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PROGRAM STATUS 3rd QUARTER – FY 1989

FUSION TECHNOLOGY DEVELOPMENT

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JULY 17, 1989

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PROGRAM STATUS REPORT
CONTRACT DE-AC03-89ER52153
3RD QUARTER - FY89

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FUSION TECHNOLOGY DEVELOPMENT

3rd QUARTER FY89

- **Reactor Studies – ARIES**

- A highly efficient TF coil structural concept was developed that could yield cost savings for ITER and other fusion reactors.
- Beryllium was added to the two blanket concepts to improve energy multiplication and reduce the COE.

- **RF Technology**

- The U.S./Japan Steering Committee reviewed and approved the proposed X2242 ICRH tube improvements. Two upgraded tubes will be tested at JAERI in April 1990.

- **Fusion Nuclear Technology**

- Ed Cheng attended the IAEA meeting on the International Fusion Evaluated Nuclear Data Library (FENDL). The first version of this international library will be available by mid-1990.

- **Plasma Facing Components**

- Integral erosion study exposure continues in DIII-D with planned removal of the 12 graphite divertor tiles in January 1990 and expected net erosion of 10 to 20 μm .
- Design work has begun on the *in situ* erosion measurements using a laser ellipsometry technique.

- **Fusion Materials**

- A NIM report has been drafted compiling data on Mn-stabilized “low activation” austenitic stainless steels that are being considered for ITER.

PROGRAM STATUS

3RD QUARTER - FY 1989

REACTOR STUDIES

HIGHLIGHTS:

- The ARIES project schedule has been re-arranged to allow continued scoping of ARIES-II and -III while conceptual design of ARIES-I is completed.
 - The cold support concept for the ARIES TF coil design was developed further by Lew Creedon. He found that the overturning forces can be supported by properly designed top and bottom caps. This will allow completely open outboard access for maintenance between TF coils. This concept not only works for aspect ratio 6 and 4.5 machines, but it also works for ITER. This can potentially ease the ITER coil support requirement of fabricating 0.4 m-thick metal parts and reduce the mass of the coil support system by 2000 tons.
 - Clement Wong and Edward Cheng re-evaluated the 0.5 MPa CO₂ gas, Li₄SiO₄ breeder particulate and Be-multiplier design. This design can have blanket energy multiplication in the range of 1.2 to 1.6, which should significantly reduce the cost of electricity for the ARIES-I reactor design.
-

During the months of April, May and June of 1989, the ARIES tokamak reactor study began detailed design of the ARIES-I "near-term physics" design. We focused our effort on TF coil support, blanket internal design, neutronics analysis and plasma vertical stabilization. Scoping studies on the ARIES-II advanced fuel reactor are continuing at a low level. GA's contributions are on advanced fuel physics and innovative current drive techniques.

1. TF Coil Support

The cold support concept for the ARIES TF coil design was developed further by Lew Creedon. He found that the TF coil over-turning forces can be supported by two properly designed top and bottom caps. This will allow completely open access for maintenance between TF coils. He found that this design approach does not only apply to the aspect ratio 6 and 4.5 ARIES-I machines but also to the ITER design. Previous designs have supported the magnet over-turning loads between the longer

load path at the outboard side of the coils. Creedon found that our design is much more structurally efficient by supporting the loads between the shorter load paths on top and bottom of the coil set. Applying this design approach to ITER will eliminate the need for the fabrication of 0.4 m thick metal parts and reduce the mass of the coil support system by 2000 tons. The key disadvantage for the application of this design approach to ITER is that the presently proposed vertical maintenance scenario will have to be re-evaluated.

Lew Creedon completed the scoping design of the vacuum boundary concept. Two vacuum boundaries are envisioned; the magnet dewar vacuum and the vacuum chamber vacuum. One of the vacuum boundaries, in fact, will interface between these two regions. Easy access is provided to all seal welds for maintenance. The inboard weld will require a special tool, but is a simple vertical seam.

