optimizing a 9- to 12-Cr steel, starting from the DIN 1.4914 steel. This is seen as the leading candidate for demonstration and commercial reactors, as KfK does not believe austenitic steels will have adequate lifetime (due to swelling and helium embrittlement). Work includes characterization, heat treatment, corrosion in Pb-17Li, and mechanical properties. They also supply material to other EC laboratories, and could probably supply material to the United States, if requested.

The elements of the low-activation materials program are activation calculations, iron alloys, and vanadium alloys. The calculations focus on sequential reactions previously ignored, and may be important with low-Z elements. For example, silicon is claimed to be worse than previously calculated, and worse than iron at times somewhat beyond 100 years. For iron alloys, the emphasis is balancing good yield strength and good fracture toughness. A 12-Cr alloy, with 1% W plus Ce and Ta additions, shows promise. With vanadium alloys, KfK will start with the V–3Ti–1Si and V–5Cr alloys which they worked on 20 years ago, with initial attention on fracture toughness, including irradiation effects. (It is not clear when they will start the vanadium alloy work; they are reluctant to start an underfunded program.)

The KfK has a dual-ion irradiation laboratory, which we toured. Two cyclotrons are used, focused into a target chamber. A 104-MeV alpha beam is used for helium implantation, after passing through two graphite wedges that degrade the beam for uniform helium concentrations in the test specimen. Displacement damage is produced by protons, with available energy range of 10 to 40 MeV. Quoted displacement rates were 10^{-7} to 10^{-5} dpa/s, yielding about 2 dpa per week. The facility is available to the fusion program about 800 h per year.

Emphasis is on the martensitic steel DIN 1.4914 (MANET) and derivative versions of it. The facility has been used to irradiate hollow, round tubular fatigue specimens for postirradiation testing. They are now completing development of facilities for in-beam fatigue testing. This uses a square cross-section hollow tubular specimen. It is irradiated parallel to a diagonal, to get near-uniform damage and helium concentrations. Wall thickness is such that the 45° distance through two walls is less than the 1.3-mm stopping distance of the proton beam. Induction heating, beam heating, and helium cooling set temperatures are measured by infrared (IR) pyrometers and thermocouples. Strain is measured from knife edges machined on the specimen or by an induction strain gage. Loading seemed to be MTS-type. A control test that demonstrated multiple crack initiation on at least three points on the specimen gage section was displayed.

Central Research Institute of Structural Materials, "Prometey," Leningrad, USSR

Attendees: R. H. Jones, R. L. Klueh, B. A. Loomis, A. F. Rowcliffe, and F. W. Wiffen

Prior to the opening of the conference, the members of the U.S. team were invited to the Prometey Headquarters in the Alexander Nevsky Monastery for a courtesy visit. The host for this meeting was Academician I. V. Gorynin, Director of the Institute. The Director described the Institute as having 3000 people working in some 16 laboratories. The Institute began as a small laboratory to improve military tanks and armor and claims credit for the outstanding performance of the World War II T-34 tank. Most of the current work is related to civilian and military power plants with responsibility for non-core materials. Materials and technologies are developed to the point of transfer to manufacturing industries. They now come under the Ministry of Shipbuilding. Approximately 1% of their total effort is related to fusion with emphasis on structural materials for first wall and blanket (FWB) and for divertors and passive stabilizing elements for ITER. Gorynin considers it unnecessary for the USSR to press forward rapidly with fusion, particularly in the face of public fear of nuclear energy and funding shortages resulting from the economic crisis. Apparently, there are changes being made in the funding system with the Institutes supported by the Academy of Sciences. In the future they will have greater financial control independent of the ministries.

International Conference on the Effects of Irradiation on Materials for Fusion Reactors, M. Gorky Academy of Sciences, Leningrad

Attendees: R. H. Jones, R. L. Klueh, B. A. Loomis, A. F. Rowcliffe, and F. W. Wiffen

This was the first Soviet conference devoted entirely to fusion materials; it is planned to hold future meetings on a two-year cycle. The conference was attended by 320 participants from the USSR, and only 14 foreign attendees (5 USA, 5 FRG, 4 Italy). Fifty-one Soviet organizations were represented; five academicians, and two ministry officials at the rank of department chief attended. A detailed program may be obtained from any U.S. team member. There was no serious attempt by session chairmen to restrict speakers or discussions to the allotted time so that it became necessary to rearrange the conference program at least once each day. As a result, not all of the papers in the program were presented. Even with the simultaneous English translation, it was difficult to extract much useful information from the Soviet presentations. Many of the Soviet speakers took the opportunity to deliver a lengthy review lecture on their topic while presenting very little new data.

The opening plenary sessions contained Soviet presentations dealing with the current status of fusion research in the USSR. Academician N. P. Liyakishev (Baikov Institute-Moscow) berated the materials science community for their timidity and lack of stubbornness in insisting upon a stronger leadership role in world fusion programs. The enormous disparity in funding between military programs and R&D will have to change if world energy shortages are to be avoided. The development of fusion will require iron optimism coupled with iron intelligence. He stressed the need for a more aggressive approach to composite materials for the long term and pointed out the importance of Soviet advances in impurity control in steel technology in regard to reducing activation.

Prof. V. V. Orlov (Nikiet, Moscow) considered that the combination of Chernobyl and the deep economic crisis has plunged power engineering into a long period of stagnation. The conversion to a market economy coupled with elimination of the current inefficiencies and waste in the power industries should result in an excess of oil and gas. At present, building up power engineering is not an urgent problem and there is no expectation of a near-term demand for any type of nuclear energy. However, nuclear power will eventually have to be widely deployed. The USSR must exclude Chernobyl-type fission designs and begin by re-examining the LMFBR with its advantages of inherent safety, simple design and control, and breeding ability. He does not consider a sodium coolant as viable for safety reasons. It is important to share the USSR experience with lead coolants which reduces the risks of fire or explosion in the event of an accident. He claimed that their Navy program has been successful in developing oxide films for corrosion protection and MHD insulation and that these results are available to the USSR fusion program work on Pb-17Li coolant blanket concepts. To achieve ecological balance, it should be possible to burn actinides in a fast reactor and convert the waste to the biological hazard level of natural uranium. After a period of aboveground storage, the fission wastes could be returned to the excavated ore deposits from which they originated.

V. A. Chuyanov (Kurchatov Institute) summarized the status of ITER/OTR. He pointed out that the only advantage of fusion over fission is the absence of fission products and it is essential to ensure that the activation problems are much less than the actinide problems. He had some sharp words for materials scientists who focus on their own scientific interests rather than on the needs of fusion engineering projects.

In the ensuing technical sessions, V. V. Rybin (Prometey) presented an overview of the status of structural materials for ITER. During the talk, data were presented on atom probe analysis of Mo-Re alloys which showed rhenium enrichment at the grain boundaries to be three times above that of the bulk concentration. The improved toughness of this alloy was attributed to this rhenium enrichment. The enrichment was about 2 atom layers thick, similar to that of monolayer-equilibrium segregation seen for impurities in metals.

L. I. Ivanov (Baikov Institute) noted that the Soviets now have their own nuclear cross-section data base for activation calculations. Their low-activation Cr-Mn austenitic steels, even with 2 to 4 wt % Ni to stabilize the austenite, still have a two to three orders of magnitude advantage over conventional steels in terms of long-term induced radioactivity. There is extensive commercial experience in the USSR in fabrication, welding, and behavior in aqueous environments for these steels. The USSR also has the technology for controlling impurities in large heats of steel within the very low levels required for activation control. During his lengthy talk, he raised the issue of enhanced deformation in the ITER FWB due to the effect of pulsing on transient irradiation creep. He also pointed out that current irradiation experiments with vanadium alloys do not address the question of transmutation-generated hydrogen, and its possible effect on mechanical properties. He also mentioned work of the Baikov Institute which has shown some beneficial effects of scandium additions on the irradiation behavior of stainless steel.

S. A. Fabritsiev (Prometey) is carrying out studies of thermal shock effects in stainless steel containing helium bubbles and on high-temperature helium embrittlement in both cyclotron and neutron irradiated materials. This work is directed toward the effect of temperature excursions following loss of coolant on the subsequent mechanical behavior of FWB materials. He presented a helium embrittlement model, supported by microstructural evidence involving hardening through bubble nucleation at dislocation nodes coupled with the accumulation of helium at the intersection of slip bands with grain boundaries.

