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Progress Report: Fusion Reactor Design Studies for the Period November 1, 1990 to October 31, 1991

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1 Introduction

Personnel of the Fusion Technology Institute played an extremely active role in the ARIES project during the present contract period. This role was reflected in numerous presentations at project meetings, in many publications, and in a great many communications, both by electronic and by regular mail.

The remaining sections of this progress report will give a detailed breakdown of the work accomplished for ARIES-III during the contract period, November 1, 1990 to October 31, 1991. The areas of effort were

1. Neutronics
2. First-Wall
3. Shield
4. Safety
5. Systems
6. Startup and Shutdown
7. Energy Conversion
8. Ripple Loss
9. Fuel Resources

2 Neutronics

The extensive, comprehensive calculations necessary for a credible design were performed for three major neutronics areas:

1. First wall and blanket neutronics,
2. Shield optimization and design, and
3. Activation analysis.

For the *first wall and blanket*, we calculated nuclear heating, radiation damage, and tritium breeding. The nuclear heating was necessary to model loss-of-coolant accidents (LOCA) and to perform the power cycle thermal hydraulics analysis. Radiation damage calculations were done to assess the blanket lifetime. Tritium breeding was accurately evaluated in order to assure that the blanket would provide sufficient tritium to support the fuel cycle. For the magnet *shield*, we performed a complete optimization and design, including evaluation of materials options, variation of composition, and computation of radiation effects on the magnets. Shielding requirements around penetrations, such as those of neutral beams, RF antennas, and divertors, were also assessed. The *activation* of the first wall, blanket, and shield was calculated in order to provide input to the safety and environmental analysis. The activity, biological hazard potential (BHP), decay heat, and dose after shutdown was computed in detail. These calculations are summarized in Ref. [4] (see Appendix A) and in the ARIES-III final report [2].

3 First Wall Design

A design of the ARIES-III first wall was performed. Structural design, neutron damage, activation, thermal hydraulics, and coating properties were all included in the analysis. A key accomplishment was the design of a steel first wall and shield that is sufficiently robust to survive the current quench phase of a disruption without damage. The organic cooling is described in Ref. [4] (see Appendix A), and the thermo-mechanical design and structural analysis are given in Ref. [5] (see Appendix B). Design details are given in more depth in the ARIES-III final report Ref. [2].

4 Shield Design

The Fusion Technology Institute has performed the design of an ARIES-III shield optimized for the low neutron wall-loading of the D-^{3}He fuel cycle. Parameters for metal, SiC/SiC-composite, and C/C-composite shields have been scoped out. Corresponding algorithms for shield thickness have been given to the ARIES systems code group. Optimizing the shield was an ongoing effort throughout the course of the ARIES-III design. Structural design, and thermal hydraulics, and neutronics calculations were done. Details of the shield design are contained in Ref. [4] (see Appendix A) and in the ARIES-III final report Ref. [2].

5 Safety

Fusion Technology Institute personnel have been heavily involved in the analysis of ARIES-III safety, which is a critical issue for D-^{3}He tokamaks. Activities included providing background material and detailed safety analyses. Loss of coolant accidents (LOCA) calculations indicate that a steel first wall and shield will suffer no damage. Analysis of activation, waste disposal ratings, afterheat, LOCA, loss of flow accidents (LOFA), and other safety issues were investigated. These calculations are included in Ref. [2] (see Appendix C).

6 Systems

UW personnel were very active during this contract period in helping benchmark and correct the ARIES systems code (ASC) and in generating cases for both first and second stability D-^{3}He tokamak reactors. This effort is partially summarized in Ref. [1] (see Appendix D), and it will be included in Ref. [2]. A comparison of the first and second stability operating regimes for D-^{3}He tokamaks is in progress and will be given in Refs. [2] and [6].

7 Startup and Shutdown

Both startup and shutdown scenarios were defined for the ARIES-III tokamak. It was found that a short D-T startup phase was necessary, but that this phase had minimal impact on the reactor design. The details of this analysis are given in Ref. [2] (see Appendix E).

8 Energy Conversion

Fusion Technology Institute coordinated the effort to select and design advanced energy conversion systems for ARIES-III. This involved the assessment of both conventional thermal conversion cycles and of non-conventional cycles such as liquid metal MHD, plasma MHD, and synchrotron radiation conversion. This work will be included in Ref. [2] (see Appendix F).

Fusion Technology Institute personnel have also contributed to the effort to define attractive thermal energy conversion cycles, including detailed design work. Parameters for a steel first wall and shield, using organic coolant for the thermal cycle were defined (see Appendix B).

9 Fusion Product Ripple Loss

In a D-^{3}He tokamak, ripple loss of fusion products is expected to lead to more stringent constraints than in a D-T tokamak, due to the larger gyroradius of fusion-product protons at their birth energy and because almost all of the fusion power is produced as charged particles. Fusion Technology Institute analyzed ripple loss for ARIES-III and generated a simple scaling relation for use in the ARIES systems code. This effort will be included in Ref. [2] (see Appendix G).

10 Fuel Cost and Resources

The present cost of ^3He fuel for ARIES-III is estimated to be \$1000/g. Fusion Technology Institute personnel have done extensive analysis of the availability and procurement of ^3He resources, for both terrestrial and lunar resources. This information, including that from separately funded UW analyses of these resources within the UW Fusion Technology Institute and the Wisconsin Center for Space Automation and Robotics (WCSAR), has been summarized for the ARIES-III final report [2].

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