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TITLED:
"FUSION NEUTRONICS EXPERIMENTS AND ANALYSIS"

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PROGRESS REPORT

FUSION NEUTRONICS EXPERIMENTS AND ANALYSIS

I. Introduction

UCLA has led the neutronics R&D effort in the U.S. for the past several years through the well-established USDOE/JAERI Collaborative Program on Fusion Neutronics. Significant contributions have been made in providing solid bases for advancing the neutronics testing capabilities in fusion reactors. This resulted from the hands-on experience gained from conducting several fusion integral experiments to quantify the prediction uncertainties of key blanket design parameters such as tritium production rate, activation, and nuclear heating, and when possible, to narrow the gap between calculational results and measurements through improving nuclear database and codes capabilities.

In contrast to previous experiments and the associated analysis performed since the start of the program in 1984 with a 14 MeV point source, the current focus is to conduct the experiments in an annular configuration where the test assembly totally surrounds a simulated line source. The simulated line source is the first-of-a-kind in the scope of fusion integral experiments and presents a significant contribution to the world of fusion neutronics. The experiments proceeded through Phase IIIA to Phase IIC in these line source simulation experiments started in 1989. The analysis for Phase IIIA and IIIB has been concluded while Phase IIC analysis is in progress. In this document, the progress made during the last year is reported in Section II. The highlights of the workshops and meetings conducted during this year are summarized in Section III. The publication plan and issued papers/reports are given in Sections IV and V, respectively.

II. Recent Technical Progress:

Phase IIIA experiment (conducted in 1989) utilized only the Li2O breeding material (20 cm-thick) that was preceded by a 15 mm-thick S.S. first wall and followed by a Li2CO3 reflector zone (20 cm-thick) and an outermost 1.6 cm-thick polyethylene zone. The test assembly has an axial length of 204 cm. The first wall is placed at a distance R=21.3 cm from the simulated line generated by axially moving the annular blanket assembly at an average speed of 6.1 mm/s over a length of 200 cm. Phase IIIB experiment (conducted in 1990) utilized the armor concept in which a 2.5 cm-thick graphite zone was attached to the first wall. In Phase IIC, a large opening experiment was performed (November-December, 1991) in which a 43 cm x 43 cm rectangular opening was placed at one side of the rectangular assembly in the toroidal direction and its impact on tritium breeding and heating rates were experimentally examined.

The experimental measurements of tritium breeding rate, neutron and gamma energy spectra, gamma heating and dosimetry reactions were carried out along the surface of the inner cavity (21.3 cm x 21.3 cm) and along the radial drawers that penetrate the test assembly. In addition, induced decay gamma radioactivity measurements were carried out on a number of foil packets that consisted of Fe, Ni, Mo, Cr, SS316, W, Ta, Zr, Al, An, Ag, Pb, Zn, Nb, Ti, V, MnCu, alloy, Co, Mg, Si, and In. The half lives ranged from 10 minutes to 5 years. Additionally, nuclear heating rates were measured using the microcalorimetric technique near the rotating target neutron source.
II.1 Tritium Breeding Measurements and Analysis of Phase IIIA and IIIB:

The analysis for Phase IIIA and IIIB were previously performed for Phase IIIA (reference configuration of the line source experiments without armor layer) and Phase IIIB (w/ armor layer) nad was reported during the Karlsruhe Workshop held June 1, 1991. However, it was observed that there is inconsistency in the experimental data for tritium production rate from Li-6 (T-6) and tritium production rate from Li-7(T-7) obtained by the Li-pellet, Li-glass measurements, and NE213 measurements (for T-7). It was decided to repeat these measurements to disclose this inconsistency. The revised measured data were taken during the month of April, 1992 and were send to UCLA May 21, 1992. The calculated-to-experimental (C/E) curves for T-6 and T-7 in both phases were generated and compared to the corresponding curves obtained with the old experimental data. The following was observed:

II.1.a Tritium Production Rate From Li-7 (T-7)

