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BLANKET SELECTION FOR THE STARLITE PROJECT*

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ABSTRACT

The Starlite team was asked to develop a power plant study for the US Demo. To define the mission of the Demo, a Utility Advisory Commission (UAC) was organized to establish the mission and requirement for the demo power plant. Based on this input, the Starlite team outlined a set of top level requirements based on the advice provided by the UAC. With the mission and requirements thus established, the Starlite Engineering team investigated various combination of the structural material, breeding material and coolant for the blanket and shield. The reference design selected was the with V-alloy as the structural material and Li as the coolant and breeder. The performance of this blanket to be able to satisfy the top level requirements was also assessed.

I. INTRODUCTION

The Starlite program was initiated to develop a Demo power plant design based on D-T Tokamak fusion. Before the design activities started, a strong dialogue was established with the US utility community to establish the role and goal of the demo power plant. From this discussion, a set of top level requirements for a fusion demo power plant was set up. This set of the top level requirements defined the performance, safety and economics requirement for the demo power plant. Starting from this, the materials selection, the safety characteristics, and the performance requirements, of the blanket and shield systems can be defined. The Starlite engineering team evaluated a number of design options which all has the potential to reach those top level requirements. After careful discussion, a blanket concept based on a self-cooled lithium with V-alloy as structural material was selected as the reference design.

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During the early stage of discussion, V-alloy was agreed upon as the reference candidate structural material for the demo. There was general agreement that the ferritic steel can provide only moderate performance. Also, the issues associated with DBTT was of concern. The SiC composite is an interesting material. However, it was judged that the path to develop SiC was too long to be considered as a candidate structural material for demo.

With V-alloy selected as structural material, the following blanket concepts were evaluated:

1. Self-cooled lithium blanket.
2. He-cooled with Li_2O as the breeding material.
3. He-cooled with (Li_2O+Li) as the breeding material.
4. He-cooled with Li as the breeding material.

This paper summarizes this blanket selection process. The reasons that each blanket was proposed, and the critical issues associated with each of them are discussed. A critical comparison between the final two candidates (#1 and #4) will be made. Also, the potential that the final candidate to fulfil the top level requirements are also assessed.

II. DEMO REQUIREMENT

Before a demo design can start, it is important to establish the characteristics of the demo power plant. Therefore, an Utility Advisory Commission (UAC) was established to advise the starlite team the missions and requirements of a demo power plant. The detailed discussion of the UAC suggestions can be found in Ref. 1. The following list is a summarized version of the recommendation:

1. A Demo power plant has to demonstrate all engineer, physics, operation, maintenance and decommission characteristics of a commercial power plant.

2. The size of the Demo power plant should be within the extrapolation range of a commercial power plant.

3. The operation of the Demo power plant will demonstrate that the commercial power plant will be economically superior than other power sources.

4. The Demo power plant should provide the data base necessary to obtain certification by the regulatory agency to ensure timely licensing for commercial plants.

With this as the design goal of the Demo power plant, a top level mission requirements for Demo was set up as shown on Table 1. It can be seen that the requirement for the Demo are essentially the same as commercial, with the exception of the size and the cost of electricity. Therefore, the characteristics of the first wall/blanket and shielded of the Demo should be essentially same as that of a commercial.

III. STRUCTURAL MATERIAL SELECTION

The selection of the structural material has a key impact on the performance and safety of the fusion power plant. To maximize the attractiveness of fusion, low activation material is necessary. The candidates of the low activation material are ferritic steel, V-alloy and SiC composite.

V-alloy was selected as the structural material in the early phase of Starlite blanket selection process by a majority decision. SiC has low activation very low afterbeat, high strength, and high temperature capability. However, the development path of SiC was judged to be too long for the Demo application.* The performance of ferritic steel was judged to be inferior to V alloy. Also, the DBTT of the ferritic steel after irradiation would reduce the temperature range of application. The assessment of the ferritic steel and V-alloy were summarized in Refs. 2 and 3. However, there was minority opinion that, due to the lower unit cost of the FS, the total COE could be lower by using FS, even at reduced performance.[4]

