ENERGY SELECTIVE INTENSE NEUTRON SOURCE

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Abstract

The conceptual design study of the high energy intense neutron source for irradiation tests of fusion materials has been carried out at JAERI. The neutrons are generated by using Li+d reaction and a high current deuteron cw linac. The linac must supply a 50-100 mA deuteron beam with variable energy, 10-40 MeV, to adjust the neutron energy spectrum.

Introduction

The conceptual design study on the energy selective neutron irradiation test facility (ESNIT) has been conducted by JAERI since 1989 [1]. Firstly, It was conceived as an advanced irradiation tool to apply the generic nuclear fields including the fusion reactor materials development. The requirements for the neutron source is summarized in Table 1 and Fig. 1 shows the conceptual view of the facility. The chief motivation is to obtain the well controlled neutron fields with the high intensity (not the highest one) and the ultimate stability for the long-term irradiation tests.

TABLE 1
Requirements for Energy Selective Intense Neutron Source

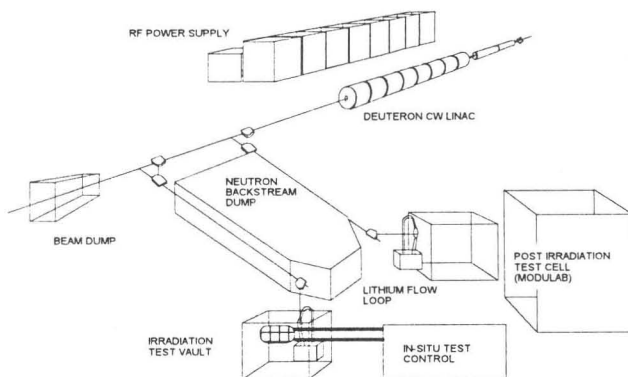| flux / volume	$1.5\text{-}3.0 \times 10^{14}$ n/cm^2/s at 5x5x5 cm^3
time structure	interval between micro pulses < 1 μs
energy range	peak around 5, 10, 14-15 McV possibility for minor adjustment
stability	total intensity, flux gradient < 1%
availability	> 80% (including scheduled maintenance)

Fig. 1. A conceptual view of Energy Selective Neutron Irradiation Test facility (ESNIT).

Base design concept

The base design parameters of the accelerator system are surveyed so that the extensive developments are unnecessary to start the construction within a few years [2]. The wide range of parameter study has been carried out with the collaboration with LANL [3-6]. Fig. 2 shows the RFQ current limit dependence for the considered several ion species with 100 kV injection and $\phi_g=-45°$; $E_g=0.49$ MeV. The neutron yield at the forward angle is approximately proportional to $E_d^{2.5}$, and E(H)= 18 MeV (or E(H$_2$)= 36 MeV), E(D)= 36 MeV, and E(D$_2$)= 72 MeV is assumed to estimate the relative yields.
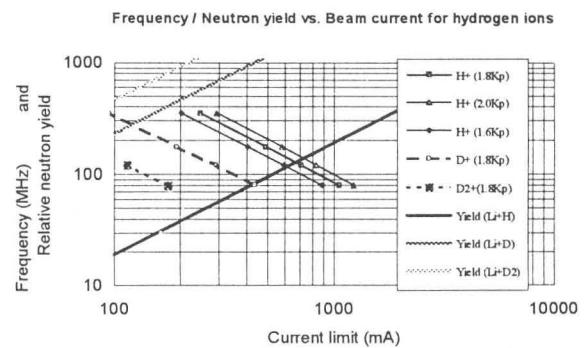

Frequency / Neutron yield vs. Beam current for hydrogen ions

Fig. 2. Current limit curves for H$^+$, D$^+$, and D$_2^+$ RFQs. The relative neutron yields at the forward angle from the reactions of lithium target are also given..

The combination of the 120 MHz RFQ and 120 MHz DTL with the separated tank structure is employed as the primary choice. The beam spot size and the energy spread at the target would be controlled to reduce the heat load to the flowing liquid lithium and also to flatten the neutron flux gradient. Both a beam redistribution and an energy dispersion system should work for the different energies of deuteron beam. Fig. 3 illustrates the accelerator components for the baseline concept.
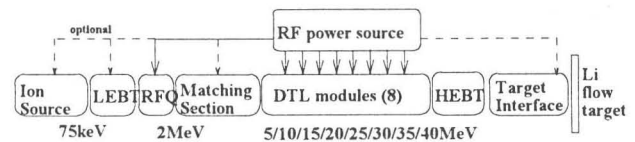

Fig. 3. A schematic layout of the accelerator system for baseline concept of ESNIT.

The descriptions of each component are as follows:
1) Ion source generates 60 mA DC ion beam with the energy 75 - 100 keV. The beam current should be doubled for the current upgraded module. The normalized full emittance should be less than 1π mm mr. Two identical units are installed as the normal injection and the backup one.

2) The LEBT consists of beam focusing channel for RFQ to accept DC ion beam from the ion source. There are several methods to transport the high current beam with low energy.

3) The RFQ linac captures the DC beam to accelerates up to 2 - 3 MeV with the CW (100 % duty) time structure. The transmission (or capture rate) should be 90 % or more to reduce the gas load and the activation.

4) The matching section is necessary when the main accelerator (DTL) requires to accept the beam from pre accelerator (RFQ).

5) The main accelerator consists of 8 tank modules of DTL tank, each of them gives the energy gain about 5 MeV.

6) The rf power source provides rf power to linacs and other elements.

7) The HEBT transports the accelerated beam to each target station without beam loss. It must be accepted beams with variable output energy.

8) The target interface must be designed to the specific target concept.
   a) energy dispersion cavity gives energy spread to flatten the energy deposit in target region.
   b) beam redistribution (expander) is requested to get variable size of beam spot on target.
   c) neutron back stream dump protects the accelerator components to allow the hands-on maintenance.

Table 2 at the last page summarizes the primary choice and other possibilities with the corresponding criteria and issues of the baseline parameters.

Critical issues

The stability requirement of the accelerator components are the most important issue to succeed the long term operation for irradiation tests. In addition to the stabilization for each element, the system must be designed to have the robustness to the fluctuations of the status or the drifts of the parameters of the equipment to keep the constant irradiation field. The method of maintenance of the components is also critical to avoid the radiation hazards and increase the availability.

To solve the such problems, the prototyping is necessary for the injector part including the ion source, RFQ, and the first tank of DTL, and the associated RF power supply. The beam control including the diagnosis, especially non-destructive beam monitor, is also the important issue to complete the final design. The efforts of understanding the physics of the high intensity beam and establishing the methods to evaluate the effects precisely are also required.

Summary

The main goal of this preliminary study was to evaluate the technical feasibility and the critical issues for the next coming detailed conceptual design works and the required R&D items. As the consequences, the extensive calculations for beam dynamics are still urgent to survey the boundary of the design parameters and optimize them partially. Many options of the accelerator system are ordered preliminary but it should be confirmed in the continued conceptual studies.

References

[1] K. Noda, et al., "Capability of energy selective neutron irradiation test facility (ESNIT) for fusion reactor materials testing and the status of ESNIT program", J. of Nucl. Mater. 191-194, 1367 (1992).

[2] M. Sugimoto, K. Noda, H. Ohno, and T. Kondo, "Accelerator system for the energy selective neutron irradiation test facility (ESNIT)", ibid. 1432.

[3] R.A. Jameson, compiled by, "Conceptual design aspects of a deuteron linac for materials testing neutron source", LA-CP-92-249 (1992).

[4] R.A. Jameson, compiled by, "Deuteron linac design aspects for ESNIT", LA-CP-93-5 (1993).

[5] R.A. Jameson, compiled by, "Deuteron linac design studies for ESNIT/IFMIF", LA-CP-94-136 (1994).

[6] R.A. Jameson, compiled by, "Review of studies, and continuing work, for JAERI OMEGA and ESNIT/IFMIF projects", LA-CP-94-151 (1994).

TABLE 2
Summary of Baseline Parameters of the Accelerator System for ESNIT

Item	Primary choice	Secondary choice	Criteria/Issues(grade)
Frequency	120 MHz (The underlined items are strongly influenced by the frequency choice.)	·80 MHz (FMIT) ·175/350 MHz (US-FMIF) ·200 MHz (JAERI-BTA) ·267/534 MHz (Chalk River)	·current limit ·facility size ·power source ·heat removal of linac
Ion source	·multi cusp-type ·60 mA [120 mA upgrade] ·$\leqq 1$ π mm mr (full. unnormalized) ·75 keV output ·pulsing capability (<1% duty. for conditioning)	·ECR-type or filament-less ·Negative (D⁻) source ·$\geqq 100$ keV output	·total current (A) ·emittance/output energy(A) ·atomic ratio (A) ·lifetime (B) ·stability/maintainability (B)
Low energy beam transport (LEBT)	·solenoid focus ·beam diagnostics	·RFQ lens focus ·helical electrostatic quad focus ·neutralization for negative ions	·emittance growth (A) ·RFQ Lens/HESQ(B) ·neutralization(B)
Pre accelerator	·4-vane type RFQ linac ·2-3 MeV output ·> 90 % transmission ·1.8 Kp max. surface field.	·higher output energy (5-8 MeV) ·higher max. surface field ·longitudinal/azimuthal fields stabilizer	·input/output energy(B) ·transmission(B) ·rf power coupler/tuner(B) ·stability(beam loading. thermal effect)(B)
Matching section	·transversal/ longitudinal matcher ·beam diagnostics		·matching between pre accelerator and accelerator with no emittance growth(B)
Accelerator	·5MV DTL module x 8 (5/10/15/20/25/30/35/40 MeV available at exit) ·2MV/m ·multiple feed of rf power for current upgrade	·superconducting linac ·higher accelerating gradient ·number of tanks (smaller for low cost; larger for stability)	·accelerating gradient(B) ·quadrupoles in drift-tube (permanent/electro-magnet. focusing arrangement)(B) ·rf power coupler/tuner(B) ·stability(beam loading. thermal effect)(B) ·beam loss(C) ·SC-Linac(C)
RF power source & components	·1 MW cw/unit tetrode ·10 units [18 units]	·several 100 kW/unit and multiple feed to each tank	·source type(tube/klystron) ·stability/maintainability ·construction/operation cost ·high power circulator/ window(B)
High energy beam transport (HEBT)	·High power beam dump for conditioning & emergency ·90deg achromatic bend		·beam loss(B) ·beam stability(B) ·beam dump(B)
Target Interface	·Energy dispersion cavity ·intensity distribution control (beam expander) ·neutron back stream dump		·neutron induced activation ·beam expander(B) ·remote maintenance(C)
Diagnostics. Safety. & Control system	·non-destructive monitor ·interlock monitor(beam breakup. beam loss) ·backup for device failure ·support system to operator		·accuracy/stability ·remote maintenance of dump

grades:　A : Currently available or minor improvement necessary, B : Prototyping necessary,　　C : R&D necessary