(1) In the three radial drawers, the calculation showed a large reduction in the local values of T-7 upon the inclusion of the armor layer (2.54 cm) in Phase IIIB. The results based on NE213 measurements, however, showed less reduction in local T-7 than those predicted by calculations. This observation was reflected on the C/E curves where it was shown that the C/E curves in Phase IIIB are lower than the corresponding curves of Phase IIIA. This observation still holds even when the revised experimental data was used (see Fig.1) , and (2) The results based on Li-pellet measurements in Drawer B showed a reversed trend. While the reduction in the local values was less than prediction in the case of NE213 measurements, this reduction was larger than prediction in the case of Li-pellet measurements. This led to having larger C/E curves in Phase IIIB than those of Phase IIIA with the Li-pellet measurements.

II.1.b Tritium Production Rate from Li-6 (T-6)

(1) The measurements with Li-glass detectors showed an increase in the local values at all locations in the Li2O zone in both Drawers B and C upon the inclusion of the armor layer. The calculations performed by DOT showed also an increase in the local values at front locations in the breeding zone but a decrease occurred at the back locations, (2) The calculations showed less increase in the local values upon the inclusion of the armor layer than those obtained by the Li-glass measurements. This was reflected on the C/E curves. The C/E curves in Phase IIIB are lower than those obtained in Phase IIIA (see Fig. 2). This observation is true in both Drawers B and C, even after using the revised experimental data obtained with the Li-glass detectors, (3) The C/E value at the first front location in the breeding zone improved with the revised experimental data, and (4) Contrary to the Li-glass experimental data, the Li-pellet data obtained in Drawer B showed a decrease in the local values at a distance from the source r = 30 cm, 35 cm, and 40 cm upon including the armor layer. Also, while the calculations showed a decrease in the local values in Phase IIIB compared to Phase IIIA at back locations, this relative decrease is larger as obtained with the Li-pellet detectors. This again was reflected on the C/E curves. The C/E for the local values in this case were larger in Phase IIIB than in Phase IIIA (reversed trend to the curves obtained with the Li-glass measurements). This effect was more pronounced when the revised experimental data obtained by Li-pellet detectors were used. Table (1) gives the range of the C/E values for T-6 and T-7 in both phases.
Table (1): Ranges of the Local C/E Values

<table>
<thead>
<tr>
<th>Drawer</th>
<th>Phase IIIA</th>
<th>Phase IIIB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>T-7 DOT</td>
<td>0.98-1.02</td>
<td>0.96-1.06</td>
</tr>
<tr>
<td>NE213MCNP</td>
<td>0.92-1.07</td>
<td>0.97-1.30</td>
</tr>
<tr>
<td>T-7 DOT</td>
<td>0.93-1.08</td>
<td></td>
</tr>
<tr>
<td>Li-pel.MCNP</td>
<td>0.95-1.15</td>
<td></td>
</tr>
<tr>
<td>T-6 DOT</td>
<td>1.06-1.13</td>
<td>1.08-1.13</td>
</tr>
<tr>
<td>Li-gla.MCNP</td>
<td>0.99-1.10</td>
<td>1.00-1.09</td>
</tr>
<tr>
<td>T-6 DOT</td>
<td>1.00-1.06</td>
<td></td>
</tr>
<tr>
<td>Li-pel.MCNP</td>
<td>0.90-0.95</td>
<td></td>
</tr>
</tbody>
</table>

II.2. The Prediction Accuracy of Local and Integrated Tritium Production Rates in all the Experiments Performed so far:

The local C/E values for T-6 and T-7 were interpreted from a different viewpoint than the approach previously followed in the work reported during the ISFNT-2 Meeting held in Karlsruhe, June, 1991 and in last year’s Progress Report. The recent work focuses on estimating the C/E values of the integrated tritium production rate (TPR) rather than the statistical treatment followed in estimating the mean value for the local TPR from T-6 and T-7. Blanket designers who optimize the design to achieve a presumed tritium breeding ratio (TBR) are interested in knowing the prediction accuracy of TBR based on results obtained from integral experiments. The C/E values for the integrated TPR are more representative of the uncertainty associated with the TBR in a fusion blanket. The new approach was applied to all the experiments of Phase I through Phase IIIB.

