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PROGRAM STATUS 3rd QUARTER – FY 1990

FUSION TECHNOLOGY DEVELOPMENT

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PROGRAM STATUS REPORT
CONTRACT DE-AC03-89ER52153
3RD QUARTER - FY90

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FUSION TECHNOLOGY DEVELOPMENT

3rd QUARTER FY90

- **Reactor Studies – ARIES**

- On May 9 DOE/OFE directed the ARIES Team to defer work on the ARIES-II second stability regime tokamak and to begin work immediately on the ARIES-III advanced fuel (D-³He) tokamak design.
- Clement Wong's exploration of first wall options for ARIES-III indicates that the synchrotron radiation reflectivity of the wall must be quite high and will be a major design driver. Thin metallic films on a low activation base should provide adequate reflectivity, but plasma erosion of the thin film is a major concern.

- **RF Technology**

- Varian EIMAC successfully assembled the two developmental X2274 Tetrode tubes and shipped them to Japan on schedule for testing.
- Doug Remsen participated in tube testing at JAERI. The tests were very successful. The tubes exceeded their design specifications, operating at 1.7 MW for 5.4 seconds at 131 MHz, limited only by the capabilities of the test equipment.

- **Fusion Nuclear Technology**

- China shipped both the U.S. and the Chinese beryllium shells to Osaka University in Japan, initiating the second phase the "Coordinated U.S./PRC, U.S./Japan, PRC/Japan Fusion Neutron Integral Experiments."
- Ed Cheng represented the OFE fusion nuclear data user community at the Cross Section Evaluation Working Group (CSWEG) meeting at BNL.

- **Plasma Facing Components**

- Design, fabrication and installation on DIII-D of the in-vessel components of the Divertor Material Exposure System (DIMES) is complete.
- Preliminary analysis of the net erosion and redeposition of carbon in the DIII-D divertor by ANL shows reasonable agreement with the preliminary reports of divertor tile measurements by SNL-L.

PROGRAM STATUS
3RD QUARTER - FY 1990

TASK: REACTOR STUDIES

B/R NO: AT-15-03

FY90 FUNDING: \$330 K

CONTRACT NO: DE-AC03-89ER52153

FY90 PLAN: \$330 K

GA PRINCIPAL INVESTIGATOR: C. P. C. WONG

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: S. BERK

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Complete conceptual design and evaluation of the ARIES-I High Field Tokamak Reactor	2 nd Q FY90		2 nd Q FY90
2. Develop the conceptual design of the ARIES-II Second Stability Tokamak Reactor	1 st Q FY91	1 st Q FY92 *	
3. Develop the conceptual design of the ARIES-III Advanced Fuel Tokamak Reactor	1 st Q FY92	1 st Q FY91 *	

REMARKS:

* At the May 9, 1990 ARIES project meeting DOE/OFE asked the team to reverse the order of the ARIES-II and -III work.

PROGRAM STATUS

3RD QUARTER - FY 1990

REACTOR STUDIES

HIGHLIGHTS:

- The ARIES-I blanket design team has completed the preparation of the ARIES-I reactor design final report.
  - For the ARIES-II reactor design we evaluated the helium-cooled, lithium breeder, SiC-composite structure blanket option and found that the corrosion resistance of the SiC in lithium is very poor.
  - At the direction of DOE/OFE, the ARIES team was asked to defer work on the ARIES-II second stability regime D-T tokamak and to begin work on the ARIES-III D-³He advanced fuel design. From the evaluation of suitable materials to be used for the ARIES-III fusion power core design, we found that in order to provide adequate synchrotron power reflection to maintain plasma power balance, Be, Cu or W are the only suitable materials to be used as the first wall synchrotron wave reflective film inside the plasma chamber. This will have strong design impacts on the ARIES-III reactor design.
-

During the months of April, May and June of 1990, we completed the preparation of the blanket design chapter of the ARIES-I reactor design final report. We evaluated the helium-cooled Li-breeder, SiC-composite structure design option for the ARIES-II design. We also evaluated different design options for the ARIES-III design. The following gives a summary of these evaluations.

