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(10/24/95)

PROGRAM STATUS

4th QUARTER — FY 1995

ITER & TECHNOLOGY

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is Submitted in Compliance with Sections A and B
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OCTOBER 24, 1995

MASTER

GENERAL ATOMICS

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**PROGRAM STATUS REPORT
CONTRACT DE-AC03-89ER52153
4TH QUARTER — FY95**

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ITER & TECHNOLOGY

4TH QUARTER FY95

- **Fusion Power Plant Studies**
 - Reduce surface heat flux to the divertor using a combination of impurities radiation, compression, and increased SOL electron density
 - Comparison of ferritic steel and V-alloy materials in DEMO blanket design in handling high neutron wall loading ranges 6 to 8 MW/m² and 9 to 11 MW/m², respectively
- **RF Technology**
 - All the components for the combine to be tested on JFT-2M are in fabrication
 - The 4" × 4" 110 GHz window was fabricated and delivered to CPI (Varian) for testing
- **Plasma Interactive Materials**
 - Second DiMES sample exposure with Be/W striped coatings to 13 s of high power ELMing H-mode plasma
 - High intake of deuterium about 2×10^{17} atoms/cm² was recorded for V. Be and C were lower by a factor of 2, and Mo and W were lowest by about a factor of 10
- **Radiation Testing of ITER Magnetic Coil**
 - The test coil and integrator are at Brookhaven awaiting reactor time
- **SiC/SiC Composite Material Development**
 - Received High-Nicalon and Super-Nicalon SiC fibers. Commenced fabrication of different composite samples with various coatings.

ITER & TECHNOLOGY PROGRAM

Fusion Power Plant Studies

PROGRAM STATUS
4TH QUARTER — FY 1995

TASK: FUSION POWER PLANT STUDIES

B/R NO: AT-15-03

FY95 FUNDING: \$255 K

CONTRACT NO.: DE-AC03-89ER52153

FY95 PLAN: \$255 K

GA PRINCIPAL INVESTIGATOR: C. WONG

OAK PROJECT MANAGER: M. FOSTER

OFE PROGRAM MANAGER: W. DOVE

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Coordinate Demo work breakdown structure and identify critical design issues	←	ONGOING ⁽¹⁾	→
2. Lead the plasma facing components design task	←	ONGOING	→
3. Support engineering designs, including first wall, blanket, shield, and power conversion systems	←	ONGOING	→
4. Support development of fusion materials	←	ONGOING	→
5. Support efforts in RAMI, safety design, safety evaluation, and licensing	←	ONGOING	→
6. Provide senior physicist support	←	ONGOING	→

REMARKS:

⁽¹⁾The U.S. Demo is a 3 year evaluation and design study initiated during October 1994.

PROGRAM STATUS

4TH QUARTER — FY1995

FUSION POWER PLANT STUDIES

HIGHLIGHTS:

- To reduce the surface heat flux to the divertor, we will have to use the combination of impurities radiation, compression, and the increase of SOL electron density.
 - Using ferritic steel, a helium Li-breeder design can handle neutron wall loading in the range of 6 to 8 MW/m². With advanced material like V-alloy, neutron wall loading in the range of 9 to 11 MW/m² can be handled by similar design.
-

1. Plasma Facing Components (PFC) Design

We performed the scoping level analysis of heat exhaust for the Demo divertor strawman design and generated the following observations for a 1.4% uniform concentration of carbon to represent the oxygen concentration in the core: (a) 18% of the 453 MW of heat deposited in the core is exhausted by bremsstrahlung radiation: (b) Essentially all remaining heat is exhausted to the divertor, operating in a high-recycling regime, where the average heat flux is approximately 80 MW/m² for a narrow flat target in a double null configuration. We performed several parametric scans to identify possible enhanced-radiation operating regimes where the average heat flux might be reduced to about 1 MW/m². Independently varying impurity species (C, Ne, Ar, Kr), impurity concentration, divertor impurity compression, and SOL electron density, we observed the following:

1. For fixed Z-effective=1.7, Ar radiates the most power ($T_{e(sep)} = 200$ eV).
2. For fixed electron density at stagnation point ($=0.7 \times 10^{20}/m^3$), increasing impurity concentration alone ($F_{rad}=1/3$) does not sufficiently reduce divertor heat flux.
3. Improving divertor impurity retention (1–3) does not sufficiently reduce divertor heat flux.
4. Increasing SOL electron density ($0.7\text{--}1.0 \times 10^{20}/m^3$ at stagnation point) alone does not sufficiently reduce heat flux at the divertor.
5. However, several prospective regimes were identified, in which impurity concentration, divertor impurity compression, and SOL electron density were increased in combination, which resulted in sufficient heat flux reduction at the divertor plate.