The integration of local TPR was performed as follows: (a) line-integration, and (b) volume integration. In the former case, integration of local TPR is performed along the central axis of the Li2O assembly in Phases I and II and along the central radial drawer in R direction in Phase III experiments. In case (b) above, the integration is performed over the entire test assembly using the results obtained from the calculated and experimental values of the TPR in the radial drawers in Phase II and the off-symmetry radial drawers (drawer A and C) in phase III experiments. Two approaches were followed in calculating the line-integrated TPR, namely (a) step method, and (b) fitting method. In the step method, the calculated value (and experimental value) of the TPR at the measuring points were considered to be flat between these measuring points while in the fitting method, the local values were used to derive a fitting curve that is either logarithmic or polynomial quadratures, depending on the steepness of the local values in the zones where integration is performed. In estimating the integrated TPR from the local calculated and experimental values based on the fitting method, the fitting coefficients and their variances (errors) were obtained first by applying the least square curve fitting method (least Chi) using the local values of TPR and their
variances (i.e. statistical errors in the calculated local TPR and the experimental errors in the local measured values). The C/E of the integrated TPR and its variance were calculated next based on numerically integrating the fitting curves and propagating the variances of the fitting coefficients to variances in the integrated TPR. The numerical approach used in deriving the fitting coefficients and their variances is based on the singular value decomposition technique for least square fitting.

A computer code was developed (TIGER) to perform the above tasks. The code can perform, as an option, a line-integration or volume integration, depending on the availability of data in the other direction (R in Phases I-II and Z in Phase III experiments). The prediction accuracy of integrated TPR in Phase I through Phase IIIB was calculated and the results were compared to the prediction accuracy of local TPR reported last year (see Table 1 for the abbreviation of the experiments in each phase). The summary of the results is as follows:

II.2.a Tritium Production Rate from Li-6 (T-6):

1. The prediction uncertainty in the integrated T-6 is large in Phase I (~15%) and in the reference (REF) experiment of Phase IIA (~20%) as compared to other experiments (see Fig. 3).
2. The prediction uncertainties based on MCNP calculations tend to be lower than those based on DOT calculations, particularly in Phase IIA (~5%), and (3) The largest variance observed in the prediction uncertainty is in the water coolant channel (WCC) experiment of Phase IIC where the results based on Step integration differ from that based on Fitting integration.

II.2.b Tritium Production Rate from Li-7 (T-7):

1. Among all the experiments, the integrated T-7 is generally over predicted by ~5-20%, with the MCNP calculations giving the lower edge (see Fig. 4).
2. The results based on Step integration and Fitting integration are comparable except in the Beryllium Edge-on (BEO) experiment of Phase IIC based on MCNP calculations, and (3) Apart from Phase I results (which give large prediction uncertainties), the largest uncertainty is observed in the heterogeneous system of Phase IIC (WCC).

II.2.c General Remarks

1. Among the systems considered, the prediction accuracies for integrated T-6 and T-7 are not necessarily better than the prediction accuracies for local TPR, but generally they follow the same trends,
2. The variances (uncertainties) in the C/E values for the integrated TPR seem to be generally larger than the variance in local TPR. This is more apparent in systems that exhibit heterogeneity (e.g. WCC),
3. The variance in the C/E values of integrated T-7 is larger than that for T-6,
4. When the mean values for the prediction uncertainty in T-6 and T-7 are estimated from all the experiments, the following is observed:

   - The prediction uncertainties in the integrated T-6 and T-7 are lower than the prediction uncertainties in local values (by ~3-4%)
   - The prediction uncertainties based on MCNP calculations are generally lower than those based on DOT calculations
   - The prediction uncertainties are lowered when the results based on Phase I are excluded
   - the uncertainties in the integrated values (based on Fitting Method) are:
     T-6: ~6% (DOT), ~2% (MCNP)
     T-7: ~6% (DOT), ~5% (MCNP)
completed. Analysis of measurements, done on foil package at zero degree, has been carried out on a number of foil packages kept near a rotating neutron target source at FNS (JAERI) in June 1989. Four identical foil packages were kept at 0, 45, 90, and ~115 degrees to the d+ beam. Each package contained foils of Ag, Al, Dy, Hf, 151Eu, 153Eu, Hf, Ho, Ir, Mo, Re, Tb, and W. The objective was to measure decay \( \gamma \) radioactivity from \(^{108m}\text{Ag}, ^{26}\text{Al}, ^{158}\text{Tb}, ^{152}\text{Eu}, ^{150}\text{Eu}, ^{94}\text{Nb}, ^{186m}\text{Re}, ^{178m}\text{Hf}, ^{192m}\text{Ir}, \) and \(^{166m}\text{Ho} \), among others. The half lives of these products range from 13.3y (\(^{152}\text{Eu} \)) to 0.72My (\(^{26}\text{Al} \)). These foils were interspersed with dosimetric foils of Nb and Zr. An estimated average fluence of \(-0.83 \times 10^{15} \text{n/cm}^2\) (range: 0.47-1.65.10\(^{15}\) n/cm\(^2\)) was obtained for the foil-package at zero degree.

After cooling times ranging from 1.3 to 2 years, \( \gamma \)-spectroscopy of some of these foils has been completed. Analysis of measurements, done on foil package at zero degree, has been carried out using four radioactivity codes, REAC-2, DKRICF, ACT4 (THIDA-2), and RACC. REAC-2 is the only code that has data for most of the observed products; RACC has data for Al, Mo and W products only. The ratio of computed to experimentally measured (C/E) activities varies from 4.10\(^{-5}\) to 377. A major update of all four cross-section libraries is recommended as waste classification of many fusion specific materials is likely to change dramatically. Figures 5 and 6 show the range for the C/E values for the Long-lived isotopes of Hf and Mo, respectively.

II.4 Nuclear Heating Experiments and Analysis

Nuclear heat deposition rates in ten different materials, \( \text{Li}_2\text{CO}_3 \), graphite, Ti, Ni, Zr, Nb, Mo, Sn, Pb, and W have been measured by the microcalorimetric technique during phase IIIC. Each of these materials was subject to spaced D-T neutron pulses from intense rotating neutron target (RNT) of FNS. The measurements for graphite, Ti, Ni, W, and Mo were also carried out during earlier phases.

The new material probes investigated this time included: \( \text{Li}_2\text{CO}_3 \), Zr, Nb, Zn, Sn, and Pb. It is to be noted that \( \text{Li}_2\text{CO}_3 \) is an insulator (ceramic) and Zr and Zn probes were essentially stacks of 10 foils each. The thermal contact was a little poor among the constituent foil pieces for Zr and Zn probes. In this phase, considerable enhancement in experimental sensitivity was obtained by the use of a more sensitive digital nanovoltmeter from Keithley. In addition, the scanner equipment used earlier was taken off from the measurement configuration employed. The scanning function was essentially implemented with the help of the controller. Both thermistsors and the platinum RTD's were fed steady currents during nuclear heating and background measurement stages.
The overall experimental error for each material was estimated to be less than 10%. Two codes, MCNP and DOT3.5, and five data libraries—BMCCS, ENDL85, ENDF5T, and RMCCS with MCNP, and JENDL-3 with DOT3.5—were employed for analysis of these measurements. Different C/E spreads were found for these materials: (1) 1.17-1.39 for graphite, (2) 0.88 - 1.06 for titanium, (3) 1.11 - 1.87 for nickel, (4) 0.31 - 2.09 for zirconium, (5) 0.79 - 1.04 for niobium, (6) 0.84 - 1.23 for molybdenum, (7) 0.98 - 3.51 for tin, (8) 1.00 - 1.46 for lead, (9) 1.17 - 1.32 for tungsten, (10) 0.98 - 1.41 for Li2CO3. In previous experiments also, we have observed considerable C/E spreads for analysis with MCNP (transport computation with RMCCS or ENDF85 libraries) and the four heat-number libraries—BMCCS, ENDL85, ENDF5T, RMCCS. For example, we found these C/E spreads:

(a) 0.84 - 1.24 for graphite,  
(b) 1.03 - 1.81 for aluminum,  
(c) 0.42 - 1.00 for titanium,  
(d) 0.90 - 1.32 for iron,  
(e) 0.46 - 1.12 for stainless steel,  
(f) 0.79 - 1.28 for copper,  
(g) 0.89 - 1.26 for nickel,  
(h) 0.77 - 0.89 for molybdenum,  
and  
i) 1.20 - 1.22 for tungsten.