1. Blanket Design

For the ARIES-II Second Stability Reactor (SSR) design, based on the guidance of utilizing moderately advanced engineering technology, we continued to evaluate the helium-cooled lithium breeder, SiC-composite structure blanket concept. We investigated the compatibility of SiC with lithium. Experimental results showed that at 816°C, the corrosion resistance of SiC in lithium is very poor, unless some protective coating can be found. Lithium doping with carbon is a promising technique to prevent erosion, but

the presence of the temperature gradients in the blanket may allow thermal transport of carbon to occur.

There was a direction change in the ARIES study. Based on the guidance of Bob Price, DOE/OFE manager of Fusion Technology and the perceived interest of NASA to receive recommendations on the performance of an advanced fuel D-³He fusion reactor in about a year, the ARIES team was directed to work on the ARIES-III advanced fuel D-³He reactor design before the ARIES-II second stability reactor design. After extensive discussions during the May 7-9 ARIES project meeting at UCLA, for the coming 9 months, the ARIES team will concentrate on the design of a first or second stability regime, advanced fuel D-³He reactor.

Based on the above direction change we initiated the design evaluation and material selection of the ARIES-III engineering design.

In order to maintain plasma energy balance, we found that the required synchrontron reflectivity of the first wall is very high. This reflectivity requirement ranges from 99% for the first stability plasma with synchrotron direct conversion, to about 80 to 90% for the second stability plasma design with thermal conversion only. These requirments restrict the selection of first wall materials to only Al, Be, Cu and W. Preliminary results indicated that for the needed high synchrontron wave reflection the required metallic thickness inside the plasma chamber is only one to a few microns thick. Therefore the selection of material used as a thin film is not crucial in the consideration of afterheat and induced radioactivity. The use of thin metallic film materials like W, Be, Cu or Al will not negate the low activation and negligible afterheat advanatages of SiC when it is used as the structural material. On the other hand, when normal conducting Ergodic Magnetic Limiter (EML) coils are used for the particle and plasma ash control to achieve a uniform spread of surface heat loading, the requirement of relatively large amounts of normal coil materials near the plasma first wall will have strong impact on induced radioactivity. The effect on afterheat is not very significant, since the neutron wall loading for the ARIES-III design is low at 0.1 MW/m². Further evaluation of the trade-off on the use of high-Z materials in the plasma chamber and the acceptable plasma operating conditions will continue.

2. Physics

The Distributed Parameter Power Rectifier (DPPR) microwave rectifier concept was reviewed and evaluated as a synchrotron power rectenna. Although there are some problems with the published analysis, the preliminary judgement is that this concept is more or less on a par with other rectenna concepts that have been considered for ARIES.

Based on a ray tracing technique, we found that the conventional converging horn wave guide design may not be suitable for the synchrotron power conversion design. This is due to the potentially high energy dissipation during transmission of the wave in the wave guide because of the large number of reflections within the wave guide. A converging and diverging horn design was proposed. This will allow the waves to be reflected at shallow angles, thus reducing the energy dissipation. We also found that in order to reduce the number of openings and the loss of surface coverage in the plasma chamber, it may be possible to locate the wave guides at the divertor chamber. Further study on the configuration of this design approach will also be continued.

PROGRAM STATUS
3RD QUARTER - FY 1990

TASK: RF TECHNOLOGY

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

FY90 FUNDING: \$210 K

CONTRACT NO: DE-AC03-89ER52153

FY90 PLAN: \$325 K

GA PRINCIPAL INVESTIGATOR: D. B. REMSEN, JR.