Table 1 Top Level Mission Requirements for Demo

Requirement	Demo	Commercial	Assessment
Must use technologies to be employed in Commercial Plant	Yes	Yes	Meet all requirements
No Evacuation Plan required	1 rem Total Dose at Site Boundary	1 rem Total Dose at Site Boundary	To be assessed, Possible
Generate no Radioactive Waste greater than:	Class C	Class C	Meet all requirements
Must Demonstrate Public's day-to-day activities not disturbed	Yes	Yes	To be assessed, Most likely
Must not Expose Workers to a higher risk than other power plants	Yes	Yes	To be assessed, Most likely
Demonstrate a Closed Tritium Fuel Cycle	Yes	Yes	Yes
Net Electric Output must greater than:	75% of Commercial	Not Applicable	Yes
Must Demonstrate Operation at Partial Load Conditions	50%	50%	Yes
Demonstration of Robotic or Remote Maintenance of Power Core	Yes	Yes	To be assessed
Must Demonstrate Routine Operation with less than Unscheduled Shutdowns/yr including disruptions	1	1/10	To be assessed
Cost of Electricity must be competitive (in 1995 $)	(Goal) 80 mill/kWh (Reqmt) 90 mill/kWh	65 mill/kWh 80 mill/kWh	Being assessed, achievable

IV BLANKET CONCEPTS

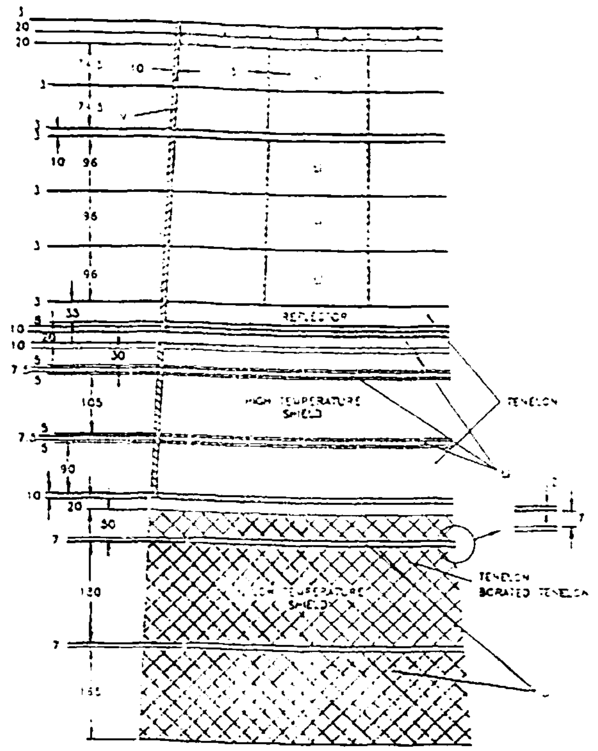
With V-alloy selected as the structural material, the following blanket concepts were proposed:

1. A self-cooled lithium blanket: The attractiveness of this blanket concept is the simplicity. It has the best potential to handle high neutron wall loading. Tritium self-sufficiency is not a critical issue. However, insulating coating has to be developed to reduce the LMMHD pressure drop. This blanket was selected for various power plant studies such as TPSS[5] and TITAN.[6] There are some concerns of lithium safety due to the chemical reactivity of lithium with air, water etc. However, two major studies[7-8] concluded that a self-cooled lithium blanket with V as the structural material is superior from safety point of view.

The configuration of the self-cooled lithium blanket is shown on Figure 1. Due to the combination of the coolant and the breeding material, this concept is very simple. The MHD pressure drop can be reduced by the development of an insulating coating.[9] With the successful development of an insulating coating, the blanket pressure will be only ~ 0.2 MPa. The tritium recovery can be accomplished by cold trap,[10] which was developed for ITER.

2. A He-cooled blanket with Li_2O as the breeding material: The key reason that this blanket concept was proposed was to improve the safety characteristics of the self-cooled lithium blanket. To improve the blanket performance, a high pressure He at 18.4 MPa pressure was used. With the high pressure helium, together with a very efficient recuperator design, a close cycle gas turbine was proposed with a cycle efficiency of 46.8%, with a He temperature of only 650C. Also, it was suggested that tritium self sufficiency may be obtainable without the use of Be.

However, it was decided that the tritium breeding is marginal to be the best. Also, protium/hydrogen control in the purge gas is difficult which can cause problem for V. The compatibility issue between the impurities in the He coolant with the V-alloy is a key concern. However, surface modification of the V-alloy is a potential solution to resolve the compatibility issue. To resolve the breeding and tritium/hydrogen control issues, this concept was modified to the next concept.



DEMO OUTBOARD FW/BLANKET/REFLECTOR/SHIELD SEGMENT CROSS SECTION

3. A He-cooled blanket with ($Li+Li_2O$) as the breeding material: The key change of this blanket over the previous one was to replace the He purge with lithium. The addition of the lithium would increase the tritium breeding potential. Also, the using of lithium as the tritium recovery medium resolves the issue associated with protium addition in the purge gas. It was suggested that the amount of lithium added was small, and its impact on the safety was minor. The close-cycle gas turbine was still used for power conversion.