2. Blanket Design

Clement Wong performed scoping thermal-hydraulics calculation on the ARIES-I blanket design. He calculated the radial temperature distribution of the solid breeder at the coolant inlet and outlet locations of the blanket module. He found that the Li_2O breeder surface temperature can vary between 604 to 907°C, and the breeder center-line temperature can vary between 654 to 1017°C. With this information, the UCLA team found that the chemical reactions between CO_2 , Li_2O and T_2O may be intolerable, since these reactions will lead to the formation and transport of LiOT and Li_2CO_3 . These chemical concerns appear to preclude use of this combination of CO_2 gas and Li_2O solid breeder.

Clement Wong and Edward Cheng then re-evaluated the CO_2 gas, Li_4SiO_4 breeder particulate and Be multiplier design. This design can have blanket energy multiplication in the range of 1.2 to 1.6, which is much higher than the value of 1.05 when beryllium is not used. The use of Be metal was proposed to and accepted by the ARIES project. Subsequently, the project directed the blanket design team to aim for a blanket energy multiplication of 1.4 which should significantly reduce the cost of electricity for the ARIES-I reactor.

We are going to evaluate and compare this 0.5 MPa CO_2 particulate design to the 5 MPa helium-cooled design. Both design concepts will be using Be metal to enhance the blanket energy multiplication.

3. Neutronics

If the blanket pressure is increased, more SiC structure will be needed. With the increase of SiC structure volume fraction from 6.4 to 14%, the blanket/shield thickness was analyzed for the ARIES-I design. In order to obtain a tritium breeding ratio of 1.13, Edward Cheng found that the Li_2O blanket thickness will need to be increased from 60 to 80 cm.

While the overall tritium breeding ratio is expected to be ~ 1.1 , the total blanket energy multiplication of the reference design is quite modest at 1.05. Cheng has investigated the impact of lithium burn-up during the blanket lifetime and concluded that the effect is negligible. Waste disposal analysis shows that ARIES-I will meet 10CFR61 Class C disposal guidelines when the blanket is disposed as a unit (averaging the first wall and remainder of the blanket together) and that the divertor will similarly meet these constraints. Careful attention must be paid to some specific impurities (Ag, Nb, and Mo) to keep them in the 1 ppm range or below, at least in the first wall material. Afterheat and shutdown dose are totally dominated by the tungsten divertor target. This material makes a significant impact on the overall low activation characteristics of ARIES-I. Cheng also investigated the potential for improvement of blanket energy multiplication by including beryllium in the blanket. A few centimeters of beryllium at the front of the blanket could significantly improve energy multiplication.

4. Plasma Vertical Stabilization Shell Design

Based on the latest ARIES-I $A = 6$, equilibrium parameters, Jim Leuer calculated the required location of the passive shell to stabilize the vertical motion of the plasma. He found that even with use of a full coverage, highly conducting, aluminum shell (the vacuum chamber wall) behind the blanket, on both inboard and outboard sides, the stability margin is too low. Passive stabilization shells must be located close to the first wall.

The vertical stability requirements for the lower aspect ratio plasma ($A = 4.5$) were then established. At a plasma elongation of 1.74, it was found that the plasma vertical stability requirements can be satisfied by passive shells (vacuum chamber) located behind the inboard and outboard blankets. This result will be confirmed by the more detailed TSC code calculation.

Lew Creedon developed a design for in-vessel passive stabilizers. The swelling tolerant in-vessel stabilizing shell is based on a multi-leaf design, which is composed of many layers of thin Be metal sheets. This multi-leaf structure is connected to the Be metal in-chamber shell. Any deformation due to the irradiation induced swelling of the Be shell can be absorbed by this multi-leaf structure. This design is proposed if in-chamber plasma vertical stabilizers are needed in addition to the vacuum vessel behind the blanket.

5. Advanced Fuels

The plasma compression and expansion concept proposed by GA is now considered as a backup to the direct electrodynamic conversion concept proposed by M. Peng of FEDC. Both concepts are to be applied to the spherical torus version of the ARIES-II reactor design.