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: T.V. GEORGE

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Assemble and ship two X2274 tubes to JAERI.	1 st Q FY90	3 rd Q FY90	3 rd Q FY90
2. Test tubes at JAERI	4 th Q FY90		3 rd Q FY90
3. Return tubes to U.S.	4 th Q FY90		

REMARKS:

PROGRAM STATUS

3RD QUARTER - FY 1990

RF TECHNOLOGY

HIGHLIGHTS:

- Varian EIMAC completed fabrication of two X2274 Tetrode tubes and shipped them to Japan for testing on schedule.
  - JAERI carried out testing to the two tubes on schedule. Both tubes operated successfully above specifications. The tubes achieved output power of 1.7 MW at 131 MHz for 5.4 seconds, limited only by the test equipment.
-

Varian EIMAC successfully overcame the X2274 tetrode tube prototype development assembly difficulties described in the previous quarterly report. Meticulous brazing of the copper septum to the exterior of the anode gave adequate strength to withstand the thermal stress and cooling water pressure. Use of a redesigned and strengthened stainless steel washer at the base of the anode gave adequate rigidity to the anode to maintain proper anode to screen grid spacing.

The two X2274 tubes were shipped to the RF Test facility at JAERI in Japan on schedule. Doug Remsen from GA and Marshal Loring of Varian joined the JAERI test team (Y. Ogawa, S. Moriyama, M. Terakado, K. Anno, T. Fujii, and M. Ohta) on June 11, 1990 for five weeks of testing.

The tests demonstrated that the tubes exceeded their design specification of 1.5 MW, delivering up to 1.7 MW for 5.4 seconds and 1.8 MW for 50 msec, both at 131 MHz. These levels are believed to be a world's record for a single grid tube. The system efficiency was 62% with a system gain of 12.3 dB. The tube performance was limited by the capabilities of the test system, not the tube itself. The negative screen grid current that had caused overheating and limited the power of the predecessor X2242 tube was reduced to less than 1% of the previous level.

Voltage standing wave ratio (VSWR) tests were carried out to determine the dependence of tube efficiency, gain and screen grid current on the magnitude and phase of the load VSWR. The tubes demonstrated that they can reliably operate at the VSWR conditions required for use on fusion experiments. Specifically, they will perform well on JT-60U, and are viable for use on U.S. devices as well, such as CIT, CMOD and DIII-D.

A copy of the JAERI brief experimental program report is attached.

US-JAPAN FUSION TECHNOLOGY COLLABORATION PROGRAM
X2274 POWER TEST

1. Period : June 11th ~ July 6th, 1990

2. Test Team : Y. Ogawa, S. Moriyama, M. Terakado,
K. Anno, T. Fujii, M. Ohta (JAERI)
D. Remsen (GA), M. Loring (Varian EIMAC)

3. Results (comparison to X2242 tested last year)

	X2274 (1990)	X2242 (1989)
Improve-ment	- Reduced RF resistance (about 1/2 of X2242's) of the screen grid by changing grid pattern. - Improvement of anode cooling efficiency.	Pyrolytic graphite grids for increasing allowable dissipation.
Maximum power output	1.8MW 50msec (131MHz) 1.7MW 5.4sec (131MHz)	1.6MW 0.5sec (131MHz) 1.0MW 10sec (131MHz) 1.5MW 6sec (110MHz)
Limitation	Limit of the test equipment, e.g. insufficiency of drive power.	Excessive screen grid RF heating
VSWR Test	Data, e.g. gain and dissipation, were taken at : VSWR=1.5, 1.2MW, and VSWR=2.0, 0.9MW (131MHz), to simulate an antenna coupled to the plasma. It was confirmed that X2274 can be used under such conditions.	Data were taken at VSWR=1.5, 1.0MW and VSWR=2.0, 0.75MW (110MHz).

4. Evaluation

The improvement of the screen grid significantly reduces the screen reverse current. The maximum power output was limited by the performance of the test equipment. The maximum power is a world record with tetrode for fusion research above 110MHz.

These tests proved that the system design changes made to use the X2274 on JT-60U perform well.

5. Possible collaboration :

Further collaboration will be determined at the US-Japan steering committee on July 11th. Japan side will propose the determination of future collaboration after the completion of the analysis, evaluation, and publication of the test results.

