The U.S. Proposal for Neutronics Experiments to Evaluate the Nuclear Performance of ITER Shield Design

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Objectives of ITER Neutronics R&D Effort during the EDA phase

- Provide the experimental databases required for approval and licensing of the device prior to construction,

- Verify the prediction capabilities of present calculational tools and databases for the purpose of codes verification and data certification,

- Generate design safety factors to assist ITER designers in implementing conservatism in components design for higher reliability, and

- Reduce the high cost associated with untested large safety factors commonly used to compensate for all sources of uncertainties.

Major Elements of the R&D Program

- Execution of integral experiments on mockups simulating major ITER nuclear components (e.g. bulk shield, shielding with penetrations .. etc),

- Measurements on Nuclear Heating and Radioactivity:

  - Improvement in present experimental measuring techniques to reduce uncertainties and as needed, development of new techniques,

- Continue to perform basic nuclear data measurements and evaluation,

- Processing basic data into working libraries for use by various codes, and

- Improvements in codes, as needed.

Present Limitations in Simulating ITER FW/Blanket/Shield In Neutronics Integral Experiments

- Using a 14 MeV external point source is not prototypical representation of the volumetric neutron source of the plasma in ITER.

- Full source coverage by test assembly is very expensive and suffers from practical difficulties.

- Conducting these experiments in an open room gives rise to an unavoidably introduced room-return effects.

- The yield in all available neutron sources is too low to perform all needed experiments

- Present measuring techniques are severely limited, particularly with available source yield/fluence.

Realizing present limitations in simulation of ITER FW/B/Shield suggests

Key Points on Strategy

- Many neutronics experiments are needed because:

  (1) Limitations of the capabilities of the facilities available make it impossible to have a perfect mock-up, therefore several experiments using different approaches are necessary

  (2) Experiments are part of the effort to select and finalize ITER design. Several aspects of the design need to be addressed and verified.

- However, *limited* number of experiments can be performed each year in a given facility. Therefore,

  (1) More than one facility needs to be operated,
  (2) A number of experiments will need to be carried out.

- Development of measurement techniques must proceed at a rapid pace because it is crucial to obtaining benefits from integral experiments.

Key Points on Strategy (Cont'd)

- Careful design of integral experiments based on strong pre-analysis is necessary to plan useful experiments.
- Comprehensive analysis and interpretation of experiments is crucial part of this effort; therefore, sufficient resources must be devoted to analysis.
- There is a need for one group to analyze and interpret all experimental results on a consistent bases using the codes and data libraries that are to be validated for ITER design and to develop recommendations on safety factors/design margins.

Note that present allocation of ITER credit to neutronics R&D is not adequate to address the most critical issues. ITER Neutronics R&D Credit needs to be ~20000 IUA in the next 4 years

U.S. Facility ??

Since the neutronics and shielding R&D budget is limited, it is essential that resources are conserved.

Therefore, the US does not propose to operate any major neutronics facilities in the US in the immediate future.

The US proposes to work with other parties using their experimental facilities.

- We have developed ***a joint proposal with JAERI.*** It builds on strong record of technical accomplishments and exemplary international collaboration (the USDOE/JAERI Collaboration on Fusion Blanket Neutronics).

What the U.S. Proposes to Do

(1) perform the necessary pre- and post analyses of the identified JAERI's bulk shielding and streaming experiments, contingent to JCT approval, and quantify the design margins/safety factors based on these experiments and other (or previous) experiments, for implementation in ITER design,

(2) perform nuclear heating measurements and analysis carried out as standalone and/or in conjunction with the shielding experiments at FNS, JAERI. Develop and apply the necessary measuring techniques,

(3) perform radioactivity/decay heat measurements and analysis carried out as standalone and/or in conjunction with the shielding experiments at FNS, JAERI. Develop and apply the necessary measuring techniques,

What the U.S. Proposes to Do (Cont'd)

(4) Serve as the Central Analysis & Interpretation Group (CAG) for all experiments,

(5) Contribute to other tasks and requests as defined and prioritized by the JCT.

Types of experiments needed are:

→ Bulk Shield
→ Streaming experiments
→ Validation of Nuclear Heating
→ Validation of radioactivity build up and decay Heat

- Nuclear heating and radioactivity experiments could be conducted in conjunction with shielding experiments as long as the fluence requirement is met. *Standalone* experiments will be needed

Function of the Central Analysis Group

- Perform the post-analyses of all approved experiments, including previous experiments when necessary,

- Meet semi-annually to review the accomplished analytical tasks performed by all parties.

  - *Outcomes and conclusions from the accomplished tasks will be examined for quality, completeness and consistency among results.*

- Provide ITER JCT with a document summarizing the status of the analyses of the approved shielding/heating/activation experiments that support ITER neutronics R&D plan.

  The progress report from each party will also be submitted to ITER JCT after revisions, if needed.

- Provide ITER JCT with recommendations on the appropriate sets of design margin/safety factors based on the interpretation of results from all parties and by accounting for both the analytical and experimental uncertainties.

- The U.S. will assume the responsibility of generating these margins/factors with participation from the other CAG members. These recommendations will be based on the proposed experiments mentioned here and other experiments performed by EC and RF (including previous experiments).

- New proposals (or enforcing already approved proposals) for the next year will be prepared by the CAG with equitable participation from the experimentalists of the four parties.

- These proposals could be separate or joint proposals.