Mike Schaffer helped W. Kernbichler and T.K. Mau to evaluate synchrotron radiation calculation methods. He provided recommendations on hole and port design to reduce unwanted synchrotron radiation escape. He also contributed antenna ideas for rectenna synchrotron power conversion.

6. DC Helicity Injection Current Drive

In order to make better estimates of requirements and efficiency of dc helicity injection current drive (DCHICD), M. Schaffer extended his analytical scrape off layer model and benchmarked it against DIII-D data and a Braams code computation. He also improved the plasma helicity dissipation model. ARIES-I and ARIES-II DCHICD performance was calculated. Overall current drive efficiencies of about 1 A/W are predicted in both cases. Ohmic power of injected current in the scrape off layer is the principal effect limiting efficiency.

PROGRAM STATUS
3RD QUARTER - FY 1989

TASK: REACTOR STUDIES

B/R NO: AT-15-03

FY89 FUNDING: \$300 K

CONTRACT NO: DE-AC03-89ER52153

FY89 PLAN: \$300 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 scoping of the ARIES-I High Field Tokamak Reactor Concept	1 st Q FY89		1 st Q FY89
2. Develop the scoping design of the ARIES-II Advanced Fuel Tokamak Reactor	2 nd Q FY89	2 nd Q FY90	
3. Develop the scoping design of the ARIES-III Advanced Physics Tokamak Reactor	3 rd Q FY89	1 st Q FY91	
4. Complete conceptual design and evaluation of the ARIES-I High Field Tokamak Reactor	4 th Q FY89	1 st Q FY90	

REMARKS:

The ARIES project schedule has been rearranged to allow continued low level scoping of ARIES-II and ARIES-III while the conceptual design of ARIES-I is done.

PROGRAM STATUS

3RD QUARTER - FY 1989

RF TECHNOLOGY

HIGHLIGHTS:

- A U.S.-Japan Steering Committee meeting on the U.S.-Japan ICRH tube test was held May 9, 1989.
 - We started testing on model tubes as part of tube anode upgrade effort.
-

ICRH Tube Tests

During this quarter a U.S.-Japan Steering Committee meeting was held on May 9, 1989 at Varian Eimac in San Carlos, California to discuss the U.S.-Japan ICRH Tube Tests. Dr. Takase Nagashima represented JAERI, Mr. Stan Staten represented Department of Energy, and Doug Remsen of General Atomics also participated in meeting.

The delegates agreed that this technology exchange benefits both countries directly and fusion research in general by providing a demonstration of a higher power and more reliable ICRH source.

Based on the success of the tests just completed this January and February at the Naka Fusion Research Establishment, the committee has recommended that continuation of the tests take place with the goal being to demonstrate 1.6 MW at 130 MHz for 10s, which they felt was possible. Additional testing should also be conducted at 120 MHz and 110 MHz which would be specific to JT-60U and CIT requirements. The committee agreed that a technical and schedule meeting would take place some time in the fourth quarter of 1989 and that JT-60 would be ready for testing at the Naka site in the 1990 April/May time frame, with April 16 being the tentative date.

Concerns were allayed after both parties had examined the inside of tube CGN-25 (the X2242 tube just used for testing in Japan) and found no heating damage. When Eimac proposed plans to further reduce the effects of rf circulating current on the screen grid by increasing vertical current-carrying conductors in the screen mesh and, in addition, blackening the inside of the collector to reduce emissivity, the committee agreed that it appeared as though sufficient steps had been taken to reduce screen heating effects to an acceptable level. The plan is to assemble the anode upgrade tube with the new grids,

and the blackened improved collector. CGN-25 will also be put together using similar components so that we have two identical tubes for the testing program at JT-60. General Atomics will instruct Varian Eimac to ship the tubes to JT-60 in March 1990 for the tests. General Atomics and Eimac personnel will arrive at Naka site on April 16 so that testing can begin. It is again expected that a period of six weeks be allowed for the testing. Upon completion of the testing, a final report will be written with the consensus of the participants.