PROGRAM STATUS
3RD QUARTER - FY 1990

TASK: FUSION NUCLEAR TECHNOLOGY

B/R NO: AT-15-02-01A

FY90 FUNDING: \$60 K

CONTRACT NO: DE-AC03-89ER52153

FY90 PLAN: \$60 K

GA PRINCIPAL INVESTIGATOR: E. T. CHENG

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: S. BERK

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Represent OFE at CSEWG and DOE NDC meetings	3 rd Q FY90		3 rd Q FY90
2. Update OFE nuclear data needs assess- ment and nuclear data request list	4 th Q FY90		
3. Participate in IAEA FENDL activities			
— Beryllium data testing	4 th Q FY90		
— Activation comparison	3 rd Q FY90		3 rd Q FY90
4. Interface with international nuclear data development activities	←	ONGOING	→

REMARKS:

PROGRAM STATUS

3RD QUARTER - FY 1990

FUSION NUCLEAR TECHNOLOGY

HIGHLIGHTS:

- The U.S. and Chinese beryllium shells were shipped from PRC to Osaka University in Japan, beginning the second phase of the "Coordinated U.S./PRC, U.S./Japan and Japan/PRC Fusion Neutron Integral Experiments," coordinated by Ed Cheng of GA.
  - Ed Cheng represented the OFE nuclear data user community at the Cross Section Evaluation Working Group (CSEWG) meeting at BNL.
  - New fusion nuclear data experiments are being initiated for $O(n, \alpha)$ and $Tc-99(n, p)$ cross sections. These multi-lab, multinational tasks are being coordinated by Ed Cheng of GA.
-

Cheng was in China in March/April 1990 participating in a U.S./PRC Workshop on Fusion Reactor Design Studies under the U.S./PRC Cooperation Agreement on Fusion Nuclear Technology. The OFE Nuclear Data Needs Coordination Activities were conducted while Cheng visited the Chinese research facilities in Beijing, Lanzhou, and Chengdu.

Cheng also visited Osaka University, JAERI/FNS, and the University of Tokyo to discuss with the Japanese scientists about the recent progress of fusion nuclear data development activities.

The U.S./PRC joint integral experiment on beryllium was completed in March. The U.S. beryllium shells were shipped from Beijing to Osaka, Japan, on March 30, 1990. The PRC beryllium shells were shipped to Osaka at the end of June, 1990. They were received by Professor K. Sumita of Osaka University.

A draft Japan/PRC Cooperation Agreement was prepared on Joint Integral Experiments on Beryllium. Cheng acted as the coordinator of this activity.

Ed Cheng attended the Cross Section Evaluation Working Group meeting at Brookhaven National Laboratory in May, representing OFE users. The latest cross section library, ENDF/B-6, has been released for unrestricted access. Due to funding cutbacks in the fusion program, however, no one in the U.S. is presently planning to use this basic data library to prepare cross section sets that can be used for actual neutronics analysis, nor are there plans for U.S. groups to do data testing with the new library. It is hoped that groups in Europe or Japan will do this work and that we can get access to the results through our international nuclear data cooperation programs.

Coordination of measurements for $O(n, \alpha)$ cross sections at 14 MeV was initiated during June. The $O(n, \alpha)$ cross section is crucial to improve the accuracy of neutron multiplication integral experiment on beryllium being performed at EG&G/Idaho. The present accuracy of the $O(n, \alpha)$ cross section evaluation is about 20%. We need about 5% accuracy. Three measurements were proposed and being coordinated: 14 MeV neutron experiments on (1) BeO samples at LANL, (2) BeO samples at ORNL, and (3) A liquid oxygen sample at the Fusion Neutron Source facility at JAERI.

As proof-of-principle for fusion applications, coordination is being conducted for the measurement of the $Tc-99(n, p)$ cross section at 14 MeV. A medical radioisotope, Mo-99 (and subsequent decay daughter nuclide, Tc-99m), will be produced by the $Tc-99(n, p)$ reaction. The Fusion Neutron Source facility at JAERI, Japan, has agreed to conduct the measurement. The Tc-99 sample, which is long-lived fission product, is being produced by Hanford for this purpose.