For the engineering Demo PFC design tasks, we completed the definition of sub-tasks and the assignment of sub-task leaders. Up-to-date ITER-EDA divertor design sketches were distributed as a starting point to evolve details of the Demo divertor design.

Beginning October, Dr. A. Mahdavi will coordinate the physics related inputs for the PFC design.

2. Demo Blanket Design

We completed the preparation on the description of the helium-cooled, lithium breeder and V-alloy/ferritic steel Demo blanket designs. We focused on addressing the issues of materials compatibility and reliability of high pressure gas system.

We assessed the neutron wall loading capability of the different breeders when ferritic steel was used as the structural material. Among the three breeders: Li_2O , LiPb and Li , the Li breeder has the highest capability of handling high neutron wall loading due to its lower volumetric power generation and higher thermal conductivity. Using ferritic steel, a helium Li -breeder design can handle neutron wall loading in the range of 6 to 8 MW/m^2 . With advanced material like V-alloy, neutron wall loading in the range of 9 to 11 MW/m^2 can be handled by similar design. This can have significant impact on the size and therefore COE of the fusion power plant.

Results of the high neutron wall loading (6–12 MW/m^2) He-V-Li blanket design was presented at the Advanced Approaches for Economical Fusion Power Workshop, at Monterey, California.

Materials Compatibility

We proposed to address the issue of compatibility between helium impurities and V-alloy by the use of highly efficient impurity extraction system, limiting ingress of impurities, using V-alloy surface modification and developing oxidation resistant alloy.

For surface modification, with a 10 μm layer of either silicon, aluminum, or yttrium, the modified V4Cr4Ti surface is believed to have a high chance for success at being compatible with low concentrations of O_2 , N_2 , H_2O , and H_2 impurities at temperatures to 650°C. This observation is based on preliminary experimental work carried out to date at ANL and ORNL.

Experiments were proposed to confirm fabricability of surface modified V4Cr4Ti and chemical compatibility with gaseous impurities that may be present in high pressure helium. Discussion of the experiments were carried out with Prof. Matsui, Tohoku University of Japan and Prof. Simnad of UCSD. Our Japanese colleagues have already carried out scoping studies with V4Cr4Ti containing Si, Al, and Y additives to enhance chemical compatibility.

Reliability of High Pressure Helium System Design

We are relying on the leak-before-break assessment method to guide the high pressure helium design, to make sure that the probability of bursting is low. We will also rely on suitable structural design to limit the propagation of blanket damage in the unlikely event of bursting. This will also rely on the performance of fast respond passive shut-off valves to limit the potential damage from the high pressure helium.

3. Safety—ARIES-IV Hazard Assessment

In order to demonstrate a method for assuring ARIES-IV compliance with the requirement that Protective Action Guides (PAG) not be exceeded above a certain frequency, we proceeded to develop an uncertainty distribution for offsite doses following a Helium Coolant Line Break. The source term information from INEL for a Helium Coolant Line Break was prepared as input to the MACCS code, which accounts for weather variability as it performs probabilistic offsite dose analysis. Tritium is expected to be the dominant contributor to dose.

The hazard assessment using the MACCS code included: 1. event definition and frequency estimate, 2. best estimate assessment of accident source terms, 3. offsite dose estimate considering site weather variability, and 4. evaluation of cumulative risk for two accidents.