Anode Upgrade Program

The results of the first series of the tests with improved anode cooling on the model tubes demonstrated a scaling equivalent that demonstrates capability with the full scale tube of 1.4 MW at 1/2 the water flow required before the new anode structure was installed. At this power level the tube gassed up, apparently due to incomplete conditioning prior to high power operation. It will require reconditioning before testing can resume but it is anticipated that those tests will continue the 2nd week of July and be completed by the end of July.

Because of JAERI's desire to do the testing in the April-May, 1990 time frame and our desire to incorporate improvements into both tubes there will be a delay on delivery of both tubes until November 1989. This slip of two months is without cost increases and is compatible with the new schedule, and allows the program to have two identical tubes for the testing in Japan.

PROGRAM STATUS
3RD QUARTER - FY 1989

TASK: RF TECHNOLOGY

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

FY89 FUNDING: \$340 K

CONTRACT NO: DE-AC03-89ER52153

FY89 PLAN: \$340 K

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

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: S. STATEN

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Purchase tube	1 st Q FY88	1 st Q FY89	1 st Q FY89
2. Tube tests at JAERI	3 rd Q FY88	2 nd Q FY89	2 nd Q FY89
3. Analyze tube test results	3 rd Q FY89		3 rd Q FY89
4. Upgrade X2242 tube	4 th Q FY89	1 st Q FY90	

REMARKS:

The tube improvements developed as part of the test program and the anode upgrade will be combined. The rebuilt test tube and the anode upgrade tube will be delivered in November 1989 for testing in the spring of 1990 at JAERI.

PROGRAM STATUS

3RD QUARTER - FY 1989

FUSION NUCLEAR TECHNOLOGY

HIGHLIGHTS:

- Ed Cheng was invited to attend the IAEA Specialists Meeting on the International Fusion Evaluated Nuclear Data Library (FENDL) and Benchmark Calculations in Vienna, Austria. The first version of FENDL should be ready for use by mid-1990.
-

Ed Cheng attended the Cross Section Evaluation Working Group (CSEWG) meeting at BNL (April 3-6) where the status of ENDF/B-VI evaluations was reviewed. There are two serious shortcomings of the present ENDF/B activities. One is the data testing for ENDF/B-VI files. The other is the evaluations for fusion-relevant elements such as F, O, Si and Al.

Ed Cheng attended the first U.S./USSR Workshop on Fusion Neutronics, April 20-21 at UCLA. The Soviet delegation visited GA on April 26 and 27 to discuss international nuclear data development activities.

Ed Cheng attended the U.S. DOE Nuclear Data Committee meeting at Germantown, Maryland, April 24-25. He represented the OFE program fusion nuclear data users at this annual meeting of all U.S. nuclear data activities.

Ed Cheng was invited to attend the IAEA Specialists' Meeting on International Fusion Evaluated Nuclear Data Library (FENDL) and Benchmark Calculations, May 8-11, in Vienna, Austria. The FENDL library will be established for national and international fusion reactor design studies in mid-1990. It appears that the 1990 version of this library will be mostly based on the U.S. ENDF/B-VI evaluations due to the delay of the release of other major evaluations such as JENDL-3 (Japanese evaluations) and EFF-2 (European Fusion Files).

A complete list of decay energy released from all radioactive isotopes was compiled and forwarded to Steve Piet of the Fusion Safety Research program at INEL for a comprehensive safety analysis of all structural, breeder, and shielding materials for fusion reactors. An INEL report based on this study, coauthored by Piet, Cheng, and Porter (MIT), will be published soon.

The joint U.S./Japan beryllium integral experiment in Japan will probably be delayed because the availability of beryllium spheres from China has not yet been determined. Discussions on this subject were scheduled to be held in June between Japan and China. The trip to China by Professor K. Sumita of Osaka University for the negotiation was cancelled due to the Tienanmen Square incident.