Objectives of the Proposed Experiments

Bulk Shielding:

- Evaluate bulk shielding characteristics and performance for deep penetration in a typical ITER inboard shield configuration
- Estimate nuclear heating at super-conducting magnet (SCM) and biological shielding performance
- Estimate design margins/safety factors based on the range of uncertainties in the calculated and measured values.

Streaming Experiments:

- Evaluate radiation streaming characteristics and component performance with gaps and large penetrations of various shapes and sizes.
- Estimate biological doses and nuclear field levels around penetrations exits.
- Estimate design margins/safety factors based on the range of uncertainties in the calculated and measured values.

Direct Measurements of Nuclear Heating in Primary Blanket/Shield Configurations

- Develop and demonstrate an enhanced sensitivity calorimeter for direct measurement of total nuclear heating distribution deep inside Blanket/Shield,

- Conduct measurements of total nuclear heating distribution in Blanket/Shield configurations in order to provide measured nuclear heating rates for various materials of importance to ITER JCT, e.g., Be, Cu, WC, B_4C, SS316, V alloy, Li metal, Li_2O,etc.

- Carry out experimental analysis in order to validate ITER JCT-recommended nuclear data bases and methods to be used in the ITER First Wall/Divertor/Blanket/Shield design.

Induced Radioactivity Experiments with Samples of Structural Materials Irradiated in Mockup Test Assemblies

- Generate an expanded measured radioactivity database for high priority structural materials irradiated inside a test assembly simulating neutron energy spectra of ITER relevance ,

- Analyze the measured Radioactivities using ITER JCT recommended inventory codes, and activation data libraries, and create an expanded data base of C/E's (calculated to experimental radioactivity) for various isotopic radioactivities,

- Estimate prediction uncertainties, and associated confidence levels for each isotopic radioactivity of significance based on the C/Es.

Experimental Qualification of Coolant Options for ITER from Radioactivity and Biological Dose Standpoint

- Execute direct measurements of radioactivity and biological dose from the circulating coolants for the following leading candidate options for ITER: Water cooled Stainless Steel structure, Helium cooled V-Cr-Ti structure with lithium, and Self cooled V-Cr-Ti structure with lithium.

- In the initial stage, it is proposed to build water loop for the measurements. Subsequently, the other coolant loops will be built up. The comparison of the performances of all these loops will be very valuable in relatively qualifying these options, on one hand, and providing invaluable data, for the designers and the safety authorities, on the other.

Codes and Databases to be used in the Analysis of Bulk and Streaming Experiments

	Japan	U.S.
Cross section Libraries	-FUSION-J3 /JSSTDL for ANISN, DOT -FSXLIB-J3 for MCNP	-MATXS 10,11,14 and multigroup FENDL library for DORT, TORT and 2-&3-DANT -Pointwise ENDF/B-VI and FENDL data for MCNP
Transport Codes	DOT3.5, MCNP	DORT, TORT, 1-&2-&3-DANT MCNP
Activation Library (Responses)	most recent dosimetric files	most recent dosimetric files

Analysis of the Radioactivity and Nuclear Heating Experiments and Analyses

Nuclear Heating

- Neutron & γ-ray transport calculation: DOT3.5, MCNP, MVP
- KERMA data libraries: FENDL-2, FUSION-J3, MATXS10, , etc.
- Time dependent temperature analysis code: ADINAT coupled with DOT3.5

Induced Radioactivity

- Neutron flux spectrum: use the data for shielding experimental analysis
- Induced radioactivity code: FISPACT, RACC, REAC, ACT4, etc.
- Activation cross section libraries: EAF3.0, FENDL/A2.0, JENDL, etc.

U.S. Resources Estimate and ITER Credit

A. Analysis of Bulk Shield Mock-up Experiments (~18 month) — **Total: 350 IUA**

- Pre-Analysis, post Analysis, interpretation, derivation of design margins, travel, and reporting — 350 IUA

B. Streaming Experiments (~ 4 years) — **Total: 650 IUA**

- Pre-Analysis, post Analysis, interpretation, derivation of design margins, travel, and reporting — 650 IUA

C. Direct Measurement of Nuclear Heating (~4 years) — **Total : 600 IUA**

- Materials, probes, equipment, and instrumentation — 150 IUA

- Planning, preparation, execution of experiment, experimental analysis, travel, reporting — 450 IUA

D. **<u>Induced Radioactivity Experiments (~4 years)</u>** — **<u>Total : 600 IUA</u>**

- Materials, samples & foils — 150 IUA
- Planning, preparation, execution of experiment, experimental analysis, travel, reporting — 450 IUA

E. **<u>Experimental Qualification of Coolant Options (~2 years)</u>** — **<u>Total : 200 IUA</u>**

- Equipment & instrumentation — 100 IUA
- Planning, preparation, execution of experiment, experimental analysis, travel, reporting — 100 IUA

F. Formation, Participation in, and Coordination of The Central Analysis Group (CAG) **Total : 400 IUA**

(~4 years) 400 IUA

US Total **2,800 IUA**

Distribution of credits in joint proposals

	US	Japan
A. Bulk Shield Mock-up Experiments	350 IUA	1,200 IUA
B. Streaming Experiments	650 IUA	2,200 IUA
C. Direct Measurement of Nuclear Heating	600 IUA	500 IUA
D. Induced Radioactivity Experiments	600 IUA	400 IUA
E. Experimental Qualification of Coolant Options	200 IUA	300 IUA
Total	**2,400 IUA**	**4,600 IUA**