A review of the helium-cooled ARIES-IV design indicated that primary coolant leaks in the blanket cooling and purge lines would be in the design basis and could challenge the meeting of PAG requirements. Assessment focused on blanket cooling line events to provide insight into the design and demonstrate the method. The blanket cooling line accident scenario assumed that following the helium coolant pipe failure the fusion reaction shutdown, the helium circulator failed, and the blanket slowly heated up. The probability for the event was estimated to be 4×10^{-4} per plant year based on LWR data. A dose estimate was made for the reference EPRI ALWR site which encompasses the weather in 80% to 85% of all U.S. sites. The results showed that ARIES IV may meet the PAG requirement depending upon the fraction of HT that converts to HTO as it is transported through the environment. Potential design changes were recommended that include ways to reduce the accident source terms, mitigate accident releases, and reduce likelihood of the accident.

4. International Exchanges

Mr. Guoshu Zhang of SWIP arrived, and is working on the modification of the Supercode to include the approximation of the divertor design.

5. Reports and Meetings

C. Wong attended the workshop on Advanced Approaches for Economical Fusion Power Workshop, at Monterey, California. He presented the results of the high neutron wall loading (6–12 MW/m²) He-V-Li blanket design.

C. Wong attended the 16th IEEE Symposium on Fusion Engineering, on September 30–October 1, 1995 in Champaign, Illinois. He presented the paper entitled “Evaluation of U.S. Demo-1 Helium-cooled Blanket options.”

ITER & TECHNOLOGY PROGRAM

RF Technology

PROGRAM STATUS
4TH QUARTER — FY 1995

TASK: RF TECHNOLOGY

B/R NO: AT-15-01-024/AT-15-01-025

AT-15-04-01C/AT-15-04-01F

FY95 FUNDING: \$440 K

CONTRACT NO.: DE-AC03-89ER52153

FY95 PLAN: \$440 K

GA PRINCIPAL INVESTIGATOR: R. CALLIS/R. OLSTAD/
D. REMSEN

OAK PROJECT MANAGER: M. FOSTER

OFE PROGRAM MANAGER: T.V. GEORGE

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Coordinate U.S./Japan RF Technology Exchange.	4 th Q FY95	1 st Q FY96	
2. Produce 110 GHz 4"x4" gyrotron distributed window	2 nd Q FY94	4 th Q FY95	4 th Q FY95
3. Design and fabricate a FWCD combine antenna	4 th Q FY95	1 st Q FY96	
4. Design a 170 GHz 4"x4" gyrotron distributed window	4 th Q FY95	1 st Q FY96	

REMARKS:

PROGRAM STATUS

4TH QUARTER — FY1995

RF TECHNOLOGY

HIGHLIGHTS:

- Orders for all the combline components have been placed.
 - The 4" × 4" 110 GHz window was fabricated and delivered to CPI (Varian) for testing.
-

The design of all the components for a combline antenna for JFT-2M has been completed. Completion of the fabrication is scheduled for 11/95. Informal agreement has been reached with JAERI to install the combline in JFT-2M, most likely in January 1996. The combline tests at JFT-2M should be completed by mid-1996.

Fabrication of the 4" × 4" 110 GHz distributed window was completed in September 1995. Vacuum tests on the window at General Atomics showed two leaks in the sapphire/niobium braze. A rebrazing attempt was unsuccessful. The window was nevertheless delivered to CPI (Varian) for hot testing with vacuum on both sides of the window. Flow tests were performed and microwave testing began.

Initially the window performed as expected, validating the overall window design. When reflections in the test chamber got unusually high, tests were stopped and the window was examined. It appears that there had been extensive arcing due to outgassing and poor vacuum conditions. The vacuum conditions are being improved, arc detectors are being added, and microwave power will be brought up more slowly in future tests to remove gases adsorbed on the window surfaces. The window will undergo more tests at CPI (Varian) after deposits are removed from the surface. Based on what was learned from this first window, a second window is being made for the DIII-D program. This window will also be tested at CPI (Varian).

Design activities on a 4" × 4" 170 GHz window were started. Interface hardware for testing a prototype 1.25" × 1.25" 170 GHz window in January 1996 is being procured.

The U.S./Japan RF Technology Exchange will be held December 4-5, 1995 in Coco Beach, Florida in conjunction with the International ECH Transmission Line Workshop and the IR and Millimeter Wave Conference. The U.S. candidates and Japanese participants have been selected.