PROGRAM STATUS
3RD QUARTER - FY 1990

TASK: PLASMA-FACING COMPONENTS

B/R NO: AT-15-02-031

FY90 FUNDING: \$155 K

CONTRACT NO: DE-AC03-89ER52153

FY90 PLAN: \$165 K

GA PRINCIPAL INVESTIGATORS: C. P. C. WONG/K. R. SCHULTZ

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: M. COHEN

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Remove divertor test tiles from DIII-D and provide to SNL-L for measurement.	4 th Q FY89		1 st Q FY90*
2. Compile DIII-D divertor operating condition history, provide to ANL for REDEP analysis and compare measured erosion/redeposition with predictions of analytic models.	2 nd Q FY90	3 rd Q FY90	
3. Design for installation on DIII-D sample transfer equipment for erosion/redeposition measurements.	3 rd Q FY90		3 rd Q FY90
4. Host the 3rd U.S./Japan Workshop on Plasma Facing Components.	2 nd Q FY90		2 nd Q FY90
5. Fabricate and install on DIII-D the in-vessel components of the Divertor Material Exposure System (DIMES).+	4 th Q FY90		

REMARKS:

*Fall 1989 vent of DIII-D delayed until 12/89.

+New Task, added 6/20/90.

PROGRAM STATUS

3RD QUARTER - FY 1990

PLASMA-FACING COMPONENTS

HIGHLIGHTS:

- Design and installation of the Divertor Material Exposure System (DIMES) in-vessel components on DIII-D is complete.
-

1. Divertor Materials Exposure System

Design and installation of the DIII-D DIMES system in-vessel components has been completed. The first DIMES graphite sample will be exposed to DIII-D plasma shots after the closing of the DIII-D vent at the end of July. This graphite sample was supplied by Sandia. During this first phase of the DIMES experiment, we will be able to remove and replace the sample during the next clean vent of DIII-D. We intend to install the in-vessel components for the second phase of the DIMES experiment in time for the next clean vent of DIII-D, expected in December 1990. With the installation of the motorized sample removal system, we will be able to remove and replace the sample after as little as one day of operation. For the third phase of the DIMES experiment, with the installation of the ellipsometric laser measurement system, we will be able to study the graphite erosion and redeposition on the DIMES sample *in-situ*.

First sample of DIMES has been installed in DIII-D, along with the leveling of the surrounding divertor tiles. After the sample was installed, a small displacement of ± 0.5 mm was detected when one pushed on the top of the DIMES' surface. This is potentially due to non-exact matching of the DIMES sample and the metallic supporting plate conical contact surfaces. This could increase the thermal resistance between the sample and the vessel cooling water and reduce the matching of the temperature of the DIMES sample to the surrounding tiles after a series of high power shots. However, this is not considered to be critical to the design since the temperature of the DIMES surface will be monitored by the RF camera during plasma operation. Tighter tolerance on the angle of the DIMES sample contact surface has been specified for fabrication of the next sample.

2. Analysis

Preliminary REDEP code calculations by ANL indicated that during the period of March to December of 1989, at a total of about 3000 shots with a broad distribution of strike points, the nominal total net erosion and redeposition of the twelve DIII-D divertor integral test tiles are 18 and 16 microns, respectively. These correspond quite closely to earlier estimates. Preliminary indications from the measurements being done at SNL-L are that the measured net erosion and redeposition will be approximately $6\mu\text{m}$ each. Since the net erosion and redeposition rates are only about 15% of the gross erosion rate this level of agreement at the preliminary analysis stage is encouraging. More accurate measurements and analysis are eagerly awaited.

Thermal analysis was performed by GA to evaluate the cooling of the DIMES samples relative to DIII-D divertor tiles. We found that at a contact pressure of 25 psi, stainless steel is a suitable base plate material for DIMES. At a cooling time of 600 sec, and after 20 shots, the initial sample temperature before the shot is 135°C , compared to the approximately 40°C temperature of the surrounding divertor tiles. If desired, the sample temperature can be made equal to the divertor tile temperature by increasing the cooling time of the sample in between shots.