The Challenges Facing Fusion Safety and Environmental Research

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A comprehensive review article on the status of the "safety and environmental aspects of fusion energy" appeared in 1991 in volume 16 of the *Journal of Annual Reviews on Energy and the Environment* that concluded that "fusion energy has the potential to deliver safety and environmental (S&E) benefits large enough to be regarded as a major part of the rationale for the fusion-development effort: fusion would have no counterpart to the problems of mining, air pollution, acid rain, and climate-change associated with coal use, and it offers the prospect of increased safety from major accidents, diminished weapons linkages, and a smaller waste-management task compared to fission." However, "… Achieving the full S&E potential of fusion will not happen automatically. The safety benefits, especially, appear to range from modest to enormous, depending on the materials used to construct the reactors, other aspects of the reactor design, and, ultimately, the particular fusion reaction that is harnessed".

In the conclusions to this article, four needs and priorities were identified by the author. The third being: "… the community of fusion S&E researchers and the resources available to them are simply too small to carry out the range of studies required even to properly support and benefit from the current and next-generation fusion machines, not to mention the generation of full-scale reactors to follow. As a result, opportunities to help steer fusion development in a timely fashion toward the technology's highest potential are likely to be missed. The resources being devoted to fusion S&E research of all kinds-from the most fundamental laboratory experiments to the integration of safety , environmental, and economic considerations in reactor design-need urgently to be increased". The author of this review is Dr. John P. Holdren, then at the University of California, Berkley.

While the funding of S&E research did increase during the International Thermonuclear Experimental Reactor (ITER) Engineering Design Activity (EDA) in the 1990s, the US fusion S&E research budget has decreased (~10%) since the above assessment was completed. When adjusted for inflation, the funding level has actually decreased by ~50%. This funding situation is not unique to S&E research and even under the continuing budget pressures faced by the Office of Fusion Energy Science (OFES) over the past two decades, S&E research remains an OFES priority.

During the ITER EDA the US safety assessment capabilities grew significantly:

1) Safety assessment methodologies were developed that formed the basis of ITER's present licensing submittal to the French Nuclear Safety Authority (ASN), which is ITER's Report Preliminary on Safety (RPrS),
2) Experimental capabilities were developed to provide licensing data for ITER that continued to evolve after the EDA into the Idaho National Laboratory's (INL's) Safety and Tritium

Applied Research (STAR) facility (an OFES National Users Facility capable of conducting experiments involving up to 1.5 g of tritium),

3) Self-consistent accident analysis tools were developed, such as the MELCOR for fusion computer code, a modified version of the US Nuclear Regulatory Commission's fission reactor sever accident analysis tool still under development at the Sandia National Laboratory (SNL-NM). MELCOR for fusion is being used by the ITER International Organization (IO) to perform the accident analyses that are contained in ITER's RPrS, and
4) The first fusion specific component reliability data base was assembled and is now being used by ITER to understand system reliability, required maintenance activities, possible accident scenarios, and worker safety assessments.

Even with these successes, when assessing the S&E understanding to a license a US DEMO reactor, a recent Fusion Energy Sciences Advisory Committee (FESAC) panel identified a number of knowledge gaps in a findings report published in 2007 entitled: "Report on Priorities, Gaps and Opportunities: Towards a Long-Range Strategic Plan for Magnetic Fusion Energy". The FESAC panel concluded that safety gaps regarding "the knowledge base for fusion systems" is presently "(in)sufficient to guarantee safety over the plant life cycle - including licensing and commissioning, normal operation, off-normal events, decommissioning and disposal". Extrapolations in present capabilities beyond ITER were identified to exist in five key safety areas:

1. *Computational tools needed to analyze the response of a fusion system to an off-normal event or accident.* While the US Fusion Safety Program has developed a series of advanced system level computational tools to analyze the response of a fusion system to an off normal events; however, for DEMO new models in the areas of tritium transport, dust and hydrogen explosions, magnet arcing, and the data required to validate and verify these new models is required.
2. *Understanding and quantifying the fusion source term will be required for licensing activities.* Two fusion source terms with greatest uncertainty are dust and tritium. In terms of dust, the key uncertainties are the magnitude of dust generated in the machine, its location and the potential for explosive dust mixtures in the presence of hydrogen and air in certain accident sequences. In terms of tritium, for high temperature breeding blankets, the key tritium issues include accountancy, control and permeation. R&D is needed (e.g., tritium permeation barriers—it is important to point out that tritium barriers will behave different under irradiation relative to out-of-pile) to help better define and hopefully resolve the issue prior to DEMO.
3. *Qualification of fusion components in the fusion DEMO environment will be required to validate the design and to demonstrate safety roles of key components.* Separate effects and integral irradiation testing in a fusion component test facility (CTF), fission reactors, particle accelerators, combined with ITER, could provide a portfolio of high damage (> 10 dpa) performance testing data for licensing case to qualify DEMO components.
4. *A waste management strategy for fusion must be developed.* Beyond the need to avoid producing high level waste, there is a need to establish a more complete, waste management strategy that examines all the types of waste anticipated for DEMO, given a more restricted regulatory environment for disposal of radioactive material in the future. DEMO designs should consider waste reduction (recycle and reuse) as much as possible,

and the inclusion fusion specific radioisotopes in the US Nuclear Regulatory Commission (NRC) guidelines for the release of clearable materials.

5. *Experience with large scale remote handling will be important prior to DEMO.* Remote handling of large components will be instrumental to the success of fusion. Activation levels in a commercial plant will be much higher than in ITER, and ITER will have significant downtime relative to a commercial plant (and will not be under the same time constraints as a commercial plant), thus additional experience with remote handling of large components is desirable prior to DEMO.

Unfortunately, these findings not only apply to a DEMO reactor but are equally valid for a CTF or fusion nuclear science facility (FNSF). In addition, recent events at the Fukushima nuclear power plants have widened these knowledge gaps, as fission reactor facilities worldwide are now being asked to assess public and environmental consequences of all conceivable beyond design basis accidents (BDBA). The French Government issued such a decree this last May directing all nuclear power installations to do just that by September of this year, including ITER. The only tool available to ITER to address this required assessment is the MELCOR for fusion code. However, not only is this code outdated (the version of MELCOR (1.8.2) used by ITER was completed in 1992 and is no longer supported by the NRC) but the code can only execute on a single computer central processing unit (CPU), that is the code is has not been parallelized. The problem is that given the sophistication of the developed ITER MELCOR models, the "wall clock" time to complete a single analysis can be as long as a single month even on today's computers; and the regulators are also asking that multiple sensitivity analyses be performed for each scenario. For the past five years the NRC has requested, as is within the agreement signed to obtain the MELCOR source code, that all fusion modifications be ported into the latest version of the code, which is MELCOR 2.1. Funding levels have not allowed the INL Fusion Safety Program (FSP) to comply with this request. While this would not solve the problem of code parallelization (plans are underway at SNL-NM to address this issue), it would resolve the question being asked by the French regulators: "Why is ITER using an outdated version of MELCOR?"

This funding problem is also affecting required upgrades of the experimental capabilities at STAR. A prime example is the Tritium Plasma Experiment (TPE). This device is the only linear plasma source in the world that can be used to study plasma driven tritium permeation in plasma facing component (PFC) materials. TPE was constructed in the mid 1980s and has not undergone any upgrades since that time. In order to shorten the plasma run time to a single day when studying permeation in tungsten, the plasma flux in this device must be increased to levels experienced by ITER PFCs, and the exhaust system must be reengineered to circulate the exhaust back into the TPE plasma chamber. The latter upgrade would greatly lower the risk of TPE operation by reducing the quantity of tritium confined within the TPE confinement system.

While the impact of limited funding has had a detrimental effect on the US FSP, perhaps the largest impact has been on staffing levels and loss of key personnel. Recently two new young scientists and a post-doc were hired to bring the staff size back to a critical level minimum of eight employees. Unfortunately, expertise in keys areas is presently not shared by the FSP personnel, for example that required to direct a licensing program for an FNSF. The two individuals in the US, in our opinion, who could lead such a program are Drs. David Petti and

Kathy McCarthy of the INL, both now working on fission projects. An opportunity to train a young safety scientist in this area was recently missed by not insisting that the ITER IO Safety Group include a US member.

Given these facts, we propose that the FESAC recommend a significant increase in the S&E research budget; and if possible, inflation should be taken into account in making this recommendation.