Safety and Environment Considerations and Analysis

Safety and environmental issues are being considered up front in the APEX project as designs evolve so that the goal of safety and environmental attractiveness is realized. Designing safety into the concepts as was done in the ITER project [1] results in less complex systems than retrofitting the design to meet safety requirements.

The designs under development in the APEX project are at a pre-conceptual stage, lacking the detail needed for a comprehensive safety analysis. However based on safety screening criteria, we look for safety issues that could be “show-stoppers,”, i.e., meeting safety guidelines does not look feasible. In particular, our initial focus has been on the ability of the designs to remove decay heat. The goal here is to ensure that temperatures remain below levels at which oxidation-driven mobilization becomes unacceptable. We have done some parametric studies to identify potential safety concerns, and improve designs to meet safety requirements. We have examined a number of concepts to determine the ability of the design to remove heat from the plasma-facing surface during an accident. If surface temperatures are low enough, mobilization of hazardous material is minimized.). The CHEMCON code [2] used in these calculations was developed to analyze decay heat driven thermal transients in fusion reactors.

The optimal result, from a safety point of view, is when long-term accidents temperatures are adequately low without relying on active (safety-grade) cooling systems. Our initial calculations for each design assumed no active cooling. If the temperatures were unacceptably high, we then looked at various cooling options. Peak temperatures and amount of time above 800°C for the APPLE, CLIFF, thick liquid wall, and He-cooled refractory alloy designs are shown in Table 1 (EVOLVE will be analyzed at a future time). Because of the large amount of tungsten used in the He-cooled refractory alloy design, active cooling was necessary to keep accident temperatures to an acceptable level. Similarly, it is primarily the Tenelon in the shield that is contributing to the high decay heat in the CLIFF design. Active cooling of the vacuum vessel reduces peak temperatures to 875°C, however temperatures are above 800°C for 3.5 days. It may be necessary to either actively cool the shield, or use a material other than Tenelon (which is a high manganese steel; manganese has high decay heat). Although the peak temperature during the transient for the APPLE design is above 800°C, the duration is less than 2 hours, and the relatively low radiological hazard of SiC makes this acceptable. The temperature in the thick liquid wall design never exceeded 675°C.

Table 1. Peak Temperature and Time Above 800°C for Apple, CLIFF, and Thick Liquid Designs

Concept	**Peak Temperature (°C)**	**Time Above 800°C (hours)**
APPLE	1275	1.2
CLIFF	875[a]	84[a]
He-cooled	800[b]	< 1[b]
Thick liquid	675	0

[a] With active cooling of the vacuum vessel (see Section 7.7)
[b] With active cooling of the blanket region (see Section 11.9)

Although the neutron and surface heat loads are higher in APEX designs than those in conventional fusion designs, these preliminary LOCA calculations indicate that safety criteria (and more specifically, no-evacuation guidelines) can likely be met. For some designs, such as the He-Cooled Refractory Alloy design, this will likely require the use of a safety-grade system to remove decay heat during accidents. It may be necessary to avoid the use of Tenelon in the shield in designs such as CLIFF; in that case, active cooling may not be necessary. For others, such as the Thick Liquid concept, a safety-grade system is probably not necessary. It is desirable to make any such system passive to increase the reliability of the system.

These preliminary scoping calculations are by no means sufficient for determining whether these designs will meet safety guidelines. They are meant as a starting point, and are used to make recommendations to designers so that safety is "built into" designs as they mature. As more design detail becomes available, further safety analyses will be done to ensure that safety requirements are met.

Reliability Issues

As part of this study, comparisons between the traditional solid wall plasma facing surface tokamak designs and the self-renewing liquid wall tokamak designs are undertaken to determine what features are attractive in each design approach. The maintenance times for in-vessel component replacements in solid wall tokamak designs are an important feature since these extended downtimes can affect the operational availability of a power plant. By surveying reported remote maintenance times for existing experiments, we can estimate times for next-generation experiments.

