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IFMIF ACCELERATOR CONCEPTUAL DESIGN ACTIVITIES

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ABSTRACT

A Conceptual Design Evaluation (CDE) for the International Fusion Materials Irradiation Facility (IFMIF) began in 1997 and will be completed in 1998, as an international programme of the IEA involving the European Community, Japan, Russia and the United States.. The IFMIF accelerator system, comprising two 125 mA, 40 MeV deuterium accelerators operating at 175 MHz, is a key element of the IFMIF facility. The objectives and accomplishments of the CDE accelerator studies are outlined.

I. INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF) requires generation, by a linear accelerator (linac), of 250 mA continuous current of deuterons at a nominal energy of 35 MeV, with provision for operation at 30 MeV and 40 MeV. Our basic approach is to provide two linac modules, each delivering 125 mA to a common target. This approach has availability and operational flexibility advantages. The deuterons would be stripped in a molten lithium target to two neutrons, with a neutron energy spectrum peaked at ~14 MeV as would be found in a fusion device. The deuteron current and energy requirements involve 10 MW of continuous beam power. An additional several megawatts is involved in rf efficiency of the amplifiers and accelerating cavities.

In 1978~1985, a Fusion Materials Irradiation Test (FMIT) facility was carried to final design, with a requirement for 100 mA at 40 MeV, or 4 MW of beam power. On this project, prototyping was completed to 2 MeV and about 50 mA. The Los Alamos Meson Physics Facility proton linac has operated for many years at 1 mA average current to 800 MeV. The technology base for making the required extension to an IFMIF is well in hand, but it is clear that the engineering must be done very carefully, especially in view of a further requirement – to insure a plant availability factor of 70% over the projected operating life of this materials R&D factory.

The accelerators begin with a deuteron ion source and a low-energy beam transport to a radiofrequency quadrupole (RFQ) buncher and preaccelerator up to ~8 MeV. For the main accelerating structure from ~8–40 MeV, two different technologies are under consideration; normal-conducting accelerating structures made from copper, or super-conducting niobium structures. Determining which is the better approach is a complex question involving physics, engineering, cost, and availability aspects. A high-energy beam transport from the accelerator to the lithium target must perform a variety of functions, complicated by the presence of strong space-charge forces within the beam. Conceptual design activities have been in progress under a formal programme organized via the IEA and ITER and involving the USA, Russia, Japan, and the European Community. Recent activities under the CDE phase are outlined in this paper.

I. RF SYSTEM DEVELOPMENT AND TEST

Development and testing of a 1 MW cw, 175 MHz rf system is identified as the highest impact development item in terms of both cost and RAM (Reliability, Availability and Maintenance). The rf amplifier power level baseline of 1 MW and the defined CDE program have important advantages. The 1 MW power level insures that a competitive bid could be obtained from two manufacturers. Accomplishing a full-scale test of the first system would allow the remaining large procurement to be on a fixed-price basis. The involvement of two manufacturers would help insure a tube supply over the facility lifetime. A major subtask of this activity is the development and test of the 175 MHz coaxial rf window.

No resources were available for this task. However, very good news has been received from Thomson Tubes, who have reported 1 MW cw operation of a 200 MHz diacrode amplifier for one hour. This scales to an even better result at 175 MHz (frequency to 5/2 power). Therefore, our first priority task has almost been demonstrated. Our specification was a cw test at 1 MW for 100 hours. Thomson could make the 100 hour test for us and have provided a cost estimate.

II. INJECTOR SYSTEM DEVELOPMENT AND TEST

The injector system has the second highest impact in terms of reaching the required performance and RAM goals for IFMIF. Two technical approaches (the ECR and volume type ion sources) are to be developed, because present status precludes a decision between them, and because substantial ongoing efforts mainly supported by other programs can, with IFMIF augmentation, be expected to progress to a decision point.

The full IFMIF CDE task will require a full operational test of at least one of the candidates. The initial goal is full cw operation meeting all the technical and RAM specifications for a period of 100 hours. The second goal would be operation for 1000 hours.

Reported progress includes IFMIF relevant work supported by other projects: In Japan, proton ion source tests are being conducted, concentrating on LaB_6 filaments in comparison to tungsten filaments. In the EU, IFMIF funding was not available for experimental work during the CDE. Some relevant experimental results were obtained from other projects, including:

- In order to compare different methods of plasma generation, theoretical considerations on an rf-drive were carried out. These will be used when direct comparisons between rf- and arc-discharge operated sources are made on parameters such as lifetime, noise, emittance, etc.
- To prove the ability of a volume type source, such a source was experimentally studied also. A maximum current density of 210 mA/cm^2 has been achieved, so far 80 mA deuterons have been measured using an extraction hole with a diameter of 8 mm.
- Neutron production in the ion source and RFQ area was investigated theoretically. At present, the theoretical estimations of neutron and gamma radiation do not correspond with the measurements carried out on the prototype test stand.
- Electrostatic LEBT calculations and experiments show good results for perveances up to 60% of the design value; further work is aimed at understanding the potential of this type of LEBT at the full space charge of the IFMIF design.
- Further calculations and simulations have been accomplished on aspects of neutralization phenomena in the magnetically-focused LEBT[1,2,3].
- Preparations for improved shielding and licensing of the IAP deuteron test stand continued.
- Collaboration with LBNL was planned for tests of the rf antenna as a plasma driver for the ion source.
- In February 1997, a 107 mA cw proton beam was extracted from the SILHI ECR source through a 8 mm diameter extraction aperture. The achieved plasma density : J = 213 mA/cm^2 is close to the one required for the IFMIF source. LEBT performance was also shown to be well suited to IFMIF.
- A 110 mA cw 94% proton beam was extracted in June 1998 from the IAP Frankfurt AMFIS source. The extracted current density is 390 mA/cm^2 and the noise level is less than 1%.

III. OTHER CONCEPTUAL DESIGN ACTIVITY

There are many other tasks necessary to reach a stage where productive preliminary design activity can start. An overall category for these detailed design tasks is maintaining beam loss and activation low enough that remote handling is not necessary. The tasks involve detailed design of the accelerator beam transport from ion source to target, fundamental investigations to gain understanding of the loss mechanisms, coordination with neutronics calculations and shielding design, coordination with engineering aspects of the accelerator design, and so on.

Fundamental work in beam dynamics and beam halo studies are required in concert with detailed computer simulations. Mechanical engineering support will be required throughout. Improved RAM analysis and cost estimates of the more detailed design will be required, and technical coordination of these closely-coupled activities is essential.

1997 work is reported below. IFMIF benefited substantially from work being done on other projects; some of this work is also included in the outline.

The 1997 CDE IFMIF Accelerator Team Meeting was held 26-30 May 1997, in Paris under the sponsorship of Saclay. The proceedings have been published as CEA Saclay Report No. CEA-DSM-GECA 97/54. In addition to the principal IFMIF partner institutes, participants from KEK, Japan and POSTECH, South Korea were invited to join the discussions of RFQ simulation. Numerous questions and team communications related to these codes had resulted in the decision to devote a large part of the meeting to this subject. Intense discussion was held on all aspects of the RFQ particle dynamics, on the simple fast code versions well-suited to optimization problems, and on source code details of the commercial MRTI RFQ codes. The meeting and subsequent work have resolved the questions satisfactorily, and more detailed design studies are in progress.

After this meeting, the IFMIF Executive Committee was asked about the possibility for recognizing future collaborative effort with the South Korean group. This was warmly answered in the affirmative. South Korea will soon become a member of the IEA, and then could become full members of the IFMIF team as well. Pending this, they are welcomed as participants in the IFMIF endeavor.

Work in the US included:

• A technical report covering issues of RFQ simulation was completed[4]. Work continued on various detailed aspects of the RFQ design, including the role of equipartitioning and possible ways to use the RFQ to prepare an optimal beam for injection into the DTL.

• An Operations and Reliability Development Activity was performed[5]. This preliminary report describes the interim results of a review of operations and reliability of existing accelerator facilities. During the International Fusion Materials Irradiation Facility (IFMIF) Conceptual Development Activity performed in 1995-1996, it was found that although accelerators have been in use for over 50 years, reliability data for accelerator components such as ion sources, focusing magnets and their power supplies, rf windows, circulators, drift tubes, etc., has not been collected. Thus, even though it is possible to develop models for analysis of accelerator reliability and maintainability using the standard reliability tools, the necessary supporting failure rate and repair time information is not available. Therefore, this effort was undertaken to collect data, review the literature, identify and visit a number of accelerator facilities to review their experience and accumulated information.

The Los Alamos Neutron Science Center (LANSCE) is an accelerator facility with enough operating history to supply meaningful reliability data. A companion paper[6] describes the data collection and analysis effort of the LANSCE accelerator operational data which was initiated to supply the accelerator reliability models with credible input data. A preliminary database of beam trips was assembled using operational data records, Central Control Room Logbook, and Operations Shift Supervisors' Summary Reports covering 1996-97. The events were classified according to the underlying cause into categories corresponding to typical accelerator subsystems. Mean Time Between Failures (MTBF) and Mean Down Time (MDT) estimates were obtained for magnets, RF stations, power supplies, etc. For the components considered, both MTBF and MDT were found shorter than expected. The results are useful for identifying development issues in high power accelerators.

Continuous and highly reliable operation has been established as a basic design criterion for IFMIF. Specifically, the overall requirement for IFMIF calls for an average 70% on-line availability performance, corresponding to 6132 hours in a calendar year of 8760 hours. To assist in achieving this goal, a comprehensive RAMI model for all the subsystems of the IFMIF facility, including the twin accelerators, test cell, target, conventional facilities, and central instrumentation and control has been developed. This model generates an allocation of the availability requirements to all the major components of the subsystems. The modeling approach, major assumptions, and the principal results are described in a second companion paper[7].

Work continued on various detailed aspects of the RFQ design, including the role of equipartitioning and possible ways to use the RFQ to prepare an optimal beam for injection into the DTL.

Work in Japan included:

• Estimates of deuteron beam induced radiation and activity in the accelerator and transport channels were surveyed, and the analysis of the measured thick target neutron yield has been reworked.

• A possible beam loss minimization technique has been considered using control optimization of the rf field transients.

• A design study of the superconducting linac option has been published[8].

• The precise beam dynamics simulation is carried out around the gap region in the segmented RFQ using an electromagnetic PIC code[9].

• An assessment of the cost of the IFMIF facility if built in Japan was presented.[10]

Work in EU included:

• A technical document[11] groups together the reports published by the CEA team during the period June 96-June 97. All these detailed technical reports summarize the high intensity linear accelerators studies done during this period, including the calculations and conceptual design relevant to IFMIF.

• The mechanism of space-charge neutralization has been investigated both experimentally and theoretically. The aim of these studies was to gain knowledge of the beam behavior in Low Energy

Beam Transport lines in order to be able to match the beam to the accelerator as perfectly as possible (beam mismatches are a main source of halo formation). The results allow the space-charge neutralization for various LEBT conditions to be known precisely, thus allowing accurate calculation to match the IFMIF beam to the RFQ.

¥ An important point concerning the beam loss problem is the ability designers have to predict them at extremely low levels. An collaborative effort of several years between CERN, CEA-Saclay and Los Alamos National Laboratory has resulted in a new powerful simulation code (DYNAC), with improved accuracy for RF field modeling and for space-charge calculation; the code is now ready for detailed simulations of the IFMIF DTL.

• Beam loss studies continue, including further investigations on halo formation in the longitudinal plane (accelerated beams) Experimental results will be obtained for unbunched beams in continuous or periodic focusing channels.

Work in Russia included:

• A 130 mA, 0.1-1.8 MeV RFQ was commissioned this year. Multipactoring was studied. Future studies will include operation under ultra-high vacuum conditions (10^{-10} Torr goal).

• A 3-dimensional model based on Poisson's equation and macroparticle motion equations solution was developed for the high level code LIDOS.PIC.

• LIDOS.RFQ.PIC code testing was done on the IFMIF RFQ. The first level was used to find an optimal version, and higher level codes are used for real field calculations and beam losses estimation.

IV. NEXT STAGE OF IFMIF ACCELERATOR DESIGN DEVELOPMENT

During the second half of 1998, discussion will proceed on the development of key technology issues for performance and cost reduction. For the accelerator, these include a 100-hour demonstration of the diacrode rf amplifier, and continued emphasis on the ion-source and low-energy-beam-transport injection system performance specifications and lifetime. Key accelerator issues include design work on the rf window, and continuing effort on the design of the beam orbit for beam loss minimization. RAM modeling will continue as a key element for achieving long lifetime, high availability, and cost optimization.

[1] A. Sauer, Diplomarbeit, "Untersuchung zum Einfluss von Strahlanpassung und S-Transport auf die Teilchendynamik am Beispiel des alten HERA-RFQ Injektors IAR", Feb. 1998.

[2] K. Reidelbach, Diplomarbeit, "Hochzeitaufgelüste Messungen mit einem Restgasionenenergiespektrometer an hochperveanten teilkompensierten Ionstrallen", 1998.

[3] J. Pozimski, Promotion, "Untersuchengen zum Transport raumladungs kompensiertes niederenergetisches und intensives Ionenstrahlen mit einer Gabor-PLasma-Linse", 1997.

[4] R.A. Jameson, "A Discussion of RFQ Linac Simulation", Los Alamos Report LA-CP-97-54, September 1997.

[5] C. Piaszczyk and M. Rennich, "Analysis of the Operations and Reliability of Existing Accelerator Based Facilities-Interim Report", ORNL document ORNL/M-6227.

[6] M. Eriksson & C. Piaszczyk, Reliabiity Assessment of the LANSCE Accelerator System", this conference.

[7] C. Piaszczyk & M. Eriksson, "Reliability Analysis of the IFMIF", this conference.

[8] Yoshio Tanabe, Nobukazu Kakutani, Tomoko Ota, Akiko Yamaguchi, Osamu Takeda, Yoshihiro Wachi, Choji Yamazaki, and Yasutsugu Morii,"Preliminary design study and problem definition for intense CW superconducting deuteron ion linac for fusion material study", Fusion Eng. and Design, 36 (1997) 179-189.

[9] M. Sugimoto, M. Kinsho, M.A. Chernogubovsky, JAERI; Y. Hojo, Hitachi Ltd., "Impact of the Beam Dynamics for the Concept of IFMIF Accelerator", 1st Asian Particle Accelerator Conference, 23-27 March 1998, Tsukuba, Japan.

[10] "IFMIF International Fusion Materials Irradiation Facility Conceptual Design Activity Cost Estimate in Japan", ed. M. Sugimoto, JAERI-memo 09-103, March 1997.

[11] "IFMIF Accelerator Studies (96-97)", CEA-DSM-GECA 97/42, June 12, 1997.