PROGRAM STATUS
3RD QUARTER - FY 1989

TASK: FUSION NUCLEAR TECHNOLOGY

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

FY89 FUNDING: \$80 K

CONTRACT NO: DE-AC03-89ER52153

FY89 PLAN: \$80 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, U.S. NDC, and IAEA meetings	←	ONGOING	→
2. Update OFE nuclear data needs assessment and nuclear data request list	4 th Q FY89		
3. Perform comparative analysis of benchmark fusion blankets using U.S. and IFENDL libraries	4 th Q FY89		
4. Coordinate the joint US/PRC and U.S./Japan integral experiment on beryllium - Complete pre-experiment analysis	4 th Q FY89		
5. Recommend improvements in nuclear data libraries and recommend libraries for use in fusion reactor development	4 th Q FY89		

REMARKS:

PROGRAM STATUS

3RD QUARTER - FY 1989

PLASMA-FACING COMPONENTS

HIGHLIGHTS:

- Exposure of 12 well-characterized graphite tiles in the divertor region of DIII-D continues. Estimates of the net graphite erosion prior to the next scheduled vent of DIII-D in January 1990 indicate erosion of 10-20 μm should be expected. This should be adequate for accurate measurement.
 - We have initiated work on the laser ellipsometry technique to be used for *in situ* on-line measurement of erosion and redeposition in the DIII-D divertor.
-

Phase 1 - Integral Tests

Exposure of the integral test tiles in DIII-D continues. Twelve well-characterized graphite tiles were placed into the divertor region of DIII-D in the March 1989 vent. They will be left in the machine during routine operation until the next scheduled vent in January 1990. Characterization of the tiles was done using mechanical profilometry by SNL-L. This technique has demonstrated accuracy and repeatability of $\pm 1 \mu\text{m}$. These 12 tiles will be removed in January 1990 and once again carefully characterized by SNL-L. The measured thickness and surface characteristics of the tiles will allow determination of the net erosion/redeposition behavior across the entire divertor region from inboard of the inner divertor strike point to outboard of the outer strike point.

Roger Vesey, a graduate student from RPI, has joined us for the summer to work on plasma edge transport modeling using the Braams code. He has obtained operating parameters and edge plasma characteristics for the DIII-D divertor from Dave Hill, and used a simple physical sputtering model to estimate the erosion expected in DIII-D. Gross erosion between now and January 1990 is expected to be $\sim 100\text{-}200 \mu\text{m}$, net erosion/redeposition is expected to be $\sim 10\text{-}20 \mu\text{m}$. This should be adequate for accurate comparison between measurement and more detailed analysis.

During a Project Workshop on June 28, we discussed the erosion calculations at length with Jeff Brooks of Argonne who will do the REDEP analysis. We are now preparing the detailed DIII-D operating information needed for Brooks to do REDEP analysis of the DIII-D divertor. We will provide nominal expected operating conditions for a preliminary estimate, and will update this as run data from DIII-D accumulates between now and January 1990. We will include an evaluation of different modes of operation, including L-mode, H-mode, and ELM effects.

Phase 2 - *In Situ* Tests

We have begun work with Wen Hsu of Sandia National Laboratories Livermore to define the design requirements of the laser ellipsometry technique to be used for on-line *in situ* measurement of erosion and redeposition in DIII-D. The ellipsometry technique is being developed by SNL-L; GA will provide experimental apparatus to facilitate this experiment in DIII-D. The basic ellipsometry technique for measuring thickness of a thin film is well developed, and in fact, is a commercial technique used for integrated circuit manufacturing. Measurements of the amplitude and phase of light reflected from the front and back face of a thin carbon film should allow determination of the film thickness to an accuracy of ± 1 nm. It is expected that the data can be obtained at the rate of 4 Hz which should give good characterization of erosion and redeposition during a single shot on DIII-D.