There appears to be much less work on ferritic steels in the USSR than there is in the rest of the world — at least it was not displayed at this conference. Ferritic steels were discussed by Soviet authors in several theoretical papers and as a secondary material in experimental papers dealing primarily with austenitic steels. Work on ferritic steel was presented by A. Moslang, KfK, West Germany; he looked at the effect of helium on strength and fatigue life by irradiating in a dual beam facility to inject alpha particles to obtain the helium and protons to create the damage. Results indicated a hardening due to the helium at temperatures below ~400°C, with a slight softening at higher temperatures. This agrees with observations on hardening during neutron irradiation. The conclusion that helium affects hardening agrees with work at ORNL that indicated that helium has a strengthening effect, in addition to the strengthening caused by displacement damage. The paper by Gondi et al. (University of Rome) examined recovery processes in cold-worked 316L and a 12-Cr ferritic (martensitic) steel (MANET) to look for a possible correlation between recovery of strain and swelling resistance. It was concluded that the good swelling resistance of the martensitic steel may involve the formation of chromium-rich α' precipitates and an accompanying chromium-depleted zone, which act as sinks.

V. R. Barabash (Efremov Institute, Leningrad) and V. V. Rybin (Prometey) presented papers dealing with the Soviet program on copper alloys for divertor structural applications. The copper program involves close collaboration between the Efremov Institute of Electro-Physical Apparatus, the Central Research Institute of Structural Materials, Prometey (V. V. Rybin, S. A. Fabrietsiev), and the Institute of Atomic Reactors, Dmitrovgrad. Conventional copper alloys are produced and fabricated by the Institute of Copper, Moscow. The production of Cu-Mo alloys by physical vapor deposition is carried out at the Institute of Electron Welding, Kiev. This effort, led jointly by Efremov and Prometey Institutes, appears to be the main thrust of the Soviet program on copper alloys. Alloys currently under investigation include unalloyed copper, Cu—0.6Cr, Cu—2Be—0.04Ni, Cu—0.5Cr—0.2Zr—0.06Mg, Cu—0.5Cr—0.1Zr, Cu—0.2Al, Cu—0.2Zr, and Cu—5Mo. Alumina dispersion-strengthened alloys are also being studied; these are referred to as the MAGT series of alloys. MAGT 0.2 contains 0.2 vol % Al_2O_3 and MAGT 0.5 contains 0.5 vol % Al_2O_3. These alloys are doped with 0.01 Hf, and 0.03 to 0.08 Ti; the oxide particles contain both hafnium and titanium. In addition to ion-irradiation studies, these alloys are being irradiated in the SM-2 mixed-spectrum reactor at 100, 300, and 400°C and in the BOR-60 fast reactor at 350 to 400°C. Data were presented on solid solution and precipitation-strengthened alloys following irradiation at 300 and 400°C to 1.0 dpa in SM-2. A copy of a paper containing this information was provided to U.S. team members. It is planned to continue these irradiations in SM-2 to 35 dpa and to include postirradiation fatigue and corrosion measurements. In the technology area, work is in progress on the joining of copper alloy tubing to a manifold, the testing of brazed components, and the irradiation response of brazes. The Cu-Mo alloys can be fabricated into 5-mm-thick plates via physical vapor deposition. The MAGT alloys ($Cu-Al_2O_3$) have been fabricated into tubing 20 mm diam and 3 m long.

In the area of vanadium alloys, the paper by S. N. Votinov (Baikov Institute) fell victim to the program restructuring; this work was presented to the U.S. team at the subsequent meeting in Troitsk (see below). Discussions with conference participants revealed that a significant effort on the physico-mechanical properties of vanadium alloys was being conducted at the G.V. Karpenko Physicomechanical Institute, Academy of Sciences of the Ukranian SSR, Lvov. The scientists primarily involved in this effort seem to be E. M. Lyutyi and V. V. Shirokov. Some research programs being conducted by these individuals are:

1. elevated-temperature creep of vanadium and vanadium-base alloys,
2. influence of heat treatment on the stress-rupture strength of vanadium alloys,
3. increasing the oxidation resistance of vanadium by siliciding,
4. effect of heat treatment on the creep rate of vanadium alloys,
5. effect of alloying of vanadium on its compatibility with liquid lithium.

T. A. Burtseva et al. (Efremov RIEPA, Leningrad, Kurchatov IAE, Moscow) presented data on dimensional changes in carbon fiber reinforced SiC composites as a function of carbon content, irradiation temperature, and heat treatment. With increasing irradiation temperature, the slope of the length change versus carbon content plot changed from negative to positive. Length change decreased or increased with fluence depending upon the final heat treatment temperature.

A. G. Zuluzhi et al. (MIFI, Kurchatov IAE, Moscow) presented data on the hydrogen permeation in iron and nickel polycrystals during ion irradiation. Data for nickel were presented for two damage rates corresponding to beam currents of 150 $\mu A/m^2$ and 7200 $\mu A/m^2$. The permeation rate was higher at the higher damage rate and in addition a sharp transient in permeation occurred at the higher damage rate. For polycrystalline iron, data were presented for ion irradiation and also for simultaneous helium and ion irradiation. Ion irradiation alone increased the permeation rate. However, the permeation rate was strongly reduced when helium was co-implanted. These results are similar to those reported by Polosuhin et al. at the Alushta meeting, where they noted a factor of 10 increase in the permeation of hydrogen during neutron irradiation of austenitic stainless steels. The mechanism for this increase is apparently enhanced diffusivity; however, the mechanism for enhanced diffusivity of an interstitial element was not explained by these authors in their paper or during personal discussion.

In general, low-activation alloys, which are receiving considerable attention in the United States and Europe, were not given much attention at the meeting. One paper appeared on the schedule for reduced-activation steels; and in the end, that paper was not delivered due to scheduling problems.

One important area the Soviets are addressing that appears to be receiving less attention in the United States is the technological aspects of fabricating a fusion reactor. Papers were presented on potential metallurgical problems on manufacturing components of a fusion reactor, including the structural steel for superconducting magnetic systems and the fabrication of heat exchangers. Several papers addressed welding problems, including the welding of irradiated materials. Brazing of fusion reactor components was also considered in one paper and another looked at the failure of brazed graphite coatings. Considerable work also appears to be in progress on thermal fatigue. Although these papers considered these various areas, because the slides were in Russian, it was sometimes difficult to determine how much of these papers represented new experimental work or simply constituted a review of previous work, perhaps in other technological areas.

V. A. Chuyanov (Kurchatov Institute) had some critical comments regarding the need for a 14-MeV neutron source following the presentation by R. H. Jones (PNL) on this topic. His perception was that the 14-MeV source would be extremely expensive and could only be accomplished on a time scale similar to ITER. He felt that building a 14-MeV source would lessen the U.S. commitment to the ITER technology phase. He feared that the United States would argue that the 14-MeV source meets all the needs for irradiation testing for fusion. Chuyanov believes that a great deal of materials irradiation work can be done in the ITER technology phase. However, he appears not to have a firm grasp of why the 14-MeV source is essential to fusion materials development.

During the post-conference summary session Prof. V. V. Rybin concluded that the most significant results presented at the Conference were (a) systematic low-temperature neutron irradiation studies on FWB materials for ITER, (b) neutron irradiation data on the relationship between fluence and properties of high-strength copper alloys, (c) mechanical property data on Mo-Re ranging from 0 to 47% Re at 100 to 800°C, and (d) initiation of new studies on non-metallic materials. He pointed out the lack of data for all ITER structural materials on fracture toughness, creep rates, and performance of welds and brazes. There was a strong sentiment expressed by several USSR speakers of the urgency of placing highest priority on the ITER-related materials problems.

A list of presentations by U.S. team members is presented in Appendix E.

<u>Laboratories of The Central Research Institute of Structural Materials, Prometey, Gatchina, USSR</u>

Attendees: R. H. Jones, R. L. Klueh, B. A. Loomis, A. F. Rowcliffe, and F. W. Wiffen

Our team was only the second group of Western scientists to visit this facility, which is a major hot-cell laboratory. This was a military installation which has conducted research on armor materials, pressure vessel materials, etc., for military applications.

The hot cells technology appeared to be similar to that used in the United States during the mid-1960s; the facilities have been very well maintained with excellent housekeeping. Two back-to-back rows of six cells each are served by a central remote distribution system. One receiving and one distribution cell are located at one end of the cell bank, all operated at 20 mm negative pressure. The main function of the cells is to investigate radiation effects in reactor pressure vessel steels. The equipment contained in the cells includes the following: disassembly equipment (saw, lathe, milling machine), electrodischarge machine (EDM), metallographic preparation, optical microscope, shadowgraph, density measurements (tensiles), tensile testing in air and vacuum, low-cycle fatigue from RT to 300°C, full-sized noninstrumented Charpy impact testing, and fracture toughness testing on 25-mm-thick plate. In-cell capability also includes static corrosion, weight loss measurements, and low strain rate testing in autoclaves. A new facility under construction will permit low-cycle fatigue measurements in water, Pb-Li, or hydrogen environments.

The corrosion group is led by Dr. Nikishina, who has considerable experience with in-reactor corrosion and stress corrosion testing. It appeared that C-rings were used for the in-reactor stress corrosion testing with postirradiation examination for weight loss and metallographic examination for cracking.

Facilities for scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are located in the same building as the hot cells. For TEM a new Philips EM400 with LINK equipment for microanalysis is set up to allow examination of radioactive specimens measuring 1 rem/h contact dose rate, which is their limit for out-of-cell handling. At this laboratory, they have developed a technique for producing electron-transparent regions at the center of a 3-mm-diam disk, removing the thinned region, and transferring it to the TEM on grids. This technique reduces operator exposure, lowers the gamma dose to the EDS detectors, and reduces astigmatism problems with magnetic materials. The Soviets would not divulge the methods used; this would be a valuable technique for the United States to obtain in return for information on some of our postirradiation measurement techniques (profilometry, densitometry, miniaturized tensile, etc.). For SEM, they have a CAMSCAN/LINK system which is partially shielded to allow examination of irradiated materials.

The entire hot cell complex and microscope facilities are certainly comparable to those in the United States and are well maintained and very productive.

During our visit, microscopy was in progress on the Cu—5Mo alloy being studied for possible application as divertor structural material. This alloy had been bombarded with argon ions to 70 dpa at 350°C; TEM foils were prepared from the mid-range region. The molybdenum particles undergo a shape change during irradiation and small cavities develop at the incoherent particle-matrix interface and nowhere else in the matrix. Similar irradiations on Cu-Cr-Mg induce recovery of the cold-worked and aged dislocation structure at 350°C, dissolution of chromium particles, and precipitation of Cu_2Mg. This work is being carried out by Barabash (Efremov) in conjunction with microscopists from Prometey. These alloys are also being neutron irradiated for creep and thermal fatigue studies.

USSR-USA Workshop on Structural Materials for Fusion, Kurchatov Institute, Troitsk, Moscow, USSR

Attendees: R. H. Jones, R. L. Klueh, B. A. Loomis, A. F. Rowcliffe, and F. W. Wiffen

This was a two-day meeting at which both sides reviewed current programs on FWB materials. The program and list of USSR attendees are presented in Appendices F and G. During his opening remarks, Prof. L. Ivanov (Baikov Institute) discussed the way in which fusion materials research is currently organized in the USSR. There are clearly two different branches of the fusion reactor materials programs in the USSR. A rivalry exists between the two groups, and offers of collaboration from each group tried to exclude participation by the other group.

The National Program, funded and managed through the Academy of Sciences and the State Committee on Science and Technology, includes the Baikov, Kharkov, and Dimitrovgrad groups that we have worked with in the past. Their programs have a strong focus on the manganese steels with a lower level of work on copper and vanadium alloys. The Academy of Sciences has a special fund for basic research in structural materials headed by Academicians Gorynin and Liyakishev.

Program 15 of the Ministry of Atomic Energy under Prof. Velikoff contains a large component on structural materials for fusion. This work appears to be restricted to ITER-relevant activities and includes the divertor structural materials work at Efremov and Prometey and the blanket structural materials work at the Institute of Power Engineering and other laboratories. The activities of this group are more closely focused, and they presented more data and less planning in their talks. The program on copper alloys seems to be well-directed at ITER applications, and appears to complement the U.S. program.

We were not able to identify all of the connections and interdependencies between the two groups, but they appeared to be complex. The United States will have to be careful to get cooperation from all of the USSR Fusion Materials programs, and avoid being trapped in the interests of only one group or subgroup.

The Soviets could not define how many people they have working on all aspects of fusion materials, but there appears to be of the order of 50 people at U.S. PhD level working at each of the Baikov, Prometey, Kharkov, and Efremov Institutes. In addition, there are an unknown number of people working in at least ten other laboratories such as Dmitrovgrad, Institute of Power Engineering, and the Central Research Institute for Technology of Machinery (CNIITMASH).

Dr. E. V. Diomina (Baikov Institute) presented a summary of current Soviet work on low-activation manganese-stabilized stainless steels, starting off with a review of some of their experience obtained over the last 20 years on which these steels have been worked on. They presently use these materials in various applications, including the wall for the TSP tokamak, at Troitsk. They also showed a fully austenitic hexagonal tube (1-mm thick by 50-mm ID) that they had fabricated by extrusion. Melting of up to 3-ton heats is carried out at Krasnask, Siberia, using super-pure iron produced by direct reduction from the ore. In a collaboration with Bulgarian steelmakers, they are able to make 10-ton melts using special techniques to control the release of manganese vapor to the environment. Diomina discussed current work on their 10Kh 12G 20V steel (Fe–12Cr–20Mn–1W–0.1C), a similar composition containing nitrogen, and on EP-838. Studies include weldability, aqueous corrosion, fracture toughness, lithium corrosion, and hydrogen permeability. Data on lithium corrosion studies at 450°C were presented for 12Cr-20Mn, 12Cr–15Mo–4Ni, and 13Cr–20Mn–0.15N.

While the nitrogen-stabilized steel exhibited the lowest corrosion rate of these steels, it had a significant drop in the ductility after corrosion testing. The formation of a Li_9CrN_5 phase along the grain boundaries was suggested as the cause of the decreased ductility.

Measurement of hydrogen permeability in the range 400 to 900°C on steels with a chemically etched surface showed that permeability depended upon composition and decreased in the order EP-838 > 10Kh 12G 20V > PCMA 21; the latter composition is the U.S. alloy which we shipped to the Baikov Institute in August 1989. Ongoing studies with the U.S. steel also include BOR-60 irradiation experiments, lithium compatibility, and corrosion resistance in aqueous environments.

Following this presentation, Prof. V. V. Rybin presented some information on the parallel program at Prometey. They have fabricated 16 melts of Cr-Mn steels with variations in Cr, Mn, C, N, and W. They also have 6 melts of reduced-activation ferritic steels with 9- to 12-Cr strengthened with tungsten and vanadium. Microstructural studies and mechanical property measurements have been carried out and irradiation experiments are about to start. Dr. V. Voevodin (Kharkov) presented a summary of his work on manganese-stabilized steels. They have ongoing irradiation studies in BOR-60 in collaboration with Dmitrovgrad. He reported on 3-MeV heavy ion irradiations of EP-838, annealed (SA) and cold worked (CW) with three different levels of pre-implanted helium. In the absence of helium, ~15% swelling occurred at 550°C and 100 dpa. Incubation doses were ~30 dpa for CW and ~40 dpa for SA materials. Voids do not occur near grain boundaries because of the formation of segregation-induced bcc α-iron at the boundaries.

A summary of research on vanadium alloys was presented by S. Votinov (Baikov Institute of Metallurgy). Vanadium alloys that have received the most attention are V–10Ti, V–35Ti, V–30Ti–1Zr–0.3C, V–20Ti–10Cr–1Si, and V–(5–8)Cr–0.6Zr–0.2C. These alloys contained 100 ppm O, 150 ppm N, and 100 ppm C. (This concentration of interstitial impurities in the alloys is significantly less than the interstitial concentration in the U.S. alloys.) These alloys were prepared from 3-kg melts, hot forged at 1200°C, warm rolled at 600 to 700°C, and then cold worked and annealed at 1000°C for 1 h in a vacuum of ~10^{-6} torr. Alloys were selected for irradiation on the basis of their relatively low weight change on exposure to liquid sodium and lithium. The alloys were encapsulated in lithium and irradiated in the BOR-60 reactor to a neutron fluence of 1.35×10^{23} n/cm^2.

These data may be compromised by the operating history of the experiment. Possibly because of a failure of the temperature control instrumentation, the experiment ran for the initial one-third (358 days) of its time at 740 to 830°C and the remaining 890 days at 350 to 400°C. The maximum swelling observed under these conditions was only 0.2%. Alloys containing chromium exhibited a significant reduction in total elongation in postirradiation tensile tests. On the basis of this limited reactor experience, this program has identified a leading alloy composition for further development containing V–10Ti–5Cr–(0.0–1.0)Zr–(0.2–0.3)C. Fabrication of 20-kg heats into various product forms is in progress. The United States preference is to use as low as possible titanium concentration for minimum tritium inventory while retaining adequate swelling resistance.

In a follow-up discussion, Prof. L. Ivanov (Baikov Institute) provided some additional information on their vanadium work. Their activation calculations for vanadium alloys subjected to ITER neutron spectrum indicate that on the basis of allowed biological dose from gamma activation, only the V-Ti system is acceptable. They find that vanadium-titanium alloys decompose under irradiation via a eutectoid reaction which is not present in thermal equilibrium phase diagrams. This transformation has also been observed in thermal aging studies carried out in Germany which indicate that the current phase diagram for this system may not be correct. Prof. Ivanov stated that as far as producing 300 to 400 tons of vanadium for a blanket structure, the USSR has the technology for producing very pure vanadium and ample supplies of raw materials including at least three ore bodies and a very high concentration in the Caspian Sea.

Although not on the original program, V. Shamardin (Dmitrovgrad) presented details of a planned irradiation program on copper alloys that appears to be in competition with the Efremov-Prometey alliance. The compositions being studied include Cu-Cr, Cu-Be, Cu-Cr-Zr-Mg, Cu-Cr-Zr, Cu-Al, Cu-Mo, Cu-Al_2O_3, and Cu-Y_2O_3. Irradiations are to be carried out in SM-2 at 100 and 300°C and in BOR-60 at 350 and 500°C. Postirradiation aqueous corrosion measurements are planned on Cu-Cr-Zr-Mg and on Cu-Al_2O_3. They are also planning to do in-reactor creep measurements in a flux of 6×10^{17} n/m^2/s at 200 to 300°C in the small pool-type reactor RBT-6. Maximum neutron fluxes in several research reactors are as follows:

	SM-2	PBT-6	PBT-10	BOR-60
Power, MW	100	6	10	50
Thermal flux, n/m^2/s	5×10^{19}	1.4×10^{18}	7.4×10^{17}	--
Fast flux, n/m^2/s	2×10^{19}	6.1×10^{17}	2.9×10^{17}	2.5×10^{19}
Availability, h/year	6400	4800	4800	7000

Dr. Shamardin stated that the USA manganese-stabilized steel is currently being irradiated in SM-2 and will remain in-reactor until the planned shutdown in May 1991 for a major reconstruction which is expected to take one year.

Following the meeting, the U.S. team visited the TSP tokamak at the Troitsk site. TSP is currently pumping to achieve vacuum after an extended shutdown to repair a hole in the vacuum liner. The liner is a manganese-stabilized austenitic stainless steel and the hole resulted from an arc outside the vacuum chamber. The failure was weld repaired using remote or semiremote techniques. The TF coils of TSP are pure copper outboard and Cu-Cr-Zr inboard in the 23 T region. The inboard coil support structure is a gamma-prime dispersion-hardened iron-based alloy, containing 16Mn4Cr(NiMoV). We were told that TSP will be run with D-T to ignition conditions in about five years.

<u>US/USSR Exchange I.5 Meeting on Fusion Reactor Materials, Baikov Institute of Metallurgy, Moscow, USSR</u>

Attendees: R. H. Jones, R. L. Klueh, B. A. Loomis, A. F. Rowcliffe, and F. W. Wiffen

After reviewing some of the information exchanged during the previous two days at Troitsk, there was a 3-h discussion about the future directions of the U.S./USSR collaborative program. The afternoons of September 26 and 27 were spent in developing and revising the text of an agreement on a collaborative program. This text is presented in Appendix H. It was agreed to continue with the current experimental program on manganese-stabilized steels and to review composition limits for reduced-activation steels in November 1991 using guidelines from the IEA Culham workshop. It was also agreed to defer any joint action on reduced-activation ferritics until after the Culham meeting and to discuss a basis for a collaborative program at the November 1991 meeting in the United States. Any further discussion on dielectric and electrical insulating materials was also deferred until the November 1991 meeting. On vanadium alloys, it was agreed to exchange materials. The USSR alloy will be included in U.S. mechanical property and lithium corrosion measurements; TEM disks will be irradiated in FFTF/MOTA. The U.S. alloys will be included in Soviet thermal creep tests at temperatures up to 750°C, neutron irradiations in the temperature range 100 to 300°C, and in welding studies. All three sets of experiments will provide important information in support of the U.S. program.

The agreement regarding copper alloys represents a new commitment for both sides. Firstly, it was agreed to exchange quantities of two U.S. GLIDCOP alloy compositions for the USSR-developed Cu-Mo and Cu-Al_2O_3 alloys. After some internal debate on the USSR side, it was agreed that the Efremov Institute (V. P. Barabash) in Leningrad would be the point of contact for this part of the exchange, rather than the Baikov Institute. ORNL (S. J. Zinkle) will organize this exchange on the U.S. side. It was agreed that each side will form a group of three or four specialists to begin immediate planning for a joint irradiation experiment on copper alloys in SM-2. A meeting of the two teams will be necessary early in 1991 if the experiment is to be ready for insertion when SM-2 goes back on line in 1992. The USSR have some serious rivalries to contend with between the liaison represented by L. Ivanov (Baikov) and V. R. Shamardin (Dmitrovgrad) on the one hand and the Efremov Institute (V. R. Barabush)-Prometey Institute (V. V. Rybin) group on the other. It appears that the latter group does not work with Shamardin's people to design, build, and irradiate capsules in SM-2. During the meeting, Shamardin made a heated statement to the effect that all copper irradiations should be done through his group.

On the topic of providing the USSR with information on the design of equipment for postirradiation testing, it was agreed to demonstrate U.S. capabilities during the 1991 USSR team visit. Details of U.S. techniques may, however, be provided at any time in exchange for details of USSR experimental methods.

Professor Ivanov expressed his concerns in summary discussions that the collaboration needs to grow. He pushed hard to specify the details for exchanging scientists between the two countries, and would like to initiate them as soon as possible. He is particularly anxious for young scientists to pursue doctoral studies abroad. He also requested publication of the proceedings of the exchange meetings on the U.S./USSR collaboration, as a book, the start of a new journal, or a bulletin. Ivanov also requested that we provide the USSR with more definitive plans on the experimental work on exchanged alloys. The U.S. response was that we would continue to try to identify U.S. scientists for exchange, and to identify appropriate projects and review the rules governing Soviet scientists working at U.S. laboratories. We did not agree with the need for a new publication of fusion materials experimental results, but reiterated that we must receive copies of USSR material presented at our exchanges. The request for more detailed plans for work on exchanged alloys was not resolved.

Research and Manufacturing Corporation of Technology for Machinery (CNIITMASH), Moscow

Attendees: R. H. Jones, B. A. Loomis, A. F. Rowcliffe, and F. W. Wiffen

This is a large integrated organization that comes under the Ministry of Heavy Machine Building. It employs 7500 people, with 3500 in the Moscow area and has an annual budget of >100 million roubles. The various departments deal with research and development, machinery/component design, steelmaking, and fabrication and construction of industrial products. We were hosted by V. P. Borisov, the Deputy Director General, together with 12 heads of various departments involved in materials research, development, and production. Materials R&D is carried out for hydroelectric power plants, thermal power plants, gas turbine blades and disks, pressure vessel steels for 1000-MW nuclear reactors, steam generators, and heat exchangers. Other parts of the organization design and build machines for power engineering. The steel technology department has major facilities at Ijora. (There has been a manufacturing plant here since Peter the Great.) In addition to steel manufacturing, Ijora produces a wide range of equipment including fission reactor components and bulldozers. For the oil industry, they are producing the reactors for their new high-temperature (500°C) hydraulic cracking process at 200 atm. Steel melting for research applications ranges from a few kilograms up to 5 tons, including vacuum induction melting, electron beam melting, and electroslag remelting. They have large departments dealing with centrifugal casting, forging, pressing, stamping, heat treating (dies, gears), welding (including production of cored wires), and nondestructive testing. This organization produces the equipment for the annealing of reactor pressure vessels, and for the remote welding of irradiated materials. Materials testing capability runs the full gamut including the ability to do fracture toughness testing on full-size components. Fatigue, corrosion fatigue, and stress corrosion testing (uniaxial, biaxial, and autoclave) capability also exists.

Materials development for nuclear applications includes boron-doped steels for spent fission fuel storage, high-strength dispersion-strengthened steels for fusion magnet structures, and 9-Cr ferritic/martensitic steels for fission reactor ducts. Design work on the USSR ITER first wall and blanket is coupled with the ability to produce small segments of conceptual designs and to carry out engineering and performance testing, including irradiation of blanket segments in SM-2. One of their designs incorporates a new blanket stainless steel containing 9% Ni and 3% Mn hardened by nitrogen. At 600°C, this steel has twice the yield stress of AISI 316, the current prime candidate. Irradiation testing on this steel is in progress at Dmitrovgrad, Obninsk, and Kharkov. Two other candidate steel compositions for ITER are (a) 16.2Cr-9.1Ni-2.0Mo-0.5Si-1.8Mn-0.04C-0.03P-0.025S (Prometey), (b) 16.2Cr-10.2Ni-2.2Mo-0.55Si-1.4Mn-0.03C-0.03P-0.025S-0.36Ti (CNIITMASH). The brazing treatment developed for their pipe-in-box geometry for the ITER blanket is at 1100°C; the inner walls of the coolant pipes are protected from flux gases during the cycle.

In their work on reduced-activation ferritic steels, V. N. Skorobogatykh said they had great difficulty in thick-section welding of steels containing >1% W. They have been working on the 8- to 13-Cr steels for over 15 years and presented data on ductile-brittle transition temperature (DBTT) shift induced by neutron irradiation at 200°C in SM-2. For a steel containing 8Cr-1Mo-(0.08–0.11)C strengthened with Nb and V, the DBTT (measured at 50% upper-shelf energy) increased from ~0 to ~+240°C following irradiation to 6 × 10^{25} n/m^2. They found that fracture properties could be greatly improved by subjecting the same steel to electroslag remelting to reduce impurities. In this case, the corresponding DBTTs were –60°C and +60°C.

This kind of integrated organization has no counterpart in the United States and obviously has a lot to offer the international fusion program in terms of materials development, irradiation testing, materials engineering, and the technology of component fabrication and testing. CNIITMASH staff expressed a willingness to enter into agreements with the United States to produce steels and other materials in any product form and specification range. They have a foreign trade firm, CNIITMASHEXPORT, licensed to enter into agreements for services with Western countries.

Research and Development Institute of Power Engineering Design (RDIPE), Moscow, USSR

Attendees: R. H. Jones, B. A. Loomis

Under the directorship of Prof. E. O. Adamov, this Institute is the primary nuclear design center for the USSR ITER activity. A full description of the organization and function of this Institute was submitted recently to the ITER Newsletter. (A copy of this writeup is available from U.S. team members.) The program for this visit and list of attendees are given in Appendix I. Of particular interest to the materials community is the work under the direction of Dr. G. M. Kalinin which includes Pb-17Li corrosion studies, effects of radiation on the permeation of tritium and helium, radiation embrittlement by helium and by hydrogen, development of hydrogen- and tritium-barrier coatings, radiation studies on beryllium, and radiation damage studies on vanadium alloys. Reactor irradiations are carried out at the Dmitrovgrad reactors and also in BR-600 at Sverdlosk which has a fast neutron flux of 5 × 10^{18} n/m^2/s. In-reactor testing capabilities include mechanical testing at 0.1 to 15 MPa, thermal cycling with Δt = 500°C, cryogenic irradiations at –196°C, elevated temperature irradiations 200 to 1500°C, and hydrogen permeability testing. A summary of hydrogen permeability of austenitic steels under neutron irradiation was given by A. P. Zyryanov.

In-reactor hydrogen permeability experiments in an 18Cr-10Ni austenitic steel with titanium additions were described. The test is conducted by pressurizing the external side of a tube with hydrogen gas mixed with 10 ppm O_2. The pressure was less than 0.7 MPa while gamma heating was used for heating the sample over a temperature range of 350 to 800°C. No explanation of the method for monitoring the permeation in-reactor was given. It is possible that they merely measured the pressure increase in the sealed tube following irradiation; however, this experiment would be difficult to interpret because of the increasing internal pressure. Alternatively, they may have had a gas line exiting the reactor to measure the hydrogen generation dynamically. The irradiations were carried out at a flux of 1.5×10^{14} n/cm^2/s to a fluence of 3×10^{20} n/cm^2/s.

Results were given for irradiated and unirradiated permeability versus 1/T, which demonstrated that the results obeyed an Arrnehius behavior. The activation energies for permeation and diffusivity changed from 68.8 kJ/mol to 41.6 kJ/mol and 55.9 kJ/mol to 22.6 kJ/mol, respectively, with irradiation. Increases of more than a factor of 10 in the hydrogen diffusivity and slightly less for permeation are induced by irradiation. Results were also reported for a 16Cr–11Ni-3Ti austenitic steel which exhibited activation energies for unirradiated and irradiated hydrogen permeation of 65.1 and 60.1 kJ/mol, respectively. The addition of titanium and presumably the presence of TiC reduces the effect of irradiation on hydrogen permeation. Particles such as TiC are known to be strong hydrogen traps in materials.

The obvious significance of this work is the impact of hydrogen transport through first wall and blanket structures. Since hydrogen-induced crack growth rate is also a function of diffusivity and permeation rates, it is possible that irradiation will enhance hydrogen-induced crack growth rates to values which are significant. The mechanism by which radiation induces this enhanced permeation was not given in the presentation or during private discussions. During neutron irradiation, gamma irradiation could accelerate the hydrogen adsorption rate by dissociating the hydrogen molecule. However, results presented at the Leningrad meeting by A. G. Zaluzhyi of Kurchatov IAE Moscow for ion-irradiated iron and nickel suggest that the enhanced permeation is associated with displacement processes within the material. So a radiation-enhanced diffisivity mechanism is the most likely explanation. The solubility apparently decreased with irradiation since the diffusivity increased more than the permeation (Permeation = Solubility × Diffusivity). However, radiation defects, especially dislocations, should trap hydrogen and at least initially increase the apparent solubility. This Institute is not involved in the current U.S.-USSR collaborative program on structural materials; staff members expressed an enthusiastic desire to enter into collaborative programs with the United States on an overwhelming range of topics.

AEA Thermal Reactor Services, Harwell Laboratory, UK

Attendee: A. F. Rowcliffe

The purpose of this visit was to make arrangements for the irradiation of SiC/SiC composite materials with 100-MeV carbon ions at temperatures up to 1000°C using the Variable Energy Cyclotron (VEC) facility at Harwell. The possibility of ORNL buying beam time on this facility had been under discussion with Dr. T. M. Williams since March 1990. However, while the traveler was in the USSR, a decision was taken to close the facility. The loss of this important facility is a direct result of dismantling the Atomic Energy Authority into nine so-called businesses operating on six of the UKAEA sites. Each director controls a site and essentially rents buildings and facilities to the various businesses (thermal reactor services, fast reactor services, fusion reactor services, full services, environmental, petroleum). Each business sells its skills in its particular area of expertise to any potential buyers it can find worldwide. There is a corporate levy on income to provide a minimal level of long-term research. The VEC was closed down because it was not making a profit for the thermal reactor services business which could no longer pay the running costs. At the time of shutdown, Dr. Williams was in the process of negotiating contracts with Toshiba, Hitachi, and Tokyo Electric Power in excess of $500K per year for accelerator services. These companies are interested in the effects of lifetime displacement damage levels ($\sim 10^{27}$ n/m^2) on grain boundary segregation and susceptibility to stress corrosion cracking in stainless steels used for thermal reactor core internals. AEA Thermal Reactor Services are looking at the possibilities of transferring some of their target facilities to the tandem accelerator at Harwell. The strong Japanese interest in this field may be an opportunity for M&C Division to utilize its capabilities in this area.

The traveler met with C. A. English and W. Phythian. In collaboration with A. E. Foreman, this group is vigorously pursuing the application of molecular dynamics calculations in radiation effects modeling. Recent impressive results include: (a) excellent agreement between molecular dynamics-based predictions and observation of a twinning transformation in 4-nm-diam coherent bcc copper precipitates in model Fe—1.3Cu alloys (this information is related to radiation embrittlement of pressure vessel steels) and (b) development of a personal computer-based model which displays the dynamics of cascade annealing in crystals containing defects (loops, voids) as a function of PKA energy. The Harwell group's developments in molecular dynamics calculations appear to be expanding a powerful approach to looking at a wide range of radiation damage problems that are fundamental to understanding radiation damage in fusion and fission environments.