Both operational experience at JET with divertor replacement and best estimates of remote maintenance times for solid wall replacements for ITER show times on the order of 26 weeks. While future innovations may refine these times, they are still lengthy. Downtimes of that duration can be used to advantage to perform other time-consuming activities, such as in-service inspections of piping or heat exchangers, cleaning heat exchangers, etc. Nonetheless, these downtimes for remote replacements will put limitations on reactor operational availability. Solid wall fusion reactor availability may experience growth similar to the early fission reactors, as the understanding of how to build a robust first wall and divertor increases. Then wall reliability would increase so that wall replacements are less frequent. Further advances in materials and their hardening to withstand radiation damage would allow longer-lived solid wall blanket/first wall designs. Some current estimates of the availability for the EU DEMO reactor blanket/first wall designs show availabilities in the range of 84.3% to 87.7%. These values are lower than required to obtain a reactor that competes with nuclear fission (i.e., a reactor plant that has 87% or more plant availability), as discussed by M. Abdou in the APEX design study. Radiation damage to the liquid wall components must be evaluated. The liquid walls would also need some periodic maintenance, such as the possibility of flow nozzle or guide vane changeouts. Like solid walls, the liquid wall system would also require visual inspections, such as the vessel walls, guide vanes, screens, and other passive items. Weld testing would be needed in both solid and liquid wall designs.

Remote changeouts of the liquid wall passive components (nozzles, vanes, screens, etc.) are expected to be less complicated than changeouts of the large, heavy blanket/first wall modules used in solid wall designs.

As the APEX design progresses, it should be possible to calculate a scoping availability value for the liquid wall system. Then comparisons can be made to the solid wall availability values from the literature.

Waste Disposal Issues

Materials choice has long been recognized as a key factor in realizing the full safety and environmental potential of fusion power. Because the materials are de-coupled from the fusion energy source (the plasma), the long-term neutron-induced activation of components can be tailored by proper selection of materials to avoid generation of waste that would require deep geological disposal. Thus, the idea of “low activation” materials was conceived for the US fusion program with the hope that such material could be disposed of as low level waste (e.g., shallow land burial) and would not pose a burden to future generations.

The environmental impact of waste material is, however, determined not only by the level of activation, but also the total volume of active material. A tokamak power plant is large, and there is a potential to generate a correspondingly large volume of activated material. The adoption of low activation materials, while important to reduce the radiotoxicity of the most active components, should be done as part of a strategy that also minimizes the volume of waste material that might be categorized as radioactive, even if low level. Waste management strategies have typically concentrated on minimizing the activity of first wall and blanket components where the level of specific activity (Bq/kg) is highest [[3]].

Some materials may become candidates for recycling, and others may be cleared from regulatory control by meeting prescribed criteria that have yet to be agreed upon internationally. Recently these concepts of recycling or clearance have been recognized as options for reducing the volume of radioactive waste from a fusion power plant. Determining if a material can be recycled or cleared from regulatory control depends largely on our ability to limit the induced activation of the component. (It should be noted that the criteria for clearance are more restrictive than for recycling.) Thus, there is a need to explore new and innovative concepts that can substantially reduce the activation of the large ex-vessel components that contribute significantly to the overall volume of activated material and to extend the capability of conventional conceptual fusion designs with proper optimization to achieve the same goal. The impact of these parameters on other aspects of plant performance must also be considered.

Summary/Future Direction

By ensuring that safety and environmental issues are considered early in the APEX design process, we are producing designs that help show the safety and environmental potential of fusion energy. As designs mature we will continue the safety analyses to guide designers toward better designs. Similarly, waste management issues will be considered, working towards clearing or recycling large volume components.

Reliability is a very important aspect of the APEX project, and an area in which liquid surface designs may have an advantage over solid wall designs. Nozzle reliability will be an important part of this, and is an area that will be studied in the APEX project.

References

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[1] D. A. Petti and K. A. McCarthy, “ITER Safety: Lessons Learned for the Future,” *Fusion Technology* Vol. 34, No. 3 (Part 2), 1998.

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[3] E.T. Cheng, P.Rocco, M.Zucchetti, Y. Seki and T. Tabara, "Waste management aspects of low activation materials", *Fusion Technology 34* (1998) 721-727.