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Report on summary session

Spallation materials R&D: Remarks on progress and future

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It is a pleasure to prepare a written summary of my remarks for the closing of the IWSMT-6. This brief contribution expresses some personal opinions on the evolution of spallation materials R&D over the nearly eight year history of these workshops. Needs for future work that can be discerned at the present time, as well as the desirability of collaborations with research efforts in closely related technologies are described.

These workshops began with IWSMT-1 in April of 1996. The aims of that workshop largely hold true for the entire series: "Future high power spallation neutron sources will subject structural and target materials to unprecedented severe radiation environments. At the same time reliable performance will be required of all technological components to meet research applications in these devices. This workshop will review materials experience from existing spallation devices, as well as applicable information from fission, fusion and charged particle irradiation programs. Coverage will include radiation effects, compatibility, and closely related mechanical engineering issues. Opportunities for collaboration among the relatively few internationally dispersed spallation materials activities will be explored.

"The objectives of the workshop are to frame what is known concerning spallation materials technology with an eye toward design decisions, to establish what further work needs to be done for near term spallation sources and to plan how to get there in a reasonable time with available resources. All participants are requested to contribute to the discussion and formulation of actions..."

Rapid progress in the tone and content of the workshops has occurred. For example, at the first workshop plans were in development for irradiations of structural materials under spallation conditions. A large experiment was in design and fabrication in connection with the APT program for irradiation at the LANSCE. Plans were in the incubation stages for replacing some of the target rods in the SINQ spallation target with hollow tubes containing materials specimens. In addition, arrangements were made for post-irradiation examination of service components removed from LANSCE and ISIS. By contrast, at the present workshop, in a gathering wave from the two previous workshops, extensive experimental observations have been presented on radiation effects in spallation environments for moderate displacement doses. Further to this point, during the present workshop we planned and made collaborative research assignments for even more voluminous new measurements on larger numbers of specimens irradiated under spallation conditions.

Similarly, for compatibility of target structural materials with the liquid metals that would make up the more advanced spallation neutron sources, the status has advanced from preliminary plans with no accomplished experiments and sparse or non-existent historical data on conditions of interest, to an extensive international suite of work. A large data bank on measures of compatibility with liquid mercury and liquid lead–bismuth has been developed. The results include measurements of surface degradation by corrosion, mass transfer in liquid metal loops and effects of liquid metal interactions on mechanical properties such as fatigue and tensile properties.

Our assessments of the most compelling issues for pulsed liquid metal spallation targets have changed recently, both as the result of planned research to master issues in the critical areas identified initially and as a result of the discovery of an additional degradation phenomenon. The most prominent key areas identified originally were radiation effects in the target container structural material and compatibility of that material

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with liquid mercury or liquid lead–bismuth. Much progress has been made in these areas and we now have quantitative bases for target design parameters and lifetime estimations that indicate that the new spallation targets will meet their service requirements. During this time, however, the additional phenomenon of cavitation erosion or pitting of the liquid mercury contact surface of specimen containers that simulate aspects of the actual spallation targets has been discovered.

The phenomenon was discussed only informally at IWSMT-4 but commanded center stage in presentations and papers at IWSMT-5 and at the present workshop, IWSMT-6. The high intensity of current work was triggered when a team of our Japanese colleagues discovered pitting. Although the phenomenon has not been confirmed in a prototype spallation target, there is now a great deal of evidence to suggest that it will occur in high power, pulsed liquid mercury targets. Cavitation erosion originates when the high intensity proton beam pulse is absorbed in the target. Thermal expansion of the mercury following the induced rapid heating produces pressure waves that propagate to the vessel walls. The pressure waves are followed by rarefactions. In these regions of tensile stress the liquid loses cohesion and cavitates. Cavitation bubbles may form and collapse throughout the volume, but those near the walls can cause erosion by creating miniscule high velocity liquid jets and shock waves. Erosion then takes place in the form of localized pits, where material is forcibly removed from the near-surface region. Much of the effort is now directed at the question of whether this erosion could, by thinning of the walls, reduce the lifetime of spallation targets to below that dictated by radiation effects.

Recently, another trend in research topics is occurring. With the SNS and JSNS in construction, and the ESS deferred to a future time, research and development activities for the liquid metal spallation targets of these neutron scattering facilities are declining. The present reduction in effort on facilities in construction is a natural result of the initial planning, and reflects the fact that the initial R&D phases are successfully completing their work. It is expected that additional work will be needed during the operational periods as questions arise. At the same time, however, there is an increase taking place in materials research for another type of facility that will employ spallation targets – the accelerator driven transmutation system. In such facilities the spallation neutrons will be used for nuclear transmutation, particularly of unstable nuclides present in the nuclear wastes produced by fission reactors. In addition, the proposed Chinese spallation neutron source with a water cooled tungsten target will no doubt require a level of materials R&D, even though the presently visualized design power is substantially lower than in the above mentioned facilities.

The effectiveness of the relatively small spallation materials efforts at individual institutions and within national boundaries has been remarkably improved by the international collaborations and shared results reported at these workshops. More countries are now participating than in the earliest workshops. In total, however, in a broader context of R&D within the field of materials for nuclear technologies, resources available for spallation materials R&D are relatively modest. Natural opportunities are available that should be pursued for leveraging resources. There are ongoing substantial efforts in the areas of fusion reactor materials and of fission reactor materials. Although based on different nuclear reactions and on largely different applications than spallation, these technologies share many common features and topics of interest with spallation. In particular, a new generation of designs for fission reactors is being developed internationally. The concepts are characterized collectively as Generation IV reactors and have reinvigorated research in fission reactor materials because of high demands on the performance of structural materials.

The physical mechanisms by which structural materials respond to irradiation in spallation, fusion and fission devices are universal, while the energies and distributions of irradiating particles differ in detail. In spallation, fusion and fission there are concepts and in some cases operating facilities employing water-cooled and liquid metal cooled designs. The operating fluid provides heat transfer and additional functions, including isotope breeding, neutron moderation and neutron production for fusion, fission and spallation, respectively. In spite of these differences, questions related to the long term microstructural and phase stability of the structural materials, and compatibility processes at interfaces with the operating fluids provide many potential areas of mutual interest. It is especially relevant to note that all three technologies rely on similar advanced materials – in some cases even the same alloy – for major components and structures. In particular, radiation resistant grades of austenitic stainless steels and ferritic-martensitic steels are prominent in the literatures of all the technologies. In addition, mechanically alloyed steels and refractory alloys are often mentioned for advanced higher temperature applications. Further, nearly all the irradiations, regardless of the program, are conducted in a relatively few available key accelerator and reactor facilities. The types of information being generated in these R&D programs are sometimes quite similar.

Therefore, although there are already some incidental activities of mutual benefit, it is clear that more deliberate planning and earmarking of designated resources for cross-cutting efforts could yield a substantially improved and more comprehensive foundation for evaluating and developing materials for nuclear systems. The exciting prospect is that each technology could move at a faster pace with a greater sense of community and productivity among researchers.