The key concern for this concept is the lack of data on tritium system. The compatibility issues between the impurities in the He and the V-alloy is still a concern. Also, there maybe the need of insulating coating development to reduce the MHD pressure drop of the purging lithium stream. Tritium breeding was still judged to be marginal.

4. He-cooled blanket with Li as the breeding material: The coolant pressure is still 18.4 MPa. Due to this high pressure, and a very efficient recuperator design

*At the Starlite assessment, the US fusion program called for the operating of Demo wold start at the year 2005.

(967°C), a cycle efficiency of 46.8% is reported. The reduction of lithium inventory is perceived to improve the safety performance over the self-cooled lithium blanket.

The He-cooled lithium blanket appears to be attractive. Therefore, the self-cooled lithium blanket and the He-cooled lithium blanket were named as the final candidates for the Starlite project.

V. BLANKET SELECTION

Both blanket concepts proposed have feasibility issues. Those issues are discussed here:

1. V-alloy development: This issue is common for both concept.

2. Insulating coating development: This issue is critical for the self-cooled lithium blanket. Experimental programs have started to assess the feasibility of the development of insulating coating which will be reliable for many years of operation. For the He-cooled lithium blanket, there may still be the need of insulating coating development.

3. Surface modification: This is critical for the He-cooled design to protect the V-alloy from the impurities in the coolant.

4. Tritium recovery: This issues is common for both concepts.

5. Power conversion: The self-cooled lithium blanket selected an advanced steam cycle, which is conventional. The He-cooled blanket selected a close-cycle gas turbine. High performance at modest temperature has to be demonstrated. The cycle efficiency of the two systems are similar.

6. Blanket pressure: The lithium cooled blanket has a blanket pressure of 0.2 MPa, if a good insulator can be developed. The He pressure is 18.4 MPa

7. Safety: The reduction of lithium inventory will improve the safety rating of the He-cooled blanket. However, the high He pressure presents some safety concerns.

8. The He-cooled design is more complex and thus less reliable than the self cooled Li design.

9. The He-cooled design will require thicker radial builds to accommodate the He coolant and manifolds, resulting in a larger and more expensive machine.

Due to this comparison, the Starlite project selected Li/V blanket as the reference design by a majority decision.

VI. DESCRIPTION OF THE Li/V BLANKET

The Li/V blanket is attractive due to its performance and safety characteristics. The features to achieve the required characteristics are summarized on Table 2.

Table 2 Li/V Blanket Characteristics

Goal	Feature to achieve the goal
Simplicity	Self-cooled design, No need for Be
Safety	Low activation materials used, Li, Ca, V and Tenelon for shield
Waste disposal	Low activation materials used
Low pressure blanket	Insulating coating
Low pumping power	Insulating coating (to reduce pressure drop) and use of lithium (to reduce volumetric flow rate)
High performance	Using high temperature material, Li and V.
Tritium self-sufficiency	Li used as the breeding material.

There are many development issues associated with the Li/V blanket which have to be resolved. The key problems are:

1. V-alloy development: The development of V-alloy is still in an early stage. Large scale fabrication and long term power plant applications must be demonstrated. Also, more information on the radiation damage, with proper He/DPA ratio, is needed.

2. Insulating coating development: To reduce the MHD pressure drop, some form of insulating coating has to be developed. This coating has to survive a severe environment with neutron irradiation, lithium corrosion,

thermal cycling etc. It also has to be reliable over many years operation. The development of the insulating coating is in a very early stage.[9]

3. Tritium recovery: Tritium has to be recovered continuously with a low tritium inventory in the lithium. Many options have been investigated.[11] A cold trap process was developed for ITER and considered can achieve the goal.

A set of top level requirements has been outlined for the Demo power plant. It is important to assess the feasibility of the Li/V blanket to be able to reach this set of requirements. The assessment of the Li/V blanket to be able to fulfill the top level requirement is summarized on Table 1. It can be see that that most requirements can be met by a power plant with a Li/V blanket.

VII. Summary

The Starlite team was set up to develop a demo power plant design study. A set of top level requirements was set up to outline the most important feature for the demo, as well as commercial, power plants. This set of the top level requirement was outlined based on the input from the UAC, as well as reviewing similar top level requirements developed for other power generating stations.

A Li/V blanket was selected to be the reference design for the demo power plant. The selection was based on the performance, safety characteristics of the Li/V blanket. Some key issues have to be resolved for this blanket, including material development, insulating coating development, and tritium recovery.

The performance of a power plant based on the Li/V blanket is assessed to see its potential to fulfill the top level requirements. Most of the top level requirements can be met by a power plant with a Li/V blanket.

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