ITER & TECHNOLOGY PROGRAM

Plasma Interactive Materials

PROGRAM STATUS
4TH QUARTER — FY 1995

TASK: PLASMA INTERACTIVE MATERIALS

B/R NO: AT-15-04-01E

FY95 FUNDING: \$290 K

CONTRACT NO.: DE-AC03-89ER52153

FY95 PLAN: \$290 K

GA PRINCIPAL INVESTIGATOR: C. WONG

OAK PROJECT MANAGER: M. FOSTER

OFE PROGRAM MANAGER: M. COHEN

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Operate & maintain the DiMES system	←	ONGOING	→
2. Coordinate & conduct erosion & redeposition experiments	←	ONGOING	→
3. Coordinate DIII-D, SNL, & ANL results	←	ONGOING	→
4. Characterize divertor conditions	←	ONGOING	→
5. Characterize the retention of deuterium	4th Q FY95	ONGOING	→
6. Measure the poloidal distribution of erosion	4th Q FY95	ONGOING	→
7. Continue the development of the in-situ measurement diagnostic	←	ONGOING	→
8. Initiate DiMES system upgrade	←	ONGOING	→
9. Support the FY95 U.S./Russia, U.S./Japan & U.S./EC exchanges	4th Q FY95	ONGOING	→
10. Coordinate the U.S./Japan Workshop	1st Q FY95		Cancelled
11. Participate in the ITER PFC project meetings	←	ONGOING	→

REMARKS:

PROGRAM STATUS

4TH QUARTER — FY1995

PLASMA INTERACTIVE MATERIALS

HIGHLIGHTS:

- We exposed the second DiMES sample with Be/W striped coatings to 13 s of high power ELMing H-mode plasma.
 - High uptake of deuterium about 2×10^{17} atoms/cm² was recorded for V. Be and C were lower by a factor of two, and Mo and W were lowest by about a factor of ten.
-

1. Erosion and Redeposition Experiments

The second DiMES sample with Be/W striped coatings was exposed to four DIII-D plasma shots, for a total of 13 s, to the outer strike point of a three source ELMing H-mode plasma. Spectroscopy of neutral and singly ionized Be during the exposure indicates constant erosion. Discoloration of the sample's surface was dramatic compared to previous erosion measurements with single source ELM-free H-modes. The sample was sent to SNL-NM for analysis.

Modeling of earlier erosion experiments has proven successful at predicting the redeposition profiles of Be and W. Preliminary efforts at deducing the erosion rate from absolute line brightnesses of Be II are promising.

2. DiMES-Disruption

The slotted DiMES head with a Silicon wafer was exposed to density limit disruptions. Although the outer strike point was positioned at the DiMES radial location, the outer heat flux leg was 5 cm outboard of the DiMES, no significant heat flux was delivered to the probe.

The DiMES slotted sample is also exposed to a non-disrupting plasma in order to benchmark the quantity of central plasma produced charge-exchanged deuterons which impact the sample. This is necessary to verify the results from disruption studies.

The DiMES triple probe has been assembled, inserted, and successfully tested for the first time.

3. Deuterium Implantation

Deuterium areal density measurements by W. Wampler of SNL showed the results from Be/W and Mo/V coated DiMES samples. High uptake of about 2×10^{17} atoms/cm² was recorded

for V. Be and C were lower by a factor of two, and Mo and W were lowest by about a factor of ten.

4. Development of V-Alloy

The screw-top DiMES head was fitted with Vanadium charpy notch samples and exposed to a DIII-D bakeout. This was to test the Vanadium's tensile properties after exposure to typical tokamak bakeout temperatures and gases. The Vanadium samples were returned to ANL for post-exposure testing.