APPENDIX A

Itineraries

1990

R. H. Jones

9/12	Travel from Richland, WA, to Minneapolis, MN
9/13–14	Attend Division of Materials Science, Office of Basic Energy Sciences, USDOE Corrosion Contractors meeting
9/14–15	Travel from Minneapolis, MN, to Leningrad, USSR
9/16	Weekend in Leningrad, USSR
9/17	U.S. team meeting and discussion meeting with Academician I. V. Gorynin, Director, CRISM Prometey
9/18–20	Conference on the Effects of Irradiation on Materials for Fusion Reactors
9/21	Discussion Meeting with CRISM Prometey Fusion Materials staff, Gatchina Laboratory
9/22	Weekend in Leningrad
9/23	Travel from Leningrad to Moscow, USSR
9/24–25	U.S./USSR Fusion Exchange I.5, Fusion Reactor Materials, Kurchatov Institute, Troitsk, USSR
9/26	U.S./USSR Exchange Program on Fusion Reactor Materials, Kurchatov Institute, Baikov, Moscow
9/27	Discussion meeting with staff of Research and Manufacturing Corporation of Technology for Machinery – CNIITMASH, Moscow, USSR
9/28	Travel from Moscow, USSR, to Richland, WA

R. L. Klueh

9/14–15	Travel from Knoxville, TN, to Leningrad, USSR
9/16	Weekend in Leningrad, USSR
9/17	U.S. team meeting and discussion meeting with Academician I. V. Gorynin, Director, CRISM Prometey
9/18–20	Conference on the Effects of Irradiation on Materials for Fusion Reactors
9/21	Discussion meeting with CRISM Prometey Fusion Materials staff, Gatchina Laboratory
9/22	Weekend in Leningrad
9/23	Travel from Leningrad to Moscow, USSR
9/24–25	US/USSR Fusion Exchange I.5, Fusion Reactor Materials, Kurchatov Institute, Troitsk, USSR
9/26	US/USSR Exchange Program on Fusion Reactor Materials, Baikov Institute, Moscow, USSR
9/27	Discussion meeting with staff of Research and Manufacturing Corporation of Technology for Machinery – CNIITMASH, Moscow, USSR
9/27	Travel from Moscow, USSR, to Knoxville, TN

B. A. Loomis

9/14–15	Travel from Chicago, IL, to Leningrad, USSR
9/16	Weekend in Leningrad, USSR
9/17	U.S. team meeting and discussion meeting with Academician I. V. Gorynin, Director, CRISM Prometey
9/18–20	Conference on the Effects of Irradiation on Materials for Fusion Reactors
9/21	Discussion meeting with CRISM Prometey Fusion Materials staff at Gatchina Laboratory
9/22	Weekend in Leningrad
9/23	Travel from Leningrad to Moscow, USSR
9/24–25	US/USSR Fusion Exchange I.5, Fusion Reactor Materials, Kurchatov Institute, Troitsk, USSR
9/26	US/USSR Fusion Exchange I.5, Fusion Reactor Materials, Kurchatov Institute, Baikov, Moscow
9/27	Discussion Meeting with staff of Research and Manufacturing Corporation of Technology for Machinery – CNIITMASH, Moscow, USSR
9/27	Discussion meeting with staff of Research and Development Institute of Power Engineering, Moscow, USSR
9/28	Travel from Moscow, USSR, to Argonne, IL

A. F. Rowcliffe

9/14–15	Travel from Oak Ridge, TN, to Leningrad, USSR
9/16	Weekend in Leningrad, USSR
9/17	U.S. team meeting and discussion meeting with Academician I. V. Gorynin, Director, CRISM Prometey
9/18–20	Conference on the Effects of Irradiation on Materials for Fusion Reactors
9/21	Discussion meeting with CRISM Prometey Fusion Materials Staff at Gatchina Laboratory
9/22	Weekend in Leningrad
9/23	Travel from Leningrad to Moscow, USSR
9/24–25	US/USSR Fusion Exchange I.5, Fusion Reactor Materials, Kurchatov Institute, Troitsk, USSR
9/26	US/USSR Exchange Program on Fusion Reactor Materials, Baikov Institute, Moscow, USSR
9/27	Discussion meeting with staff of Research and Manufacturing Corporation of Technology for Machinery – CNIITMASH, Moscow, USSR
9/27	Travel from Moscow, USSR, to Harwell, UK
9/28	Discussions on utilization of ion irradiation facilities, UKAEA, Harwell, UK
9/29–30	Weekend
10/1–2	Vacation
10/3	Travel from London, England, to Oak Ridge, TN

F. W. Wiffen

9/7–8	Travel from Gaithersburg, MD, to Karlsruhe, Germany
9/9	Weekend in Karlsruhe
9/10	IEA Fusion Materials — Meeting of Annex II Working Group
9/11	IEA Fusion Materials — Meeting of Executive Committee
9/12	Discussion meeting with KfK Fusion Program staff
9/13	Travel from Karlsruhe to Frankfurt, Germany
9/14	Desk work in Frankfurt
9/15	Travel from Frankfurt, Germany, to Leningrad, USSR
9/16	Weekend in Leningrad
9/17	U.S. team meeting and discussion meeting with Academician I. V. Gorynin, Director, CRISM Prometey
9/18–20	Conference on the Effects of Irradiation on Materials for Fusion Reactors
9/21	Discussion Meeting with CRISM Prometey Fusion Materials staff at CRISM Gatchina Laboratory
9/22	Weekend in Leningrad
9/23	Travel from Leningrad to Moscow, USSR
9/24–25	US/USSR Fusion Exchange I.5, Fusion Reactor Materials, Kurchatov Institute, Troitsk, USSR
9/26	US/USSR Exchange Program on Fusion Reactor Materials, Baikov Institute, Moscow, USSR
9/27	Discussion meeting with staff of Research and Manufacturing Corporation of Technology for Machinery – CNIITMASH, Moscow, USSR
9/28	Travel from Moscow, USSR, to Gaithersburg, MD

APPENDIX B

TENTATIVE AGENDA FOR 12TH WORKING GROUP ANNEX II MEETING

Karlsruhe, FRG

September 10, 1990

9:00 pm

1. Approval of the Agenda
2. Minutes of the Last Meeting
3. Follow-Up Joint Experiments
   3.1 BEATRIX I and Oak Ridge Test Matrix
4. Workshop Activities
   4.1 Ceramic — Report of the Workshop Held at Los Alamos
   4.2 Intense Neutron Source — Current Status and Future Activity
   4.3 Data Base — Progress of Data Base Activity
   4.4 Low-Activation Materials — Future Activity
   4.5 Molecular Dynamics — Current Status and Future Activity
5. New Activities
   5.1 Small Specimens Test Techniques
   5.2 Others
6. Reviewing of Annex II Relative to the Amendment of the Implementing Agreement
7. Next Chairman
8. Time and Place of Next Meeting

Attendees

Working Group Members

A. Hishinuma, JAERI, Japan (Chair)
G. Phillips, AECL-CRNL, Canada
P. Schiller, Ispra, Italy
M. Victoria, PSI, Switzerland
F. W. Wiffen, OFE-DOE, USA

Other Attendees

T. Kondo, JAERI, Japan
K. Ehrlich, KfK, Germany
D. R. Harries, EC Consultant, UK
R. E. Price, OFE-DOE, USA
T. C. Reuther, ORNL, USA
E. Yamada, IEA, Paris
H. H. Yoshikawa, WHC, USA

APPENDIX C

AGENDA

11TH EXECUTIVE COMMITTEE MEETING

Karlsruhe, FRG

September 11, 1990

1. Agenda
2. Minutes 10th Executive Committee Meeting
3. Review U.S. Fusion Policy Advisory Committee Report and EC Fusion Review
4. Implementation Progress FPCC Endorsed SAP Recommendations
   - A. Common Program
   - B. Hi-Energy, Hi-Flux Neutron Source Development
5. Annex II
   - A. Working Group Program Report
   - B. Annex Extension
   - C. Low-Activation Materials
   - D BEATRIX I and Oak Ridge Matrix
   - E. Ceramics
   - F. Data Base
   - G. Molecular Dynamics
6. Annex III
   - A. Working Group Progress Report
7. Proposal for Outside Participation
8. U.S. Program Review
9. Proposed Plans for Coordination of Materials R&D in Support of ITER
10. New Business
11. Election of New Chairman
12. Date and Place for Next Meeting

Attendees

Working Group Members

M. Victoria, PSI, Switzerland
K. Ehrlich, KfK, Germany
T. Kondo, JAERI, Japan
G. Phillips, AECL-CRNL, Canada
R. E. Price, OFE-DOE, USA

Committee Secretary

H. H. Yoshikawa, WHC, USA

Other Attendees

J. Darvas, EC, Brussells
A. Hishinuma, JAERI, Japan
T. C. Reuther, ORNL, USA
F. W. Wiffen, OFE-DOE, USA
E. Yamada, IEA, Paris

Part-Time Attendees

K. Anderko, KfK, Germany
D. R. Harries, EC Consultant, UK

APPENDIX D

Discussion of the KfK Fusion Technology Program

Karlsruhe, FRG

September 12, 1990

List of Attendees

USDOE Office of Fusion Energy
- R. E. Price
- F. W. Wiffen

KfK
- J. E. Vetter, Head, Fusion Program
- H. Sebening, Deputy Head, Fusion Program and Leader of Blanket Program
- K. Anderko, Director, IMF (II), KfK
- K. Ehrlich, Head, Materials Program, INF, KfK
- S. Cierjacks, Neutronics Calculations, Neutron Source
- R.-D. Pienzhoru, Tritium Technology
  Ion Beam Irradiations

APPENDIX E

Presentations Made by U.S. Team Members

International Conference on the Effects of Irradiation on Materials for Fusion Reactors, Leningrad, USSR

"High Dose Irradiation Behavior of Copper and Its Alloys," F. A. Garner (PNL) and S. J. Zinkle (ORNL); presented by F. W. Wiffen

"Effects of Helium on the Mechanical Properties of Neutron-Irradiated Cr-Mo Ferritic Steels," R. L. Klueh (ORNL)

"Irradiated Assisted Stress Corrosion Cracking of Fission Reactor Materials," R. H. Jones, S. M. Bruemmer, and E. P. Simonen (PNL)

"Swelling and Tensile Properties of Neutron-Irradiated Vanadium Alloys," B. A. Loomis and D. L. Smith (ANL)

"Property Changes in Austenitic Stainless Steels Irradiated in a Spectrally Tailored Reactor Experiment," A. F. Rowcliffe, M. L. Grossbeck, and P. J. Maziasz (ORNL)

"Damage Parameters for Candidate Fusion Materials Irradiation Test Facilities," D. G. Doran, F. A. Mann, and L. R. Greenwood (PNL); presented by R. H. Jones

US/USSR Fusion Exchange I.5, Fusion Reactor Materials, Kurchatov Institute, Troitsk, USSR

"Fusion Materials Research at PNL," R. H. Jones

"Summary of the ORNL Program on Fusion Reactor Materials," A. F. Rowcliffe

"The U.S. Fusion Reactor Materials Program," F. W. Wiffen

APPENDIX F

PROGRAM

USSR-USA WORKSHOP ON STRUCTURAL MATERIALS FOR FUSION REACTOR MATERIALS
September 24-25, 1990

Kurchatov Institute of Atomic Energy, Troitsk, USSR — September 24

10:00 am	Beginning of the Meeting — presentations of: E. Azizov, Head of Department, Kurchatov Institute of Atomic Energy F. Wiffen, Head of U.S. delegation, DOE, USA Prof. L. I. Ivanov, Head of Laboratory, Baikov Institute of Metallurgy
11:00	The Report of the Soviet Delegation about Works on Low-Activated Steels E. Diomina, Baikov Institute of Metallurgy
11:30	COFFEE BREAK
12:00	The Report of the American Delegation about Works on Low-Activation Steels R. Klueh, Oak Ridge National Laboratory
12:30	The Report about USSR/USA Collaboration on Plasma-Facing Materials A. Zakharov, Institute of Physical Chemistry
13:00	LUNCH
15:00	The Report of the Soviet Delegation about Imitation Researchs of Phase Stability of Chromium-Manganese Steels V. Voevodin, Kharkov Institute of Physics Technology
15:30	The Report of American Delegation F. W. Wiffen, The U.S. Program R. Jones, Program at PNL A. Rowcliffe, Program at ORNL
16:00	COFFEE BREAK
16:30	Discussion on Topics Reported
18:00	The End of First Day of Meeting

Kurchatov Institute of Atomic Energy, Troitsk, USSR — September 25

10:00 am	The Report of the Soviet Delegation about Works on Vanadium-Based Alloys S. Votinov, Baikov Institute of Metallurgy
10:30	The Report of the American Delegation about Works on Vanadium-Based Alloys B. Loomis, Argonne National Laboratory
11:00	The Report About the Researchs of Radiation Resistance of Carbon/Graphite Materials and Pirolitic Boron Nitride O. Buzginski, Kharkov Institute of Atomic Energy (Troitsk)
11:30	COFFEE BREAK
12:00	Discussion on Topics Reported
13:00	LUNCH
15:00	Visit to Laboratories of Kurchatov Institute of Atomic Energy (Troitsk) S. Mirnov, Kurchatov Institute of Atomic Energy
18:00	The End of Second Day of Meeting

APPENDIX G

LIST OF PARTICIPANTS OF SOVIET-AMERICAN WORKSHOP ON FUSION REACTOR MATERIALS

Baikov Institute of Metallurgy, Moscow

Prof. L. I. Ivanov, Head of Laboratory
Prof. S. N. Votinov, Head of Laboratory
Ju. M. Platov
E. V. Demina
A. P. Komissarov
I. L. Pojmenov
N. A. Litvinova
V. T. Zabolotny

The Kurchatov Institute Branch; Institute

V. E. Chercovez, Vice-Director
E. A. Azizov, Head of Department
O. I. Buzinskyi, Head of Laboratory
S. V. Mirnov, Head of Laboratory
K. H. Jusupov
I. V. Opimach
A. N. Trachenkov
V. G. Otrochenko

The Kurchatov Institute of Atomic Energy, Moscow

M. I. Guseva, Head of Laboratory
I. V. Altovskij, Head of Laboratory
G. A. Eliseev

The Institute of Physical Chemistry of Academy of Science

A. P. Zacharov, Head of Laboratory
V. M. Sharapov

Physical and Technical Institute, Kharkov

V. N. Voevodin

Institute of Atomic Reactors, Dmitrovgrad

V.K. Shamardin, Head of Laboratory

Institute of Electronic Industry, Moscow

Prof. G. G. Bondarenko

Moscow Engineering Physical Institute, Moscow

L. B. Begrambekov, docent

Tomsk Polytechnical Institute

V. V. Lopatin, Head of Laboratory

Institute "Graphite"

Ju.S. Vergiljev, Head of Laboratory
E. N. Kurolenkin

Firm "Red Star"

V. A. Evtichin, Head of Department

Institute of Geological and Analytical Chemistry

V. P. Kolotov, Head of Laboratory

Central Scientific Institute, Prometey

V. V. Rybin, Head of Department

Atomic Energy Department, USSR

N. S. Cheverev, Vice-Director of Department
L. P. Zavjalskiy

United States

R. Jones, Pacific Northwest Laboratory
R. Klueh, Oak Ridge National Laboratory
B. Loomis, Argonne National Laboratory
A. Rowcliffe, Oak Ridge National Laboratory
F. Wiffen, Department of Energy

D. V. Efremov Institute of Electro-Physical Apparatus, Leningrad

V. R. Barabash

It was agreed that composition limits for low activation steels will be reviewed in the November 1991 meeting using guidelines from the IEA Culham Workshop on low activation materials.

2. COPPER ALLOY INVESTIGATIONS.

Information on copper alloys is needed for the design of high heat flux and other components in ITER, DEMO and power reactors. Agreement was reached on the basic elements of a collaborative program.

1. Exchange of materials for inclusion in the experimental programs of each side. The USSR agreed to supply Cu-Mo and $Cu-Al_2O_3$ currently under study. The US agreed to supply two compositions of $Cu-Al_2O_3$ Glidcop alloys. Oak Ridge National Laboratory and the Efremov Institute will organize the exchange of these alloys.

2. Joint irradiation experiments in the SM-2 and FFTF reactors. It was agreed that each side will form a team of 3-4 specialists to plan details of the experiments. It is recommended that preliminary planning should begin immediately and that the two teams should meet for detailed planning in early 1991.

3. Corrosion experiments that include the effects of irradiation are needed. The USSR will design an experiment to explore these effects, and will include USSR and US alloys.

3. VANADIUM ALLOYS.

It was agreed to begin this collaboration with the following topics

1. Exchange of materials for experimental studies. The USSR will provide a supply of their favored base composition, V-10Ti-5Cr-Zr-C. The US will supply 2 base compositions, V-5Ti, V-5Cr-5Ti.

2. The US side will perform the following tests on USSR alloys:

a) Mechanical properties
b) Corrosion testing in a flowing Li loop
c) Irradiation of TEM disks in FFTF/MOTA

3. The USSR side will perform the following tests on USA alloys:

a) Welding studies
b) Creep measurements at temperatures up to $750^{o}C$
c) Neutron irradiations at temperatures in the range $100-300^{o}C$

4. REDUCED ACTIVATION FERRITIC STEELS.

While only limited information was exohanged on this topio at this Meeting, the importance of continuing work in this area was recognized. It was agreed that at the next exchange meeting in November 1991, each side will

a) present an overview of their program including a summary of experimental data.

b) discuss a basis for future collaboration.

5. DIELECTRIC AND ELECTRICAL INSULATING MATERIALS

While only limited information on this topic was exchanged at this meeting the importance of irradiation damage in these materials to the successful operation of ITER was recognized. It was agreed that at the next meeting in November 1991 each side will

a) present an overview of their program including a summary of experimental data

b) develop plans for future collaboration.

6. TECHNIQUES AND EQUIPMENT FOR INVESTIGATING PROPERTIES OF FUSION REACTOR MATERIALS.

It was recognized that both sides have techniques of potential value to the other. Details of these techniques and on-site inspection visits will be provided when requested.

7. STRUCTURAL MATERIALS RESEARCH FOR ITER.

Research in support of the ITER project needs is receiving a high priority in each country. The collaborative work on copper and on dielectric materials is in direct support of these needs. It was agreed that further collaboration work on other materials should be carried out within the 4-party ITER agreement on research and development. An exchange of up to 10 kg of 316 steel was requested by the USSR.

8. CERAMIC-COMPOSITE MATERIALS FOR STRUCTURAL APPLICATIONS.

This is a subject of interest to both sides. The US agreed to provide copies of the proceedings of a Workshop on this subject held in May 1990 in the US.

APPENDIX H

USSR/USA EXCHANGE I.5 for 1990

Exohange Meeting in the Area of Fusion Reaotor Materials.

September 24-26 1990
Baikov Institute of Metallurgy
USSR Aoademy of Soienoes
49, Lenin Avenue, 117234, Mosoow

The Exohange Meeting was held under the Agreement reaohed by the Soviet-Amerioan Coordination Committee on Thermonuolear Power. The purpose of the Meeting was to review progress in the US-USSR program on struotural materials for fusion reaotors. Future plans under this oollaboration were developed . The 20 member USSR delegation and the 5 member USA delegation partioipating in the meeting represented the following organizations:

USSR delegation

- Baikov Institute of Metallurgy
- The Kurohatov Institute (Troitsk)
- The Kurchatov Institute of Atomio Energy
- The Institute of Physioal Chemistry of Aoademy of Soienoes
- Physioal and Teohnioal Institute, Charokov
- Institute of Atomio Reaotors
- Institutes of Eleotronio Industry, Mosoow
- Mosoow Engineering Physioal Institute
- Tomsk Politeohnioal Institute
- Institute "Graphite"
- Firm "Red Star"
- Institute of Geologioal and Analytioal Chemistry
- Central Soientifio Institute "Prometey"
- Atomic Energy Department

US delegation

- Offioe of Fusion Energy, US Department of Energy
- Argonne National Laboratory
- Oak Ridge National Laboratory
- Paoifio Northwest Laboratory

INTRODUCTION

There was mutual agreement between both sides on the value of the technical information exchanged during the first two days of the meeting and the advantage of a similar format in future exchange meetings. It was agreed that to improve the exchange of information in future meetings, each side will provide copies of their presentation material for distribution on the first day of the meeting. The USSR side further agreed to provide English translation of captions and labels for all figures, data and tables. It was recognized that on both sides there is an increasing emphasis on materials work related to ITER. This emphasis is reflected in the proposed collaboration discussed below.

COLLABORATIVE PROGRAM

The main features of our proposed collaborative work are as follows

1. DEVELOPMENT OF LOW ACTIVATION AUSTENITIC STAINLESS STEELS.

Collaboration is continuing on manganese stabilized steels; the two sides agreed to continue work on the following topics:

a) Program in the USA

1. Long term aging and tensile testing of US and USSR alloys.
2. Irradiation in FFTF/MOTA of TEM disks and tensile specimens of US and USSR alloys.
3. Irradiation in FFTF/MOTA of USSR-supplied pressurized tubes for irradiation creep measurements.
4. Complete aqueous corrosion studies on US and USSR alloys.
5. Provide information to the USSR on melting practice.

b) USSR Program.

The following investigations to be carried on both US and USSR alloys.

1. Lithium corrosion in a flowing loop.
2. Hydrogen permeation.
3. Aging, thermal creep and tensile properties.
4. Susceptibility to intercrystalline corrosion in aqueous environments, including welds.
5. Welding studies including irradiated materials.
6. Irradiations in SM-2 and BOR-60.

SUMMARY

This collaboration on fusion reactor structural materials is of continuing benefit to both sides. At the present meeting a useful exchange of recent technical data was accomplished. The above text outlines plan for the continuation and expansion of experimental studies. Both sides will continue to exchange information, materials and techniques, and to strongly encourage the exchange of scientists, as soon as details can be arranged. These visits should be for not less than 3 weeks duration with no more than 3 exchanges taking place in any one year.

L.I.Ivanov, USSR

for the Academy
of Sciences
Sept. 27 1990

F.W.Wiffen, USA

for the US
Materials Team
Sept. 27 1990

APPENDIX I

VISIT OF U.S. DELEGATION TO RESEARCH AND DEVELOPMENT INSTITUTE OF POWER ENGINEERING MOSCOW, USSR

September 27, 1990

1.	Brief Information on RDIPE Activities — Main Activity Directions of the Institute	... V. N. Arlamkin	− 5 min
	A Film About RD!ᴾE	... V. I Perekhozhev	− 15 min
2.	Organization of Works on ITER/EFR Program	... G. M. Kalinin	− 10 min
3.	FR Blanket − Designs, Developed in RDIPE	... A. M. Epinatiev	− 15 min
4.	Program of Works on Materials Science to Substantiate Design Developments	... G. M. Kalinin	− 15 min
	BREAK		
5.	Some Investigation Results of Radiation Effect on Properties of Materials Used or Supposed to be Used in FB Blanket System		
5.1	A Review of Works on Hydrogen Effect on FR Structural Materials Properties. Radiation Effect on Permeability of Hydrogen and Its Isotopes	... G. M. Kalinin, A. P. Zyryanov	− 20 min
5.2	A Brief Review of Achievements in Beryllium Studies (From the report, Made on the Conference in Obninsk, May, 1990)	... G. A. Sernyaev	− 10 min
5.3	Studies of Radiation Effect on Vanadium Alloys	... V. M. Nalesnik	− 10 min
5.4	Radiation-Resistant Stainless Steel Looking Promising for Application in FR	... V. M. Nalesnik	− 10 min
6.	A Film about Chernobyl NPP		− 15 min

USSR PARTICIPANTS AT RDIPE MEETING

Prof. V. V. Orlov, Deputy Director, President of USSR Nuclear Society (absent)
Dr. V. N. Artamkin, Director, International
Dr. G. M. Kalinin, Head of Material Science Department
Dr. V.Ya. Abramov, Head of Structural Materials Laboratory
A. V. Sidorenkov, Senior Engineer
A. M. Epinatiev, Senior Engineer
Dr. V. I. Perekhozhev, Deputy Director of Sverdlovsk Branch
Dr. A. P. Zyryanon, Head of Laboratory of Sverdlovsk Branch
Dr. V. M. Nalesnik, Senior Staff Scientist of Sverdlovsk Branch
Dr. L. P. Sinelnikov, Head of Department of Sverdlovsk Branch
Dr. E. V. Demina, Senior Staff Scientist of A.A. Baikov Met. Inst.
Dr. V. T. Zabolotny, Senior Staff Scientist of A.A. Baikov Met. Inst.
Dr. A. P. Komissarov, Senior Staff Scientist of A.A. Baikov Met. Inst.
S. V. Simakov, Senior Staff Scientist of A.A. Baikov Met. Inst.
N. T. Serdukova, Interpreter
N. D. Bobrova, Interpreter
L. N. Kharitonova, Interpreter

END

DATE FILMED

12 / 05 / 90