Inclusion of C/E results from DOT3.5+JENDL-3 analysis, led to a larger spread in the C/E's for all these materials. However, it has emerged clearly that analyses with MCNP + ENDL85, on one hand, and DOT3.5 + JENDL-3, on the other, systematically yield C/E's that are closest to 1.00.

II.5 Induced Activity Experiments and Analysis

Documentation of induced radioactivity/decay-heat measurements conducted in Phases IIC through IIIC of the collaborative program is in progress and is targeted to be completed soon. Neutron energy spectrum, source neutron intensity, sample mass, irradiation time, cooling time, γ-detector efficiency, and counting time are among the most important parameters characterizing the measured decay-γ emission spectra. Irradiated materials have included the following: Fe, Ni, Cr, Mo, Si, SS316/AISI316, Al, MnCu alloy, Cu, Ti, V, Ta, W, Nb, Sn, Zn, Ag, Pb, Mg, In, Au, YBa2Cu3O7, and ErBa2Cu3O7.

Phase IIC experiment was driven by the intense 14 MeV neutron source, RNT, in point source mode. However, the experimental assemblies in phases IIIA through IIIC were driven by a simulated line source in a large room of FNS. The neutron source intensity is a factor of 10 lower in this room even for point source mode of operation. The documentation of decay γ-emission spectra has been done, for each material, as a function of neutron energy spectrum, irradiation and cooling times. Over 300 cases are accounted. However, only 32 cases have been retained for detailed representation of the spectra due to premium put on data quality and the need to cover all materials. Figure 7 shows, as an example, the emission of the integrated decay gamma rays per gram of irradiated Tungsten as predicted by four codes/libraries. The C/E values for the emission rate (reaction-wise) are shown in Fig. 8, where C/E values as large as 4 can be observed.

It is to be stressed here that, although the features of the experimental data and its analyses have already been discussed extensively in numerous joint USDOE/JAERI publications, the current documentation will permit the radioactivity code/library developers and the designers, at large, to use this documentation as a standard reference to validate their tools before making any meaningful
projections on the decay-heat/radioactivity performance of any nuclear system driven by 14 MeV neutrons.

II.6 Outlines of a Plan for ITER Shield Neutronics R&D

A plan was developed during the month of May, 1992 that aims at resolving the critical shielding neutronics R&D issues for ITER. The plan was thoroughly discussed with participants from the international community (Japan, Germany, U.S) during the Informal International Workshop on Fusion Neutronics held at UCLA on June 5, 1992. The plan calls for an equitable participation from the parties involved in ITER EDA phase (EC, Japan, U.S., and ex-USSR) to execute its elements. The elements of the plan are: (a) performing integral shielding experiments to validate nuclear data and codes and to give realistic estimates for the design safety factors that have been routinely used in the design with no experimental verification, (b) performing integral experiments to verify the adequacy of nuclear heating and radioactivity cross-sections/decay data through concurrent and stand-alone experiments, and (c) devote effort to generate, improve, and update multigroup, continuous energy/angle, and DDX cross-section data libraries, and to develop specialized codes as needed that are required for the pre- and post-analysis of the integral experiments (e.g. cross-section sensitivity/uncertainty analysis code in 3-D). The plan also indicates the level of effort to be shared by participating parties in the areas of man power, equipments' cost, material cost, and machine operation cost.

The type of experiments identified are: (a) Thick (> 70 cm) bulk shield experiments W/ and W/O Openings/Gaps, (b) Thin (< 70 m) bulk shield experiments W/ and W/O Openings/Gaps, (c) Activation/afterheat experiments: in conjunction with bulk shield experiments and as stand-alone experiments, (d) Nuclear Heating experiments: in conjunction with bulk shield experiments and as stand-alone experiments, and (e) Biological Shield experiments: biological shield is directly exposed to the 14 MeV neutron source and biological shield exposed to incident spectrum that resembles the transmitted neutrons emerging from ITER bulk shield. The leading facilities proposed for this plan are: FNS (JAERI, Japan), (b) FNG (Frascati, Italy), and (c) TUD (Dresden, Germany). Also outlined in the plan is the mode of operation among participants and the experimental period assigned for each facility. Table (1) shows the yearly experimental activity in each of the proposed facility. The annual expenditure shared by the parties was also outlined in the plan. It estimated that the annual cost per party is ~ $620K to carry out the experiments (including the man power cost of 4 analysts and experimentalists from each party) and ~ $150K for coed/data improvements with a total annual cost of ~ $3.08M.
**Table (1): Yearly Experimental Activity by Facility**

<table>
<thead>
<tr>
<th>Activity</th>
<th>FNS</th>
<th>FNG</th>
<th>TUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Experimental Period/yr</td>
<td>4 mon.</td>
<td>2 mon.</td>
<td>1 mon.</td>
</tr>
<tr>
<td>- Number of Different Assemblies to be Tested</td>
<td>4</td>
<td>2</td>
<td>--- (a)</td>
</tr>
<tr>
<td>- Type of Experiment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ Bulk Shield Experiment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Thick Shield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/o Openings/Gaps</td>
<td>√</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>w/ Opening/Gaps</td>
<td>(√(b))</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>- Thin Shield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/o Openings/Gaps</td>
<td>---</td>
<td>√</td>
<td>---</td>
</tr>
<tr>
<td>w/ Opening/Gaps</td>
<td>---</td>
<td>√</td>
<td>---</td>
</tr>
<tr>
<td>- Biological Shield</td>
<td>---</td>
<td>---</td>
<td>√</td>
</tr>
<tr>
<td>Σ Activation/Afterheat Experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- In Conjunction with Bulk Shield Expts.</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>- Stand-Alone</td>
<td>√</td>
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<td>√</td>
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<tr>
<td>Σ Nuclear Heating Experiments</td>
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<td>- In Conjunction with Bulk Shield Expts.</td>
<td>√</td>
<td>√</td>
<td>(√(a))</td>
</tr>
<tr>
<td>- Stand-Alone</td>
<td>√</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

(a) There are two assemblies to be constructed at TUD for biological shield experiments during the six (6) years' period in which also nuclear heating measurements will be taken.

(b) Simulated line source will be used in these experiments.
III. Workshops and Meetings

III.1 The Technical Meeting of the USDOE/IAERI Collaborative Program on Fusion Blanket Neutronics. June 4, 1992, UCLA:

This was the Annual Technical Meeting with JAERI's personnel to review the technical progress of the program since the last meeting held in Karlsruhe, Germany, June, 1991. The status of the experiments and analyses pertaining to Phase III experiments were reviewed during that meeting. Also reviewed were the experimental results and analyses pertaining to the radioactivity and nuclear heating measurements. A report will be issued shortly (July, 1992) that summarizes the presentations given during that meeting.

III.2 The Informal International Meeting on Fusion Neutronics, June 5, 1992, UCLA:

Scientists from the EC, Japan, and the U.S. participated in this Informal Meeting to discuss the status of the current activities in each country in the area of fusion neutronics and to explore areas for multilateral international collaboration to resolve short- and long-term neutronics R&D issues for the next fusion device, and in particular for ITER. Also discussed in this meeting were several pathways to implement the IEA agreement in the area of fusion neutronics. While the U.S. plan calls for focusing the near term effort on resolving ITER shielding neutronics R&D, the Japanese discussed long term plans for blanket neutronics benchmarks, advanced investigation of neutron induced radioactivity in a simulated fusion neutron environment, and advancing the methods and present techniques for neutronics testing in the next Demo reactor. The outlines of the proposed plan discussed in Section II.6 were reviewed in detail during that meeting.

III.3 The Steering Committee Meeting (SCM) of the USDOE/IAERI Collaborative Program on Fusion Neutronics, June 6, 1992, UCLA:

The meeting was held after the Technical Meeting of the collaborative program. Issues discussed were: (a) progress made during the last year, (b) future plans during this last year of the current collaboration, (c) items related to this last year, particularly retaining materials sent by the U.S. to Japan, (d) personnel exchange, and (e) Publications. Several reports and Journal publications were identified and the effort during the upcoming year will focus on preparing these publications in the areas of tritium breeding, activation and afterheat measurements.

IV. Publications

Collaborative efforts related to the recent work reported above have been published in Refs. 1-10. Most of the effort in the remainder of 1992 and the upcoming fiscal year of 1993 will focus on documenting the experimental and the analytical results on TPR, induced activation and nuclear heating. There will be reports as well as journal publications that will appear in a special issue of either Nuclear Science and Engineering or the Fusion Technology Journal. The tentative target dates of the issuance of these reports and journal papers were discussed during the Steering Committee Meeting (SCM, see above) and are listed below:

IV.1 Reports and Journal Publications on Tritium Production Rate, Spectrum, In-system Reaction Rates, and Source Characterization:

Reports on Phase II C (Vol. I: experiments, JAERI lead author; Vol. II: analysis, U.S. lead author) and Papers:
<table>
<thead>
<tr>
<th>Item</th>
<th>Target Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Exchange Drafts</td>
<td>End of July, 1992</td>
</tr>
<tr>
<td>- Submission for Printing</td>
<td>End of September, 1992</td>
</tr>
<tr>
<td>- Exchange Draft papers (2, one led by JAERI, one led by U.S.) on Phase IIC</td>
<td>End of October, 1992</td>
</tr>
<tr>
<td>- Submission to Journal</td>
<td>End of November, 1992</td>
</tr>
</tbody>
</table>

**Reports on Phase III (Vol. I: experiments, JAERI lead author; Vol. II: analysis, U.S. lead author) and Papers:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Target Date</th>
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</thead>
<tbody>
<tr>
<td>- Exchange of Drafts</td>
<td>Mid September, 1992</td>
</tr>
<tr>
<td>- Submission for Printing</td>
<td>End of October, 1992</td>
</tr>
<tr>
<td>- Exchange Draft Papers (2, one led by JAERI, one led by U.S.) on Phase III</td>
<td>Mid December, 1992</td>
</tr>
<tr>
<td>- Submission to Journal</td>
<td>Mid January, 1993</td>
</tr>
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</table>

* Paper by JAERI as a lead author on Production of Line Source and its Characteristics;

* Paper (Summary, Lead Author; JAERI) on Annular Blanket Experiments with a Line Source;

**Papers on Phase II Experiments:**

- 2 Papers (one led by JAERI, one led by U.S.) on the Experiments and Analysis of Li2O/Be blankets of Phase IIA and IIB;
  Draft: End of March, 1993 Submission: End of April, 1993

- Paper by JAERI as a lead author on Neutronics Experiments and Techniques for Simulated Fusion Blanket;

- Paper by JAERI as a lead author on Neutron Source Characteristics in Concrete Cavity of Phase I and in Rectangular enclosure of Phase II;

- Paper (Summary, Lead Author; JAERI) on Engineering Benchmark Experiments for Fusion Reactors (Phase II);

**General Papers**

Other general papers will be issued, for example:

- The Prediction Accuracy in Local and Integrated Tritium Production Rate in Fusion Blankets, led by the U.S., Draft by December, 1992.

**IV.2 Reports and Journal Publications on Induced Activation and Nuclear Heating**

**Reports**
Journal Papers

(a) Decay Radioactivity : 2 papers

Paper#1> 'Measurements and Analysis of Decay Radioactivity Induced in Structural Materials', led by JAERI [ paper finalization by August 1992]
Paper#2> 'Measurements and Analysis of Decay Radioactivity Induced in Plasma Facing Component Materials', led by UCLA [ paper finalization by August 1992]

(b) Nuclear Heating : 2 papers

Paper#4> 'Direct Nuclear Heating Measurements and Analyses for Ti, Zr, Mo, Pb, Cu, Sn, Pb', led by UCLA [ paper finalization by September 1992]

(c) Long-lived Radioactivity : 2 papers

Paper#5> 'Measurement of Cross-Section Data for Production of Long-lived Isotopes by 14 MeV Neutrons', led by JAERI [ paper finalization by November 1992]
Paper#6> 'Measurement and Analysis of Long-lived Decay Radioactivity Produced by 14 MeV Neutrons', led by UCLA [ paper finalization by November 1992]

in addition, two papers on the experimental techniques for decay radioactivity and nuclear heating measurements could be prepared:

Paper#7> 'Techniques for Decay Radioactivity Measurements', led by JAERI [ paper finalization by January 1993]
Paper#8> 'Microcalorimetric Technique for Direct Nuclear Heating Measurements', led by UCLA [ paper finalization by January 1993]

V. References


(3) Youssef, M.Z., Kumar, A., and Abdou, M.A., "The Prediction Capability for Tritium Production and other Reaction Rates in Various Systems Configurations for a Series of the


Table (1): Abbreviation for the Experiments Conducted in Phase I through Phase IIIA

<table>
<thead>
<tr>
<th>Phase</th>
<th>Experiment (s)</th>
<th>Abbreviation</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>Reference Experiment</td>
<td>REF</td>
</tr>
<tr>
<td>I</td>
<td>First Wall Experiments</td>
<td>WFW</td>
</tr>
<tr>
<td>I</td>
<td>Beryllium Experiments</td>
<td>WBE</td>
</tr>
<tr>
<td>IIA</td>
<td>Reference Experiment</td>
<td>REF</td>
</tr>
<tr>
<td>IIA</td>
<td>Beryllium Front Experiment</td>
<td>BEF</td>
</tr>
<tr>
<td>IIA</td>
<td>Beryllium-Sandwiched Experiment</td>
<td>BES</td>
</tr>
<tr>
<td>IIB</td>
<td>Reference Experiment</td>
<td>REF</td>
</tr>
<tr>
<td>IIB</td>
<td>Beryllium Front Experiment</td>
<td>BEF</td>
</tr>
<tr>
<td>IIB</td>
<td>Beryllium Front With First Wall Exp.</td>
<td>BEFWF</td>
</tr>
<tr>
<td>IIC</td>
<td>Water Coolant Channel Experiment</td>
<td>WCC</td>
</tr>
<tr>
<td>IIC</td>
<td>Beryllium Edge-On Experiment</td>
<td>BEO</td>
</tr>
<tr>
<td>IIIA</td>
<td>Reference (Line Source) Experiment</td>
<td>REF</td>
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</tbody>
</table>
C/E Values for T-6 in the Radial Direction (Drawer B) Li-glass measurements

Fig. 2: The C/E values for T-6 in the Radial Direction of Drawer B of Phase IIIA and IIIB (Li-glass Detectors)

C/E Values for T-7 in the Radial Direction (Drawer C)- NE213 Measurements

Fig. 1: The C/E values for T-7 in the radial Direction of Drawer C of Phase IIIA and IIIB (NE213 measurements)
Fig 3: The Prediction Uncertainty (%) of T-6 in all the experiments of Phase I through IIIA

Fig 4: The Prediction Uncertainty (%) of T-7 in all the experiments of Phase I through IIIA (NE213 Measurements)
Fig. 5. Hf: Long-lived Isotopes

Cooling time = 1.34 y

Fig. 6. Mo: Long-lived Isotopes

Cooling time = 1.52 y
Fig. 7. Integrated (100 KeV - 3 MeV) decay γ emission rate as a function of cooling time for a tungsten sample irradiated for 9h.

Fig. 8. Computed to experimentally measured ratios, C/E's, for reaction rates from four codes as a function of product half life for tungsten.
END

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