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Summary of discussion session: Design and materials

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1. Focus of session

The focus of this discussion session was the relation between fusion materials research and development and fusion reactor design activities, near term (e.g., ITER) and long term (e.g., DEMO or power reactor designs). Clearly the goal of the materials science and reactor design communities is the successful development and deployment of fusion power reactors. The properties and characteristics of the materials from which a fusion power system is designed and built are major determinants of critically important attributes of fusion power such as economics, safety and environmental attractiveness. Fusion power system concepts and design studies set the general direction and goals for materials R&D. Likewise, input on the properties and characteristics (e.g., cost, fabricability, mechanical properties important in design, chemical compatibility, radiation effects on properties, etc.) of the potential materials systems must be factored into the concept and design studies in order that their end products guide the program in the correct and optimum direction. The goal of this discussion session was to explore the areas and ways in which the materials science and design communities should communicate more effectively and work more closely in order to find an efficient and successful path to fusion power.

2. Discussion points

In his plenary address, 'The Role of Materials R&D in the Development of Commercial Fusion Power Plants', John Davis (see previous paper) discussed how the high-level system requirements which are established at the beginning of a concept study or design have a major impact on the materials systems that are ultimately selected for various applications. For example, the requirement in the Starlite Project (reference) that materials used in the plant produce no radioactive waste greater than class C leads to SiC composites, vanadium alloys or low-activation ferritic/martensitic steels as possible blanket structural materials. The rules used in the design process should identify the mechanical properties that are most important in the performance of the component or structure. At this point there is a dilemma, however, because design rules do not exist for components used in either near-term fusion experiments or future power systems. Conversely, the response of materials in the fusion environment is not sufficiently known to identify and evaluate all aspects of materials performance that will be critical in the design, construction and operation of fusion systems.

Professor G.L. Lucas of the University of California, Santa Barbara, noted that given the long time scale for development of fusion power systems, the design community cannot provide clear direction to the materials community relative to what information on materials property and behavior is required. Left to our own devices, the materials community will use tests that provide data for screening materials response, understanding the fundamentals of materials behavior and developing new alloys and ceramics with improved performance. With this approach we generate only part of the materials property database that will actually be required for designing, and we often generate data that cannot be used in the design process. As an example of the latter, Lucas noted measurement of the DBTT, a measurement near to the heart of many in the materials community, used in screening body-centered cubic alloys, but of little use in the actual design process. Looking to the future, Lucas proposed that we develop and use testing methods that satisfy all needs – understanding the fundamental behavior of materials, support materials development and

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in the end provide a database that can be used in designing. One area of materials response in which significant progress towards this goal has been made is the description of fracture behavior using a Master Curve technique (reference to Lucas paper in ICFRM8 proceedings). With this technique one obtains data/information that not only provides an insight into the micromechanics of fracture but is ultimately pertinent to the designing and operation of irradiated, defect-tolerant structures.

Dr M. Kikuchi of the Naka Establishment of the Japan Atomic Energy Research Institute described the study leading to the SSTR and Advanced SSTR (steady-state tokomak reactor) concept or design. The SSTR concept relies on boot strap current to achieve steady-state operation. It is water cooled and uses F82H ferritic steel as the blanket structural material. The blanket is divided into permanent and replaceable sections. The replaceable sections have a life of 10 MWy/m^2 and are replaced every 2–3 yr. The maximum wall loading is 5 MW/m^2 and maximum heat flux is about 1 MW/m^2. The operating temperature for the F82H was assumed to be about 550°C. With these performance parameters, the cost of electricity (COE) was estimated to be about 1.5 times that of LWR. The advanced SSTR concept was developed to achieve economic competitiveness with LWRs. The key to improving economic performance is a structural material with higher temperature capability and longer life in the irradiation environment. In the advanced STTR, the wall loading was increased to 10 MW/m^2 and the life of the replaceable blanket was increased to 14 MWy/m^2. Development of oxide dispersion strengthened (ODS) ferritic steels is seen as an approach to achieve the stated goals. Questions associated with using a ferromagnetic material in the blanket of a magnetically confined fusion reactor are recognized and are under investigation in a program to install a ferritic steel liner in the tokamak JFT-2M. If further studies are required, the possibility of doing experiments in JT60 upgrade exists.

Professor Akio Sagara of the National Institute for Fusion Science presented a second concept in which performance in the blanket structural material was critical to achieve the very attractive goals. This concept is the Forced Free Helical Reactor (FFHR) which is based on the stellerator approach to confinement. The blanket structural material is a ferritic steel and the system is cooled with FLiBe. The low solubility of tritium in FLiBe, and the low reactivity of FLiBe with air and water vapor give attractive aspects of the design from the viewpoint of safety. The operating temperature must be above 450°C, the nominal melting temperature of the FLiBe salt, leading to the selection of an ODS ferritic steel as the structural material. The neutron wall loading is rather low, 1.5 MW/m^2, thus in a 30 yr life the structural material would be subjected to a damage level of 450 dpa. The basic question posed to the materials community is 'Can we develop an ODS ferritic steel that will survive 45 $MMWy/m^2$ (i.e., 450 dpa)?' If this is possible, then the FFHR also becomes a very attractive concept from the viewpoint of radioactive waste generation and disposal (environmentally attractive).

Dr Paolo Fenici of JRC Ispra, Italy, discussed the need and value of a materials property handbook as a tool for communicating with the design community. Creation of a useful materials handbook requires a mechanism of collecting and evaluating the accuracy of databases, presentation of databases to the design community and for preserving evaluated databases for use by future generations. The process used during the ITER EDA was given as a working example. The need to report all relevant information that is necessary for the process of evaluating and correlating data from different sources was stressed. Information such as the source, composition and processing history of the material is essential. Also one must provide all relevant experimental parameters (along with uncertainties) such as test temperatures, strain rates, stresses, irradiation conditions, etc.

3. Summary

This discussion session, once again, highlights the importance of a continuing and effective dialog between the design and materials communities. Reactor concept studies are important in pointing the direction that development of fusion power should take and in convincing the policy makers and the general public that we have a product that is worth pursuing. It is incumbent on the materials community to provide best estimates of achievable materials performance as well as known limitations. To assure credibility this information must be incorporated into the concept study. Concept studies are important to the materials community in that they provide goals or targets and help to guide materials development efforts. In the conceptual design process, the importance of providing and incorporating accurate information on all aspects of materials including processing and fabrication, basic mechanical and physical properties and the response of materials in the operating environment become even more critical. Decisions relating to all aspects of the fusion power plant are dependent on such knowledge and information. In the final stages, i.e., final design, construction and licensing, a comprehensive and validated data base dealing with all aspects of materials behavior and performance will be required.