ITER & TECHNOLOGY PROGRAM

Radiation Testing of ITER Magnetic Coil

PROGRAM STATUS
4TH QUARTER — FY 1995

TASK: RADIATION TESTING OF ITER MAGNETIC COIL

B/R NO: AT-15-04-02G

FY95 FUNDING: \$50 K

CONTRACT NO.: DE-AC03-89ER52153

FY95 PLAN: \$90 K*

GA PRINCIPAL INVESTIGATOR: R. SNIDER

OAK PROJECT MANAGER: M. FOSTER

OFE PROGRAM MANAGER: W. WIFFEN

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Complete the fabrication of test magnetic coil	4 th Q FY94	4 th Q FY95	4 th Q FY95
2. Complete fabrication and testing of long pulse integrator	1 st Q FY95	4 th Q FY95	4 th Q FY95
3. Test of coil/integrator in the Brookhaven reactor	2 nd Q FY95	1 st Q FY96	

REMARKS:

*Includes \$40K carryover from prior year.

PROGRAM STATUS
4TH QUARTER — FY1995
RADIATION TESTING OF ITER MAGNETIC COIL

HIGHLIGHTS:

- The test coil has been assembled and is at Brookhaven awaiting reactor time.
 - The long pulse integrator has been tested successfully and is at Brookhaven awaiting reactor time.
-

1. Magnetic Coil Design

A magnetic coil has been fabricated and assembled and shipped to Brookhaven awaiting reactor time. ORNL completed the pressure vessel "rabbit" and will participate in the test at Brookhaven. The reactor test was scheduled for late August 1995 but has been delayed until early October 1995 due to reactor schedule changes and concerns from the Brookhaven safety committee on the thermal calculations done on the probe. The thermal concerns have been resolved. A paper on coil design and test was presented at the SOFE conference.

2. Long Pulse Integrator

The long pulse integrator has been tested successfully and shipped to Brookhaven awaiting the reactor test. A paper on the integrator development and results was presented at the SOFE conference.

ITER & TECHNOLOGY PROGRAM

SiC/SiC Composite Material Development

PROGRAM STATUS
4TH QUARTER — FY 1995

TASK: SiC/SiC COMPOSITE MATERIAL DEVELOPMENT

B/R NO: AT-15-05-01-0

FY95 FUNDING: \$50 K

CONTRACT NO.: DE-AC03-89ER52153

FY95 PLAN: \$50 K

GA PRINCIPAL INVESTIGATOR: C. WONG

OAK PROJECT MANAGER: M. FOSTER

OFE PROGRAM MANAGER: W. WIFFEN

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Develop, fabricate and evaluate advanced composite materials	←	ONGOING	→
2. Develop, fabricate and characterize leak tight tubes	←	ONGOING	→
3. Develop and evaluate different joining techniques	←	ONGOING	→
4. Assess the need of low activation materials for advanced fusion power plant operation	←	ONGOING	→

REMARKS:

PROGRAM STATUS

4TH QUARTER — FY1995

SiC/SiC COMPOSITE MATERIAL DEVELOPMENT

HIGHLIGHTS:

- High-Nicalon and Super-Nicalon SiC fibers were received. We proceeded on the fabrication of different composite samples with different coatings.
-

Sample Fabrication

We received both High-Nicalon and Super-Nicalon fibers from PNL. We also met and exchanged ideas with Prof. Kohyama of Japan. A program plan to fabricate SiC composite materials with alternate fibers and coatings was established. Samples will be fabricated with the indicated reinforcement coating in the following:

1. CG Nicalon fabric with 0.2 mm C coating.
2. CG Nicalon fabric with 0.2 mm porous SiC coating
3. CG Nicalon, unidirectional fiber, with 0.2 mm C coating
4. Hi Nicalon, unidirectional fiber, with 0.2 mm C coating
5. Hi Nicalon, unidirectional fiber, with 0.2 mm porous SiC coating
6. Hi Nicalon, unidirectional fiber, with 0.4 mm porous SiC coating
7. Super Nicalon, unidirectional fiber, with 0.2 mm C coating
8. Super Nicalon, unidirectional fiber, with optimized coating from Hi Nicalon study (*e.g.* 0.2 mm porous SiC coating)
9. Super Nicalon, unidirectional fiber, with optimized coating from Hi Nicalon study (*e.g.* 0.4 mm porous SiC coating)

The tooling was designed and fabricated to fit the experimental Chemical Vapor Infiltration (CVI) reactor. Samples 1, 4 and 7 were completed. The development of porous SiC coating is on-going.

A summary report on the assessment of SiC/SiC composite material was reviewed by C. Wong and returned to PNL.