Hsu has informed us that to apply the ellipsometry technique to DIII-D, the laser beam should impinge on the target at an angle of $45 \pm 15^\circ$. To accomplish this, we will need 3 ports in a straight line. Two sets of DIII-D ports have been identified as attractive. The primary choice is to use upper ports $150^\circ\text{R}+2$ and $240^\circ\text{R}+2$ as the input and output ports, and $195^\circ\text{V}-1$ for insertion and removal of the target material into the divertor region. Meetings were held with SNL-L on April 7 and during the June 28 Workshop to further define the requirements for the ellipsometry technique. A detailed schedule has been prepared for the Phase 2 *in situ* test activities. Our goal is to have the Phase 2 *in situ* ellipsometry apparatus ready to install on DIII-D during the March 1990 vent currently planned for fast wave current drive installation. To allow adequate time for design, review, fabrication, and assembly before the vent, we must hold a conceptual design review and begin preliminary design prior to the end of August. This means that ellipsometry technique verification, design requirement specification, and conceptual design must be completed by that time. This is a very tight schedule.

Project Workshop

On June 28, we held a very informative Project Workshop to coordinate all aspects of the erosion/redeposition experiments and analysis. This program is a cooperative effort of SNL-L, ANL, LLNL and GA, and is part of ITER R&D Tasks PC-3. The meeting was attended by W. Hsu and D. Buchenauer of SNL-L, D. Hill and M. Rensink of LLNL, B. Braams of PPPL, J. Brooks of ANL, R. Vesey of RPI/GA, and R. Gallix, K. Schultz, J. Smith and C. Wong of GA.

PROGRAM STATUS
3RD QUARTER - FY 1989

TASK: PLASMA-FACING COMPONENTS

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

FY89 FUNDING: \$100 K

CONTRACT NO: DE-AC03-89ER52153

FY89 PLAN: \$ 95 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. Fabricate and install in DIII-D a set of 12 graphite divertor tiles for erosion/redeposition studies.	3 rd Q FY89		3 RD Q FY89
2. Remove divertor test tiles from DIII-D and compare measured erosion/redeposition with predictions of analytic models.	4 th Q FY89	2 nd Q FY90	
3. Design for installation on DIII-D sample transfer and optics support equipment for time-resolved erosion/redeposition measurements.	4 th Q FY89		

REMARKS:

DIII-D will not be vented until January 1990. The 12 divertor tiles will be removed at that time. Longer exposure will give better erosion/redeposition results.

PROGRAM STATUS
3RD QUARTER - FY 1989
FUSION MATERIALS

HIGHLIGHTS:

- A NIM report has been drafted compiling published and unpublished data on Mn-stabilized "low-activation" austenitic steels. These steels are being considered for the ITER.
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A contribution to the Neutron Interaction Materials (NIM) program semiannual report, formerly the Alloy Development for Irradiation Performance (ADIP) report, entitled "Fe-Mn-Cr Alloys for Low-Activation Fusion Service," was submitted. This report highlights work performed under other DOE programs on the development of Mn-stabilized austenitic steels. Currently ITER is considering this class of steels as low activation alternatives to the current alloy being considered, AISI 316 stainless steel. This paper reviews several alloy variants that have major implications on the alloy development programs at ORNL and HEDL being performed under the NIM program. GA feels strongly that this work should be studied by the NIM participants in order to efficiently guide the researchers in choosing the strongest candidate alloys for further research.

This completes our milestone for ITER Materials Data Base Coordination.

PROGRAM STATUS
3RD QUARTER - FY 1989

TASK: FUSION MATERIALS

B/R NO: AT-15-02-03A

FY89 FUNDING: \$25 K

CONTRACT NO: DE-AC03-89ER52153

FY89 PLAN: \$25 K

GA PRINCIPAL INVESTIGATOR: T. A. LECHTENBERG

SAN PROJECT MANAGER: C. BEIGHLEY

OFE PROGRAM MANAGER: T. REUTHER

PLANNED ACTIVITIES/GOALS	ORIGINAL TARGET	CURRENT TARGET	COMPLETION DATE
1. Coordinate the ITER Structural Materials Data Base with ANL	3 rd Q FY89		3 rd Q FY89
2. Coordinate with the ITER Structural Materials Working Group to review material properties for ITER and to disseminate physical and mechanical properties data sheets for review and comment by the international community	←	ONGOING	→

REMARKS: