Forschungszentrum Karlsruhe
Technik und Umwelt

Wissenschaftliche Berichte
FZKA 5553

Proceedings of the IEA-Technical Workshop for an International Fusion Materials Irradiation Facility Karlsruhe, Germany September 26 – 29, 1994

IEA-Implementing Agreement for a Programme of Research and Development on Fusion Materials

K. Ehrlich, R. Lindau

Institut für Materialforschung
Projekt Kernfusion

Juli 1995

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Institut für Materialforschung
Projekt Kernfusion
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Forschungszentrum Karlsruhe GmbH, Karlsruhe

1995

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International Fusion Materials Irradiation Facility
Karlsruhe, Germany
September 26 - 29, 1994

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	- Drift tube Linac Normal vs. superconducting structures beam dynamics, high energy beam transport etc.	
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	- Different concepts for D-Li-target	

SG 3 Test cell and users — Chairman K. Ehrlich

- Neutron field characteristics for different target configurations
- Test matrices for different material groups
- Small specimen technologies
- Baseline concepts for test assemblies and irradiation facilities

15:45-17:00 Subgroup meetings II
R&D-requirements
Need for prototyping and engineering demonstration
Definition of work packages for the CDA-study

17:00 Departure to hotel

Wednesday, September 28

8:30 Bus pick-up from hotel

9:00-10:30 Plenary Session III — Chairman T. Shannon, H. Katsuta, K. Ehrlich

- Interim Reports from SG's 1, 2 and 3
- Matching of parameters for the "Basic Concept"

Discussion

11:00-12:30 Subgroup meetings III
and
14:00-15:30
- Organisation of work breakdown structures
- Distribution of CDA-tasks for the parties

15:45 Departure to the cathedral of Speyer and dinner in Deidesheim

22:00 Departure to the hotel

Thursday, September 29

8:30 Bus pickup from hotel

9:00-12:30 Subgroup meetings IV

- Complete subgroup reports, proposals for work packages and national tasks

14:00-15:30 Final plenary session Chairmen T. Kondo, F. Cozzani

- Brief report on work packages by subgroups's chairmen
- General conclusions and discussion
- Organisational issues
- Future plans

15:30 Departure to hotel, main station etc.

IEA - Technical Workshop for an International Fusion Materials Irradiation Facility IFMIF
Karlsruhe, Sept. 26 - 29, 1994

Schedule

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14.00	Plenary II Continuation	SG - Meetings I Discussions			SG - Meetings III Continuation			Plenary IV Reports General conclusions Org. issues Future plans
15.30	Break							
15.45	Discussion	SG - Meetings II R & D Requirements			15.45 h Departure to Speyer and Deidesheim			
16.30	Organisation of Subgroups I-III							
17.00	Departure	Departure			22.00 h Departure to hotel			

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Introduction:

Under the IEA-Implementing Agreement for a Programme of Research and Development on Fusion Materials, scientists identified in a succession of meetings (San Diego, 1989, Tokyo 1991 and Karlsruhe 1992) an immediate and urgent need for a high flux International Fusion Materials Irradiation Facility **IFMIF**. The activities resulted in a consensus that among the different alternatives an accelerator-based D-Li neutron source would fulfill the requirements of the materials community; it also could be realized in a timely manner (Karlsruhe 1992). The IEA-Fusion Power Coordinating Committee accepted at meetings in 1993 and 1994 the reports and the conclusions of the Executive Committee and recommended to start a Conceptual Design Activity (**CDA**) for IFMIF.

In a first CDA-planning meeting June 13-15, 1994 at the JAERI-Tokai Research Establishment an agreement was reached on the necessary input of money and manpower for each party, on a possible working structure and organisation, on the main technical fields of activities and on a preliminary time schedule for the performance of a CDA. For the start of the technical activities a workshop was proposed to be held in Karlsruhe in September 1994. This workshop was initiated to deal with the following objectives:

1) Critical review of the requirements for IFMIF from the user´s point of view
2) Definition of a baseline concept for the CDA-study
3) Formation of working groups for main fields of activities
4) Identification of tasks and critical issues for main components
5) Development of a working break-down structure, distribution of work and milestones for CDA-activities
6) Documentation of main results

The workshop was organized on September 26-29 by the Institute for Materials Research I and the Project "Nuclear Fusion" at the Forschungszentrum Karlsruhe. According to the enclosed agenda the mission for a Conceptual Design Study, the requirements for an intense neutron source from the user´s point of view and the baseline concept for an accelerator-driven D-Li neutron source were discussed in several plenary sessions. In three subgroups (SG 1 Accelerators, SG2 Lithium Target and SG3 Users and Test Cell) technical concepts for the different components and facilities were discussed in detail, critical issues and tasks for the concept study were identified. Finally, the sharing of tasks to the different national parties, questions of organisation of the work, flow of information and definition of milestones was agreed upon. The detailled summary reports of the subgroups and the contributions of the plenary sessions are presented in the following sections of the Proceedings.

The workshop was attended by 41 delegates of the European Community, Japan, Russia and the United States of America; enclosed photo shows the participants who have made this workshop a success.

K. Ehrlich, T. Kondo, H. Katsuta and T. Shannon for the Organizing Committee

Summary Reports

Summary Report
Accelerator Sub-Group SG-1

Participants:

EU

F. Cozzani	(Brussels)
H. Deitinghoff	(Uiversity of Frankfurt)
H. Klein	(University of Frankfurt)
J. Lagniel	(CEA/Saclay)
M. Martone	(ENEA/Frascati)
M. Olivier	(CEA/Saclay)
M. Promé	(CEA/Saclay)

Japan

A. Miyahara	(Teikyo U.)
M. Sugimoto	(JAERI)

US

D. Berwald	(Grumman)
R. Jameson	(LANL)
J. Rathke	(Grumman)
T. Shannon	(ORNL)
M. Wilson	(DOE)

Summary of Findings, Results, Conclusions:

- Consensus - Accelerator can meet IFMIF Requirements. Issues involve selection among component technologies.
- Major Decision - 2 parallel CW beamlines (proven technology, avoids funnel, provides increased flexibility). Beam funnel is back-up.
- Baseline Parameters:
  - 2 x 125 mA, 35 MeV (Nominal Parameters)
  - Energy breakpoints also at 30 - 40 MeV
  - Availability consistent with 70% overall IFMIF availability.

- Beam profile: 5 cm x 20 cm beam spot, uniform flat top (10%), ramp in vertical profile with sharp edge with <20 w/cm2 beyond (detailed requirements to be provided by target group).

- Major Issue
  - Room temperature or superconducting accelerator structure above 8 MeV.
  - R/T technology appears to be more straight forward.
  - S/C technology appears to provide advantages in areas including: enhanced operational flexibility, lower costs (e.g. lower power, common spares), and lower activation.
- Major Issue (continues)
  - Approach to Selection
    - 7 month decision point
    - Based upon engineering assessment and quantification of above advantages, evaluation of risk and developmental requirements, programmatic requirements.
    - See tasks defined below.
- Other Accelerator Components Technology Alternatives to be Evaluated
  - Ion source: ECR or RF volume (not critical path decision
  - LEBT: Dual solenoid (electrostatic is alternate)
  - RFQ: Rod or vane structure (selection ~ 6 months)
  - 3→8 MeV medium energy linac: longer RFQ. DTL, BCDTL, CCDTL, or I-H.
- Areas for Evaluation
  - Choice/layout of accelerator structure
  - RF frequency (175 or 350 MHz)
  - Accelerating gradient
  - Cooling/cryostat/refrigeration
  - Ability to meet multiple energy requirement
  - HALO/activation
  - RF design & distribution (circulators?)
  - Failure modes and effects

- Implications of possible future addition of beam funnel

CDA Task Breakdown

Task 1 - Decision on room temperature (R/T) or superconducting (S/C) 8-35 MeV linac

Task 1 A (complete by 31. Ec. 1994)

- complete reference designs for R/T and S/C beamlines. (R/T designs from 3 parties)
  - Emphasis on layout, mechanichal design and technology issues of 8-35 MeV section
- Prepare methodology for comparison of reference designs
  - Budgetary cost estimation
  - Plant availability
  - Development requirements (risk mitigation)
  - Other guidelines and assumptions

Task 1 B (complete by 31. March 1995)

- Distill task 1A reference designs down to one R/T and one S/C design.
- Complete first draft of R/T vs. S/C comparison

Task C (meeting tentatively scheduled for 8-12 MAY 1995)

- Conduct accelerator team meeting in Dallas, TX (after particle accelerator conference)
- Selection of R/T or S/C baseline for IFMIF
- Finalize baseline configuration.

Task 2 - **Baseline Design of low energy (<8 MeV) section**

- Prepare recommendations for low energy configurations consistent with R/T and S/C high energy designs (complete by 31 March 1995)
- Finalize baseline configuration (complete at 8-12 May MTG)

Task 3 - **Baseline design development**

- Refine baseline design as required for integration with remainder of facility
- Develop facility interface requirements
- Support integration meeting in August 1995.

IFMIF Technical Areas of Interest/Responsibility

Japan

- Ion source lifetime assessment
- LEBT beam transport evaluations
- RFQ-rop vs. vane evaluation
- Preliminary design of R/T DTL
- S/C accelerator technology evaluation
- Beam control studies
- RF source & transmission system (window) designs

Saclay

- RF systems
- ECR Deuteron Source
- R/T accelerating structures above 3 MeV
- HALO plasma studies

University of Frankfurt

- Analytical and experimental evaluation of RF driven ion source (D^+ to IFMIF parameters)
- Analytical and experimental evaluation of LEBT Alternatives (Dual Solenoid & Electrostatic)
- Physics and RF design including mechanical layout of rod RFQ with investigation of output energies to 8 MeV.

LANL/Grumman

- ECR and RF drifen ion sources
- Engineering analysis of Frankfurt rod RFQ design
- Design of superconducting accelerator option (physics, RF, engineering analysis, and layout)
- Integration of R/T accelerator option
- HEBT final optics design for required beam profile
- Beam HALO modeling
- Accelerator system performance, reliability & maintainability, cost estimation, and design

Potential Russian Support

- Contributions are offered per attached smeet.

Summary Report
Lithium Target / Lithium System Sub-Group SG 2

Outline:

Participants
Reference Design Description
(parameters)
Reference Interface Requirements
Major Issues
WBS/Work packages
(responsibilities)
Schedule
Communications standards and formats

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Interim Report

The lithium target / lithium system working group reviewed work performed during FMIT, ESNIT and FMIF activities, and found no insurmountable issues associated with extrapolating those results to IFMIF parameters. Both the target and lithium systems for IFMIF appear straightforward for the reference beam (5 cm x 20 cm, 35 MeV, 250 mA).

The lithium target/lithium system working group reference target design is based on the FMIT Mark-II target geometry. Specific target geometry, including wall radius, nozzle shape and drain geometry can be varied to improve user access to the high flux volume.

Reference Beam Interface Parameters:

Beam Current:	250 mA
Beam Width:	20 cm
Beam Height:	5 cm
Beam Distribution:	
Horiz:	Flat (edge peaks are undesireable)
Vert:	Flat with Gaussian edges (sharp gradients are undesireable)
Beam Tails:	TBD (<20 w/cm2) (Beam tails, halos, etc are very undesireable)
Beam Energy:	35 MeV (30 & 40 MeV alternate energies)
Energy Dist.	500 keV 1-sigma gaussian or equivalent (greater may be unnecessary)
Alternate Beam Shapes:	
	2.5 x 40 (issue: structural stability of wide backwall,pumping power required) 10 x 10 (issue: stability of the jet surface)

Discussion:

There are several concerns regarding the beam current distribution. In particular, the tails of the beam are of concern to the target structure. Total power in the tails of the beam must by limited to ensure structural integrity of the target side-walls, nozzle and other structures. The power flux at the target structures must yet be established. However, some general observations can be made. The converging beam concept illuminates the walls with a higher angle of incidence than the parallel beam concept. This implies that the converging beam concept should have less current in the beam tails. Initial estimates suggest the beam tails density should be less than about 20 w/cm2 at the surface of target structures.

The vertical distribution is important. The target needs some gradient at the edges of the vertical distribution. Edges with a distribution equivalent to that of a 1-cm (full-width-at-half-maximum) gaussian would appear acceptable.

Design to accomodate a 2.5 cm x 40 cm beam appears hydraulically straightforward. There is some concern regarding the geometric stability of the very wide backwall under intense irradiation. A consensus that the wide backwall would be more susceptible to distortion than the reference 20-cm wide design was arrived at. The additional distortion could result in decreased target lifetime, and/or could require structural modifications such as a thicker backwall or differently shaped backwall that could have a minor on available flux-volume.

Design to accomodate a 10 x 10 beam appears hydraulically feasible with regard to the main jet flow and structural issues. However, the surface stability of the longer jet is a very significant concern. FMIT experience shows that the 11-cm radius jet maintained sufficient stability for the needed 4 cm of flow. Surface roughness increases for increasing flow distance and for increasing wall radius of curvature. A target to accomodate a 10-cm high beam must have a larger radius of curvature and a longer flow distance. Both effects will increase surface roughness far beyond that demonstrated for FMIT. Therefore, design of a target for this configuration will require carefull attention to surface stability, including hydraulic testing, and possibly including lithium testing.

Reference Target Parameters:

Jet Width:	22 (to 24 cm)
Jet Height:	7 (to 9 cm)
Jet thickness:	1.9 cm (nominal)
Jet Velocity:	17-20 m/s
Flowrate:	75 - 100 l/s
Inlet Temperature:	220 C
Mixed Outlet Temp:	˜ 270 C
Target Material:	TBD
Target Goal Lifetime:	9 full-power months

Discussion:

In this context, we consider "beam tails" to include all beam current outside the limits of the nominal beam-on-target spot dimensions. This includes both the tail of the nominal beam distribution and any beam halo. The jet width and height must be greater than the beam dimensions in order to accomodate the beam tails and uncertainty in beam position. Increasing the jet width is hydraulically simple, but requires increasing the flowrate and corresponding increase in the lithium system parameters. Increasing the jet height increases the concerns related to jet stability. Thus, minimizing the beam tails and minimizing beam position uncertainty is an important goal.

Selection of material for the target, and especially for the backwall, has been left open. FMIT used 304 stainless steel. SS 316 has been suggested for IFMIF. However, materials data obtained since the end of the FMIT project suggest that damage rates in austenitic stainless steels are much greater than previously assumed. However, the target structure is frequently replaced. Furthermore, the first several targets will certainly be replaced much sooner than the 9-month design life. Thus, there are many opportunities to modify the target during the life of the facility, and the first few target themselves can be used to determine the radiation damage characteristics of candidate target designs under actual IFMIF operations.

IFMIF Lithium System Reference Design:

Based on FMIT/ESNIT layouts
Design for single pump @ 250 mA, allow 2-pump operation for 500 mA.

Discussion:

We expect the IFMIF lithium system design to be closely derived from the FMIT/ESNIT designs. Although specific component designs will depend on the final flowrate requirements, the general system layout and the conceptual design of individual components will be very similar to those of FMIT.

Critical Interface Issues:

Beam Current distribution
- Vertical gradients
- Horizontal current peaking

Beam "Tails"
- impact on sidewall heating

Energy distribution
- effect on stopping power profile

Dual-beam operation
- parallel vs convergent beams
- impact on sidewall heating

Approach to 500 mA operation
- Single cell/lithium system vs 2-cell

Target-Vacuum system interface
- Target/Vacuum isolation valve

R&D Issues:

Front surface stability of taller target window

Optimum backwall shape

Nozzle shape, impact on surface stability

Lithium evaporation/transport

Lithium Impurity requirements and monitoring

"Beam-on-target" test:

The IFMIF target design concept is based on the FMIT design, and as such, enjoys substantial conservatism in both design and design analysis. The target thermal performance is very conservative, and the primary benefit of reducing conservatism is to reduce lithium system pumping requirements. The jet geometry is also conservative, and the potential benefit obtained in performing a prototypic beam-on-target test might be a slight (sub-millimeter) reduction in the jet thickness. Thus, the inherent conservatism reduces the need for a prototypic beam-on-target experiment, and the major benefits of such a test are for overall confidence reinforcement.

The prospects for a prototypic beam-on-target test, complete with the deeply submerged hot spot, vacuum surface condition, high surface tension, low vapor pressure and low total pressure appear unlikely. However, a number of important features can be tested, either in lithium or a modelled fluid. Improved tests of lithium vaporization and transport from the free surface are possible, and offers an avenue for significantly decreasing the uncertainties in this important interface issue.

Other, less aggressive modelling techniques offer potential for studing individual aspects of the jet response to beam heating. Several concepts for internally heating a modelling fluid, as well as concepts for hydraulically modelling the jet dynamics were offered. While none promises simultaneous modelling of all important parameters, each can be used to help benchmark analyses, thus improving the overall confidence in target design and development.

Work Breakdown Structure, Work packages and responsibilities

(See attached)

Schedule

(See attached)

Communications

Network: Internet
Platform: IBM-PC
Text: WordPerfect 5.1 or ASCII text file
Drawings: AutoCad 12 or IGES / DXF formats

Li Target System Subgroup

1. FMIT Overview

2. ESNIT Overview

3. Establish IFMIF Concept

    * 30,35,(40) MeV
    * 250 mA (125 x 2)
    * 50 x 200 mm^2

4. Extract the Different Points Between IFMIF and FMIT/ESNIT

5. R & D for IFMIF

    * Li - Target
    * Li - Loop System

6. Discuss the Beam on Target Experiments

7. WBS for IFMIF

8. Time Schedule for IFMIF/CDA

9. Mile Stone for IFMIF/CDA

10. Cost Evaluation for IFMIF/CDA

11. National Contributions

Proposed Reference Design for IFMIF-Target

Target Concept:	Curved Wall, Free Surface Jet (FMIT MK-II)	
	Beam Height: 5 cm	Target Height: 7 cm
	Beam Width: 20 cm	Width: 22 cm
	Beam Current: 250 mA	
	Beam Energy: 35 MeV (30-40)	
	Energy Dispersion (500-750 KeV)	
	Flow Velocity: 17-20 m/s	
	Flow Rate: Evaluation	
	Inlet Temp.: 220 C	
	Mixed Mean Outlet Temp.: Evaluation	
	Materials: 304/316 SS	
	Back Wall Life Time: 9 Month	

Li Loop System Concept

: Based on FMIT /ESNIT Design

IFMIF/CDA Technical Planning Workshop
at Karlsruhe, September 26-29, 1994

IFMIF/CDA
Target System
Proposed Work Breakdown Structure

Items	Critical Issue
I Lithium Target I-1 Target Assembly 1-1 Straightener 1-2 Nozzle 1-3 Backwall 1-4 Down stream guide 1-5 Target instrumentation 1-6 Target Li system interface	Followed by the conditions: Free surface size, Max. flow velocity and Error estimation.
I-2 Target Interface 2-1 Beam-Target structural interface target/vacuum/isolation valve 2-2 Evacuation system Li mist evacuation H, He evacuation 2-3 Emergency shutdown system 2-4 Configuration with target assembly / test cell	Evaluation of the production rate of: Li mist, H, He
II Li Loop System II-1 System Design 1-1 Structural material 1-2 System concept (inclu. 2ry loop) 1-3 Heat removal system concept	Selection of structural (and component) materials

JAERI

II-2 Primary Loop 2-1 Loop Components EM pumps Heat exchanger Valves Piping Quench tank Draintank Instruments	Engineering feasibility test.
II-3 Li Chemical Processing loops 3-1 Chem. processing components Impurity monitoring system Cold trap Hot trap	Conditions of impurity level: H(D,T), O, N, ^{7}Be. Engineering feasibility test.
III Test Cell Design III-1 Configuration III-2 Radiation Shielding Pipes & Loop Components Cold Trap & Hot Trap III-3 Design for Large Scale Li Leak III-4 Gas-tight Structure for Li Loop Room and Test Cell Room	Distribution of radioactive products: T, ^{7}Be. Safety criteria for Li leak. Neutron flux level at the test cell room.

IV Remote Handling Systems IV-1 Exchange of Target Assembly IV-2 Exchange or Repair of Loop Components	Fundamental design concept to make: exchangeable repairable excess capacity
V System Safety	
V-1 Li Leak Countermeasure 1-1 Leak drain and fire-proof construction 1-2 Radioactive isotopes release control	Tentative safety criteria
V-2 Backwall Damage Countermeasure 2-1 Direct damage under normal Li flow 2-2 Damage by beam current	(Interaction with HEBT) Water mock-up test
V-3 Safety Control Sequence	Conditions of beam stop or HEBT gate-valve off
V-4 Facility or Device for Safety Backup: Emergency power source etc.	

VI Design of Experimental Facilities VI-1 Target Hydraulic Characteristic Test Loop 1-1 Water test loop 1-2 Li test loop VI-2 Li Engineering Test Loop 2-1 Chemical control test loop 2-2 ^{7}Be trapping test loop 2-3 Component test loop VI-3 Beam on Target Experiment	Selection of possible accelerator: beam power, current
VII Liquid Li Data Base	

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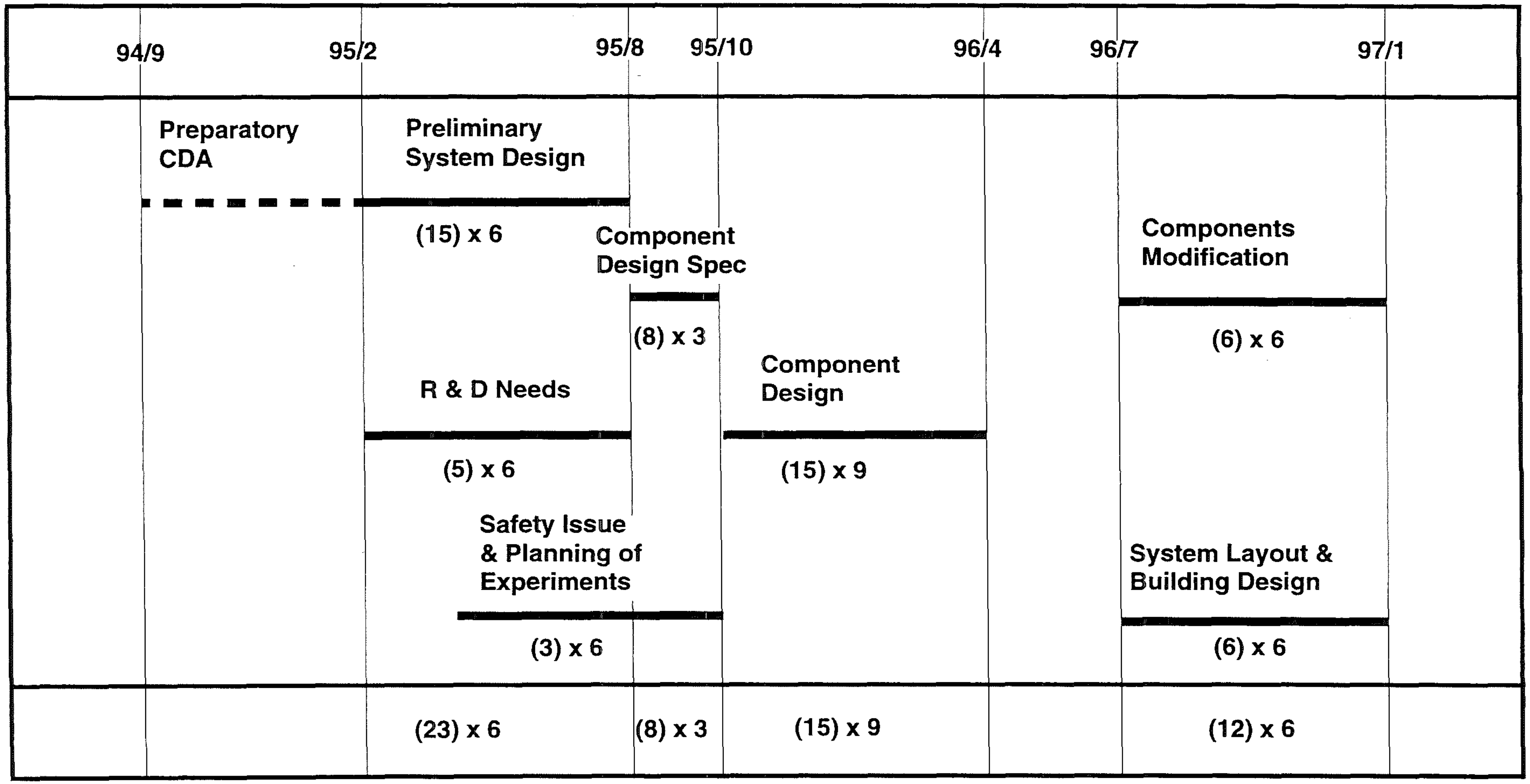
IFMIF / CDA
Estimated Time Schedule and Milestones



Total 369 (man) x (month) [JAERI]

Summary Report
Users and Test Cell Sub-Group SG 3

Participants:

EU

R. Conrad	JRC Petten
E. Daum	KfK Karlsruhe
K. Ehrlich	KfK Karlsruhe
R. Lindau	KfK Karlsruhe
M. Martone	ENEA Frascati
U. von Möllendorff	KfK Karlsruhe
A. Möslang	KfK Karlsruhe
M. Monti	ENEA Bologna
H.D. Röhrig	KfK Karlsruhe

Japan

S. Jitsukawa	JAERI Tokai Mura
T. Kondo	JAERI Tokai Mura
H. Maekawa	JAERI Tokai Mura
H. Matsui	Tohoku University
K. Noda	JAERI Tokai Mura

Russia

L. Zavialsky	MINATOM Moscow

US

J.R. Haines	ORNL Oak Ridge
F.W. Wiffen	US-DOE Washington
St.J. Zinkle	ORNL Oak Ridge

Summary:

The users and test cell group reviewed and refined at first the requirements for an IFMIF which had been formulated earlier for the d-Li- source at the Karlsruhe Workshop 1992. According to Annex I and in comparison to the earlier assumptions more precise conditions have been formulated for the neutron flux - test volume relation which has to be based on collided flux calculations using a refer-

ence loading scheme for the test cell. This condition could eventually increase the beam current of 250 mA to higher values.

The proposed changes in beam spot size and shape with a tendency for a larger and more flat irradiation volume for experimentation is based on new developments for a possible miniaturisation of specimens for different test techniques, the engineering concepts for the design of test modules and their instrumentation and would facilitate the general accessibility to the test cell. In combination with the defined low flux gradients and the spacial and time stability of the beam the uniform target illumination is eventually a critical issue.

Beside a high availability of the machine an additional condition has been formulated with regard to unintended beam interruptions. These could eventually influence radiation-induced effects which are sesitively dependent on the time strucuture of the neutron flux. However, periodic beam-on/off cycling in periods of hours would be attractive for the simulation of ITER-like operation conditions.

The variation of deuteron energy between 30 and 40 MeV with 35 MeV as reference is a desirable possibility to change the neutron yield and neutron spectrum. This is especially important for the adaption of displacement damage and certain transmutation reactions in dependence of the material to be investigated.

The user and test cell group, further divided in three subgroups, finally elaborated a total of eleven tasks (CDA-D1 - CDA-D11) in which the aims of the investigations are described in detail. Furthermore the contributors for the different tasks and a possible time schedule for the performance of the work and preliminary milestones have been defined. These data are compiled in Annex II and III.

Requirements for an International Fusion Materials Irradiation Facility
Subgroup 3 Users and test cell

	Parameter	Value
❶	Neutron flux and neutron spectrum (collided flux)	Equivalent to a First Wall loading of 2 MW / m^2
❷	Volume of "high-flux region" with a neutron flux equivalent to ≥ 2 MW/m^2	min. 0.4 l (1l)
❸	Flux gradient in vertical and radial direction	≤ 10% / cm
❹	Beam size and shape	50 x 200 mm as reference and a variability between 25 x 400 mm and 100 x 100 mm
❺	Target illumination	Beam intensity variation in target area ≤ ± 10% over time
❻	Beam current and beam interruptions	250 mA [1] Less than one beam interruption per week with t_{off} > 1 hour Less than 20 beam interruptions per hour with $10^{-3} < t_{off} < 1$ s
❼	Availabilty	70%
❽	Deuteron beam energy	35 MeV as reference, with a possible energy variation to 30 and 40 MeV resp.

[1] Depends upon new calculations for the relation flux⇔ dpa⇔2 MW/m^2
(Reference test cell loading , "DEMO"-spectrum)

Tasks for SG3 for the Conceptual Design Activity of IFMIF

CDA-D-1 Provide neutron source function for given target-, beam- and energy parameters

Oyama, Gomes

Completion Date: 15 Nov, 1st set

CDA-D-2 Define further work. Perform detailled neutronics analysis and other parameters for a test cell with standard loading configuration

Parameters: neutron-flux-volume relations
displacement per atom
transmutations
γ-field characteristic / γ-heat
activation

Standard loading condition:

Li cooled	50% Fe, 30% NaK, 20% void
H_2O cooled	50% Fe, 50% void
(He cooled)	50% SiC, 30% NaK, 20% void
	50% SiC, 50% void

Target size: 50 mm x 200 mm (Ref)
{25 mm x 400 mm and 100 mm x 100 mm}

Oyama, Gomes, Fischer

CDA plan: 15 Nov (1page)
preliminary result: 1 Feb

CDA-D-3 Define miniaturized standard specimen geometries and develop a loading for high flux region and outer regions (Matrix!)

Zinkle, Jitsukawa, Möslang
initial output: 15 Dec

CDA-D-4 Develop engineering concept for "standard loading" (defined under 3); include provisions for instrumentation and cooling

Conrad, Haines, Jitsukawa, Noda
15 Feb

CDA-D-5 Define necessary in-situ experiments for all classes of materials investigated and develop concepts for in-situ test-facilities

Zinkle, Jitsukawa, Möslang

CDA-D-6 Develop design concepts for 2-3 typical test modules and their interface with test cell.

Conrad, Haines, Jitsukawa, Noda

CDA-D-7 Provide processed nuclear data between 20-50 MeV for relevant elements

Oyama, Attaya, ENEA, Fisher, Daum
1 Nov Initial Date, Mar 95 Interim Report, Mar 96 Completion

CDA-D-8 Identify requirements for a common facility for materials testing at the IFMIF-site. Define test equipment required.

Zinkle, Jitsukawa, Noda, Möslang
June 95

CDA-D-9 Develop an overall test matrix

Zinkle, Jitsukawa, Noda, Möslang
June 95

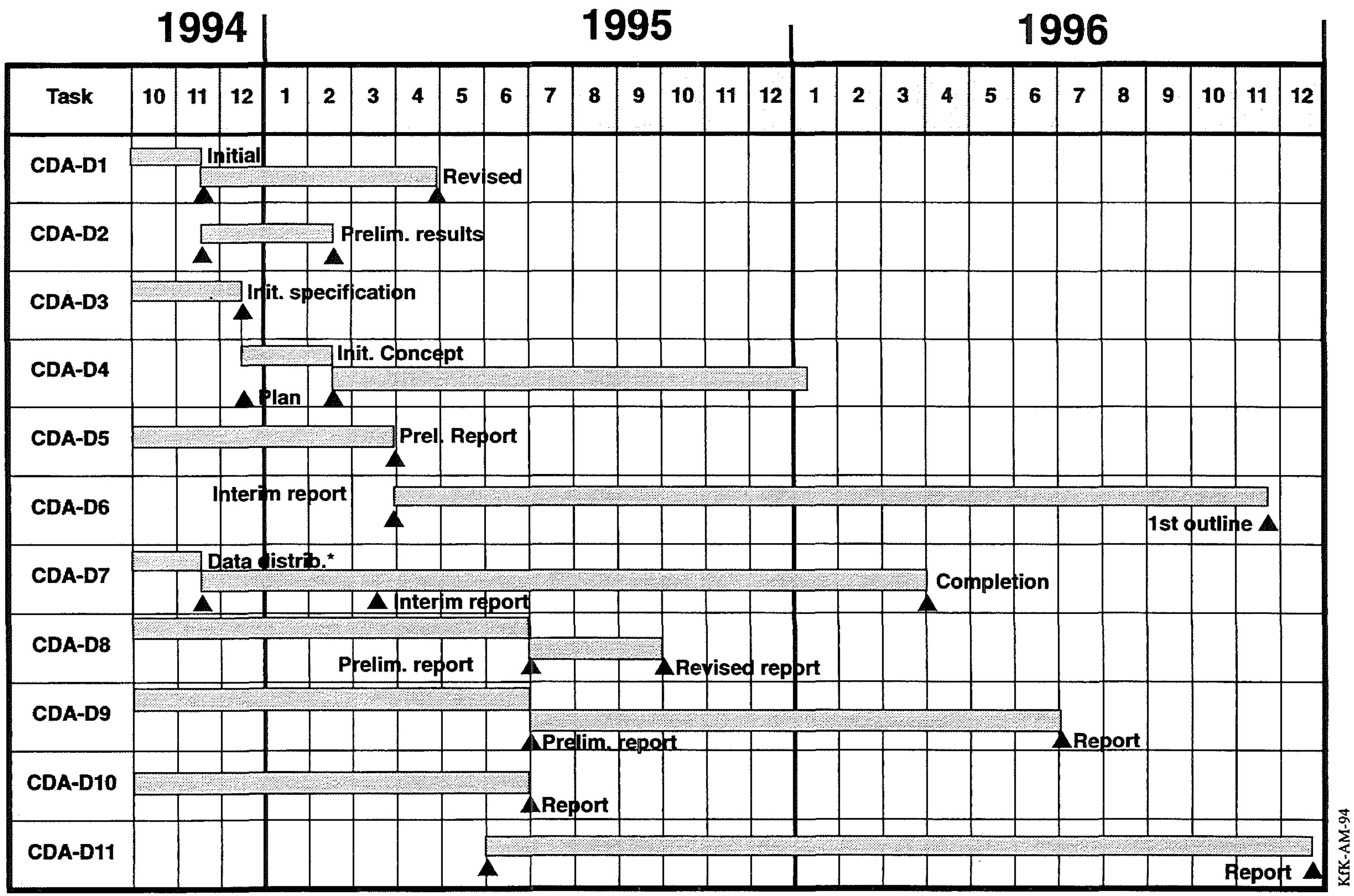
CDA-D-10 Define design concept for dosimetry

Greenwood, ENEA, JRC-Petten, Oyama
June 95

CDA-D-11 Develop design concept for entire test cell

Conrad, Haines, Noda
May 95

IFMIF-CDA Tasks for Test Cell Users Group



* DLC87/HILO & ORNL/TM-7818 (1981)

Plenary Session I

Introducory Remarks

T. Kondo

JAERI

IEA Technical Workshop on Planning IFMIF-CDA

INTRODUCTORY REMARKS

T. Kondo
JAERI

September 26 - 29, 1994
Karlsruhe, Germany

MILE STONES OF INS

FMIT PROJECT(USA, 1978 ~ 1984)
IEA COTTREL PANEL(1983)

" An increased effort should be made immediately to provide suitable facilities for irradiation of materials including **at least one high energy, high flux neutron source "**

IEA AMELINCKX PANEL(1986)

"..that **the selection, the detailed design and the construction of a high energy, high flux neutron test facility be initiated immediately with the highest priority."**

IFMIF/ESNIT ACTIVITIES

-International Reviewing on ESNIT(Japan,1989~1993)
-IEA Workshops and Working Group(1989 ~1992)

IEA/FPCC COMMITTMENT

-High Flux and High Volume Charters (1983)

-IFMIF(High Flux) CDA Planning (1994)

FPCC Charters for High Flux Neutron Source for Materials

January 1993

"Develop as a technical approach to a possible international agreement, ***the design choice, a judgment of feasibility and a possible route of implementation to a single , acceptable design for IFMIF "***

February 1994

"The Materials Executive Committee should proceed with the development and conduct of a conceptual design activity including the interested Contracting Parties and possible Associate Contracting Part(ies). ***The first task should be to complete any necessary regal formalities and research agreement on a detailed organizational and management arrangement while conducting the technical homework foreseen in the report."***

IEA Working Group Conclusions - 1

General Conclusions on D-Li Source

1) Only acclerator-based sources meet near-term requirements

2) ***Test volumes, while small, are adequate for materials development.*** Appropriate combination of ***accelerator size and use of miniaturized specimens*** (if approved) could provide engineering data for DEMO.

3) The question of appropriate sizes for obtaining engineering data for a DEMO reactor should be addressed soon by a combination of ***designers and materials specialists***, in order to better define test volume requirements.

4) D-Li Provides fusion-relevant spectra. The concept is well advanced. It is considered ***the best choice for a near-term source***.

For example, a 250 mA, 35 MeV D-Li source gives
(while dependent on beam spot size/geometry)

Displacement Rate (Fe)	Approx. Test Volume
> 5 dpa / year	3 liter
>20 dpa / year	0.4 liter
>50 dpa / year	0.1 liter

IEA Working Group Conclusions - 2

Simulation of Fusion Neutrons with Transmutation Rates / DPA Rates

D-Li (35 MeV) , He/dpa ratios within factor of 3 of DEMO (similar to beam plasma source) with some exceptions

- Hydrogen production from light elements, especially carbon, much higher than in DEMO. *Improved some by lowering deuteron energy** , but lowers neutron yield also.

* note: ***Energy selectivity,*** eg. from 30 and 35 (+ 40?), is recommended.

ACCELERATOR-BASED SOURCE(D-Li) CONCEPT FEATURES

- **Approximate Fusion Reactor Neutron Spectrum**
  - Acceptable He/dpa Ratio (Factor < 3)
  - Spectral Peaking ~14 MeV, (with Small >14MeV Energy Tail)

- **Mature Baseline Design**
  - Acclerator, Target and Experimental Systems

- **Issues and Up-Grade Potentials**
  - Beam-on-Target Test Remains to be Demonstrated
  - Volume-Flux Distribution Controllable by Beam Technology
  - Reduction of High Energy Tail by Energy Selectivity(ESNIT Concept)
  - Neutral Particle Beam Accelerator Experience Available

- **Modest R&D Requirements**

- **Reliable Cost and Schedule Estimation**

IFMIF MISSIONS EXPECTED

Materials Development Exploration, Engineering Data Base and Performance Demonstration

First Wall / Blanket Materials (High Flux Regions):

- -Accelerated Testings
  (Fluence Sensitive Properties)
- -In-Situ Testings(Flux Sensitive Properties)
- -Studies on Rate Effects at High Damage Rates
- -Studies on Effects of Transmutants
- -Determination of Spectral Effects for
  Fission/Fusion Correlation in Data Applications

Insulators:(Medium-Low Flux Regions)

- - In-Situ and Post Irradiation Measurements of Electrical , Thermal, Optical and Mechanical Properties

Subcomponents and Breeder Materials:(Low Flux Regions)

- - Performance Testing of Semi-Components and Test Modules

Neutron Field Characteristics Expected in IFMIF of Current Layout-1

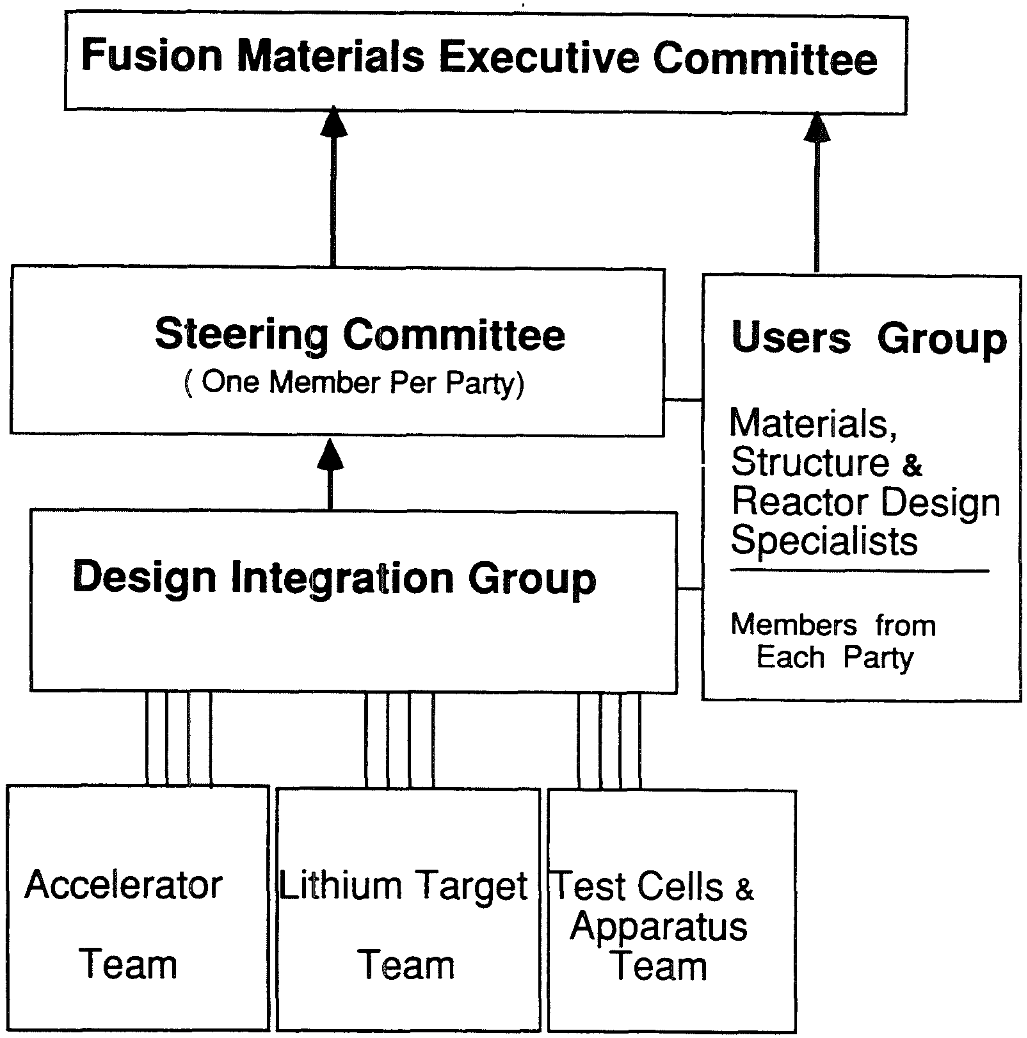
Major Beam/Target Specification

(Specification)

Deuteron Energy:	30 and 35 MeV
Deuteron Total Current:	250 mA
Target Configuration:	Single Li Target with Two Injecting Beam
Typical Beam Size:	10 cm X10 cm (uniform current distribu.)

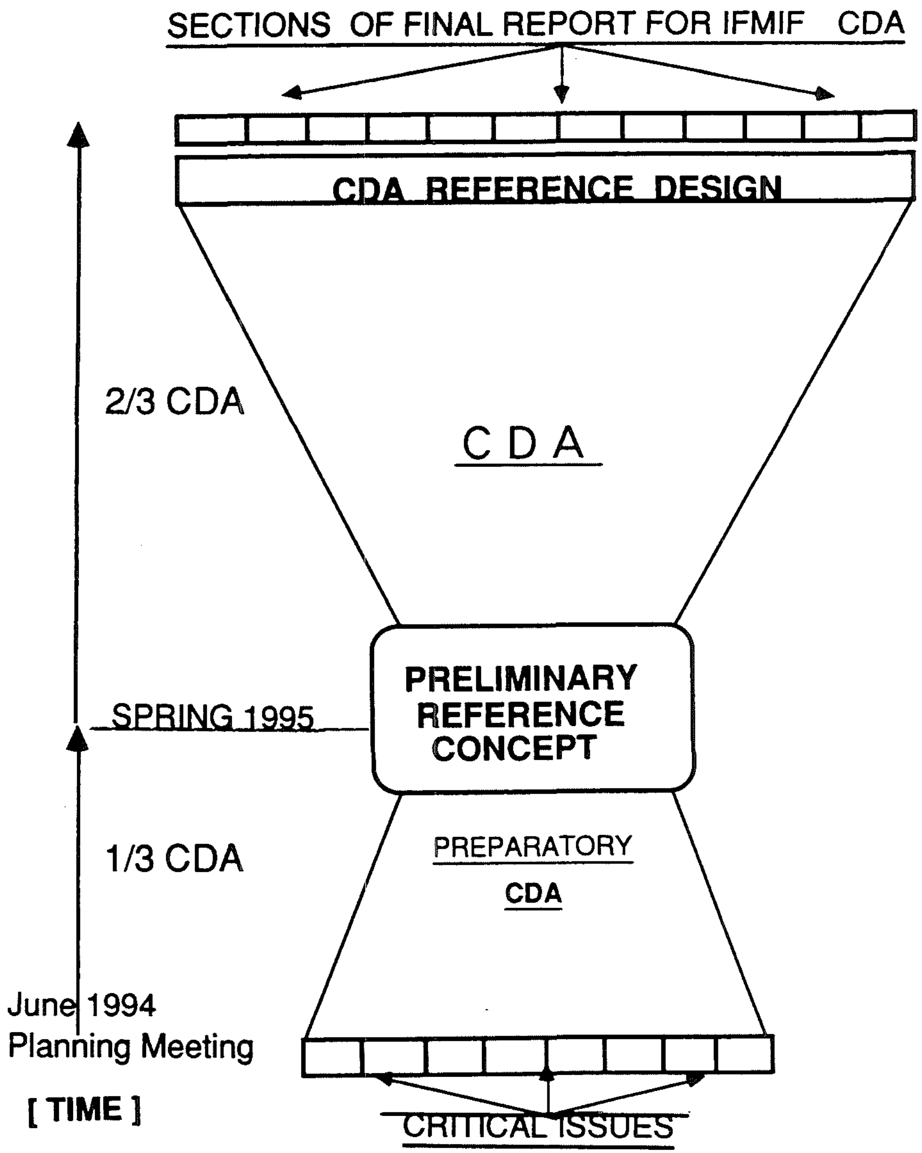
ORGANIZATIONAL STRUCTURE FOR IFMIF-CDA

The First Planning Meeting, June 13 -15, 1994



APPROXIMATE TIME SCHEDULE FOR THE IFMIF-CDA

The First Planning Meeting, June 13 -15, 1994



MILESTONES FOR THE IFMIF CDA
(Tentative as of June, 1994)

A possible schedule of milestones was discussed in the Planning Meeting(June, Tokai;-mura, Japan). It is a first suggestion that should be reviewed and possibly revised at the Karlsruhe workshop,

- Form International Procedural Concept	6/94
- *Initial Requirements and Design Layout*	***9/94***
- Establish Baseline Design	4/95
- Preliminary System Design Lay-outs	7/95
- Interim Report, Design Requirement, & Plan	10/95
- Define Engineering Development Needs	12/95
- Estimate Cost/Schedule for Construction	4/96
- Environment, Safety & Site Requirements	9/96
- Conceptual Design Completed	1/97

IEA IFMIF-CDA Technical Planning Workshop
Scope

Objective

1) Review the state of art in facility technology and outcomes from past activities on the facility concept evaluation

2) Define a baseline facility concept and identify issues in each technical element and of the integrated system

Goal

3) To agree on
   - milestones for the conceptual design activity (CDA) and prepare a detailed work plan for the activity
   - A common framework for defining a facility layout

4) To define the next technical works to be carried out
   - Conceptual phase tasks
   - Engineering phase tasks (Technical development)

The Requirements for IFMIF from the User's Point of View

Karl Ehrlich

KfK

IEA - Technical Workshop for an International Fusion Materials Irradiation Facility

Karlsruhe, September 26-29, 1994

The Requirements for IFMIF from the User's Point of View

Karl Ehrlich

Key assumptions and main requirements for the development of DEMO-structural materials

Key assumptions:

1. **Loading conditions under normal operation**
   - Quasi-steady state operation
   - Neutron Wall Loading ~ 1-5 MW/m^2
     (First wall and blanket structural materials)
   - Integrated Wall Loading ~ -10 -20 MWy/m^2
     (First wall and blanket structural materials)
   - Thermal Loading ~ 10 MW/m^2
     (Divertors)
   - Component life time > 10 years

2. **Off-normal loading conditions (disruptions) have to be minimized**

3. **Selected materials are the reference for future Commercial Fusion Reactors (CFR)**

Key assumptions and main requirements for the development of DEMO-structural materials

Main requirements:

1. Establishment of complete data base for unirradiated material properties
   (Code-relevant data sets)

2. * Generation of data on irradiation behaviour of materials, e.g. on following topics
   - Microstructural development
   - Swelling and irradiation creep
   - Radiation hardening and embrittlement
   - Post-irradiation and in-pile fatigue/creep
   - Radiation-induced fracture toughness
   - Radiation-induced segregation RIS
   - Irradiation-induced stress-corrosion cracking IISCC

3. * Determination of material-specific activation and other radiological properties and analysis of data for safety, maintenance, recycling, decomissioning and waste disposal

* For topics 2 and 3 an Intense Neutron Source is indispensible

Tasks for an International Fusion Materials Irradiation Facility - IFMIF

An intense high-energetic neutron source is required for:

(1) • Development of an engineering data base for DEMO-materials

(2) • Development of new materials (primarily "Low Activation" alloys)

(3) • Calibration and validation of data from fission reactor- and accelerator-based simulation irradiations

(4) • Lifetime tests of ITER-materials

Material classes to be investigated:

- First Wall- and Blanket-Structural Materials
- Insulator and Special Purpose Materials
- Divertor- and FW-Protective Materials

Main types of experiments to be provided:

- Instrumented and parameter-controlled In-pile experiments
- Instrumented irradiation capsules for P.I. tests

The IEA has held three workshops on neutron sources for the Fusion Materials Programme

1. San Diego - February 14-17, 1989

   - General definition of requirements of an INS for Fusion Materials Research
   - Comparison of different alternatives like stripping-, spallation-, beam plasma-reversed field pinch and high density Z-pinch sources

2. Tokyo - January 14-16, 1991

   - Neutron sources based on accelerators
   - ESNIT-d-Li-, and t-H_2O n-sources

3. Karlsruhe - September 21-23, 1992

   - Comparison of different sources regarding suitability and feasibility
   - Comparison of damage parameters in different sources and for different materials
   - Conclusion that only the d-Li-stripping neutron source fulfills presently all selection criteria
   - Recommendation to start a CDA for an accelerator-based d-Li-neutron source

Requirements for an Intense Neutron Source (IEA-Workshop in San Diego 1989)

1. Neutron flux/volume relation:
   Equivalent to $2 MW/m^2$ in 10 l volume
   $1\ MW/m^2$ $\hat{=}\ 3 \cdot 10^{18}\ n_{tot}/m^2$ for a DEMO-spectrum
   $\hat{=}\ 4{,}5 \cdot 10^{17}\ n(m^2)$ for $E = 14$ MeV
   $\hat{=}\ 3 \cdot 10^{-7}$ dpa/s for Fe

2. Neutron spectrum:
   Should meet FW neutron spectrum as near as possible
   Quantitative criteria are:
   Primary recoil spectrum, PKA
   Important transmutation reactions, He, H

3. Neutron fluence accumulation:
   $1\ MWy/m^2 \simeq 10\ dpa_{NRT}$
   Demo-relevant fluences in few years
   $\Rightarrow$ Machine availability $\geq 70\%$

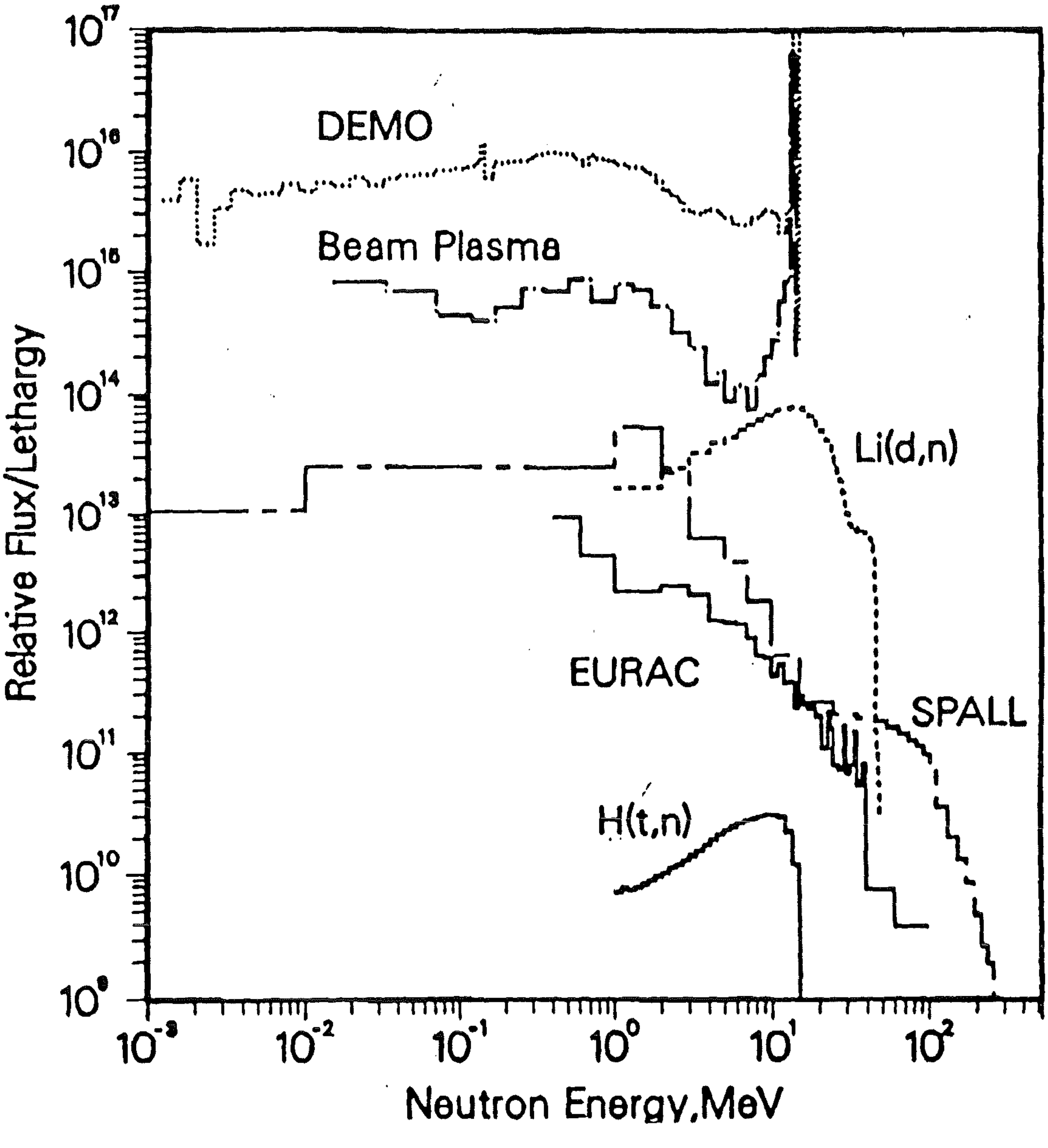
4. Neutron flux gradient
   $\leq 10\%$/cm based on minimum dimensions of CT- and Charpy-V-specimen

5. Time structure
   Quasicontinuous operation

Neutronic Characteristics and Flux Contours of different Neutron Sources
(IEA - Workshop, San Diego, 1989)

	Stripping	Spallation	Plasma Target	RFP
1) Neutron Generation	d-Li 500 mA	Spallation	D-T	D-T
2) Characterization				
a) Total neutrons n/s	$1.9 \cdot 10^{17}$	$4 \cdot 10^{17}$	$4 \cdot 10^{17}$	$4 \cdot 10^{19}$
b) Fraction of n $E > 14$ MeV	10-20%	5.75%	0	0
c) Dicplacement cross section (m^2) for Fe	$3 \cdot 10^{-25}$*	$1.5 \cdot 10^{-25}$*	$3 \cdot 10^{-25}$	$3 \cdot 10^{-25}$
3) Flux Contours (n/m^2s) and Volumes (liters)				
$> 10^{17}$	800	200	600	$>10^4$
$> 10^{18}$	40	20	15	10^4
$> 10^{19}$	0.6	2	0	4000
Flux gradients **	7-8%/cm	< 5%/cm	5%/cm	5%/CM

* Flux-averaged values
** For flux region of 10^{18} n/m^2s
*** For 50 Hz



Comparison of neutron spectra for different neutron sources
Curves have been shifted arbitrary amounts for clarity
[D.G. Doran et al., J. Nucl. Mat. 174 (1990) 125

IEA Neutron Source
Working Group Activities
IEA - NSWG

The IEA-NSWG was created in September 1990 by the Executive Committee of the IEA-Implementing Agreement on Fusion Materials Research

Members:

D. Doran (USA, Hedl, Chair), S. Cierjacks (EU, KfK)

F. Hegedus (Switzerland, PSI), E. Hodgson (EU, CIEMAT)

S. Ishino (Japan, Univ. Tokyo), K. Noda (Japan, JAERI)

P. Schiller (EU, IRC)

IEA-NSWG activities:

- Neutron source comparison studies for different neutron source concepts [1,2,3]

  (Beam-Plasma, d-Li, t-H_2O and spallation neutron source)

  - Source neutronics (flux, spectrum, spatial distributions available volume)
  - Spectral-averaged damage parameters for selected elements i.e.
  - Damage energy and displacement cross sections
  - Recoil spectra
  - Transmutation cross sections
- Test volume considerations for an IFMIF [3,4]

Results from neutron source comparison studies
(IEA-Neutron Source Working Group 1990-94)

1. **Comparison of spectral-averaged damage energy cross sections [1]**

Spectral-averaged damage energy cross sections(keV barns [1]

Spectrum	C	Fe	Mo
DEMO	31	66	67
B-P	41	271	245
B-P w/refl.	40	188	171
D-Li, Pt. 1	44	240	241
D-Li, Pt. 2	45	220	223
Spall. (Pepin)	51	81	89
Spall. (Perlado)	49	55	63
T-H	41	182	182
14 MeV	41	293	265
20 MeV	49	319	351

- For low Z-materials (carbon) no real difference in damage cross section for different sources
- For high Z-materials the softer spectra (DEMO/Spallation) have reduced displacement efficiency per neutron

●	DEMO	-	First Wall Spectrum, 2.5 MW/m2 wall loading
X	D-Li	-	Single Beam, 100 mA, 35MeVd, 3.5 MW; 4,0,0,Pos
O	t-H20	-	Single Beam, 170 mA, 21 MeVt, 3.5 MW; 4,0,0 Pos

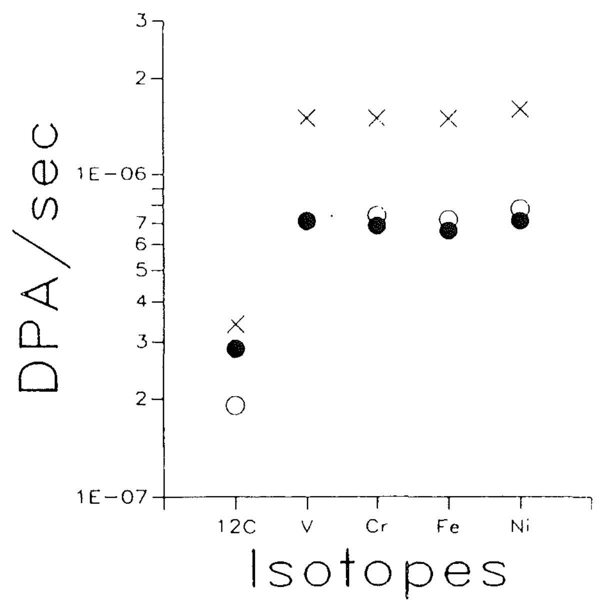


Fig.: Comparison of displacement rates for different elements calculated for a 1st Wall Demo Spectrum and at (4,0,0) positions of d-Li and t-H_2O neutron sources (Target size 3 x 1 cm) [5]

Results from neutron source comparison studies

(IEA-Neutron Source Working Group 1990-94)

Continuation:

- Displacement rates corresponding to a neutron wall loading of ~ $2 MW/m^2$ in the First Wall can be achieved by single-beam versions of d-Li and t-H_2O neutron sources
- Uncertainties in calculations are due to a lack of evaluated cross sections above 20 MeV neutrons.

2. Comparison of recoil spectra

The primary recoil spectra, i.e. the spectra of recoil energies of primary knocked-on-atoms (PKA) determine not only the energy for elastic collisions, but also the partitioning of free migrating defects and defects in cascades. This partitioning influences many radiation damage phenomena.

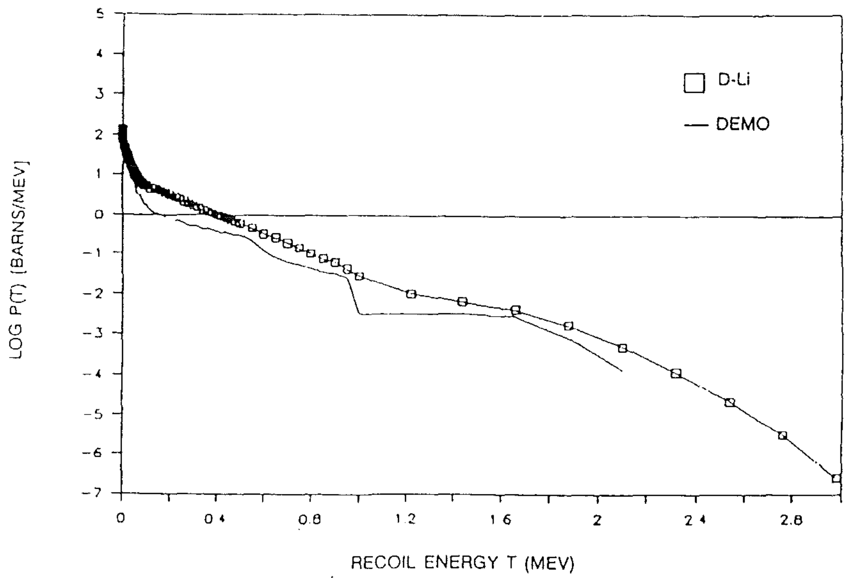


Fig.: Comparison of the iron PKA spectrum for the D-Li source (Pt. 2 at 8.5 cm) with that for the DEMO first wall [1]

- With the exception of a high energy deviation for carbon the PKA Spectra of a d-Li source agree rather well with the DEMO-First Wall position
- Uncertainties in calculating very high-energetic PKA are again due to a lack of cross-sections above 20 MeV neutrons

Results from neutron source comparison studies
(IEA-Neutron Source Working Group 1990-94)

Continuation:

3. Comparison of transmutation cross sections

The production of light elements like H and He - nonsoluble in solids - leads in many structural materials to embrittlement and is of most concern. Hence their production rates are important suitability criteria for different neutron sources.
The generation of solid elements mostly in solid solution (e.g. Mn, Cr etc.) are of minor concern with few exceptions.

Table: Transmutation (appm) in iron for 1000 days DEMO equivalent exposure (80 dpa iron)[1]

Element	DEMO First wall	Beam-plasma w/o refl.	Beam-plasma w/refl.	D-Li 14 cm	D-Li 8.5 cm	T-H	Spall. Pepin	Spall. Perlad o
				dpa				
	80	80	80	80	80	80	80	80
H	4900	7500	6060	7000	5800	2300	2200	1400
H/dpa	61	94	76	88	73	29	28	18
He	700	1150	930	1200	1040	470	460	230
He/dpa	9	14	12	15	13	6	6	3
Ti	0.3	0.6	0.4	3.4	4.1	0.1	1.4	0.4
V	70	110	86	110	110	56	76	27
Cr	930	1300	1000	1600	1400	1100	490	300
Mn	4600	5400	3600	6400	5300	1200	1700	1000
Fe								
Co	10	0.7	0.9	0.6	0.6	0.3	0.5	1.2
Ni	0.1							

- The spallation neutron source produces too little of important transmutations
- The greatest uncertainties in the calculation of transmutation products stem from unknown cross sections of high energetic neutrons of the spallation source

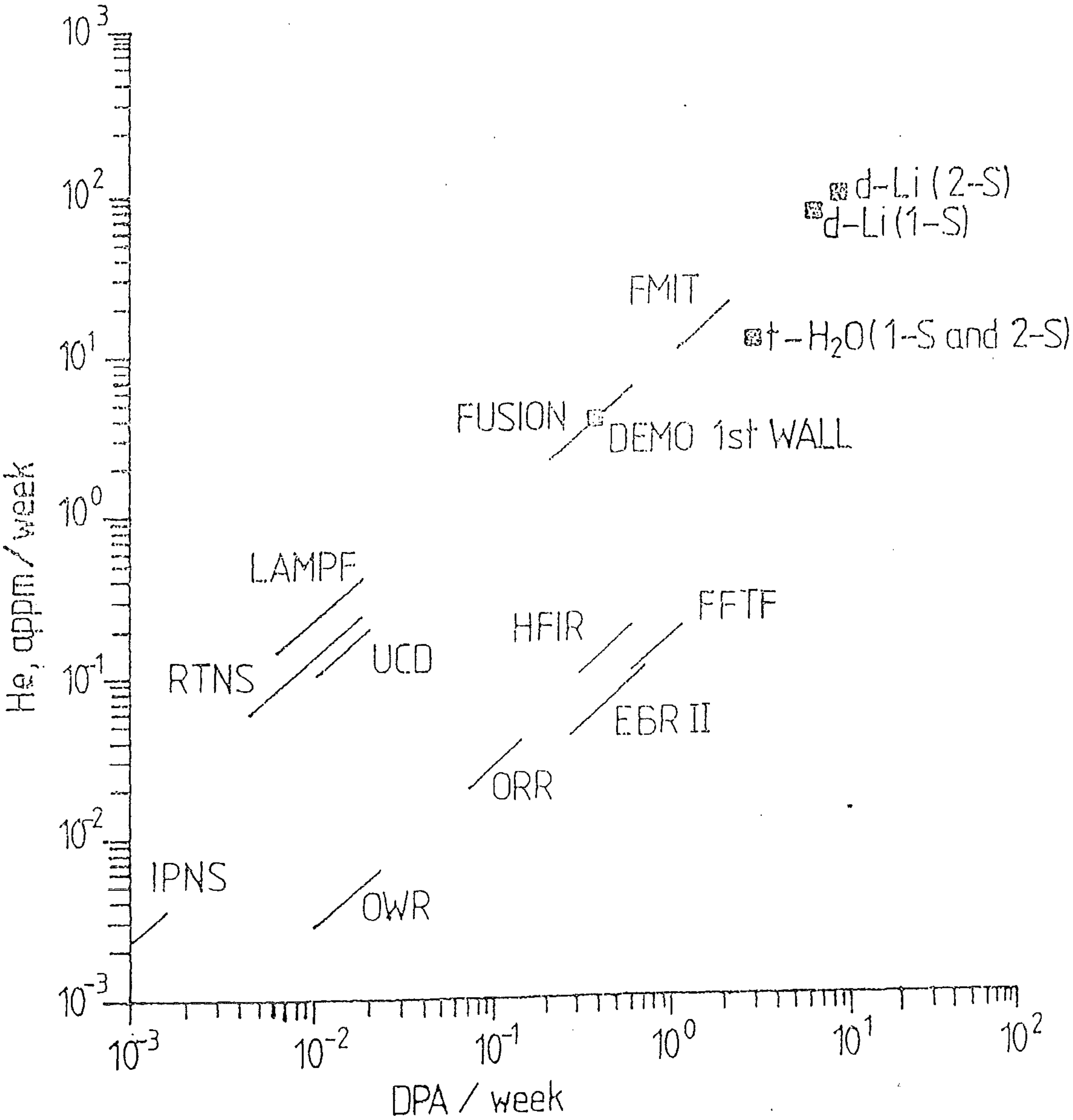


Fig.: **Comparison of the weekly DPA and helium production rates in iron for various irradiation facilities**

Test volume considerations for an IFMIF (IEA-Neutron Source Working Group D. Doran et al.* 1993)

1. Matrix of P. Schiller for qualification of one structural material for DEMO data base in P.I. tests

   450 samples à 4 cm^3 + 50% cooling ⇒ 2.7 liters

   In addition: In-beam tests with pressurised tubes and fatigue specimen (instrumented) ⇒ 4.5 liters

   Remark: Overestimation of necessary irradiation volume because simultaneous irradiations are possible

2. Matrix of Grossbeck/Bloom for a mixed loading: (2 structural, 1 composite/shield, 1 insulator material) and data base generation for DEMO

   450 samples à 0.5 cm^3 ⇒ 225 cm^3

   No in-beam tests taken into account

   Remark: Use of makro-miniaturized specimen multiple use of available space!

Conclusions:

a) Small specimen test technology (SSTT) plays the key role for the definition of necessary test volume and hence the parameters for the Basic Concept

b) The necessity of in-reactor tests has to be assessed and limited to few experiments

---

* S. Cierjacks, F. Hegedus, E. Hodgson, S. Ishino, K. Noda, P. Schiller

[1] D.G. Doran, F.M. Mann, L.R. Greenwood; J. Nucl. Mater. 174 (1990) 125-134

[2] D.G. Doran, S. Cierjacks, F.M. Mann, L.R. Greenwood, E. Daum; J. Nucl. Mater. 218 (1994) 37-41

[3] K. Ehrlich, E. Daum (Eds.); IEA-Workshop on Intense Neutron Sources, KfK-Bericht 5296, May 1994

[4] D.G. Doran; Test Volume Considerations for an IFMIF; IEA-WG Report, Washington State University, Tri-Cities, May 1993

[5] E. Daum; User and reference manual for the KfK Code INS, KfK-Report 5230, September 1993

Conclusions:

1. Key assumptions and main requirements for the development of DEMO-structural materials are explained

2. Main tasks for an International Fusion Materials Irradiation Facility, IFMIF, have been identified

3. The IEA-activities for the study of suitability and feasibility of alternative neutron source concepts and the main conclusions are summarized

4. The main findings of the IEA-Neutron Source Working Group , NSWG, regarding:
   - neutron source comparison studies
   - test-volume considerations for IFMIF are illustrated

Proposed Organization and Work Breakdown Structure

T.E. Shannon

ORNL

T. E. Shannon
Oak Ridge National Laboratory

Proposed Organization and Work Breakdown Structure

IEA Technical Workshop on
International Fusion Materials Irradiation Facility

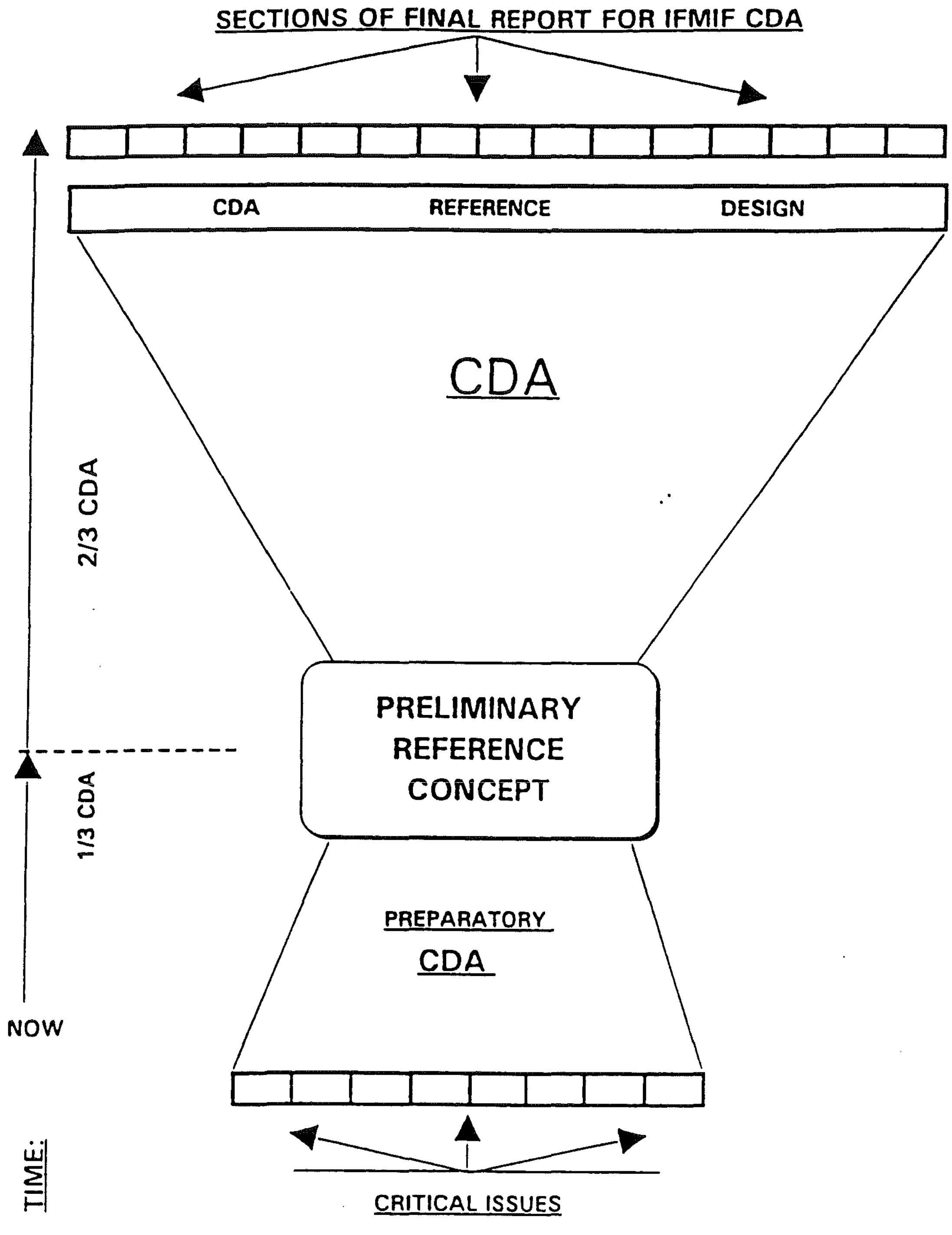
September 26-29, 1994
Karlsruhe, Germany

Topics

1. Conceptual Design Methodology
2. Work Breakdown Structure (WBS)
3. Schedule and Milestones
4. Organization and Responsibilities
5. Objectives of this Meeting
6. Overall Design Requirements

Conceptual Design Methodology

1. Establish Project Mission and Goals
2. Define Overall Design Requirements and WBS
3. Establish System Design Requirements
4. Define Baseline Design Configuration
5. Evaluate Options and Develop System Design Concepts
6. Perform Design Integration
7. Develop Cost Estimates and Schedules
8. Evaluate Environmental, Safety and Site Requirements
9. Produce Conceptual Design Document


SECTIONS OF FINAL REPORT FOR IFMIF CDA
CDA
REFERENCE
DESIGN
CDA
2/3 CDA
PRELIMINARY
REFERENCE
CONCEPT
1/3 CDA
PREPARATORY
CDA
NOW
TIME:
CRITICAL ISSUES

SYSTEMS ENGINEERING

- Document Mission and Goals
- Establish WBS
- System Design Descriptions
- Baseline Design
- Interface Definition
- Configuration Control

DESIGN INTEGRATION

- Establish Accelerator/Target Design Configuration
- Develop Overall Facility Layout
- Plan for Assembly and Maintenance
- Establish Design Standards and Specifications
- Coordinate Cost Estimates and Schedules

ENVIRONMENTAL, SAFETY, AND HEALTH

- **Perform Environmental Assessment**
- **Conduct Preliminary Safety Analysis**
- **Develop QA Plan**

CDA DOCUMENTATION

1. System Design Requirements

2. System Design Description

3. Cost Estimate

4. Schedule

WORK BREAKDOWN STRUCTURE

1. Project Management
   - 1.1 Project Planning
   - 1.2 Systems Analysis
   - 1.3 Design Integration
   - 1.4 Cost & Schedule
   - 1.5 Project Documentation
   - 1.6 Environmental, Safety, and Site Requirements

2. Accelerator
   - 2.1 Ion Source/Injector
   - 2.2 RFQ and DTL
   - 2.3 HES
   - 2.4 HEBT
   - 2.5 Accelerator Support Systems

3. Lithium Target System
   - 3.1 Lithium Target
   - 3.2 Lithium Loop System
   - 3.3 Target Interfaces

4. Test Cell
   - 4.1 Test Assembly
   - 4.2 Test Module Assembly
   - 4.3 Coolant Loop
   - 4.4 Material Sample System

5. Remote Handling Systems
   - 5.1 Manipulator Systems
   - 5.2 Accelerator Handling Equipment
   - 5.3 Target and PIE Handling Equipment
   - 5.4 Test Assembly Handling Equipment
   - 5.5 Hot Cell Equipment

6. PIE Laboratory
   - 6.1 Facility
   - 6.2 Testing Equipment
   - 6.3 Support Equipment
   - 6.4 Utilities

7. Conventional Facilities
   - 7.1 Building Layout and Structure
   - 7.2 Utilities (power, water, air)
   - 7.3 Shielding
   - 7.4 Cryoplant
   - 7.5 Site utilities and Improvements
   - 7.6 Plant Safety

8. Central I&C
   - 8.1 Instrumentation/Control Equipment
   - 8.2 Computers/Data Acquisition

9. Assembly and Installation

10. Associated R&D

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CONCEPTUAL DESIGN PLAN AND SCHEDULE

(IFMIF Japan Workshop, June 13–15, 1994)

1.	Form International Procedural Concept	6/94
2.	Initial Requirements and Design Layout	10/94
3.	Initial Report to FPCC	2/95
4.	Establish Baseline Design	3/95
5.	Preliminary System Design Lay-outs	7/95
6.	Interim Report, Design Requirements, & Plan	10/95
7.	Define R&D Needs	12/95
8.	Estimate Cost/Schedule for Construction	4/96
9.	Environment, Safety & Site Requirements	9/96
10.	Conceptual Design Complete	1/97

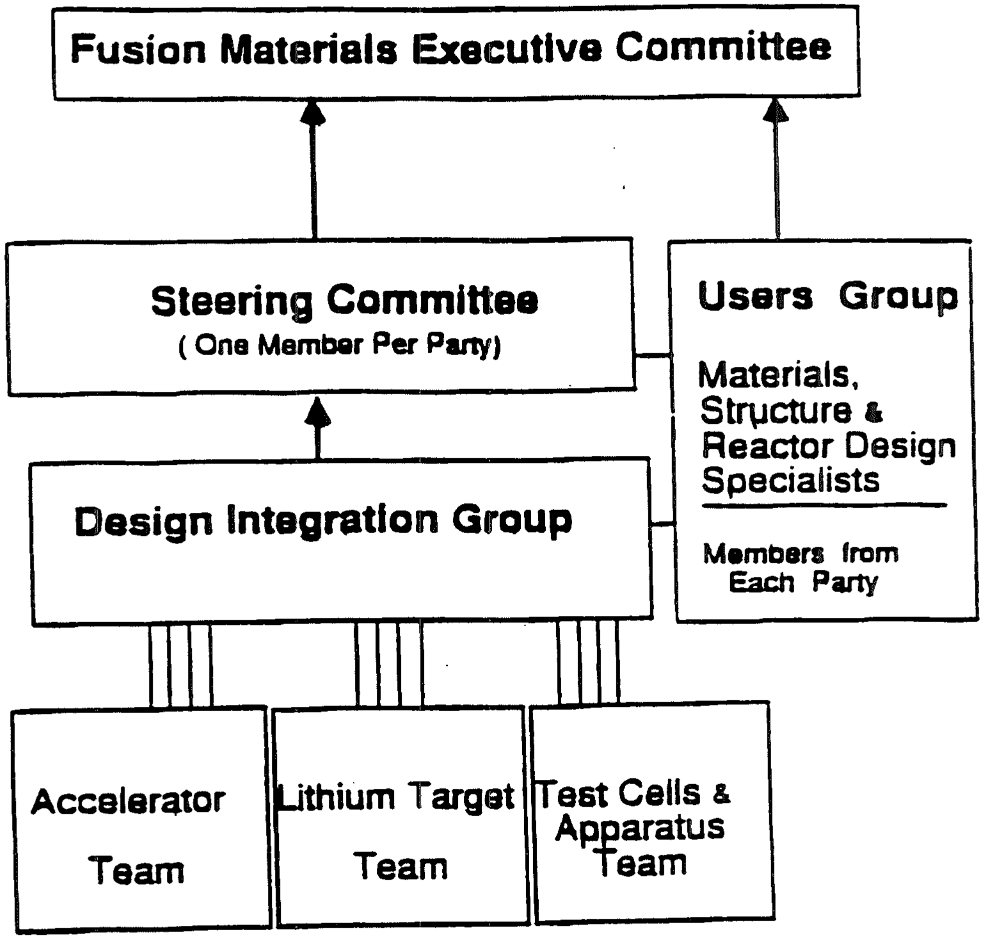


Fig. 1. Organization Structure for International Fusion Material Irradiation Facility Conceptual Design Activity

Proposal for IFMIF Project Responsibility

Following the example of ITER, individuals representing the four Parties can be assigned primary responsibility for each area. These area leaders will coordinate the work within their own country and will allow for contributions from all parties offering support.

Initial areas of Focus

WBS Area	Area Leader	Participants/Task Responsibility
• Accelerator System		
• Lithium Target System		
• Test Cell		
• Design Integration		

FIRST TECHNICAL MEETING

Karlsruhe, Germany

September 26–30, 1994

Approximately Five Technical Participants Per Party To:

- Define a baseline concept and critical issues,
- Identify working groups and shared procedures such as a computer system for communications and document sharing,
- List and distribute all available information, accumulated on the D-Li neutron source approach as soon as possible,
- Define the next work to be accomplished following an approximate format and time schedule

Primary Objectives for this Meeting

1. Agree on Overall Design Requirements

2. Discuss System Requirements for Primary Areas and Establish Reference Concept

    - Accelerator
    - Target
    - Test Cell

3. Identify Design Issues and Critical R&D Needs

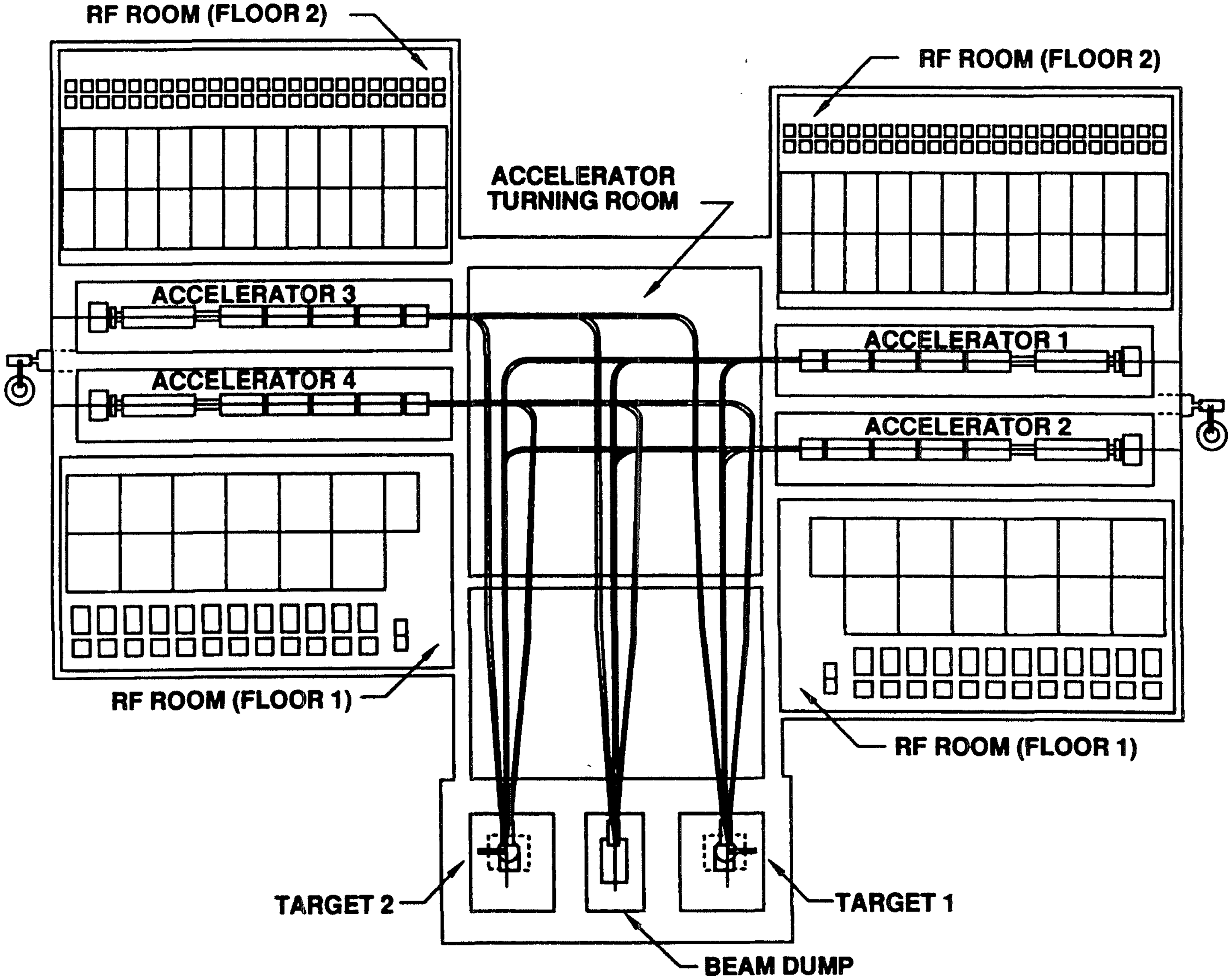
4. Establish Area Leaders, Party Interests/Involvement and Contacts

5. Layout Homework for Next Workshop and Set Date

DESIGN REQUIREMENTS

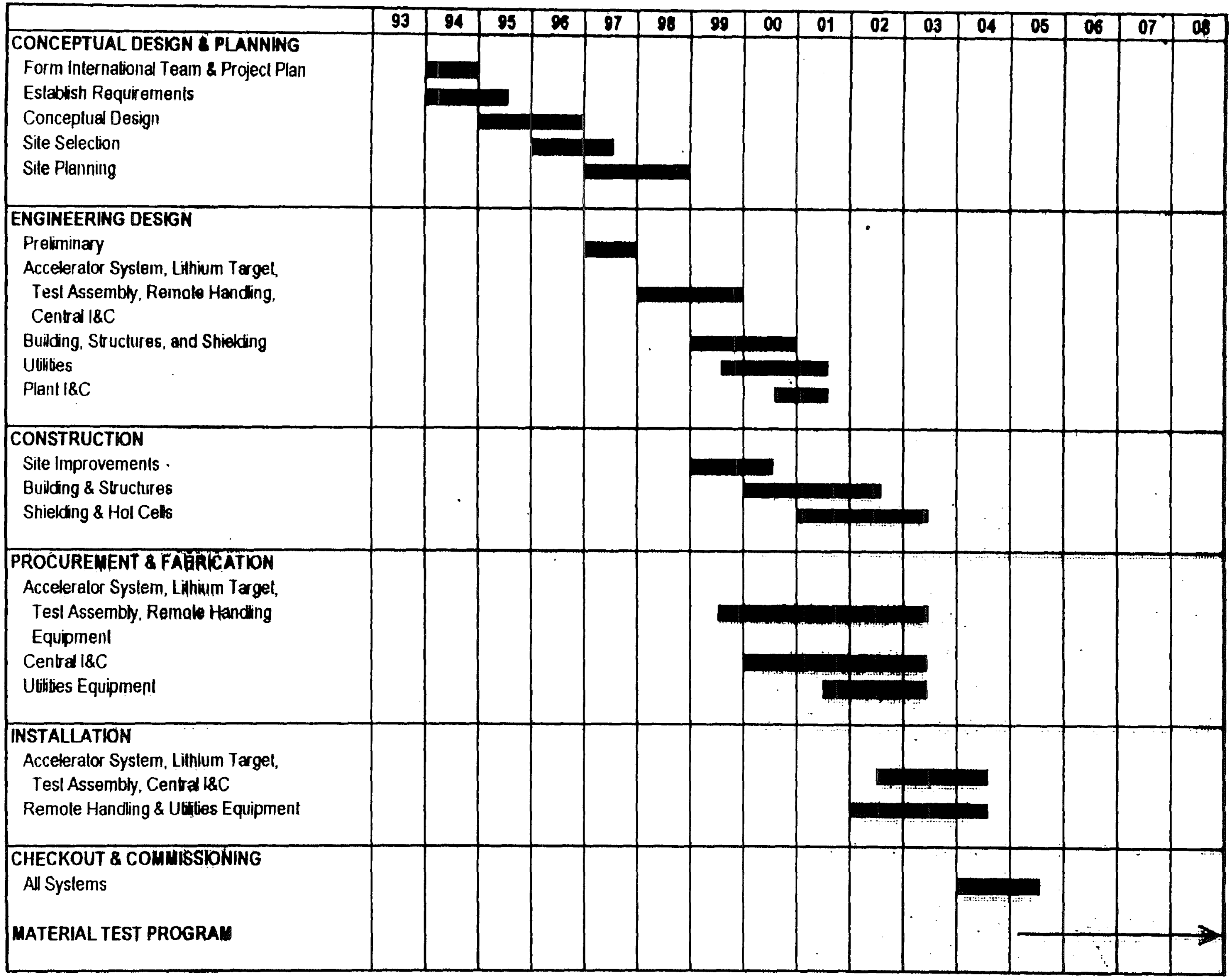
- A deuteron accelerator,
- Operated at 35- and 30-MeV energy,
- With 2-beam modules of 125 mA, for a total of 250 mA, and extendable to allow more beam modules if needed,
- With a typical single spot of deuterons incident on a 10-cm by 10-cm area of lithium,
- Giving a continuous supply of neutrons at 2 MW/m^2 beyond the target, in at least 1 liter test volume,
- Flux gradient less than 10% per cm,
- With 70% availability of the facility.

Accelerator and Beam Transport Arrangement



ORNL-DWG 94M-3604 FED

"AGGRESSIVE" IFMIF SCHEDULE



Plenary Session II

Baseline Accelerator Concepts for IFMIF

H. Klein

University Frankfurt

Baseline accelerator concepts for IFMIF

presented by:
H. Klein
Universität Frankfurt
Institut für Angewandte Physik

Karlsruhe
September 1994

IFMIF

Accelerator baseline and options

Design requirements

Beam current = 250 mA
Deuteron energy 35MeV; -5 MeV ; +5 MeV
Energy spread +/- 500 keV
Plant Factor ~ 70%
High energy beam losses < 1nA/m

N = 10 MW!

Injectors (two)

ECH driven cusp field source. RF driven is an option.
100-125kV ; 140mA

Low Energy Beam Transport

Magnetic focussing. Neutralization and electrostatic focussing are options.

RFQ (two)

Room temperature. S/C is an option.
Energy up to 2MeV. 125mA. 175 MHz

Beam Funnel

7/6/93

LANL data

ornl

Accelerator baseline and options
(continued)

Drift tube linac

350 MHz , 250mA
Room temperature up to 8MeV
S/C from 8MeV to 35 +/- 5MeV
Options include all room temperature, all S/C

High Energy Beam Transport

Variety of spot sizes (5x5,10x10,15x3 etc)
Uniform beam densities
Energy Dispersion Cavity
Radiation hardening

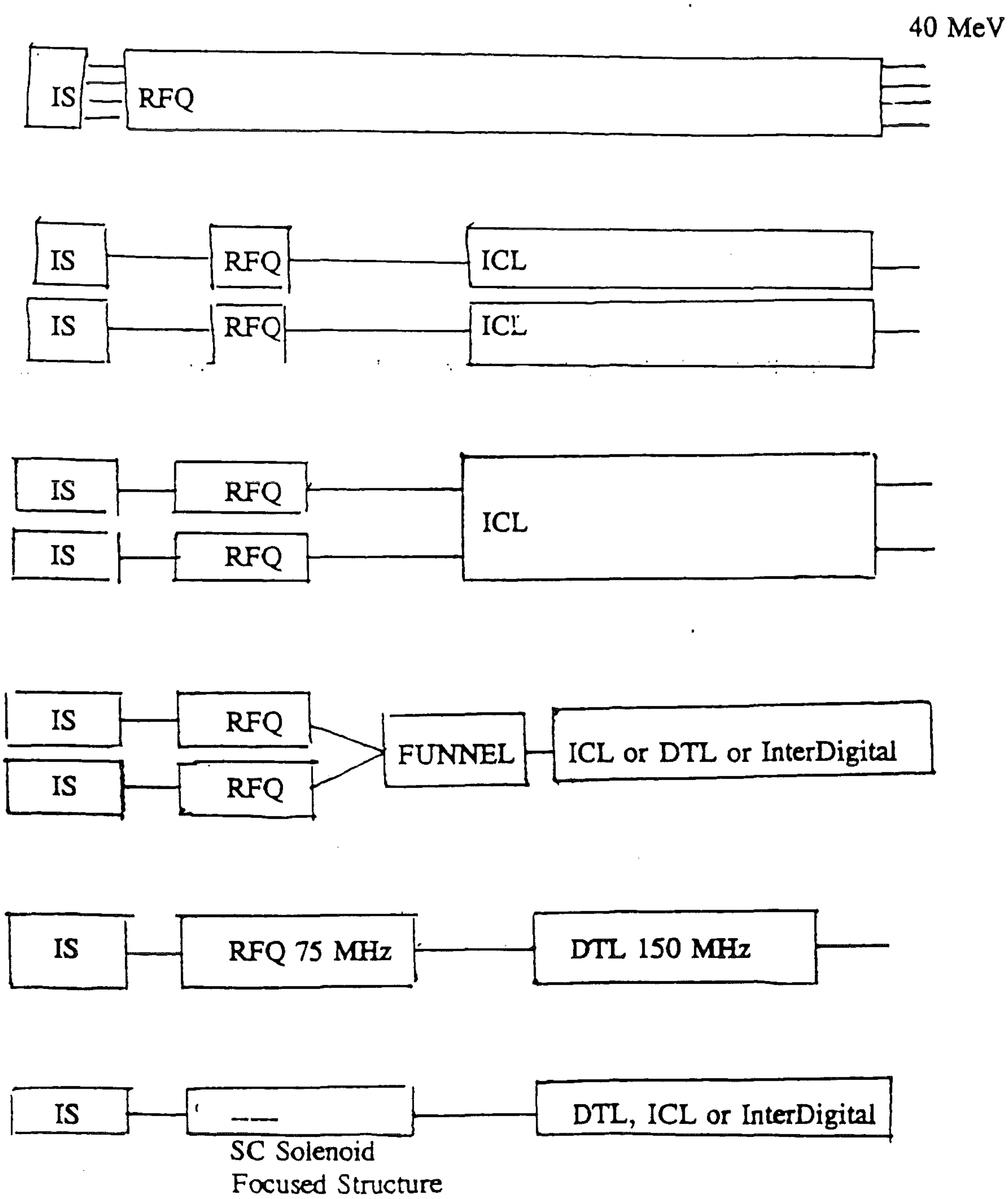
Trade off studies are needed to confirm optimum approach

7/6/93

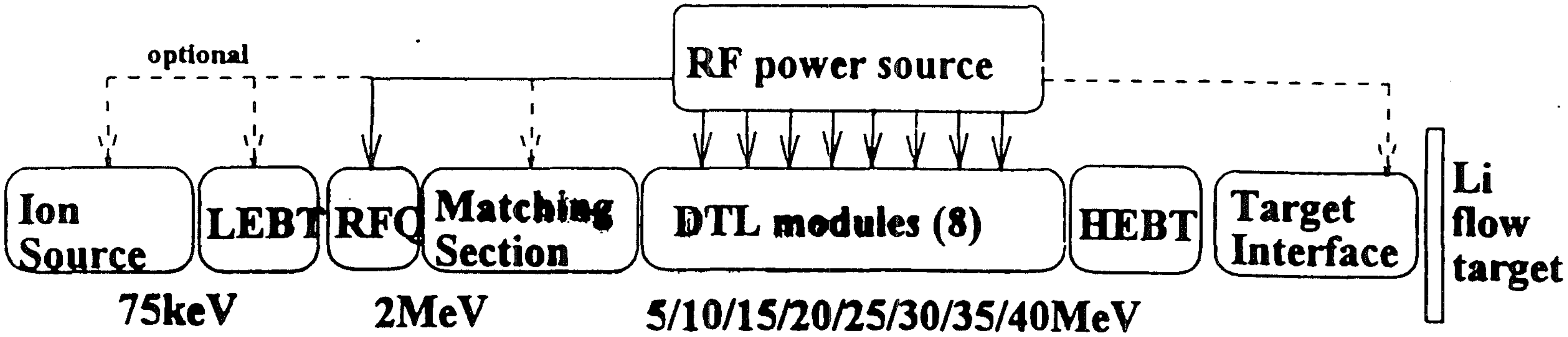
LANL data

Figure 1.

IS = ion source
RFQ = radiofrequency quadrupole
ICL = superconducting independent cavity linac
DTL = room-temperature drift-tube linac



Layout of the standard module



● The figures are reference values and are not optimized.

SPECIFICATIONS FOR ESS

- **5 MW** AVERAGE POWER AT TARGET(S), 50 Hz
  average thermal neutron flux comparable to high flux reactor ILL

- ~1 μSEC PROTON PULSES
  (100 kJ, peak power about 30 x higher than ISIS)

- 10 AND 50 Hz REPETITION RATE

- TWO TARGET STATIONS

- upgrade possibility:
  - long linac puls $\bar{P} \geq 2$ MW, 10 Hz
  - very short comp. puls $\tau \leq 0,5$ μsec

A MAJOR CHALLENGE

Accelerator Options for the ESS

5 MW

~ 1 μs pulse

50 Hz and 10 Hz Targets

Energy: 0,8 – 3 GeV

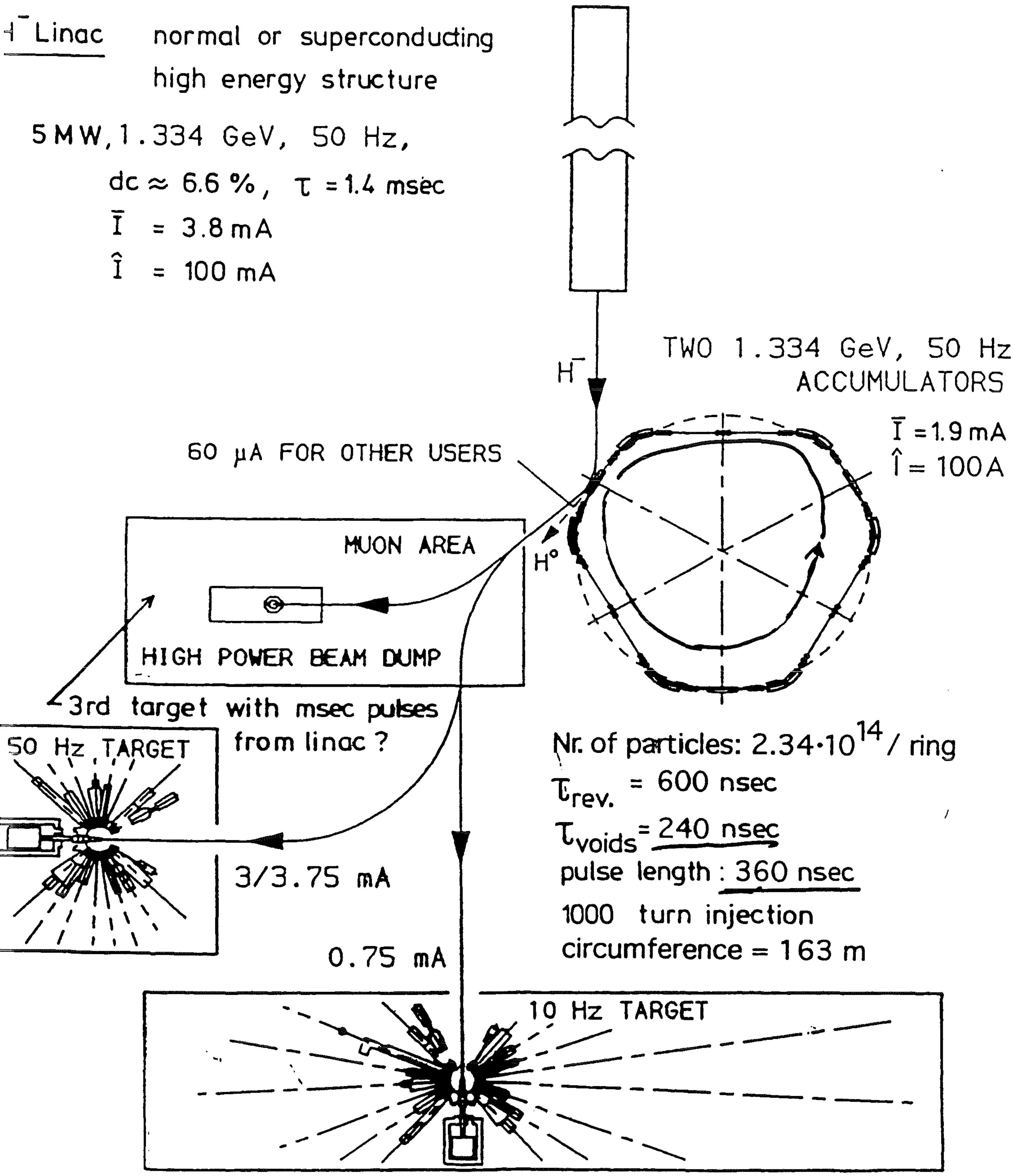
1 Linac + Compressor Rings

2 Linac + FFAG

3 Linac + RCS

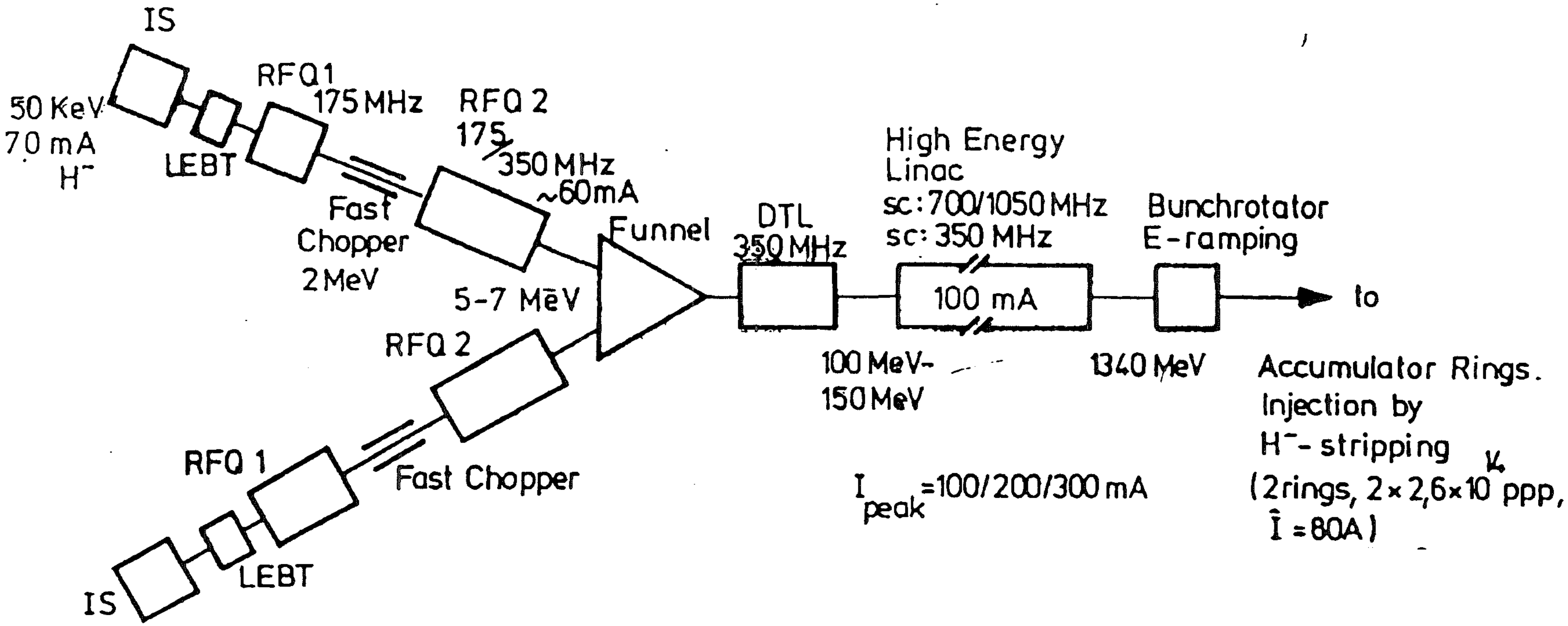
4 Induction Linac

5 Kaon Factory (50 GeV)



EUROPEAN SPALLATION SOURCE

Foreseen Scheme for ESS Linac



Beam losses $\leq 0.4 \frac{nA}{m}$!

R. Glückstern TU 1-4

M. Reiser TU 75

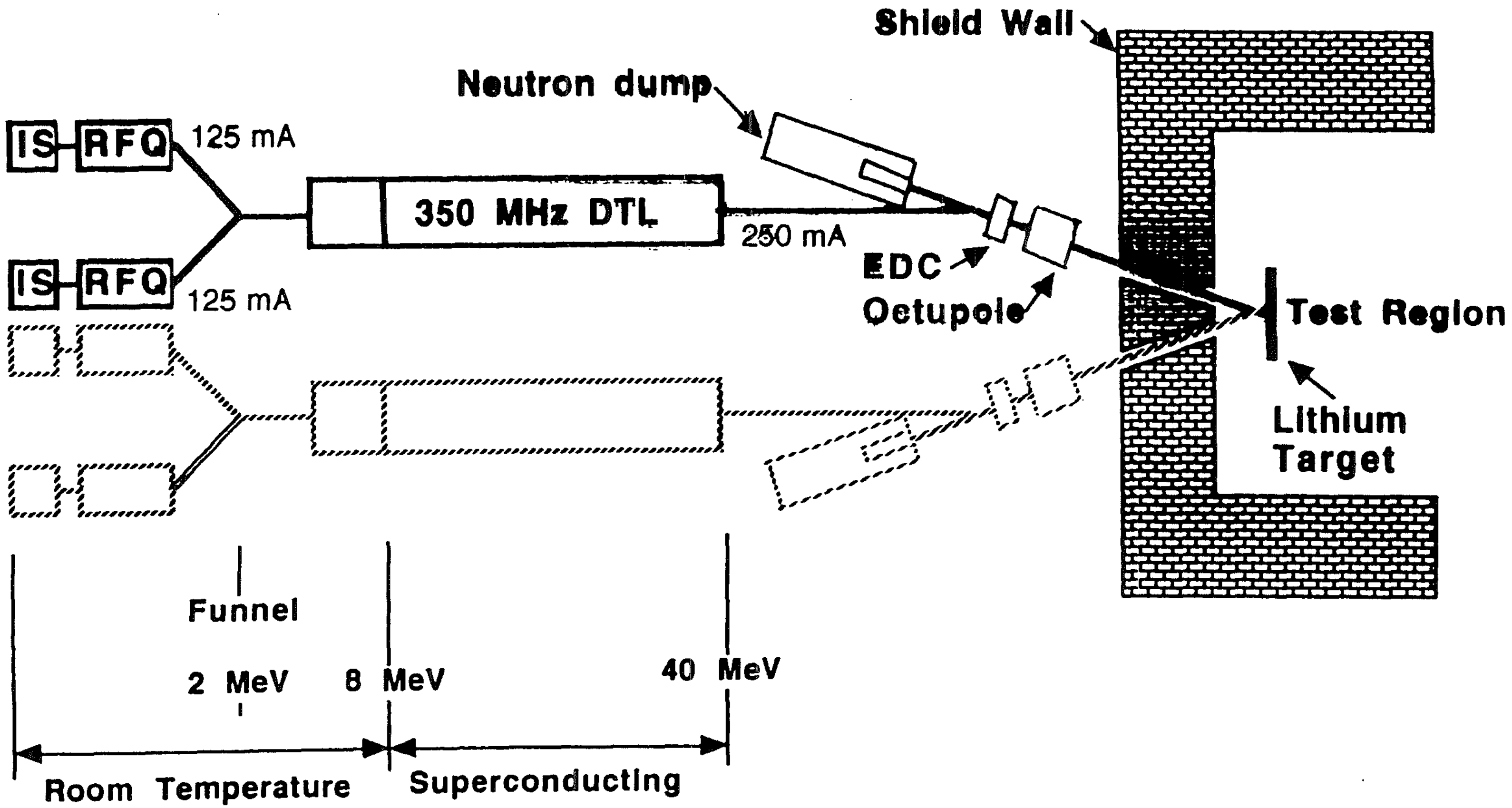
M. Pabst, K. Bongardt MO-83

IFMIF

Reference D-Lithium Neutron Source Concept

One 250 mA accelerator module
One lithium target. I=250 mA

Lightly drawn module suggests upgrade path to 500-mA system



6/25/93

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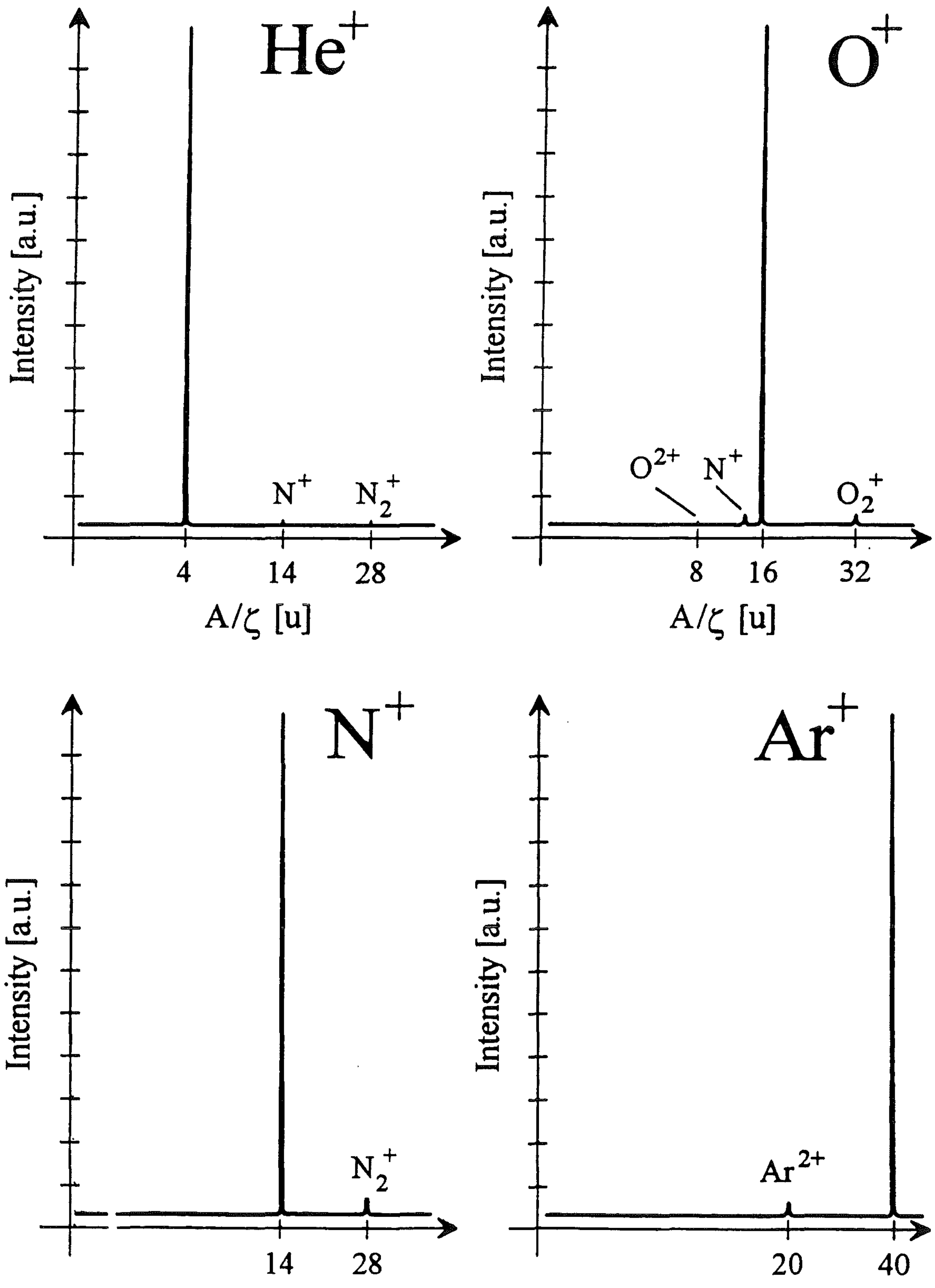
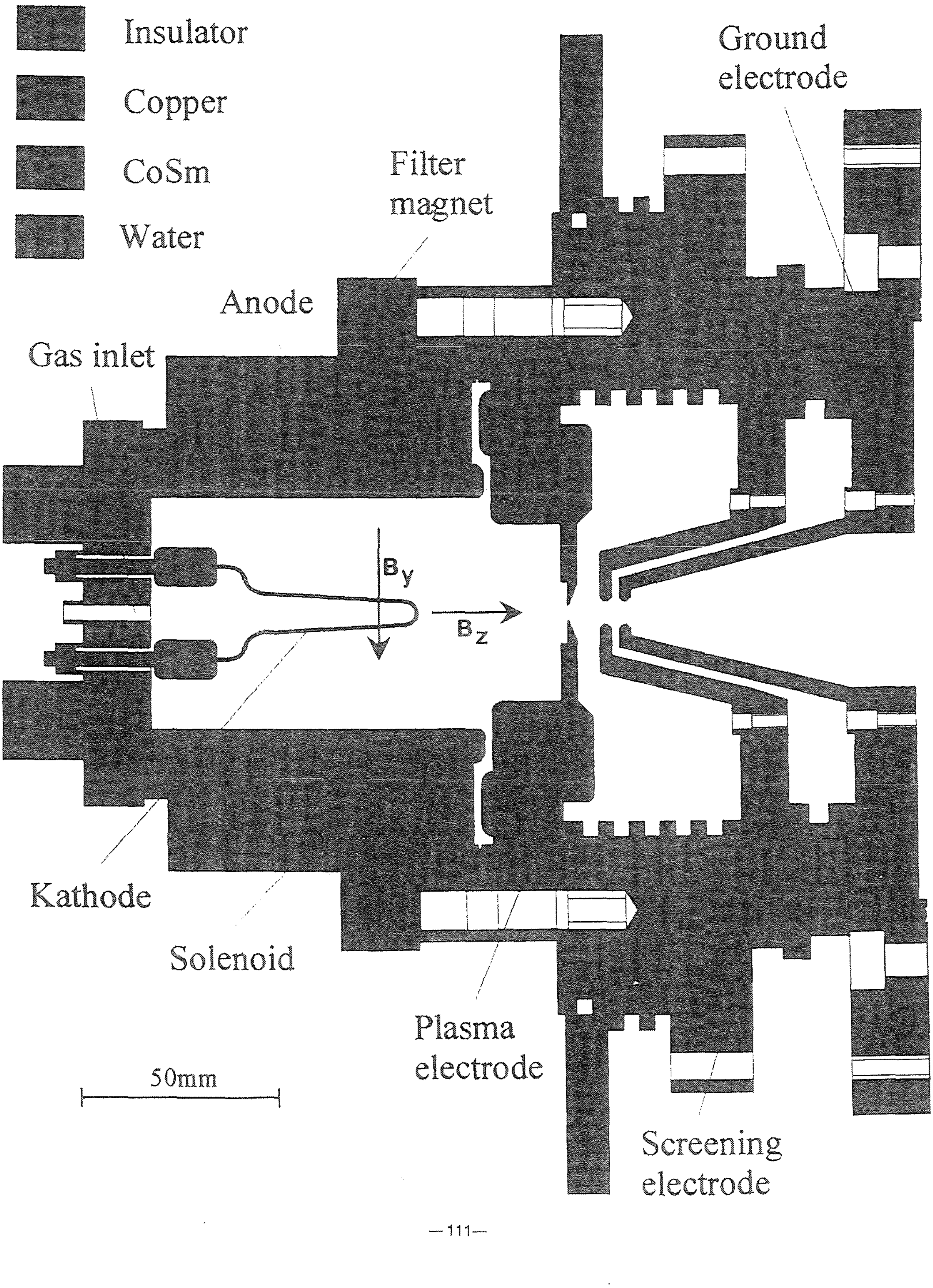
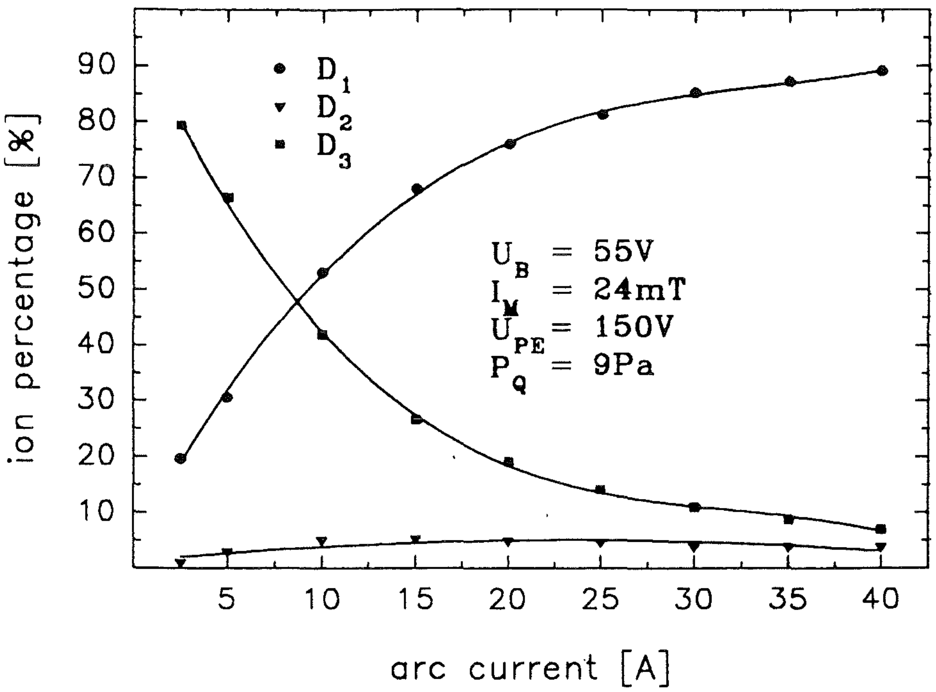
Mass spectra of the HIEFS



Schematic drawing of the deuterium source

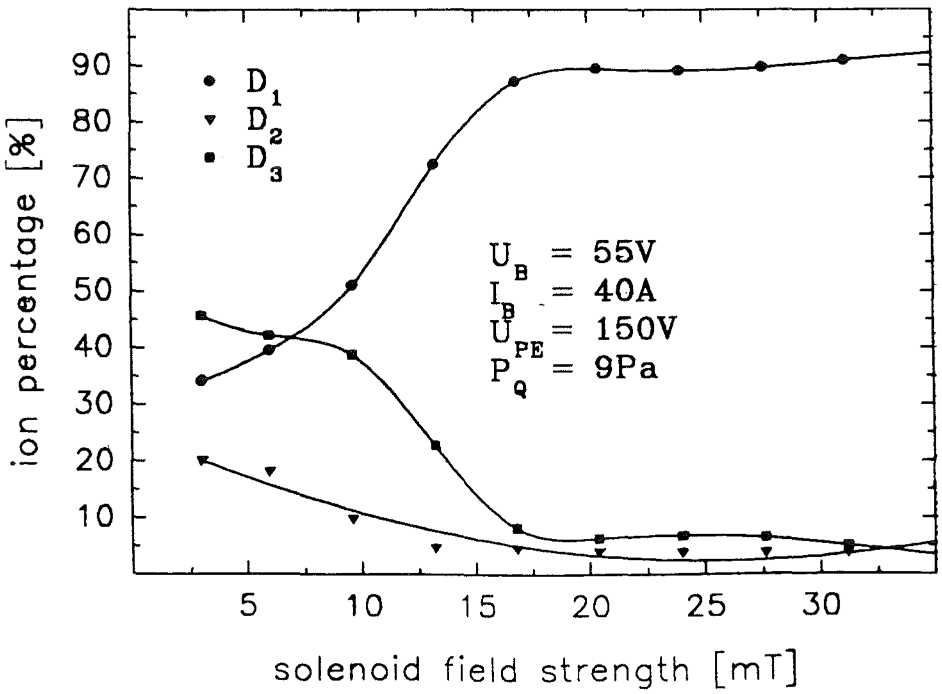


Influence of the Plasmaparameter to the D^+ fraction



a)

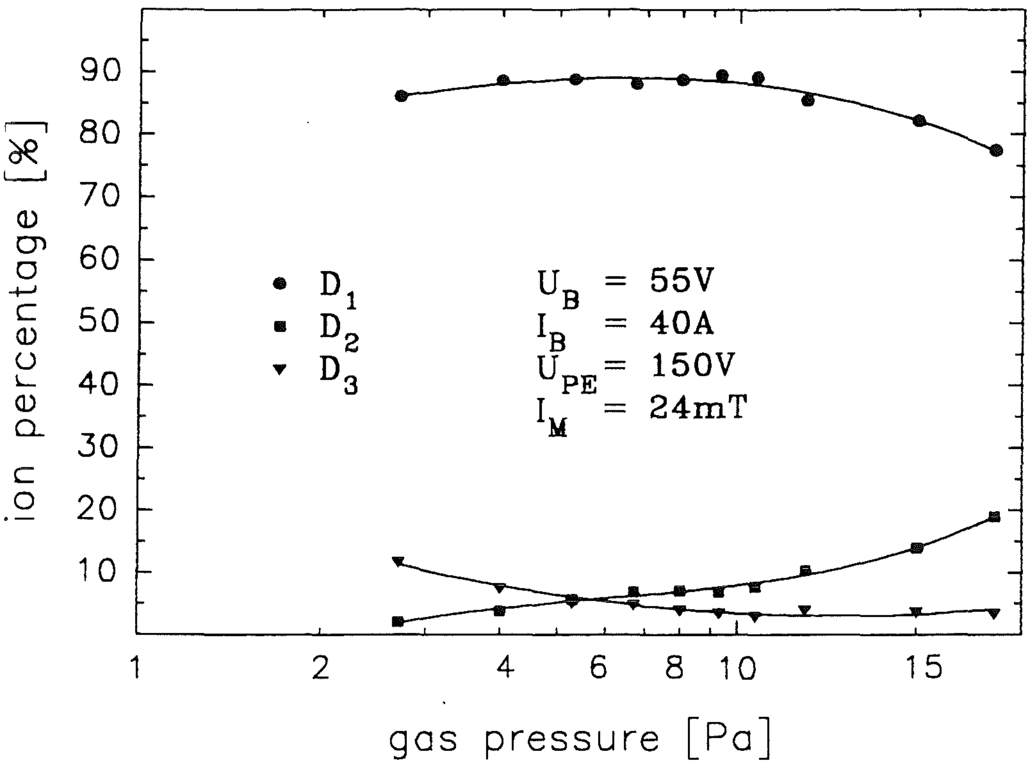
plasma density



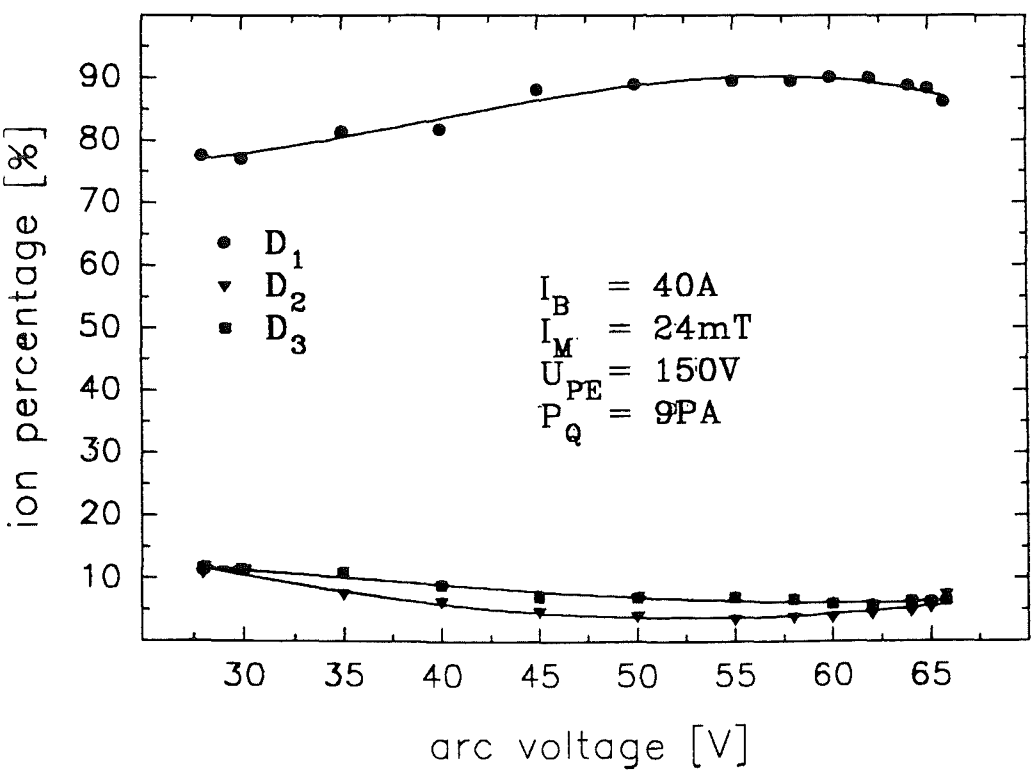
b)

solenoid

field strength

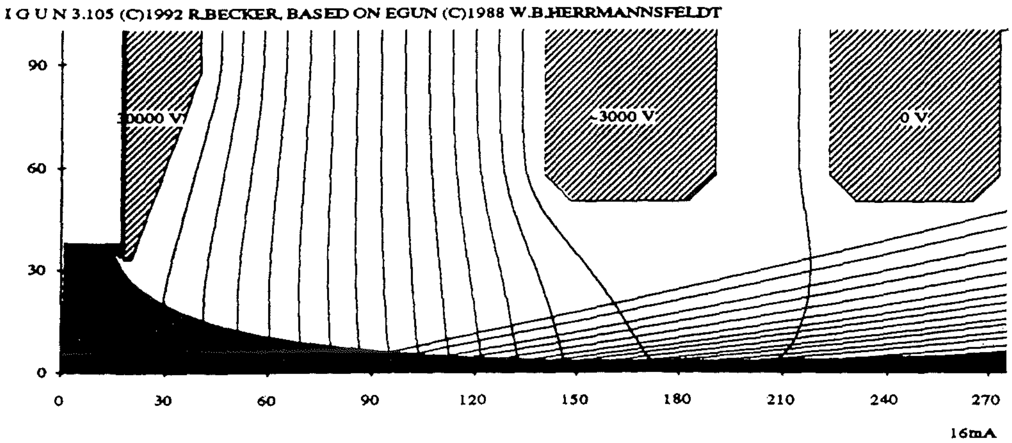


c) gas pressure



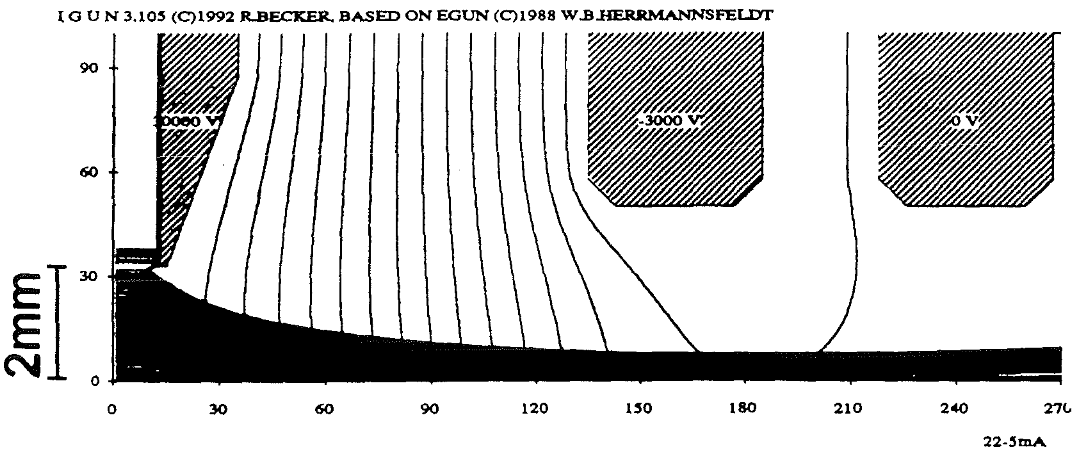
d) arc voltage

Beam formation in the 30kV extractor



I_{EX} = 16mA

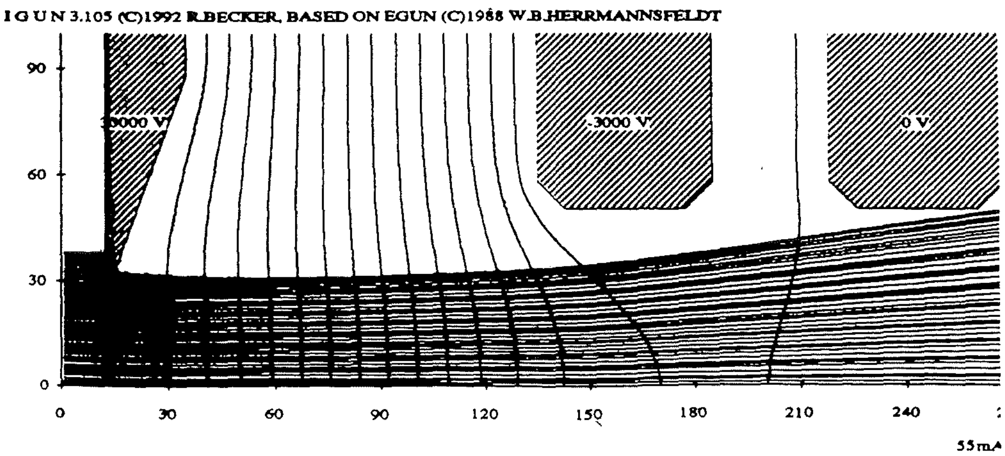
plasma density:
to low



I_{EX} = 22,5mA

"matched case"

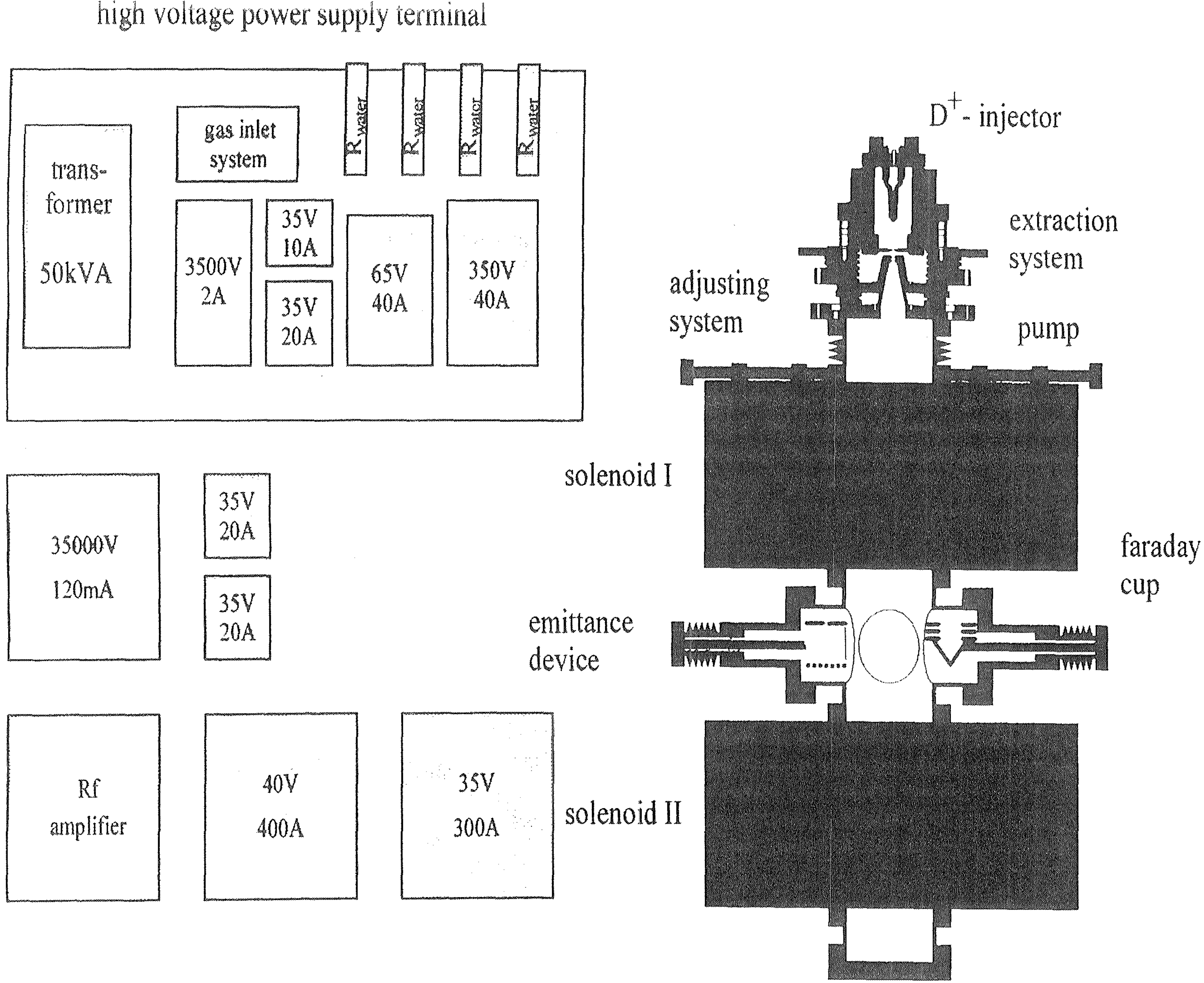
α ~ 30mrad
r ~ 0,5mm



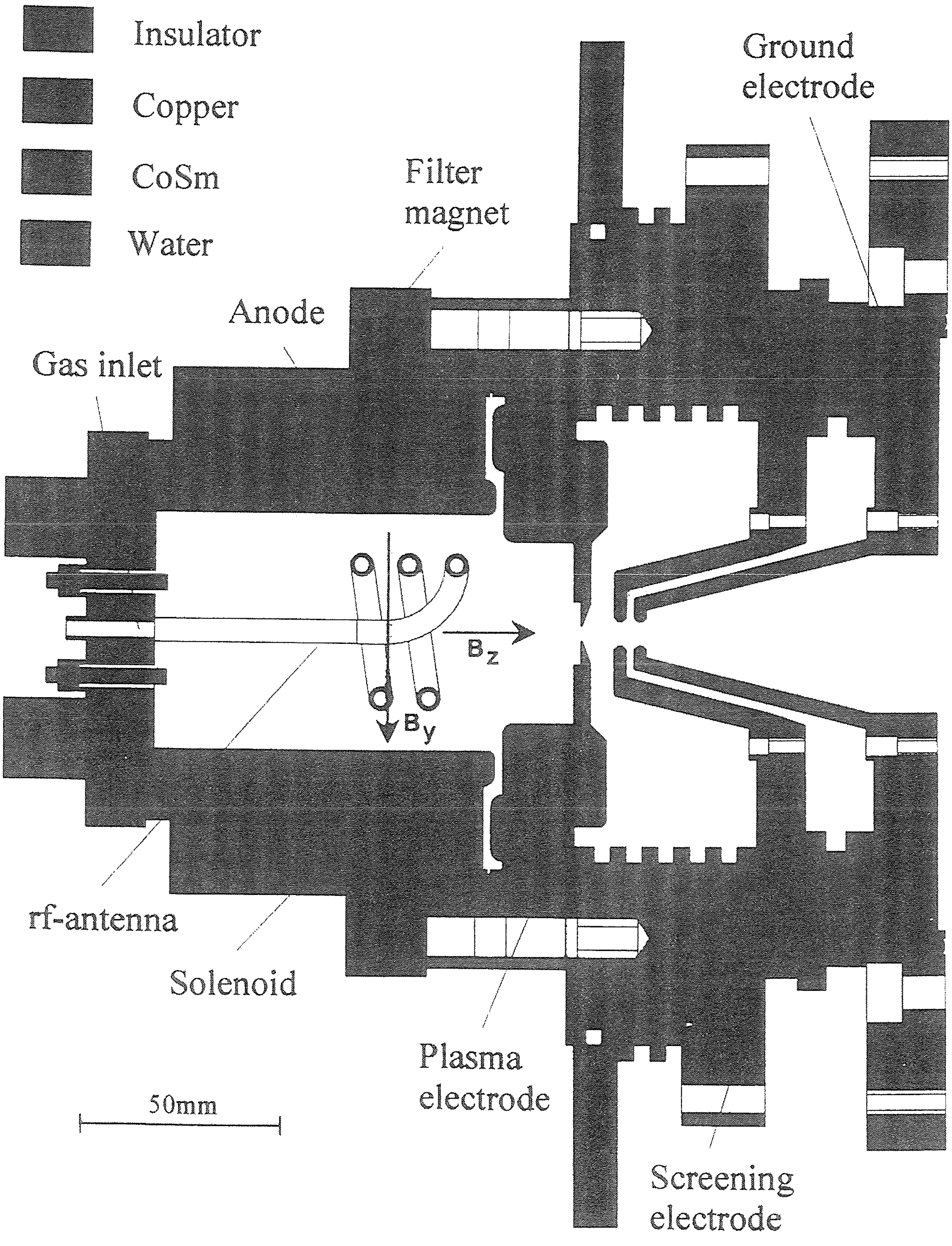
I_{EX} = 55mA

plasma density:
to high

Experimental set up



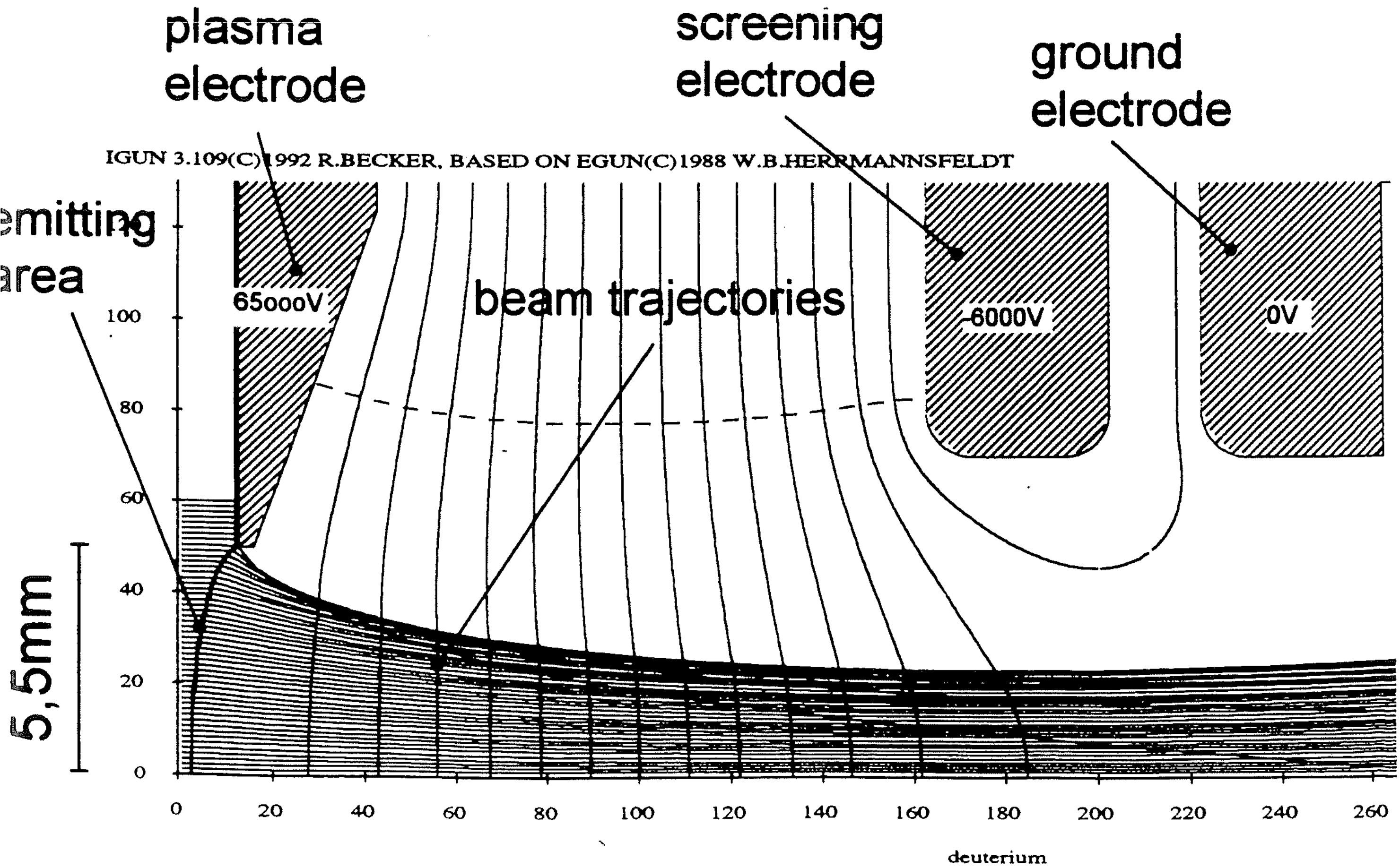
Schematic drawing of the deuterium source



Layout for the 140mA D^+ source

field strength in the gap	[kV/mm]	5
radius of the emitting hole	[mm]	5,5
emitting area	[cm^2]	0.95
gap distance	[mm]	13
aspect ratio		0.42
extraction voltage	[kV]	65
extraction current	[mA]	140
current density	[mA/cm^2]	147
rms emittance	[π mmmrad]	<0,1

Beam trajectories for a 65kV 140mA D^+ beam



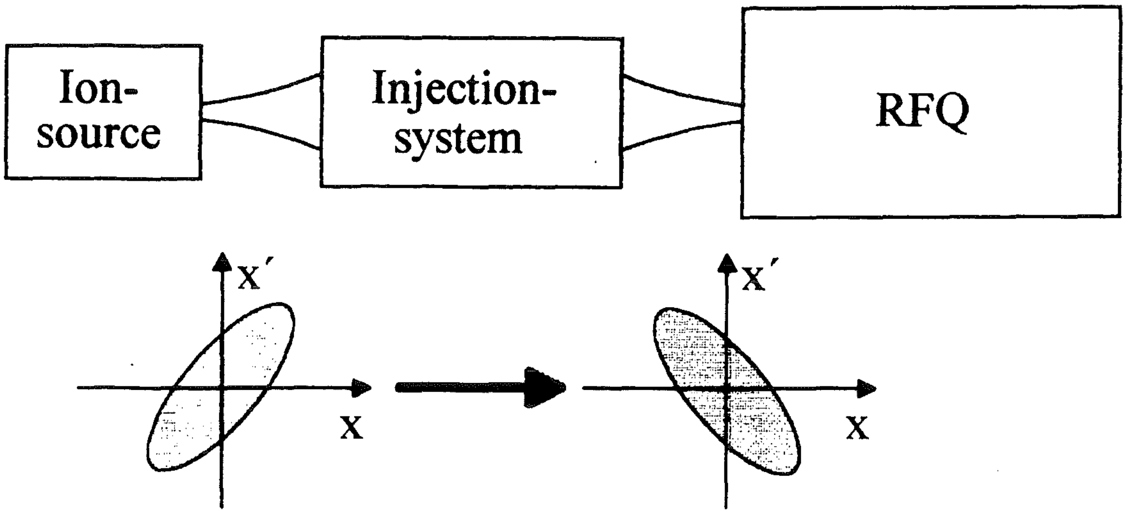
Conclusions

- **The plasma density for a 140mA D^+ source (= 147mA/cm^2) has been reached, corrensponding to a 160 mA/cm^2**
- **20mA (40mA) D^+ with a 2mm aperture radius has been achieved**
- **A beam composition of > 90% (75%) D^+ has been reached**
- **5.5mm aperture ⇒ 140mA**

Work to be performed

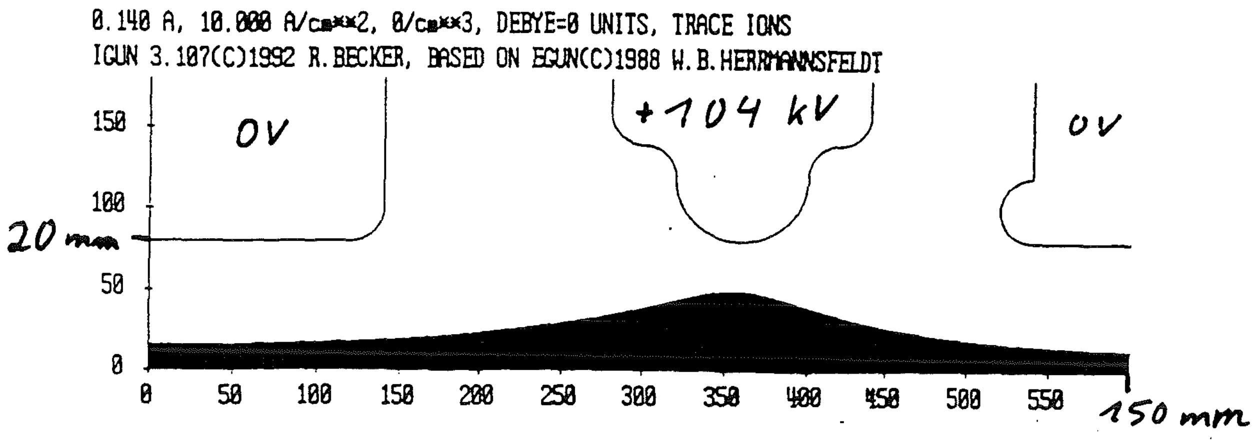
- **Development of a 65kV, 140mA extraction system with 5.5mm aperture radius**
- **Optimization of magnetic filter position**
- **RF driven plasma generator (lifetime)**
- **Development of high current-high power emittance device**
- **cw-experiments with full current injection into the LEBT section**

The problem of beam injection into an RFQ-accelerator

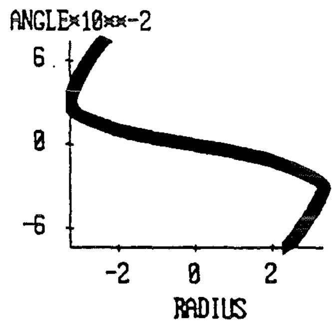


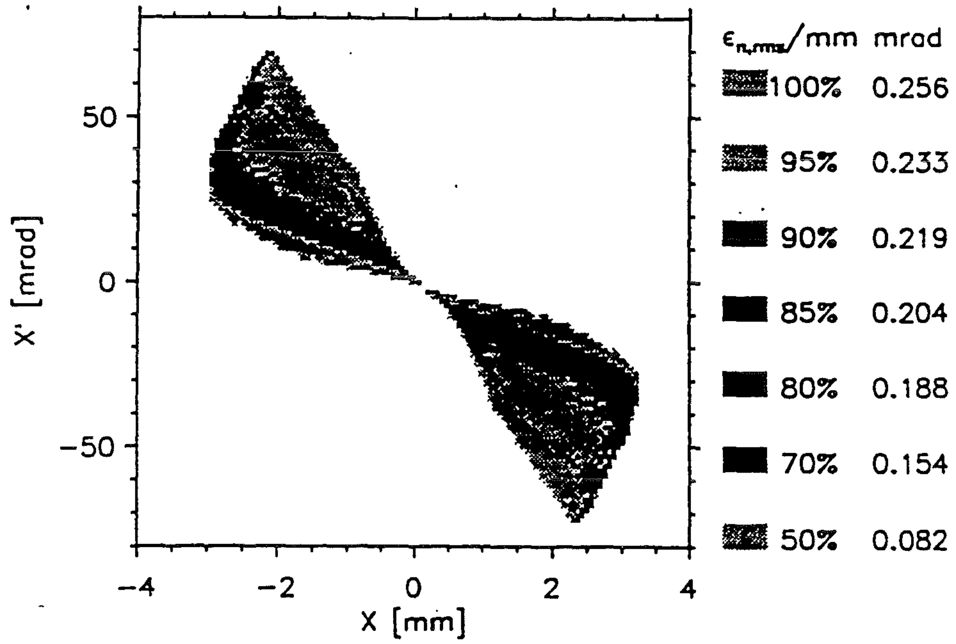
Einzellens Injection

IGUN simulation: 140 mA, 100keV. D^+



r-r′-emittance ➡ x-x′-emittance



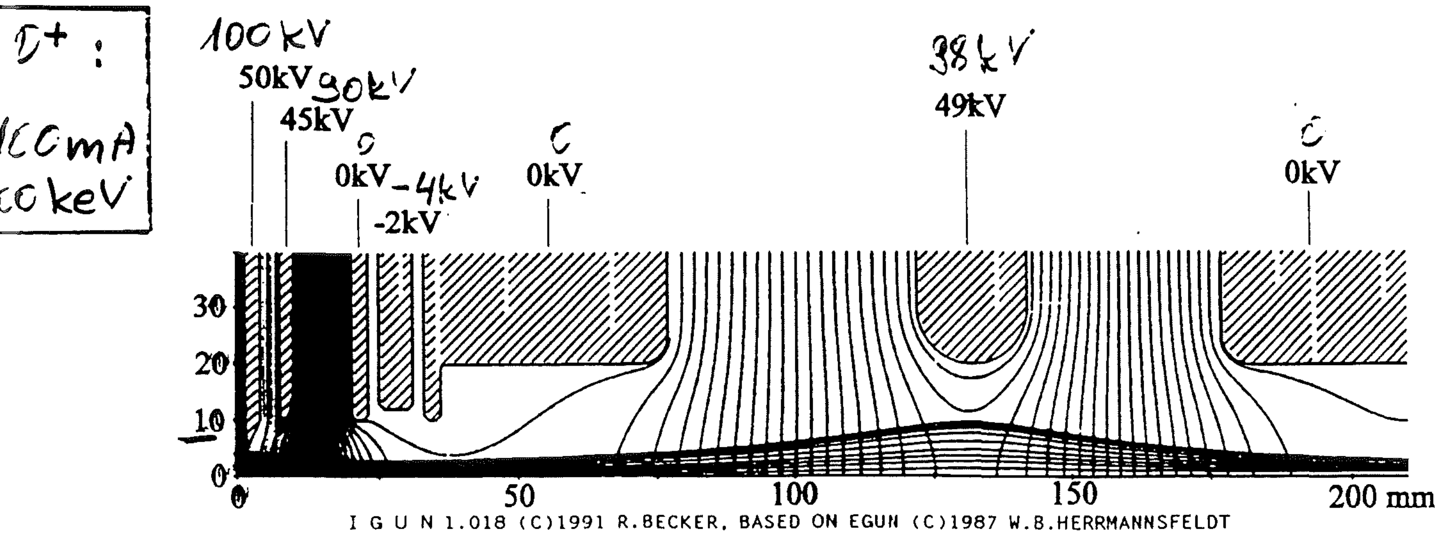


➡ PARMTEQ ➡ RFQ output

Transmission	73% (102mA)
$\Delta W/W$	$\pm 0.7\%$
$\Delta\phi$	$\pm 25°$
rms emittance growth	0.96 (100%)
	0.82 (90%)

Injection System consisting of:

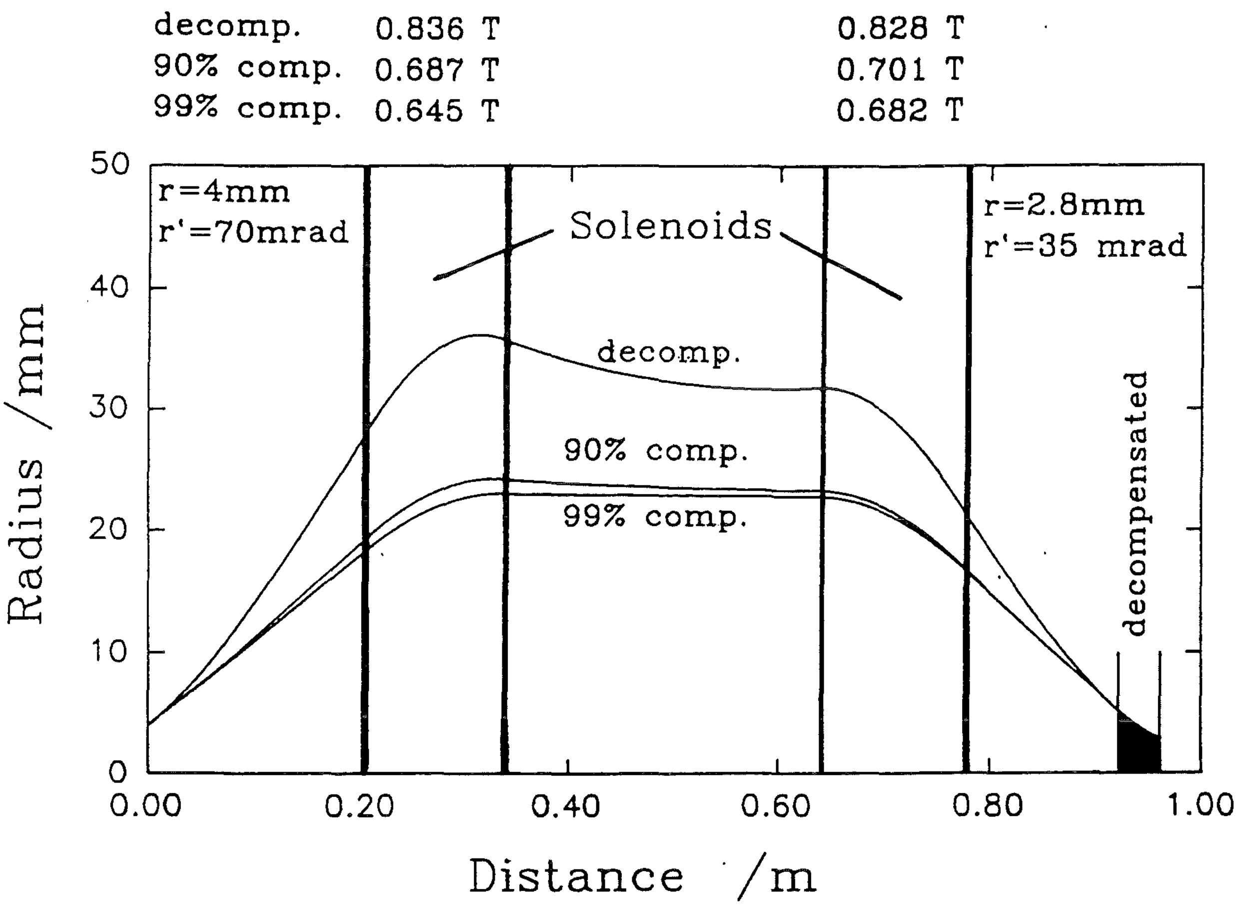
- Pentode extraction system for beam formation
- ring-shaped einzel lens



pentode-extraction with einzellens: 50mA H^+

Two Solenoid Injection

140 mA, 100 keV, D^+, $\epsilon_{n,rms} = 0.1$ mm mrad



- Space charge compensation is necessary for a small beam radius
  ⇒less emittance growth due to nonlinear focusing.

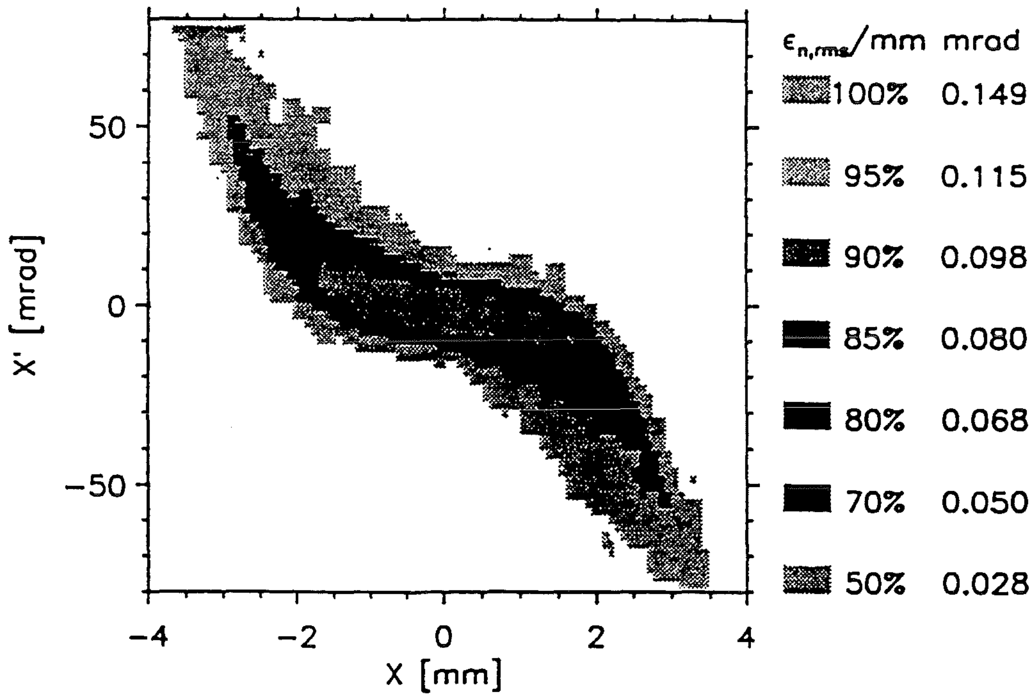
- Charge redistribution in the decompensated region near the front end of the RFQ will cause emittance growth.

Charge Redistribution

- Compensated beam: ≈ Gaussian density profile. (α=-14.2, β=95, $\epsilon_{n,rms}$ =0.072 mm mrad)

- 4cm decompensated drift. (PARMTRA) (140mA, 100keV, D^+)

➡



➡ PARMTEQ ➡ RFQ output:

Transmission	85% (117mA)
$\Delta W/W$	±1%
$\Delta\phi$	±25°
rms emittance growth	1.1 (100%) 1.1 (90%)

LEBT - Conclusions

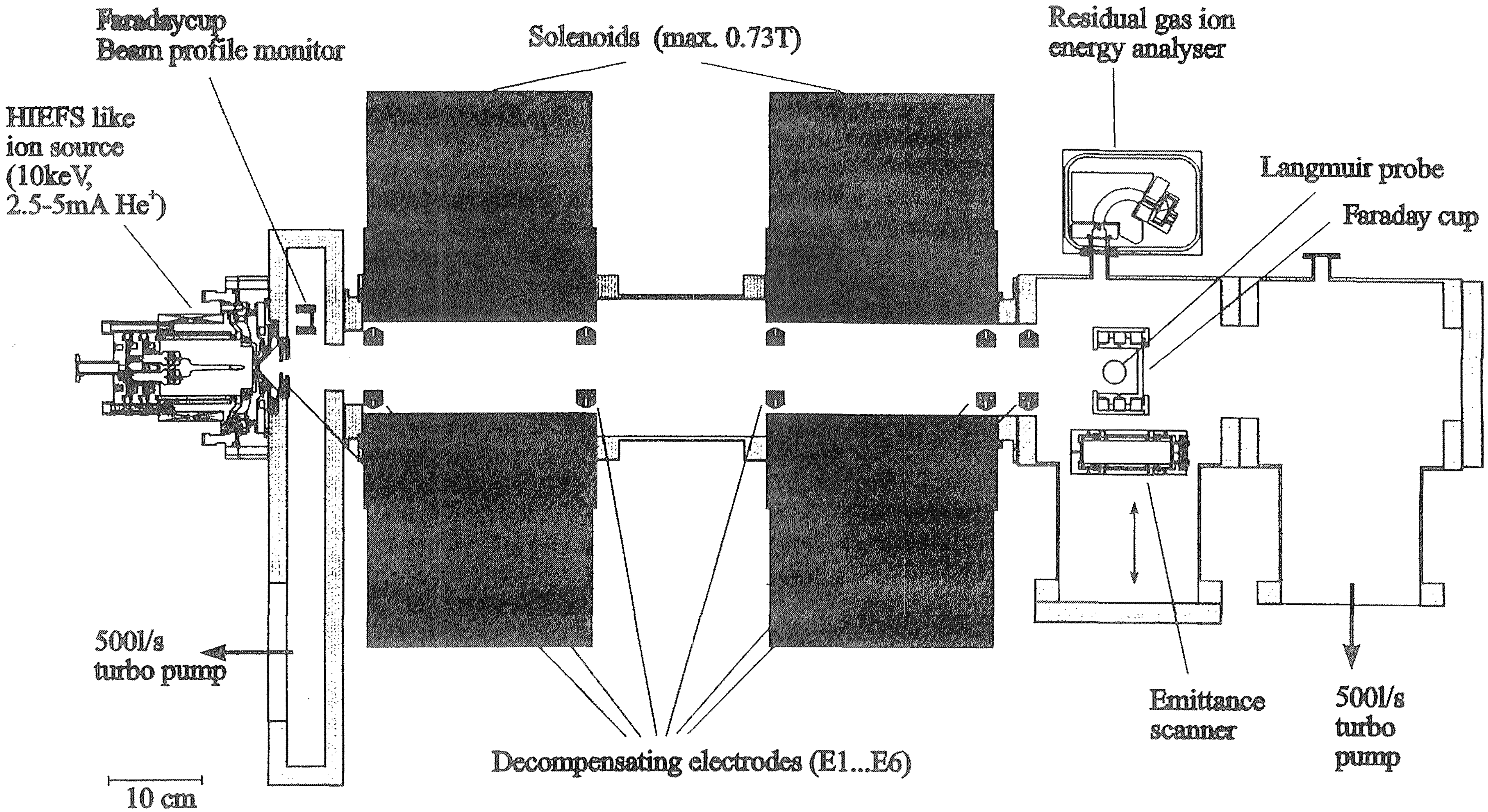
Space charge compensated transport
with two solenoids is favourable.

➡ Small beam radius in long LEBT
➡ Less emittance growth due to lens aberrations.
➡ Space for diagnostics.

➡ Emittance growth due to charge redistribution.
➡ Emittance growth due to instabilities ?
➡ Beam loss due to stripping.
➡ 'Theory' of space charge compensation (scc)?

Work to be performed

➡ Experimental examination of scc.
➡ Improvement of theoretical understanding.
➡ Improvement of computer modelling of scc.
➡ Experimental simulation of RFQ injection
with precise emittance measurements.



Schematic drawing of the Frankfurt LEBT

G. Lawrence, B. Jameson

Parameter	RFQ	DTL
Length (m)	5.4	16.3
Accelerating Field, EoT (MV/m)		2.0 to 2.45
Aperture Radius (mm)	6.0	9.0
Structure Power (MW)	0.3 x 2	3.0
Beam Power (MW)	0.4 x 2	8.0
Total RF Power (MW)	1.4	11.0
RF Efficiency	0.57	0.73
Output Emittance (Norm., RMS)		
Transverse (π mm-mrad)	0.27	0.34
Longitudinal (π mm-mrad)	0.46	0.52
RMS Beam Size (mm)	1.5	1.4

Example of parameters of the ESS-injector-RFQs

		RFQ 1	RFQ 2	or RFQ 2
f	[MHz]	175	175	350
T_{in}	[MeV]	0.05	2.0	2.0
T_{out}	[MeV]	2.0	5.0 (7.0)	5.0 (7.0)
L	[m]	2.9	5.5	2.9
N_{rf}	[kW]	350	700	350
N_{beam}	[kW]	100	150	150
I_{lim}	[mA]	100	100	200

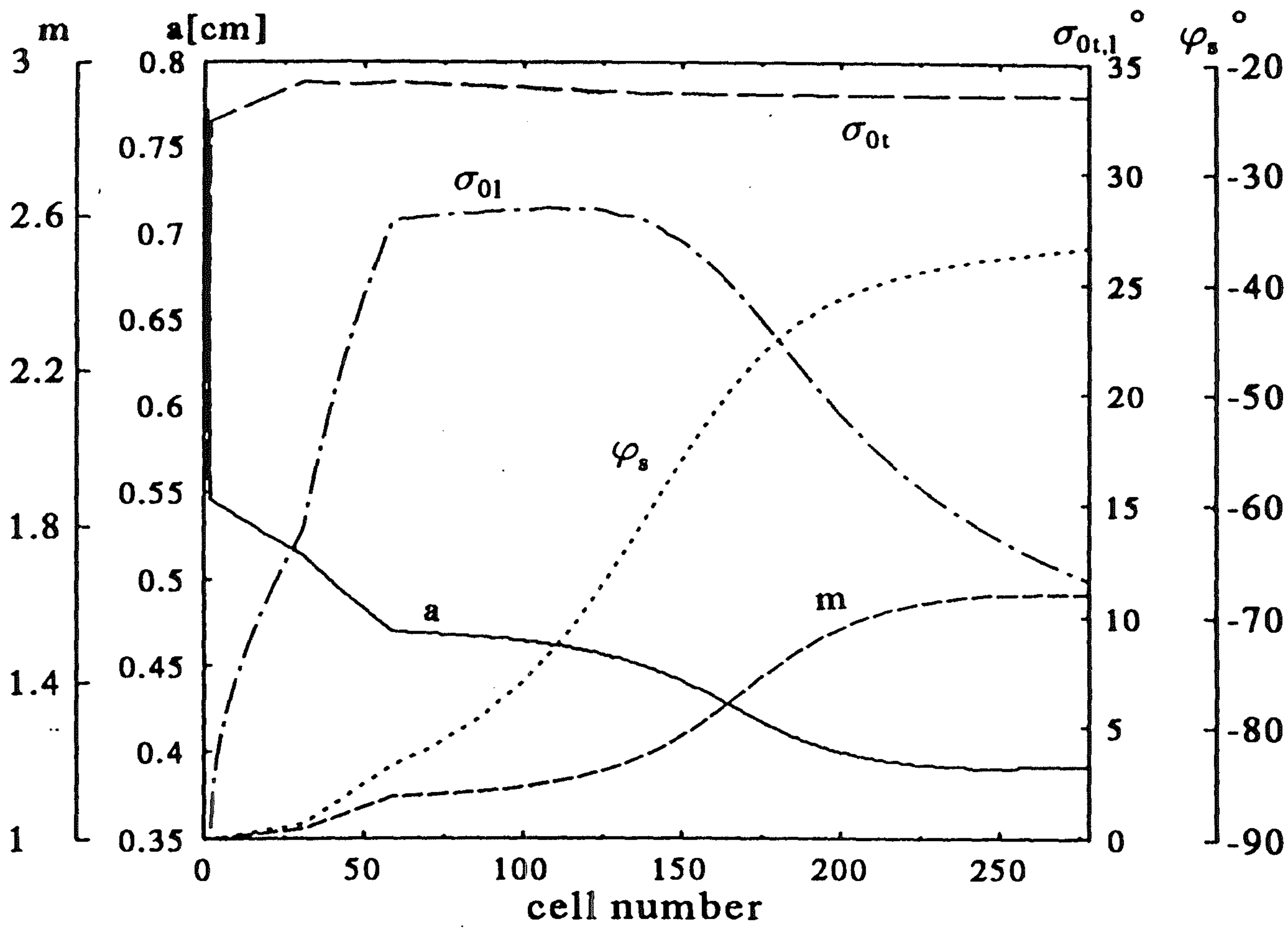
A. Schempp, H. Deitinghoff (IAP-FRA)

D-Li RFQ PARAMETERS I

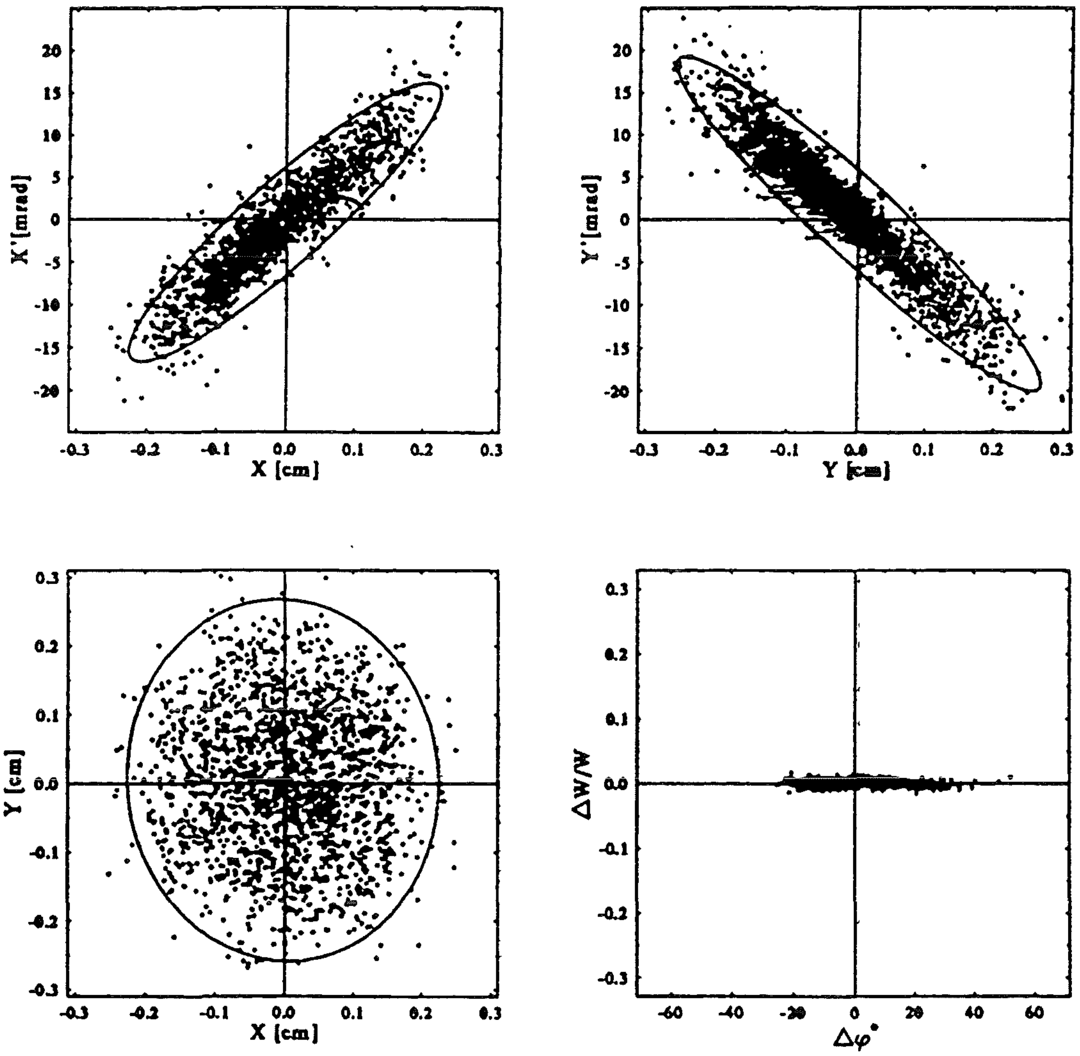
Frequency [MHz]	175.0
Voltage [KV]	95.0
Power [KW]	600.0
Input Energy [MeV]	0.1
Output Energy [MeV]	3.0
Current Limit [mA]	250.0
Length [m]	5.72
Cell Number	278.0
Modulation Factor	1.0-1.63
Radius [cm]	0.55-0.39
Synchronous Phase [°]	-90.0--36.6
Transmission	90.7%
Input Emit.(norm. rms) [mm mrad]	0.10 π
Output Emit.(norm. rms) [mm mrad]	0.14 π

Li Dezhan, H. DEITINGHOFF

RFQ FOR D-Li: AMU=2.01 Q=1.0 I=125mA F=175MHZ U=95KV



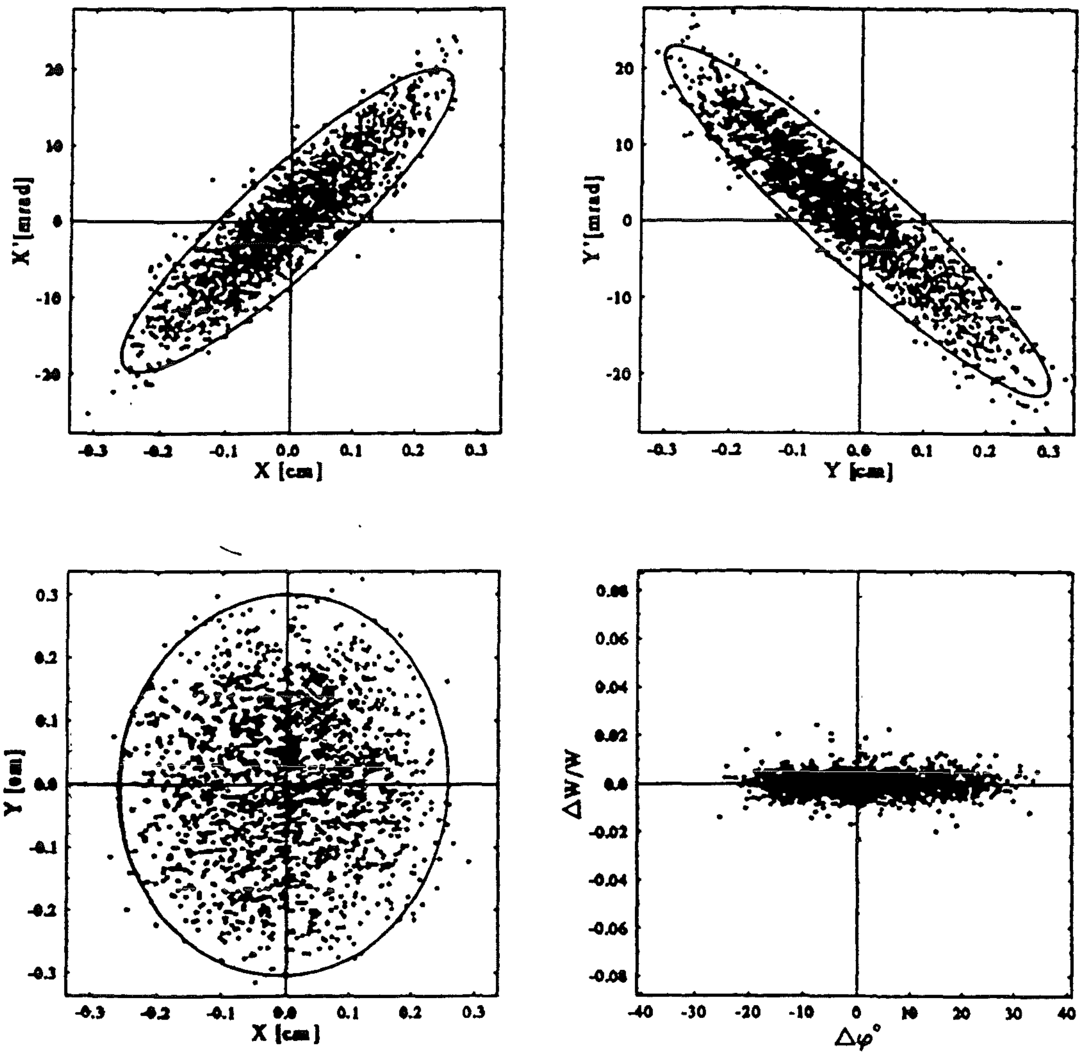
RFQ FOR D-Li: AMU=2.01 Q=1.0 I=125mA F=175MHZ U=95KV
NCELL=278 , NPOINT=1814 , NTOTAL=2000 , Iin=125 mA



ε_{in} (norm. rms) = 0.1 π mm mrad

ε_{out} (norm. rms) = 0.14 π mm mrad

RFQ FOR D-Li: AMU=2.01 Q=1.0 I=125mA F=175MHZ U=95KV
NCELL=278 , NPOINT=1796 , NTOTAL=2000 , Iin=125 mA

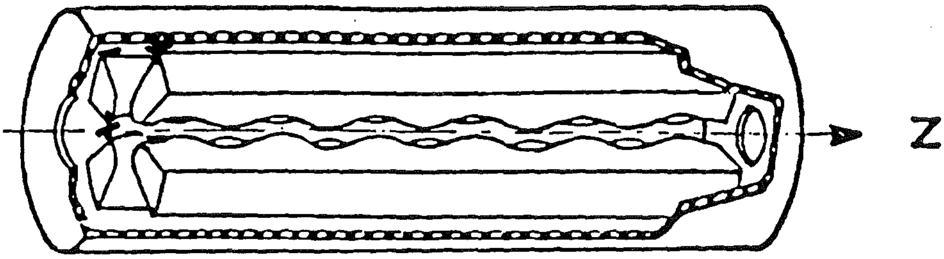


ε_{in} (norm. rms) = 0.2 π mm mrad

ε_{out} (norm. rms) = 0.22 π mm mrad

4 - vane

100 - 600 MHz



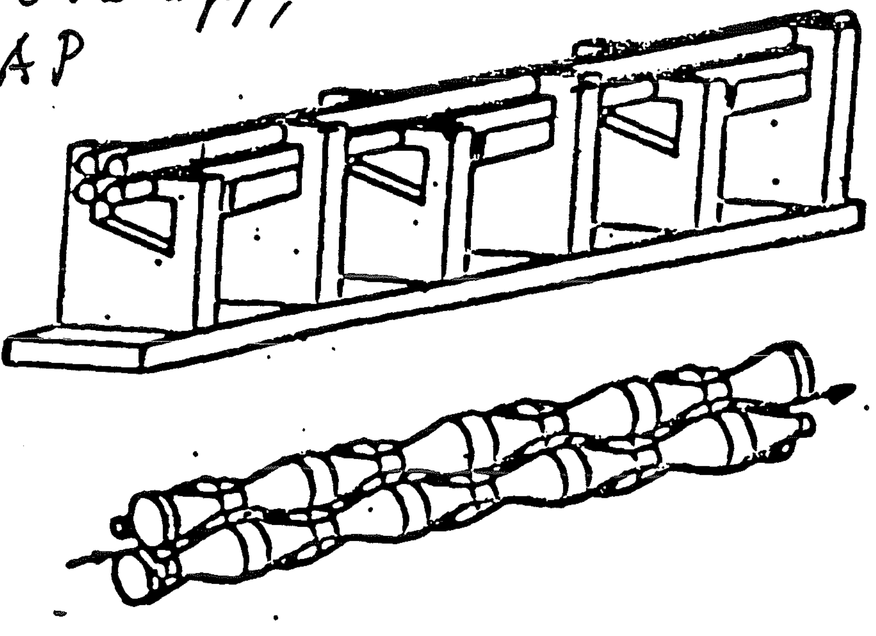
4 - rod

A. Schempp, IAP

50 - 400 MHz

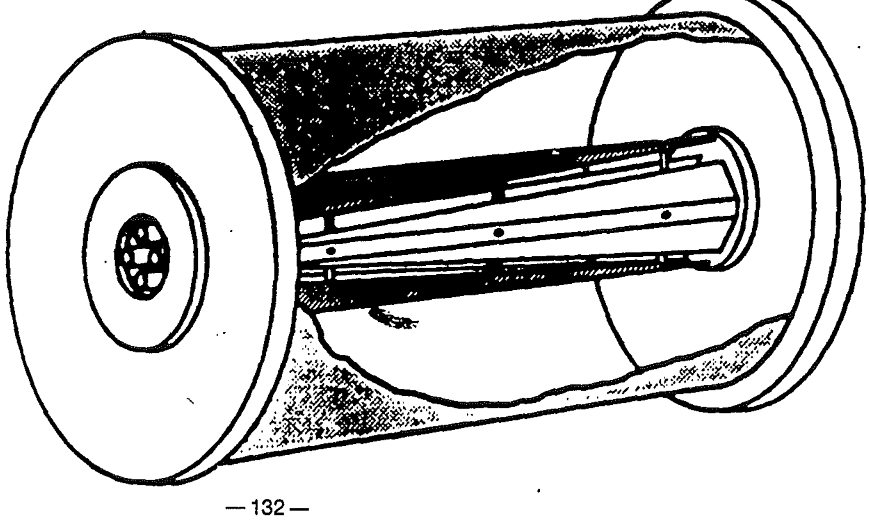
10 - 50 MHz

(spiral-4-rod)



SCR

10 - 60 Mhz



ENGINEERING DESIGN & FABRICATION OF A CW DEUTERIUM RFQ

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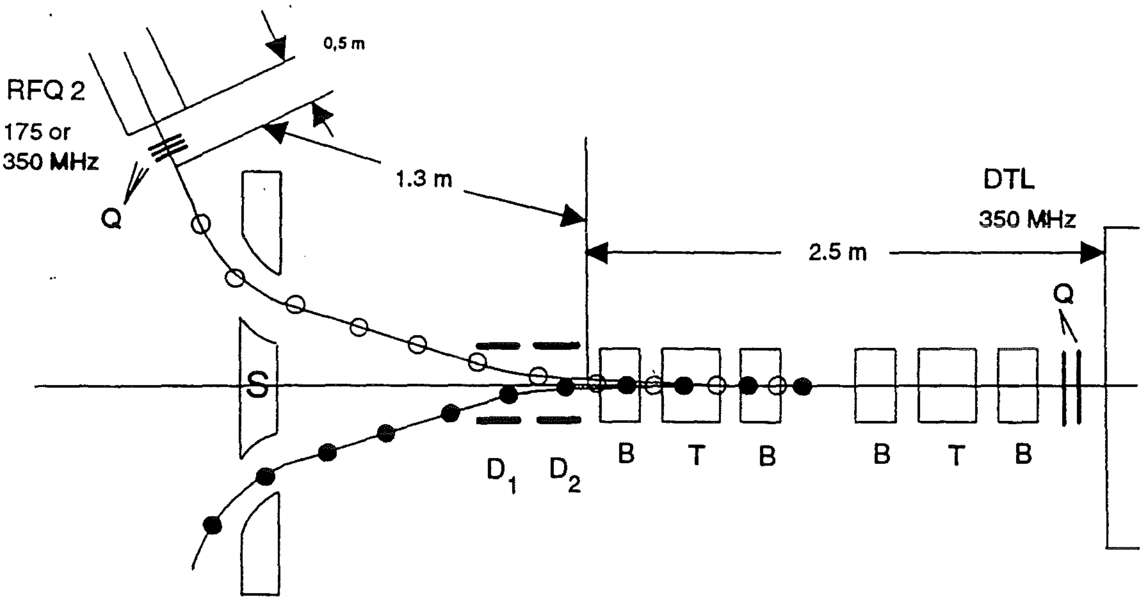
Abstract

A 352 MHz CW Deuterium RFQ has been designed and fabricated for the Continuous Wave Deuterium Demonstrator (CWDD) Program. The RFQ is designed to operate at a peak metal temperature of 35 Kelvin with supercritical neon coolant at 26K. Analysis shows that the RFQ can also operate at room temperature with water cooling. The accelerator is 4 meters long (4.66λ) and fabricated in four one meter segments. Each of the segments is constructed from four vane/quadrant machinings which are made of tellurium copper (TeCu). The four machined parts are then assembled using a copper electroforming technique to yield a pseudo-monolithic structure. The RFQ has been fully constructed and is installed in the beamline at Argonne National Laboratory[1].

Particle	D^-
Operating Frequency	352.2 MHz
Duty Factor	100% (CW)
Input / Output Energy	0.200 / 2.004 MeV
Input / Output Current	92.0 / 80.2 mA
Transmission	87.1%
In / Out Trans. Emitt.	0.075 / 0.099 π mm-mrad
Output Long. Emitt.	0.175 π mm-mrad
Intervane Voltage	87.7 kV (92.0 kV Final)
Peak Surface Field	33.7 MV/m (1.8 x Kp)
RF Power	544 kW (RT), 136 kW (35K)
RF Drive	1 MW Klystron, 4 Drive Loops
Coolant	Supercritical Neon @ 26K
Cavity Operating Temp.	<35K (Peak Metal Temp)
Coolant Pressure	450 psi
Cavity Length	3.96m (4.66 λ)
Cavity Material	Tellurium Copper
Cavity Construction	Electroformed

K. Bongardt
(KFA-Jülich)



ESS - Funneling line.
D_1, D_2 : rf-deflectors, 175 MHz,
S : septum magnet, Q: quadrupols
T: triplett, B : bunching cavity, 350 MHz.

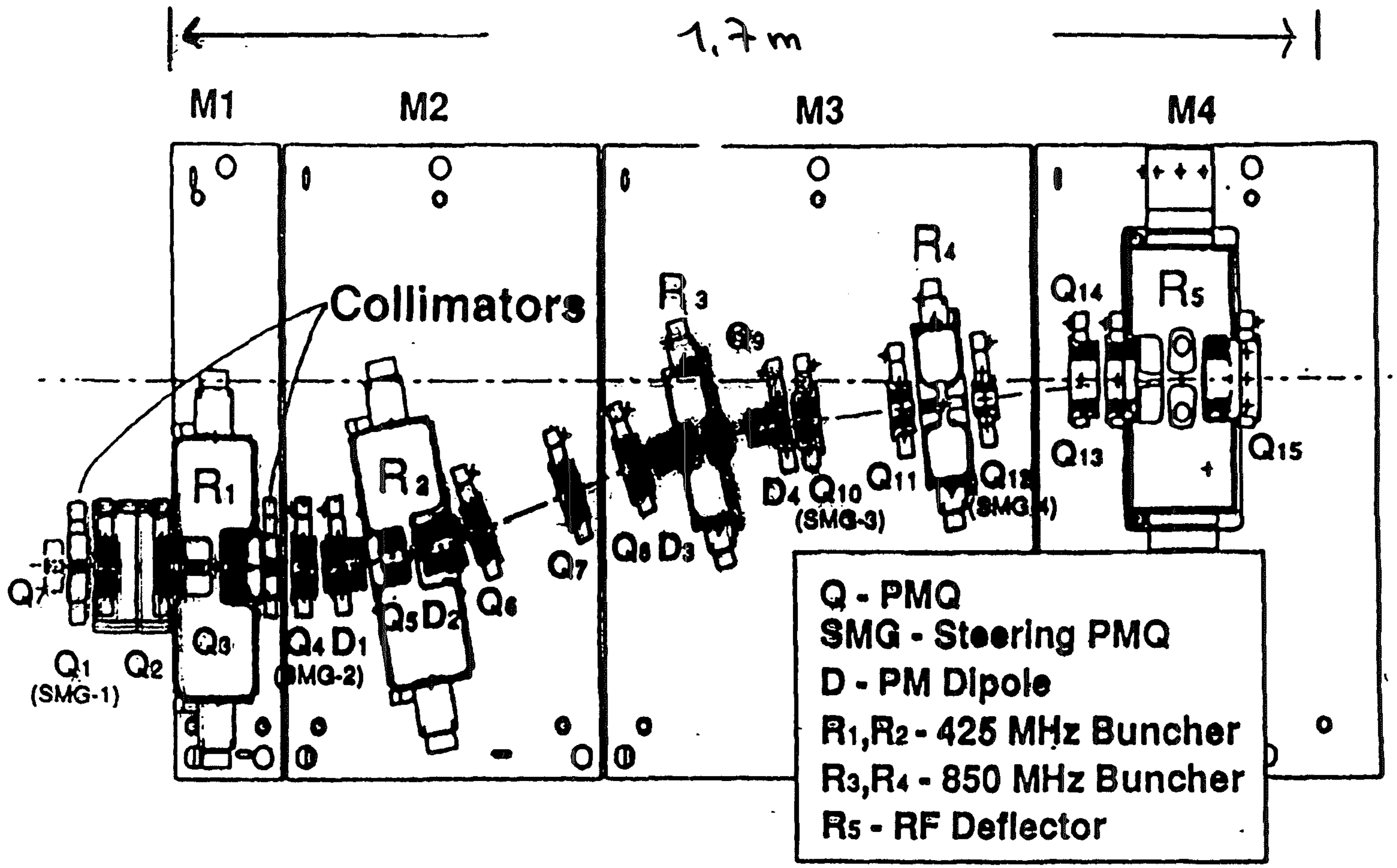


FIGURE 19: Funnel beamline schematic showing the locations of the optics elements.

f = 425 MHz, 5 MeV, I ~ 20 mA

LANL

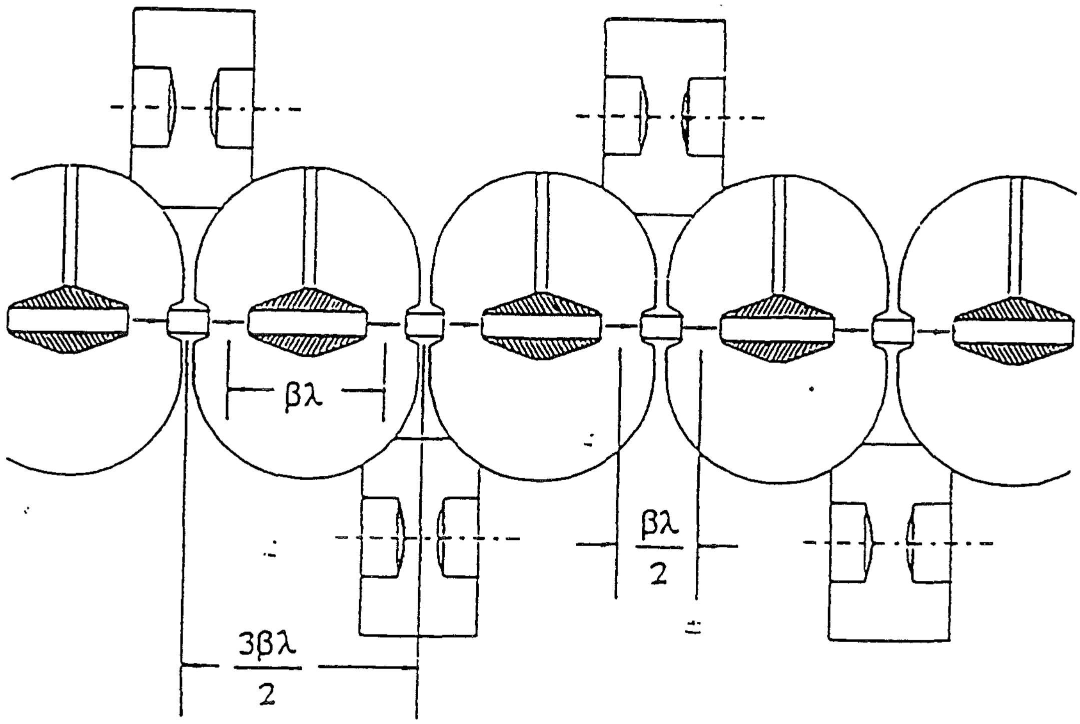


Figure 1. A coupled-cavity drift-tube linac structure for $\beta = 0.314$ with a single drift tube in each cavity.

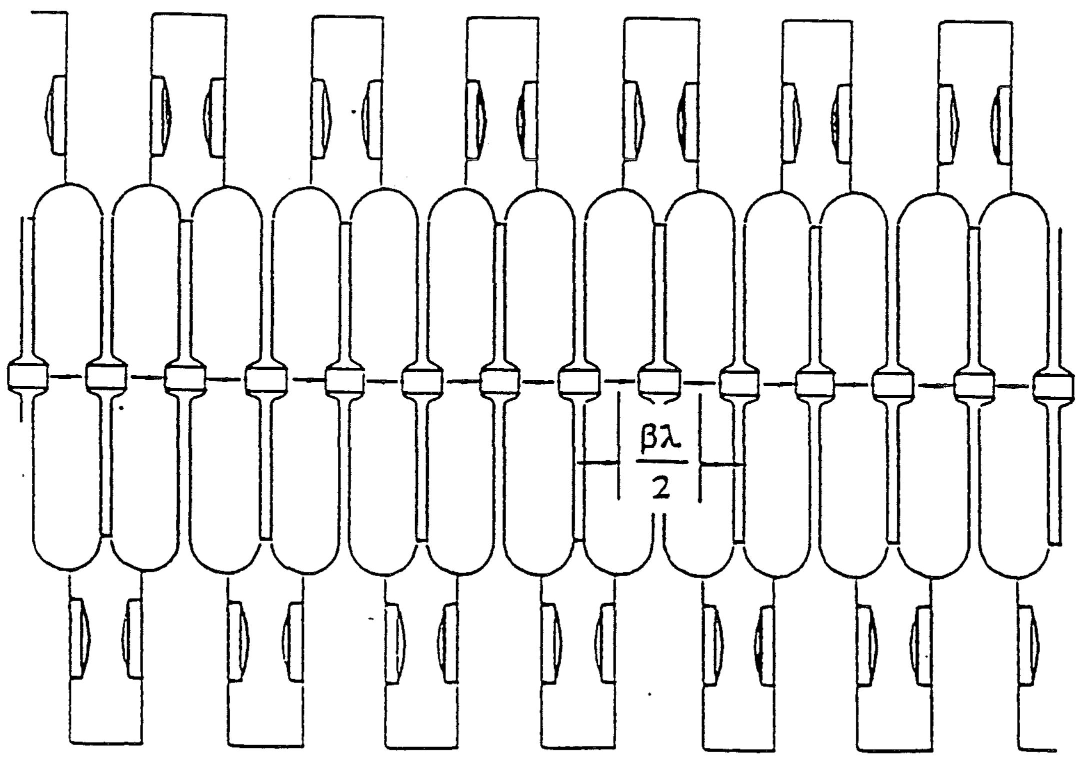


Figure 2. A coupled-cavity linac structure for the same particle velocity as the CCDTL in Fig. 1.

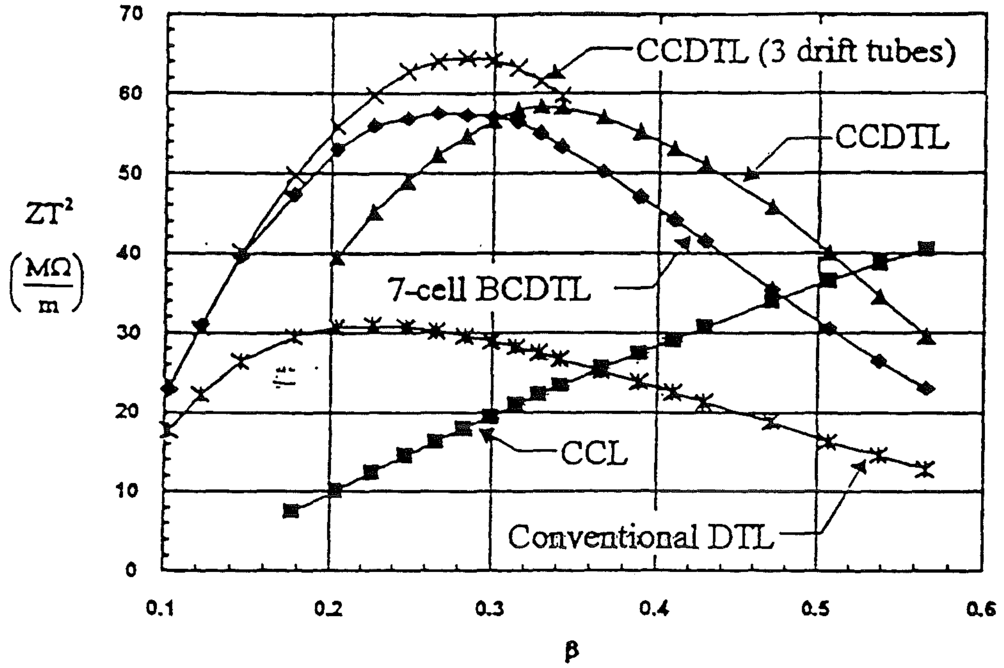


Figure 5. ZT^2 versus particle velocity from Figure 4 corrected for power losses not included by SUPERFISH. Also shown are curves for a CCDTL with 3 drift tubes per cavity and a conventional DTL with drift tubes large enough for focusing magnets.

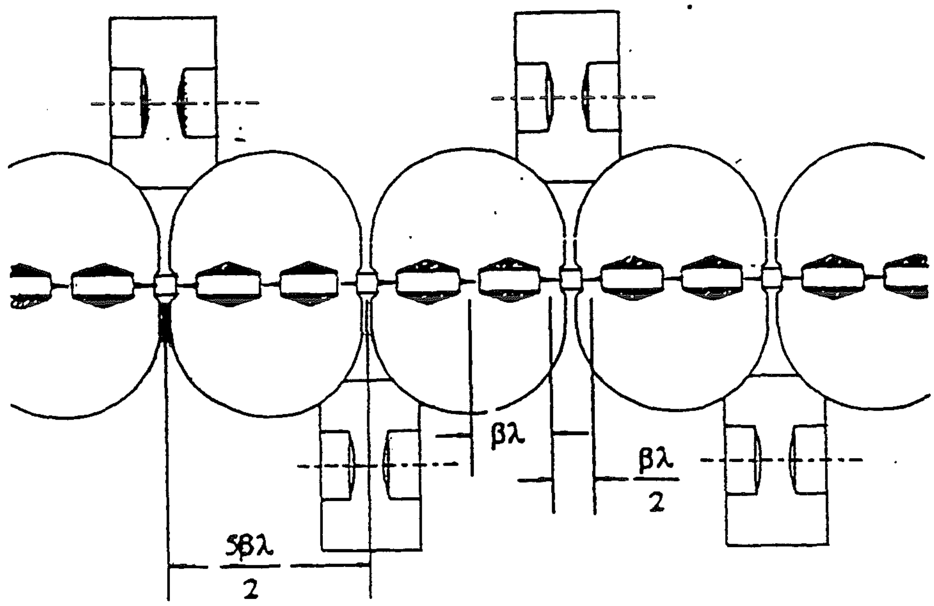


Figure 6. A two-drift-tube CCDTL structure for $\beta = 0.188$. The cavities are the same length as the cavities for $\beta = 0.314$ shown in Figure 1.

ESS - superconducting module

H. Heinrichs. Univ. of Wuppertal

Tab. 1: Typical parameters of the superconducting 350 MHz structure

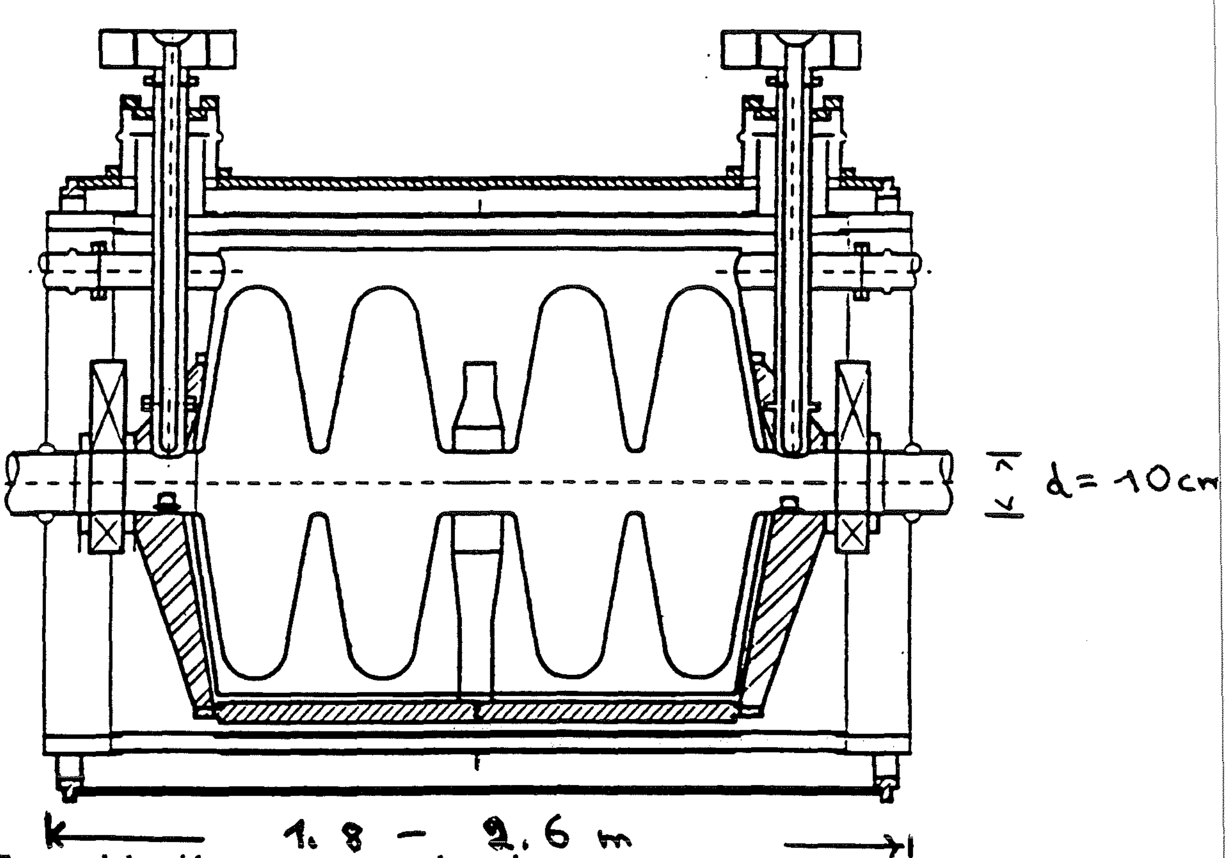


Fig. 2: Cryomodule with two structures and couplers

$Q_0 = 5 \cdot 10^9$ at 4.5 MV/m

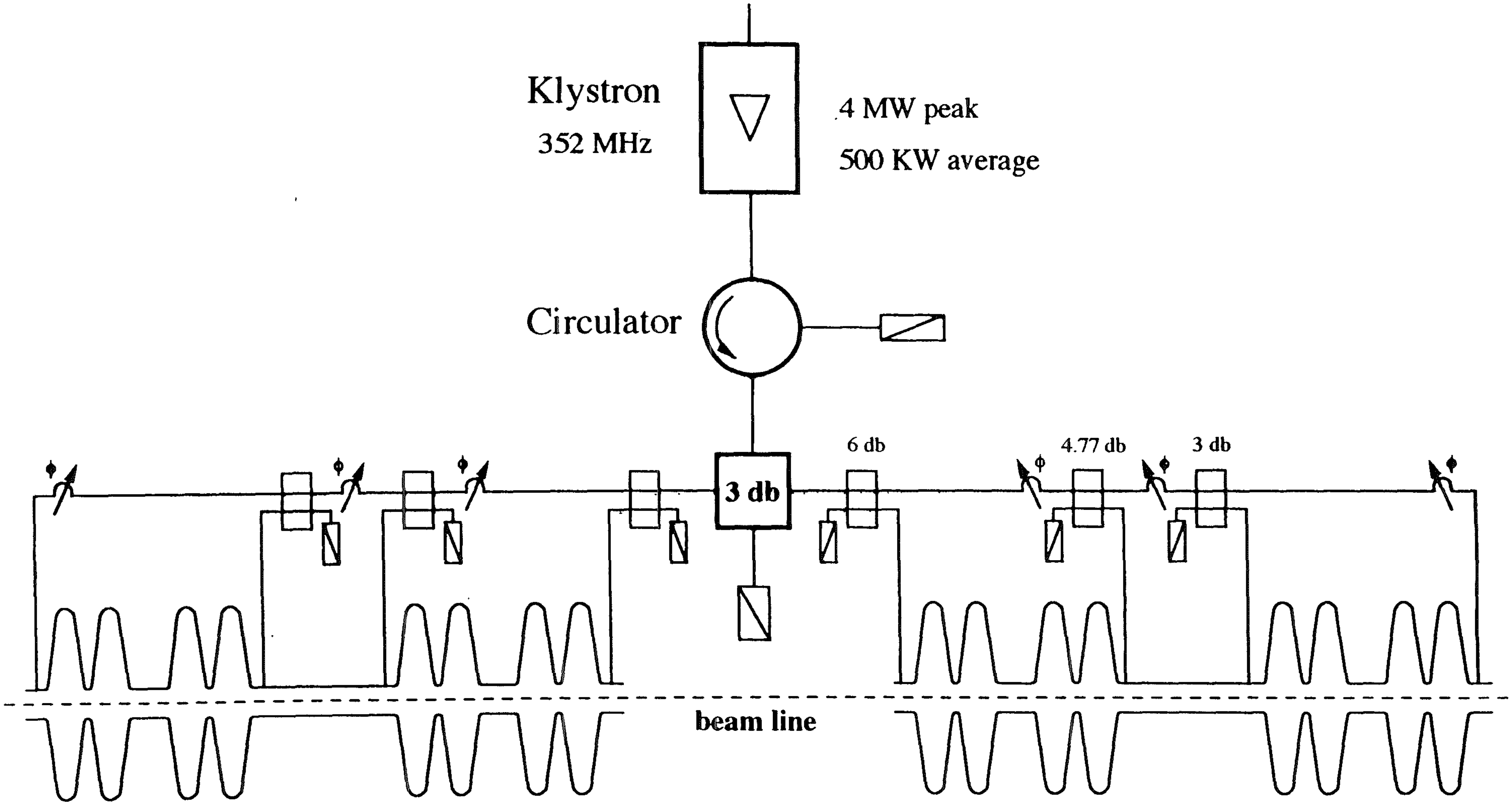
$R/Q = $ 167 Ω/m (T = 150 MeV)

230 Ω/m (T = 1.356 eV)

range of Epeak / Eacc	4.7	to	3
range of Hpeak / Eacc	52	to	42 Oe m /MV

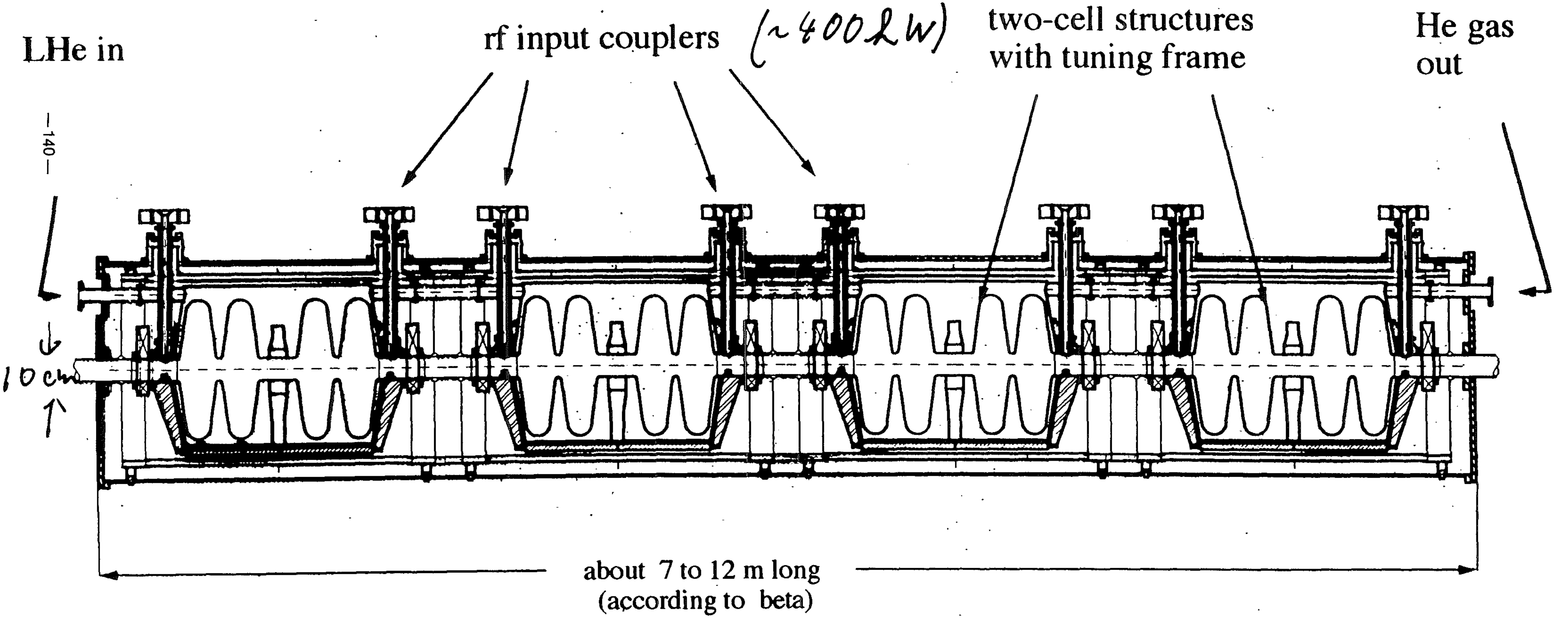
$$P_c = \frac{(E_0 T)^2}{(R/Q) \cdot Q_0}$$

RF Distribution System



Superconducting Linear Accelerator Cryo-Module

H. Heinrichs,
Univ. of Wuppertal



Conclusions

Advantages of superconducting structures are

- large aperture
  small non-linear forces
  low beam losses

- low frequency
  no frequency jump from low to high energy part of accelerator

- high efficiency
  low costs

- for high power applications cw operation possible

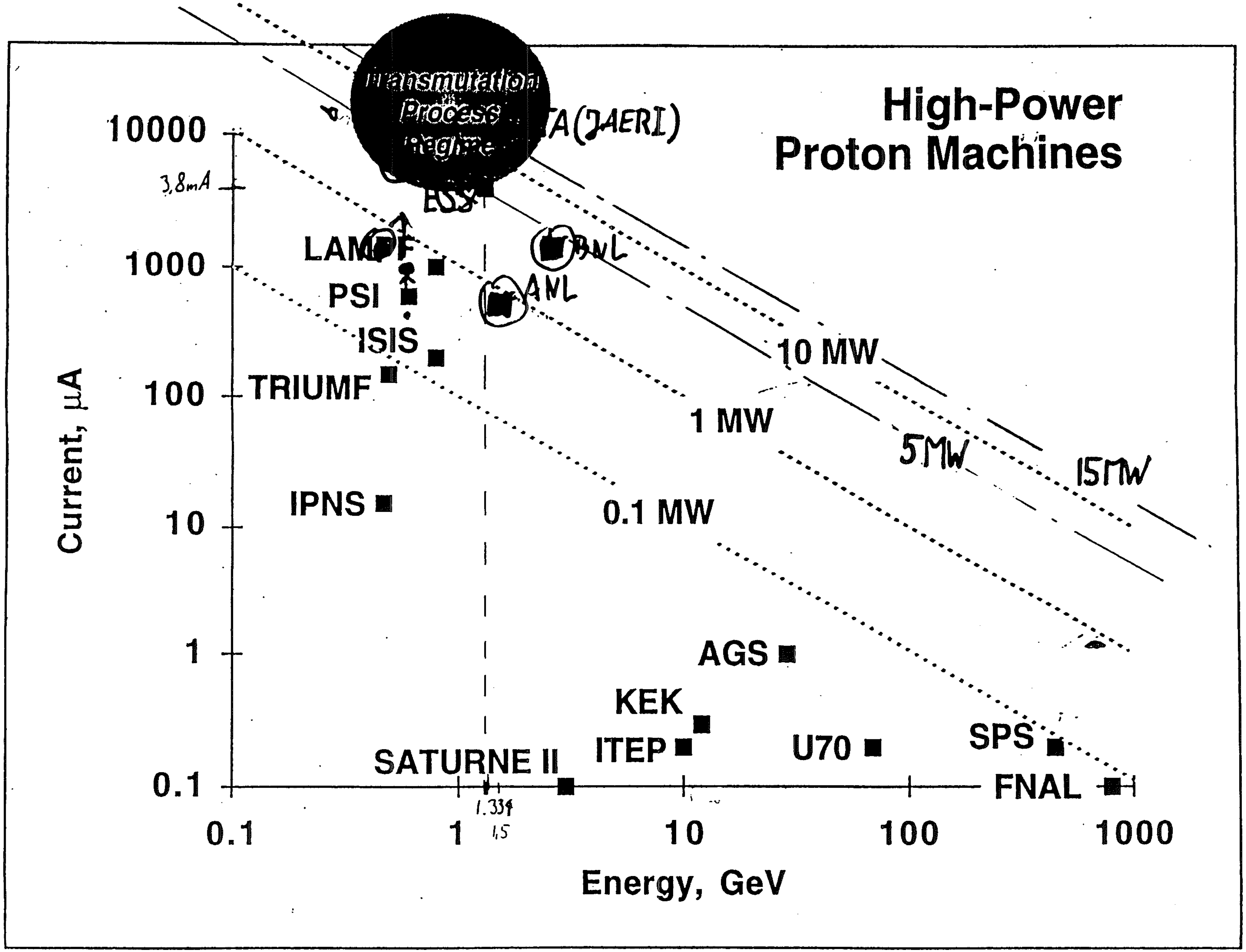
Problems

- high power input couplers
  R&D is necessary, today only 200 KW can be handled, 400 KW are needed for ESS

Work to be done

RFQ:	Design: ε, I, CW (FOUR RCD), Prototype Final Energy?, 175 MHz
Funneling:	Layout, Deflector cavities (Prototyping)
LINAC:	350 Mhz, choice of structure: ALVAREZ, Bridge Coupled DTL, Cavity Coupled DTL, IH-structure, CW Superconducting Cavity
High Energy Transport:	Target Illumination
Beamstop, Shielding	
Beam dynamics:	Particle losses, Halo problem Hands on Maintenance

Energy production



Brief Perspective on Accelerator Technology for IFMIF CDA

R. A. Jameson

LANL

Brief Perspective
On Accelerator Technology
For IFMIF CDA

IEA-Technical Workshop for an
International Fusion Materials Irradiation Facility
Karlsruhe, September 26 - 29, 1994

R.A. Jameson

BRIEF PERSPECTIVE ON ACCELERATOR TECHNOLOGY FOR IFMIF/CDA

Technical approach must consider customer's schedule. May have shorter schedule? Risk/benefit analysis.

Review of Approach — 3 themes:

Theme 1). Preparation of preconceptual room-temperature and superconducting point designs for the ESNIT or IFMIF-class deuteron accelerator.

Major design criteria:

- Very low beam loss
- High efficiency, minimum life-cycle cost
- High availability; goal ≥ 70%

Theme 2). Development of design techniques based on understanding the total transverse extent of the beam. Relative losses of ≤ 1 part in 10^6-10^8 are so small they may have little effect on the rms properties of the beam.

Equipartitioning
Charge redistribution
Beam halos
Nonlinearities

Time scales: betatron, tune, plasma, synchrotron

Theme 3). Development of innovative, practical methods to realize the desired beam dynamics, efficiency, and availability; and synthesis of information in system modeling codes.

RFQ: Extended RFQ
Brazed construction

DTL: New types: Bridge-Coupled DTL (BCDTL)
Side-Coupled DTL (CCDTL)

Superconducting Linac 8-35 MeV: independently phased 2-gap or 3-gap cavities - "Independent Cavity Linac" (ICL)

Funneling design

Tailored beam distribution on target

Reliability, Availability, Maintainability, Inspectability (RAMI)

Summary of Point Designs for ESNIT/IFMIF

RFQ to 8 MeV - 175 MHz

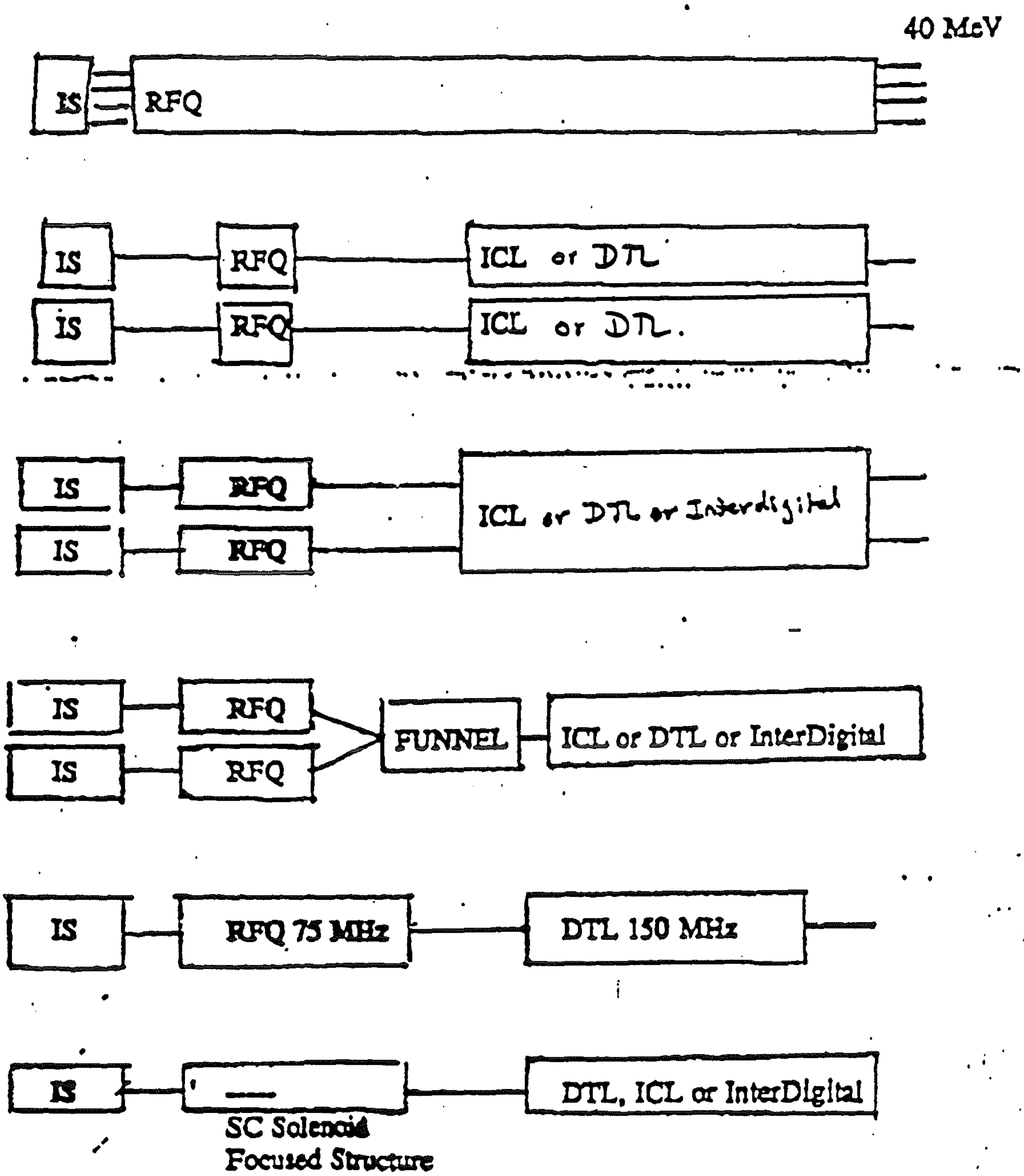
Room Temperature 8-35 MeV
- 175 MHz or 175/350 MHz
  - higher frequency for: better control of beam loss; smaller, easier to handle

Superconducting 8-35 MeV
- 175 MHz or 175/350 MHz
- Better control of beam losses: larger aperture; tapered longitudinal field; dimensional stability
- Energy selectivity
- Graceful degradation with missing cavity
- Cheaper? - Higher gradient -> shorter accelerator

Either 8-35 MeV approach needs
- Beam test
- RAMI demonstration

Figure 1.

IS = ion source
RFQ = radiofrequency quadrupole
ICL = superconducting independent cavity linac
DTL = room-temperature drift-tube linac



DEUTERON ACCELERATOR DESIGN OPTIONS

Discussion of the deuteron accelerator system concentrated on developing the list of basic machine architectures that could provide the required 250 mA of cw beam current at 40 MeV with very low beam loss along the accelerator. The architecture options are distinguished by the consideration of space charge forces acting on the lower energy ion beam., and by the choice of accelerator structures used at the lower and higher energies. The amount of beam current that can be accelerated with good beam quality is more limited at lower beam energies, leading to consideration of using only one channel or of subdividing the beam into two or four channels. At a few MeV, when the space charge forces are weaker, the beams could be merged using a process called funneling, or they could remain separated. Figure 1 sketched these options.

An IHEP proposal would maintain four beams through the entire accelerator, using an advanced type of radiofrequency quadrupole (RFQ) structure that also has attractive features for cw service, such as low stored energy, no transitions, and strong focusing. The advantages of smaller beam current per beamlet would have to be weighed against a more complicated high-energy beam transport system to the target.

Two-beam schemes have been considered in the US, particularly if it were desired to have two beams on target. At the higher energies (a few MeV) the two beams could be accelerated in separate channels or perhaps in a two-beam structure.

A third option is to maintain two separate beams up to ~2 MeV and then merge the beams by funneling into one channel for acceleration to 40 MeV. Preliminary experimental work has confirmed this procedure, and detailed simulations have been done that show the beam quality is preserved.

Only one channel might be used, if strong enough focusing at low energy can be provided to maintain good beam quality and low beam losses. An ITEP proposal uses one RFQ/DTL channel with low rf frequencies. An MRTI design uses a superconducting solenoid for transverse focusing at low energy, around an interdigital accelerating structure.

The higher energy portion of the accelerator, and perhaps even the whole accelerator, could be made using superconducting accelerator structures. RF losses in such structures are very low, so there is no need to optimize the design for high shunt impedance. Thus the beam bore can be made larger to make it easier to maintain low beam losses, and a higher accelerating gradient can be used, making a shorter machine. The accelerating gradient can be ramped up with energy for better control of the space charge forces. Superconducting structures have very good dimensional stability, are naturally suited to cw operation, and could use many short sections, which allows flexibility in energy variability and fault recovery. However, superconducting accelerator structure performance with high-intensity ion beams has not been demonstrated, either for possible beam-related problems or for long-term accelerator maintainability and availability. Control of the rf field is also more difficult. Therefore it would be essential to do long-term (~1year) prototyping tests.

The goal of the Conceptual Design Activity would be to thoroughly evaluate the performance characteristics of these architecture options and select a single reference design for further development. Detailed beam dynamics simulations would be necessary, as well as detailed engineering assessment of construction, availability and cost factors.

San Diego Concept for High-Flux D-Li Source

Two 250 mA, 35 MeV cw D^+ accelerator modules, producing overlapping neutron outputs irradiating a common test volume.

Funneling from two 175 MHz RFQs to single ramped-gradient 350 MHz DTL.

Higher frequencies (than FMIT) provide more compact accelerating structures, and higher beam quality.

High power cw RF sources commercially available.

Funnel design similar to that used in GTA.

Nonlinear optics in HEBT flatten transverse beam density distribution at target.

Energy-dispersion cavity & space charge increase beam energy spread at target.

Two liquid lithium jet targets, with peak beam-power deposition held to FMIT limits.

30, 35 and 40 MeV beam energy.

Los Alamos

IFMIF Staging Program

One 25 mA, 350 MHz DTL
One 25 mA, 175 MHz RFQ
No funnel

25 mA

↓ Add RF stations

One 125 mA, 350 MHz DTL
One 125 mA, 175 MHz RFQ
No funnel

125 mA

↓ Add RFQ, funnel, RF stations

One 250 mA, 350 MHz DTL
Two 125 mA, 175 MHz RFQs
One funnel

250 mA

↓ Add accelerator module

Two 250 mA, 350 MHz DTLs
Four 125 mA, 175 MHz RFQs
Two funnels

500 mA

↓ Add two accelerator modules

Four 250 mA, 350 MHz DTLs
Eight 125 mA, 175 MHz RFQs
Four funnels

1000 mA

Accelerator-Technology Advances Since FMIT

Better analytical understanding of emittance growth, space-charge effects, and halo reduction.

Ramped linac accelerating gradients to preserve longitudinal beam emittance.

PM quadrupoles to provide strong low-energy focussing, preserving transverse beam emittance.

Beam funneling to provide current multiplication with minimal increase in transverse emittance.

Higher RF frequencies to reduce beam emittance growth, and allow more compact accelerating structures.

Improved beam-dynamics codes for simulating high-current behavior in RFQs, DTLs, and beam transport systems.

Improved high-order optics codes; new methods for controlling spatial intensity distribution of beam.

Accelerator baseline and options

Design requirements

Beam current = 250 mA
Deuteron energy 35MeV; -5 MeV ; +5 MeV
Energy spread +/- 500 keV
Plant Factor ~ 70%
High energy beam losses < 1nA/m

Injectors (two)

ECH driven cusp field source. RF driven is an option.
100-125kV ; 140mA

Low Energy Beam Transport

Magnetic focussing. Neutralization and electrostatic focussing are options.

RFQ (two)

Room temperature. S/C is an option.
Energy up to 2MeV. 125mA. 175 MHz

Beam Funnel

10/5/92

LANL data

Accelerator baseline and options
(continued)

Drift tube linac

350 MHz , 250mA
Room temperature up to 8MeV
S/C from 8MeV to 35 +/- 5MeV
Options include all room temperature, all S/C

High Energy Beam Transport

Variety of spot sizes (5x5,10x10,15x3 etc)
Uniform beam densities
Energy Dispersion Cavity
Radiation hardening

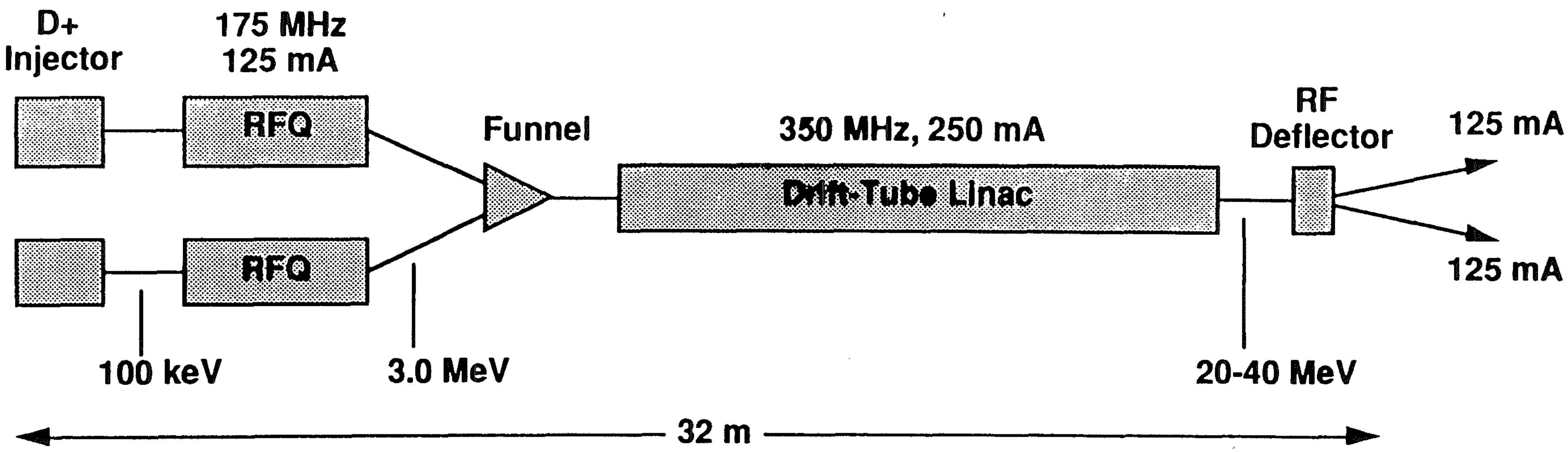
Trade off studies are needed to confirm optimum approach

9/15/92 LANL data

Design Issues
for High Power Proton Linacs

- Beam loss control
- RF power cost & efficiency
- Machine availability
- Integrated system operability

Proposed Accelerator System for International D-Lithium Neutron Source



Parameter	RFQ	DTL
Length (m)	5.4	16.3
Accelerating Field, EoT (MV/m)		2.0 to 2.45
Aperture Radius (mm)	6.0	9.0
Structure Power (MW)	0.3 x 2	3.0
Beam Power (MW)	0.4 x 2	8.0
Total RF Power (MW)	1.4	11.0
RF Efficiency	0.57	0.73
Output Emittance (Norm., RMS)		
Transverse (π mm-mrad)	0.27	0.34
Longitudinal (π mm-mrad)	0.46	0.52
RMS Beam Size (mm)	1.5	1.4

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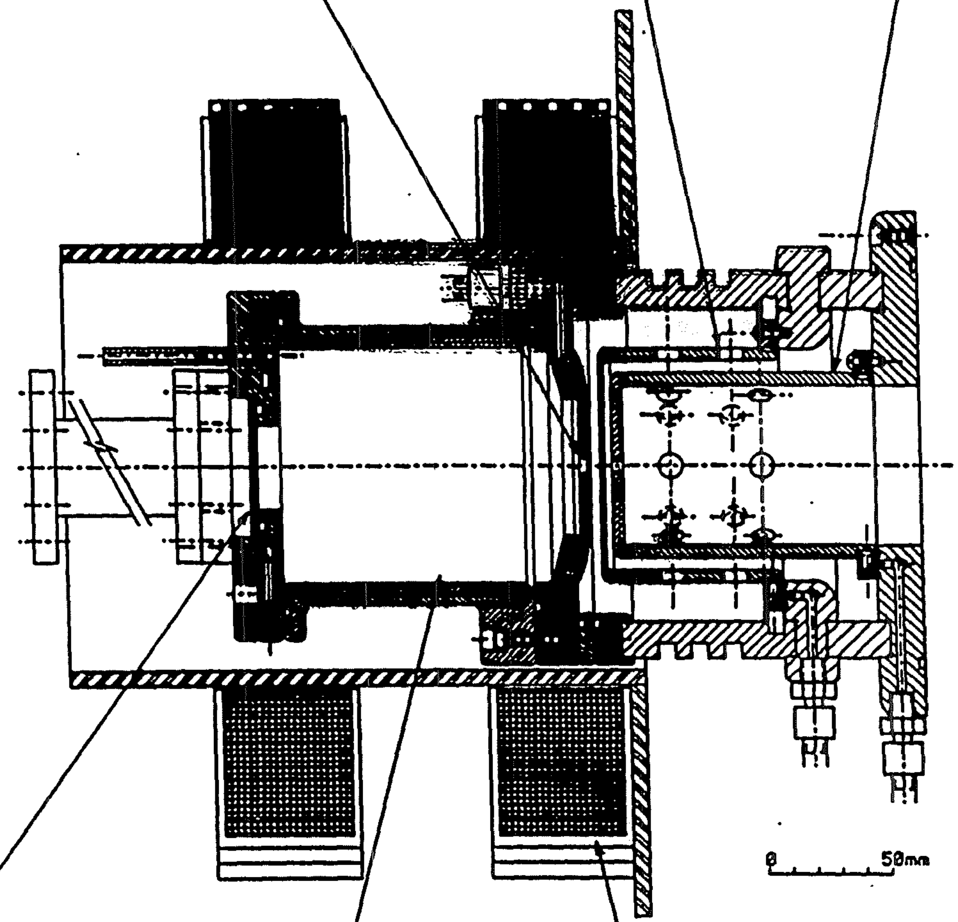
CW Injector Design Considerations
Ion Source

Ion Source

- Reliability, long-life, consistency & constancy
- High current (to provide comfort margin)
- Power Efficiency
- Gas Efficiency
- Plasma Uniformity
- Temporal Stability of Plasma
- Proton Fraction

LEBT

- Steering and matching flexibility
- Preference for short, straight LEBT
- Lifetime limitations due to sputtering
- Turn-on & turn-off beam control


PLASMA ELECTRODE
ACCEL ELECTRODE
DECEL ELECTRODE
0
50mm
MICROWAVE WINDOW
PLASMA CHAMBER
SOLENOID

CRL ECR Ion Source

Advantages

- Excellent power efficiency
- Frequently shows very high gas efficiency
- Unit is small, simple and clean
- High-voltage interfacing is very simple
- Has proven cw performance (>100 mA protons) and RFQ matching

Unknowns or Suspected Problems

- Microwave matching into plasma
- Beam-quality effects from extraction inside magnetic field
- Uniformity over large area emission surface
- Lifetime of microwave window
- Performance with deuterium

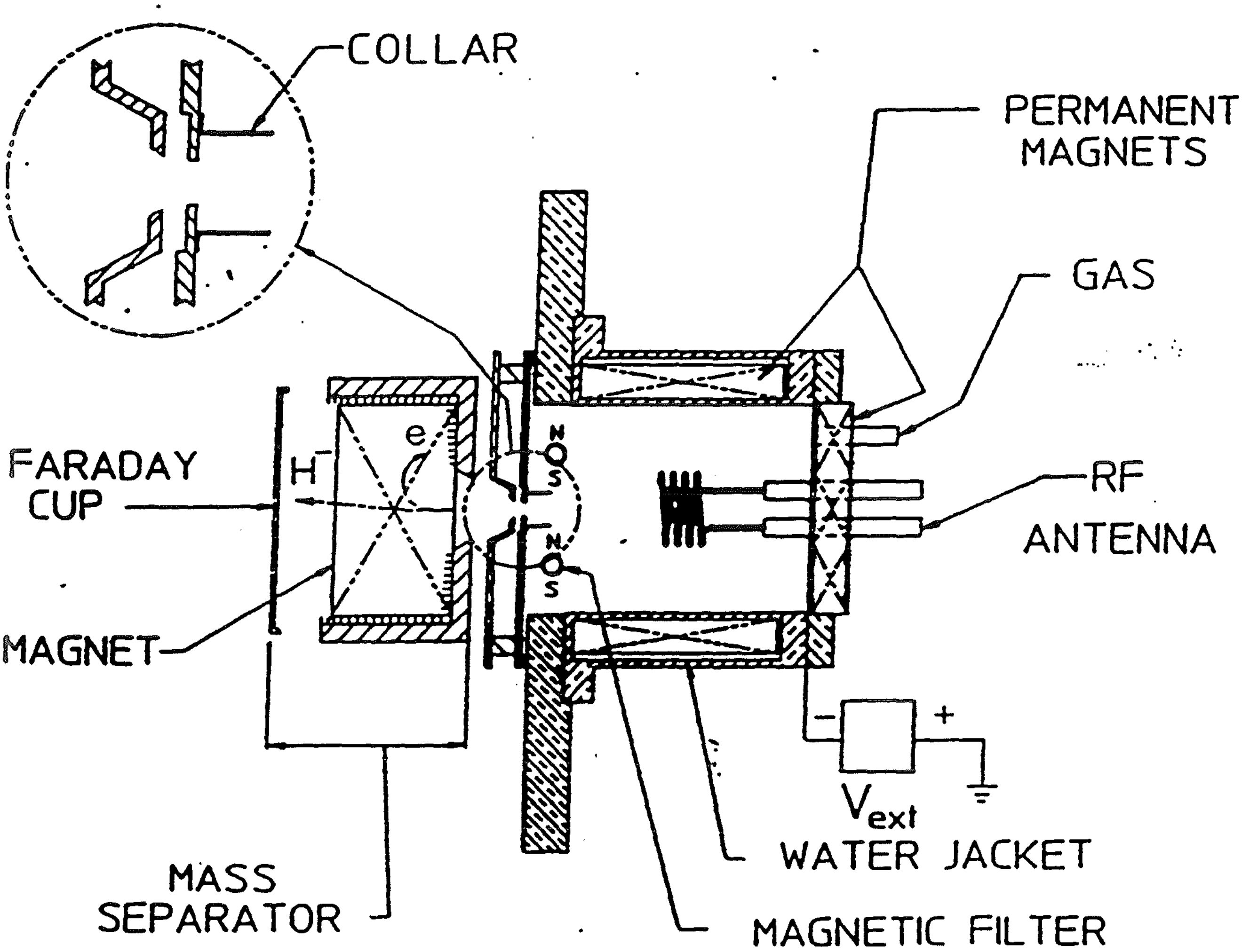


FIG. 1. Schematic diagram of the multicusp ion source modified for operation with an rf induction coil. The mass separator and the Faraday cup are both at ground potential.

RF-Driven Volume Ion Source

Features

- Operational stability is well-proven
- Scalable to high currents

Advantages

- Demonstrated 120 mA protons at low DF
- Magnetic filter enhances proton fraction
- Very simple construction and operation

Issues

- High rf power required
- Poor gas efficiency

Unknowns

- RF antenna lifetime
- Heavy-ion contamination
- Heat distribution on chamber walls

Preferred Approach for FMIF Injector

- Initial configuration should be a lower-current, lower-voltage stand. (≤100 mA, ≤100 keV) to achieve initial high reliability.
- Several promising ion sources should be tested in parallel.
  - ECR
  - RF-Driven, volume, cusp-field
  - Single-ring cusp
- Upgrade RFQ by replacing vanes when a higher current and optimum injector configuration is identified.

Estimated RFQ Parameters

Structure Type	4-Vane
Peak Surface Field	25 MV/m
Tank Diameter	36 cm
Length	5.4 m
Full Aperture	1.2 cm
Transmission	89.3%
RF Source	0.5-MW tetrodes
RF Power (copper)	0.3 MW (x 2)
RF Power (beam)	0.4 MW (x 2)
RF Power (total)	0.7 MW (x 2)
RF Efficiency	57%
Output Emittance (n, rms)	
Transverse	0.027 π cm-mrad
Longitudinal	0.046 π cm-mrad

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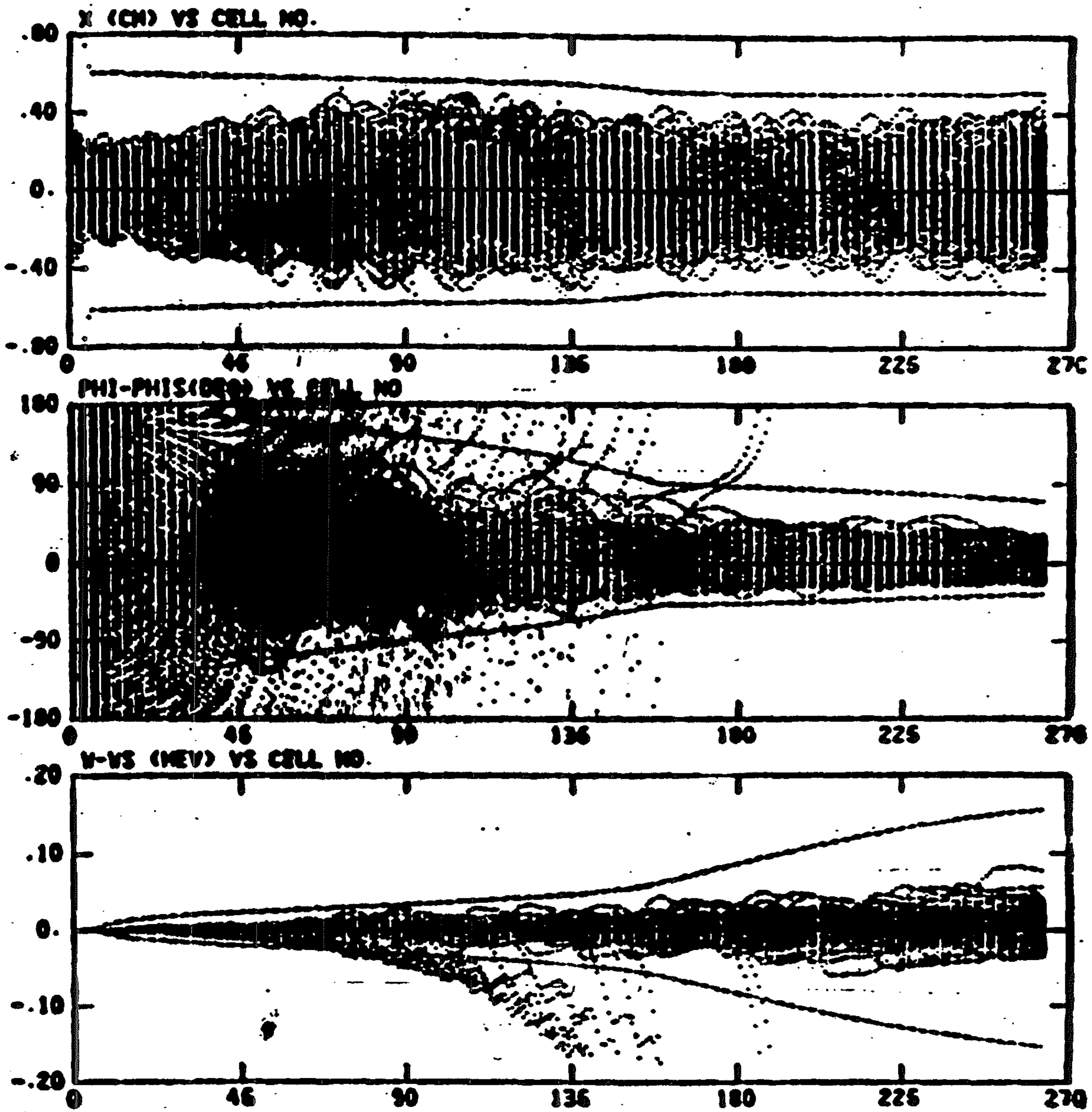
175 MHz 125 mA

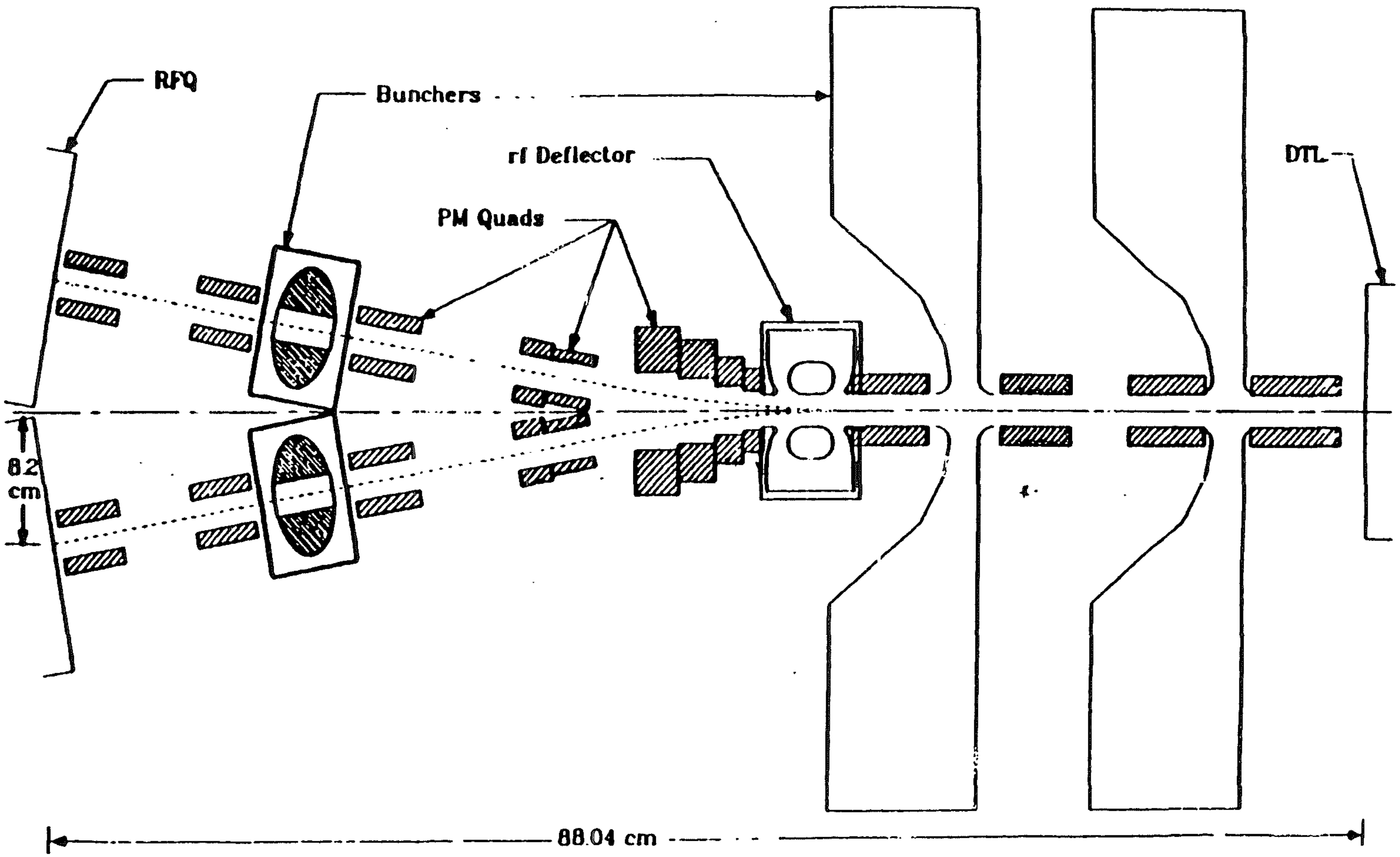
Transverse Beam Size (cm)

Bunch Phase Width (degrees)

Beam Energy Spread (MeV)



Funnel for 250 mA Concept

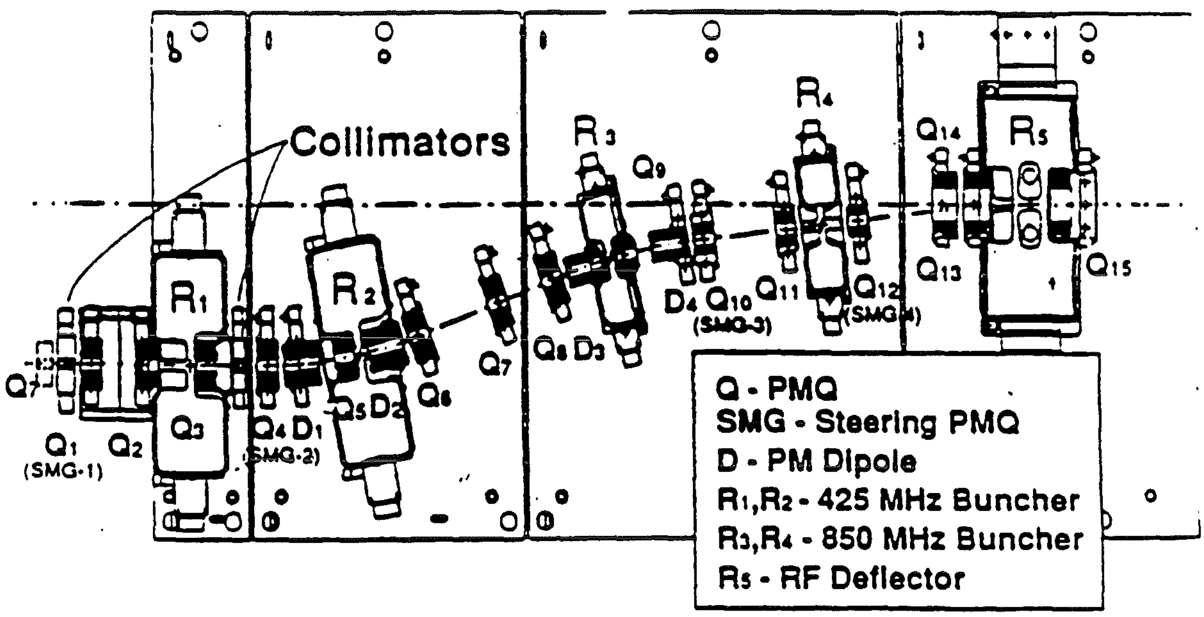


Funneling

Single-beam funneling experiment
- Los Alamos ATS, 1990
- 5 MeV, 425 MHz, 60-mA peak current

Beam simulations predicted
- Zero (unmeasurable) transverse emittance growth
- Small longitudinal emittance growth
- 100% beam transmission, within sensitivity

Experimental results consistent with simulations



Concerns
- Impact on beam tails of non-constant deflector fields
- Sensitivity to momentum variations in beam

Comments:
- Emittance filtering at 40-80 MeV is a design option
- Deflection field can be corrected with 3rd harmonic
- Bend is nearly achromatic; large momentum acceptance
- Detailed measurements in ATW front-end demonstration

Los Alamos

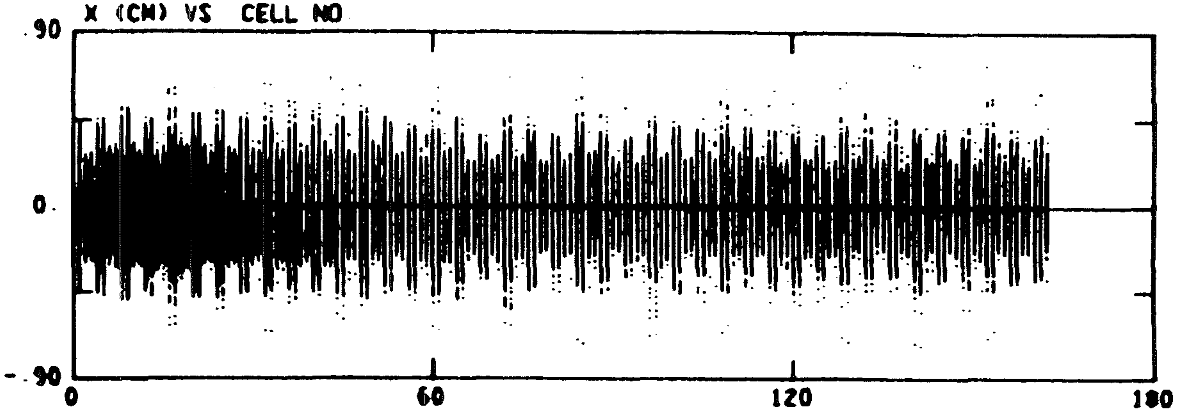
Estimated DTL Parameters

Structure Type	1βλ
Focusing Pattern	FOFODODO
Accelerating Field (EoT)	2.0 to 2.45 MV/m
Tank Diameter	50 cm
Length	16.3 m
Full Aperture	1.8 cm
Number of drift tubes	162
RF Source	1-MW klystrons
RF Power (copper)	3.0 MW
RF Power (beam)	8.0 MW
RF Power (total)	11.0 MW
RF Efficiency	73%
Quadrupoles	
Gradient	106 - 100 T/m
3 - 10 MeV	SmCo PMQs
10 - 35 MeV	Rad-hard EMQs
Output Emittance (n, rms)	
Transverse	0.34 π mm-mrad
Longitudinal	0.52 π mm-mrad

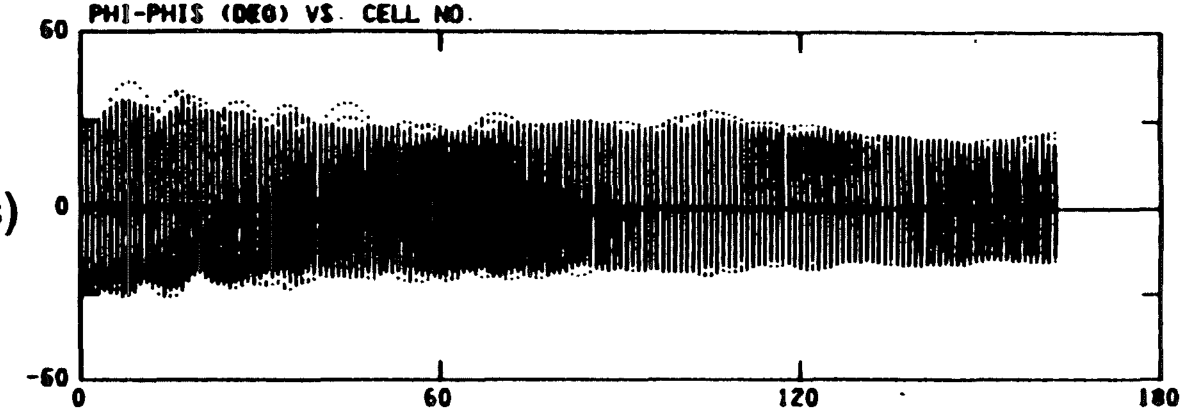
Los Alamos

Beam Parameters in DTL
(350 MHz, 250 mA)

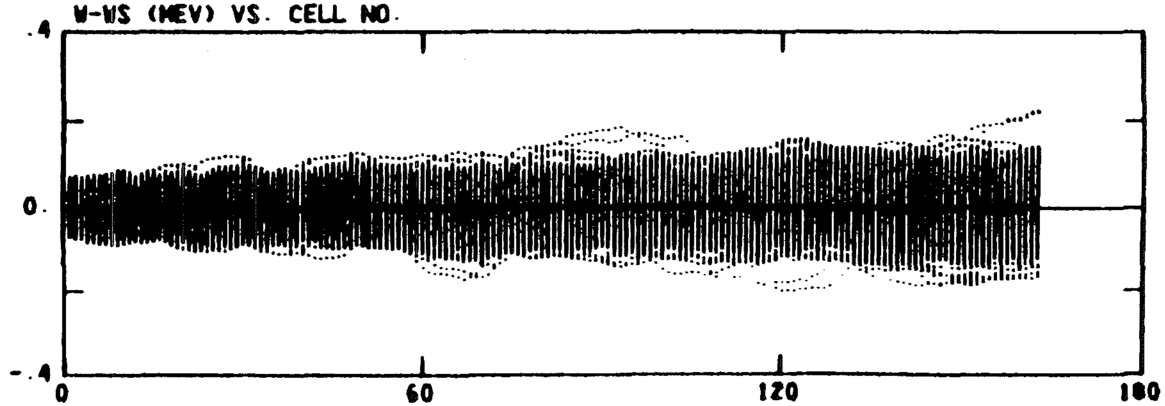
Transverse Beam Size (cm)



Bunch Phase Width (degrees)



Beam Energy Spread (MeV)



SC LINAC SECTION
(TRACE3d/PARMILA Analysis)

Energy Range:	8-35 MeV
Cavities Type:	2 gap
Cavities β's:	0.12 up to 20 MeV; 0.17 from 20 MeV to 35 MeV
Focusing Cell:	FODO with 2 cavitiies per focusing cell
Focusing Elements:	SC quads with L=3.5 cm, B'l < 100 T/m
Bore Radius:	3 cm

Baseline Designs

	I	II	III
Accelerating Gradient	6 MV/m	4 MV/m	6 MV/m
Frequency	175 MHz	175 MHz	175 MHz to 20 MeV 350 MHz 20-35 MeV
Synchronous Phase	- 24 to - 30 deg	- 30 deg	- 24 to - 30 deg
Length	10 m	14 m	12 m
Transverse Beam Size (rms radius)	0.5 -2.5 mm	1.0 -2.2 mm	0.7 -3.2 mm
Longitudinal Beam Size (rms half-length)	4.0-4.5 mm	3.3-4.5 mm	3.0 -4.0 mm
Transmission	100%	100%	100%

ISSUES

- BEAM PHYSICS
  - BEAM BREAKUP (function of peak current)
  - RADIOACTIVATION FROM BEAM IMPINGEMENT (function of avg. current)
- ACCELERATING STRUCTURES
  - FREQUENCY
  - GEOMETRY
- RF POWER
  - AMPLIFIERS
  - COUPLERS
- RF CONTROL OF PULSED BEAM-LOADED RESONATORS

BEAM IMPINGEMENT

- FOR LONG-LIFE, HIGH-CURRENT, CW ION ACCELERATORS BEAM IMPINGEMENT ISSUE IS NOT THERMAL MANAGEMENT BUT ACTIVATION
  - Maximum tolerable amount of beam impingement of the order of 0.1 nA/m at 1 GeV
  - Heat load due to beam impingement : 100 mW/m
  - Heat load due to rf : 20 to 40 W/m

- VERY LOW BEAM IMPINGEMENT MAY BE EASIER TO ACHIEVE IN SUPERCONDUCTING LINACS THAN IN NORMAL-CONDUCTING LINACS
  - Because of frequency dependence of surface resistance, superconducting accelerators favor lower frequency, normal-conducting accelerators favor higher frequency
  - Lower frequency implies larger beam aperture
  - At same frequency, superconducting cavities can be designed with larger apertures since optimization of shunt impedance is of secondary importance

DESIGN OF
HIGH-CURRENT SUPERCONDUCTING SECTION

- INPUT BEAM: 7.5 MeV, 80 mA D^-

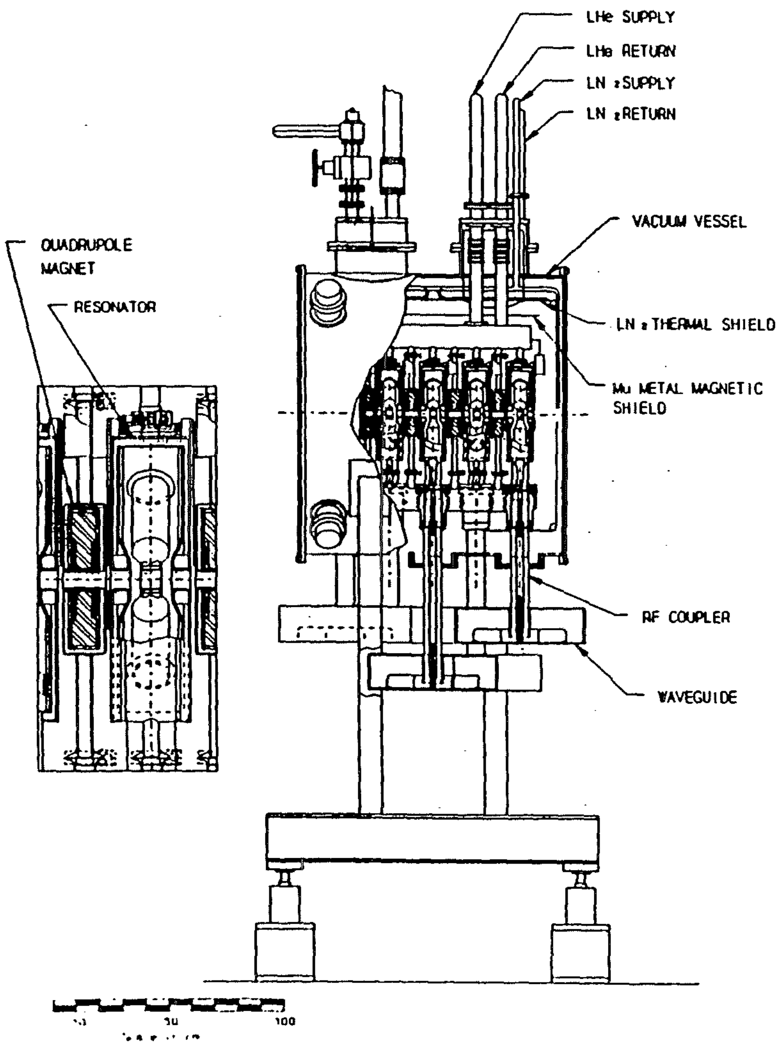
- 5 SPOKE RESONATORS AT 352 MHz
  2 0R 3 GAP
  10 MV/m AVERAGE GRADIENT INSIDE CAVITIES

- 4 SUPERCONDUCTING QUADRUPOLE FOCUSING MAGNETS

- INDEPENDENT OPERATION AND CONTROL OF ALL CAVITIES AND MAGNETS

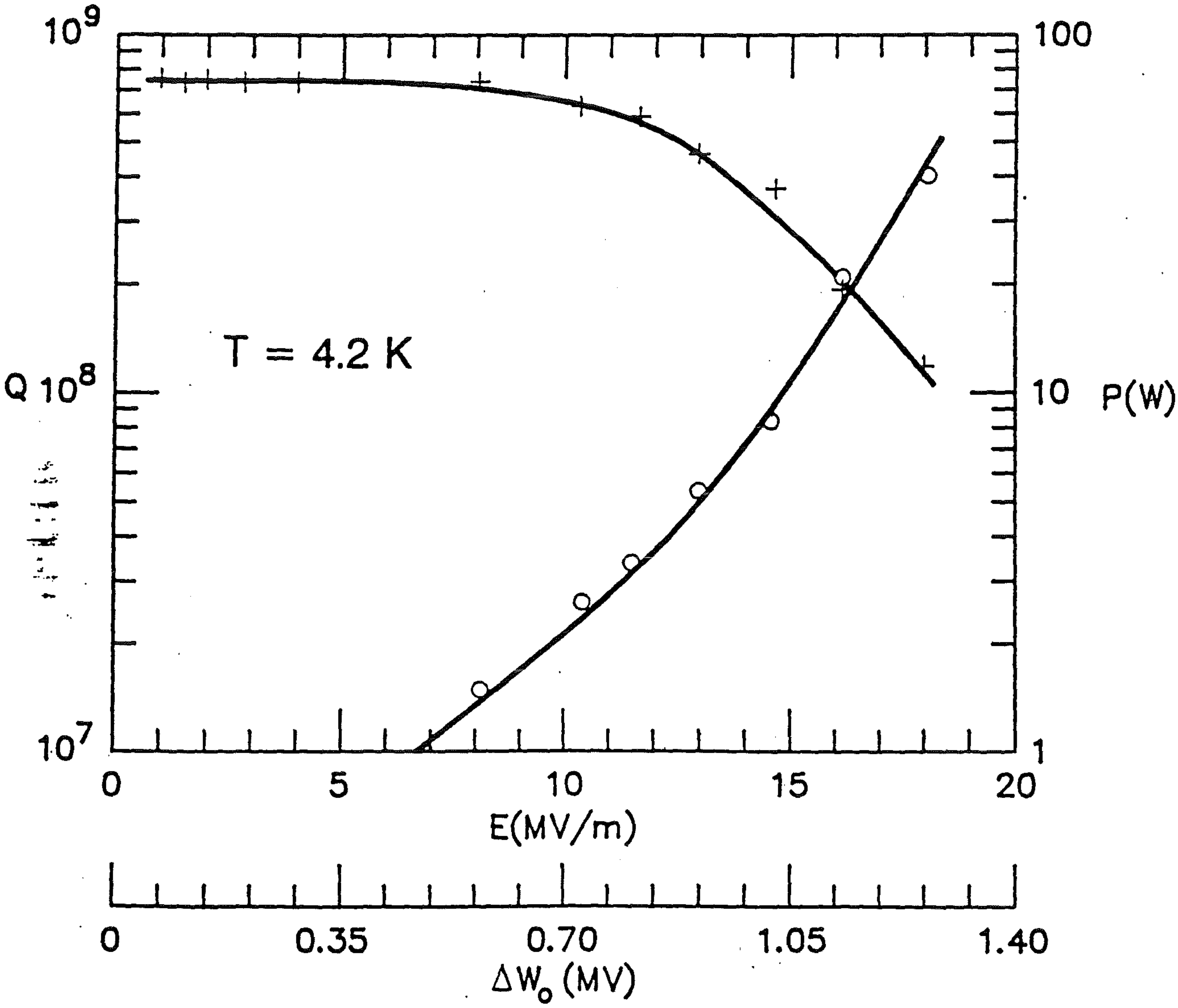
- PURPOSE:
  - DYNAMICS OF HIGH-CURRENT, HIGH-BRIGHTNESS IONS BEAMS
  - BEAM IMPINGEMENT
  - BEAM BREAKUP
  - STABILITY WITH RESPECT TO BEAM MODULATION AND NOISE
  - EFFECT OF POINT FAILURE OF COMPONENTS
  - EMITTANCE GROWTH
  - BEAM AND ACCELERATOR CONTROL SYSTEMS

DESIGN OF HIGH-CURRENT SUPERCONDUCTING SECTION



Q-CURVE FOR COAXIAL HALF-WAVE RESONATOR

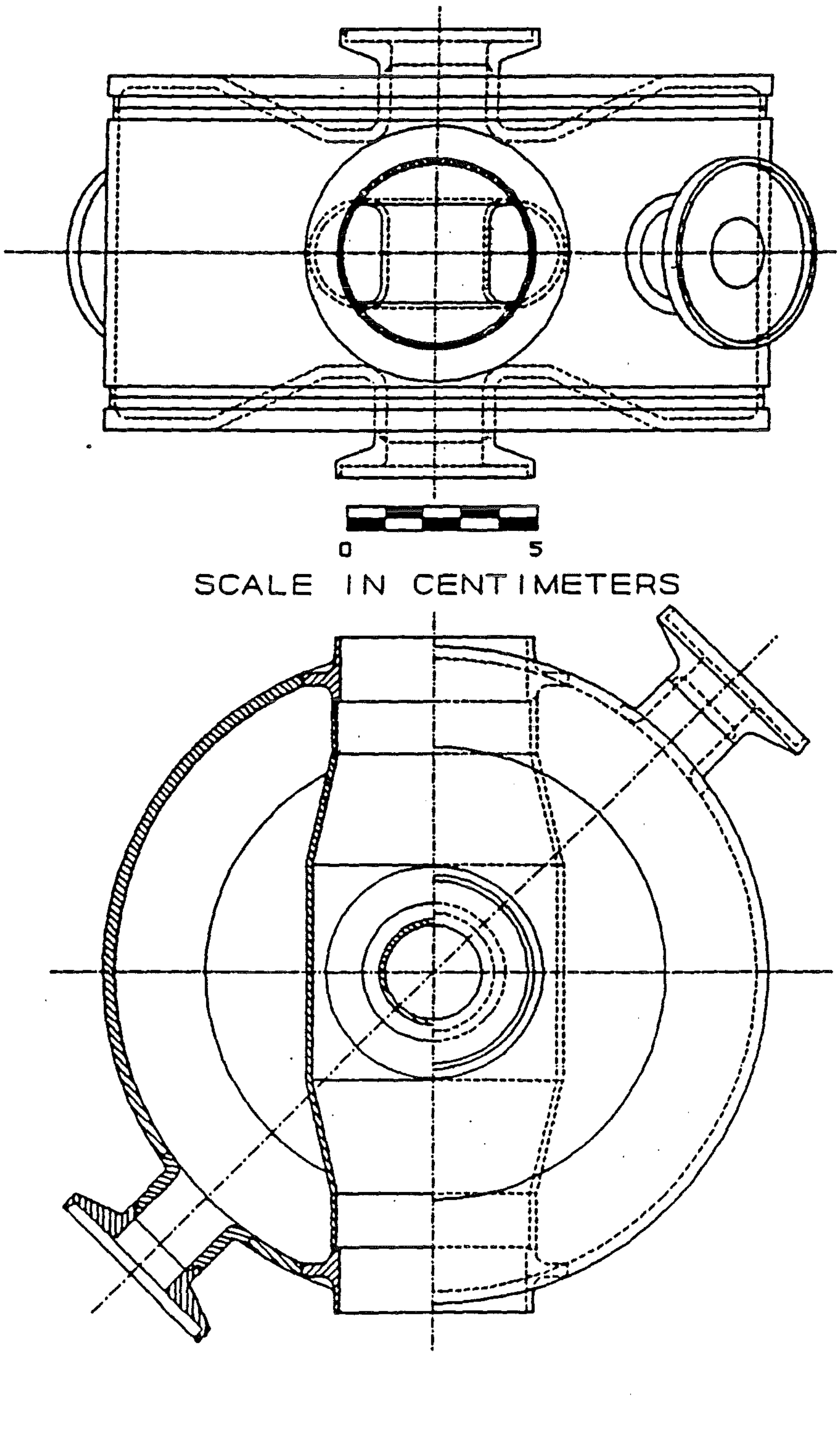
355 MHz, $\beta_o = 0.12$



03687

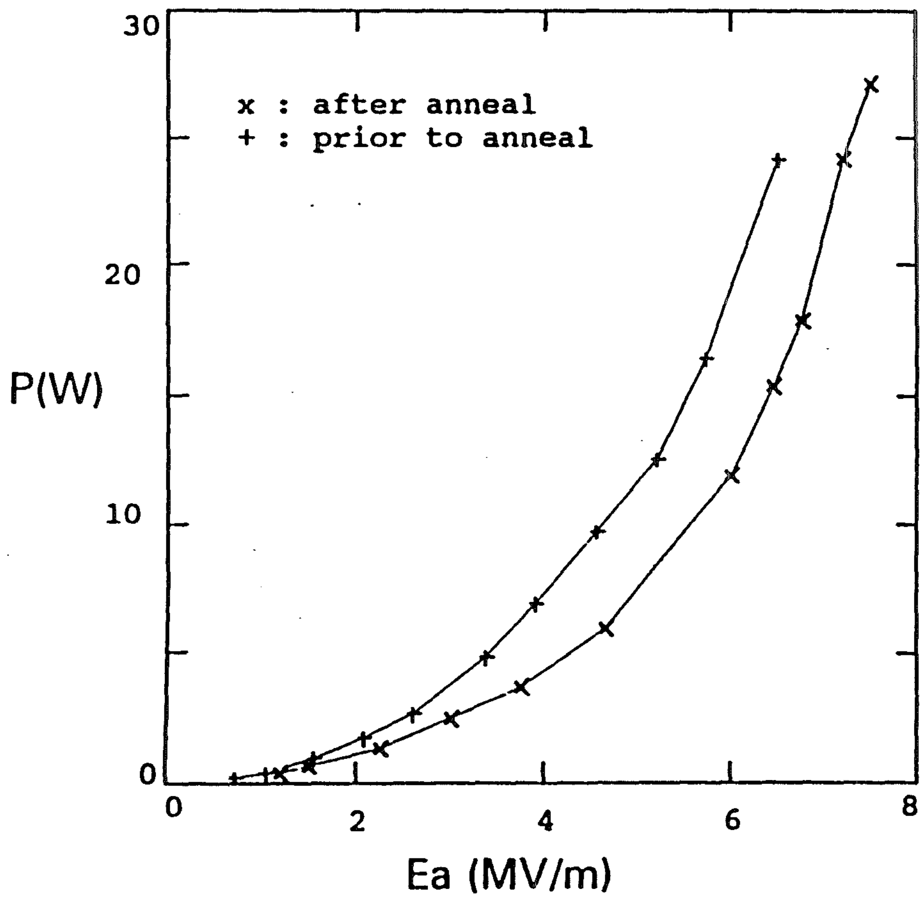
2-GAP SPOKE RESONATOR

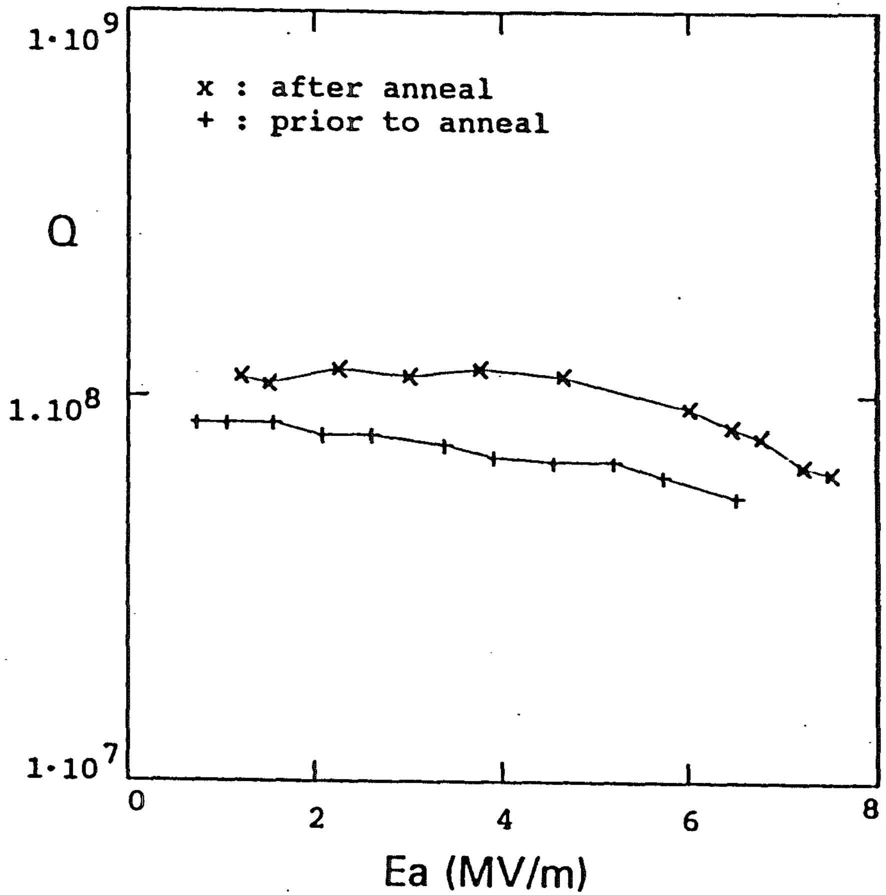
855 MHz, $\beta_o = 0.30$



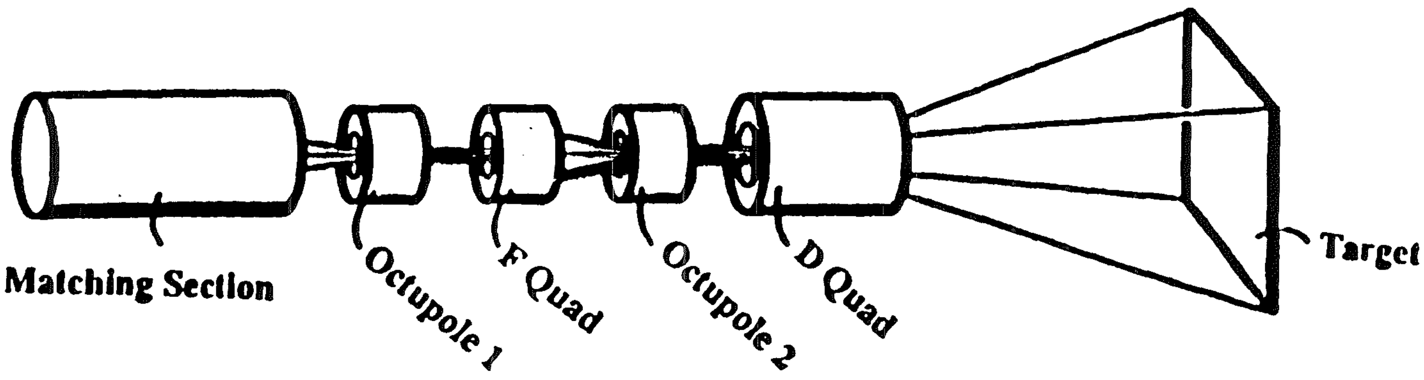
PERFORMANCE OF 855 MHz SPOKE RESONATOR

T = 4.2 K





2-Dimensional Nonlinear Expansion



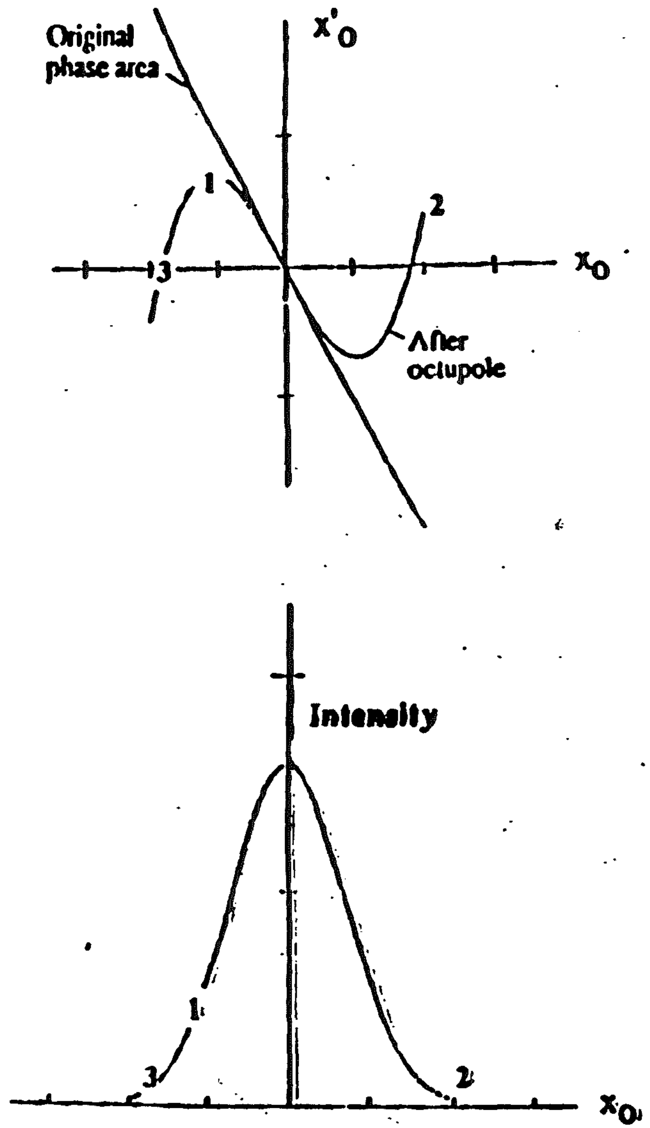
Beam on Target

- Has desired 4 x 2 m footprint
- Sharp intensity drop outside this area
- Beam intensity relatively uniform
- Some distributions produce corner spikes

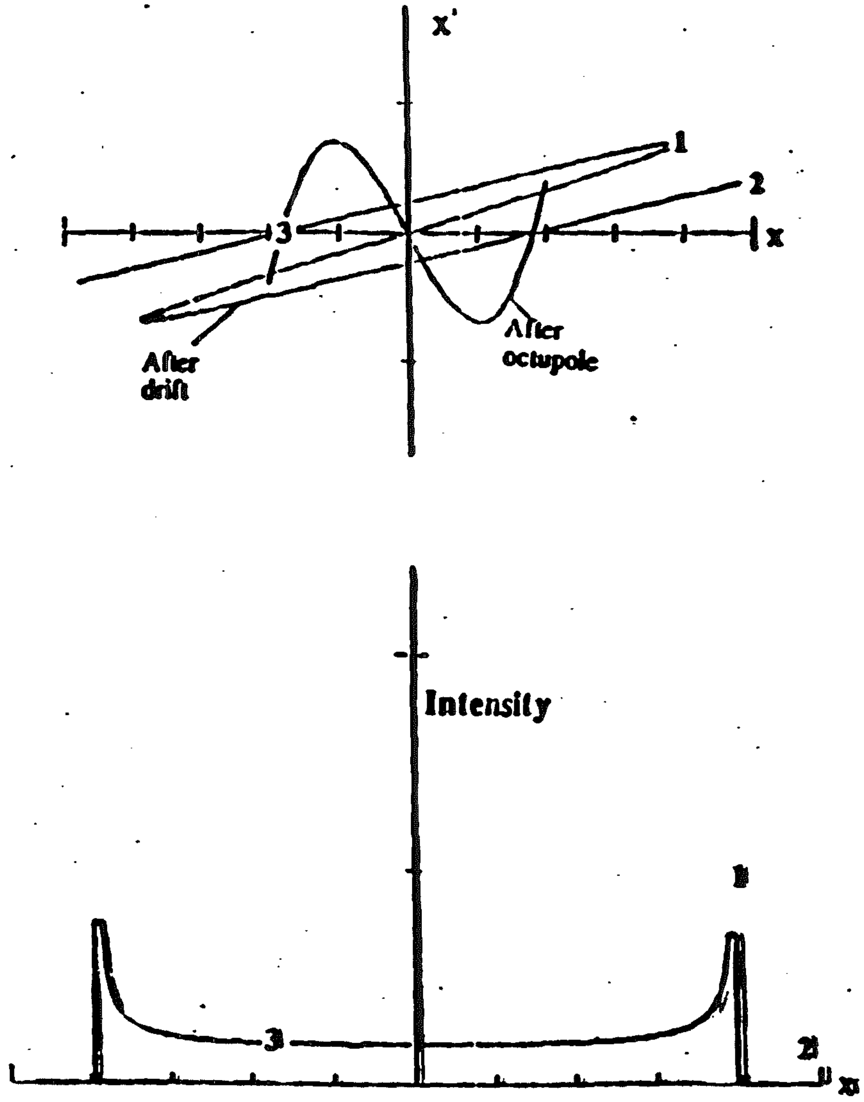
Expander System

- Magnets practical; poletip fields < 1.5 T
- Power requirements modest; < 2 MW
- Beam jitter control is important

One-Dimensional Calculation



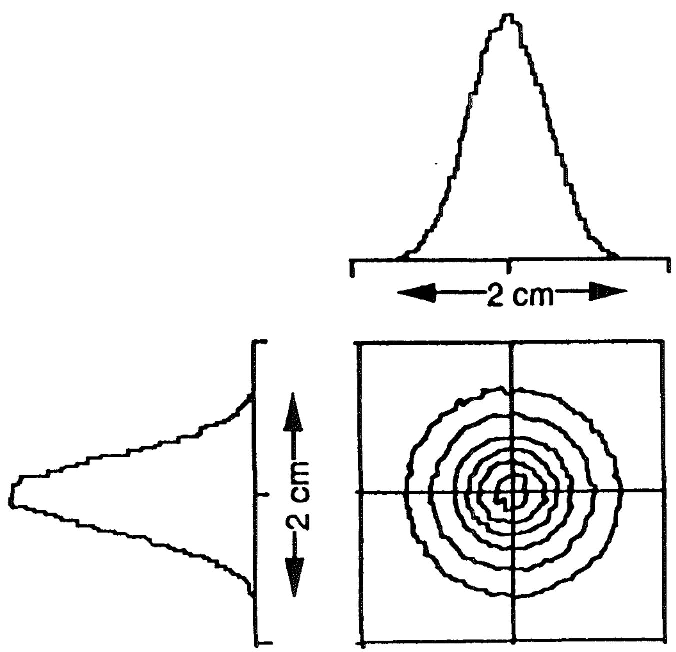
Before octupole



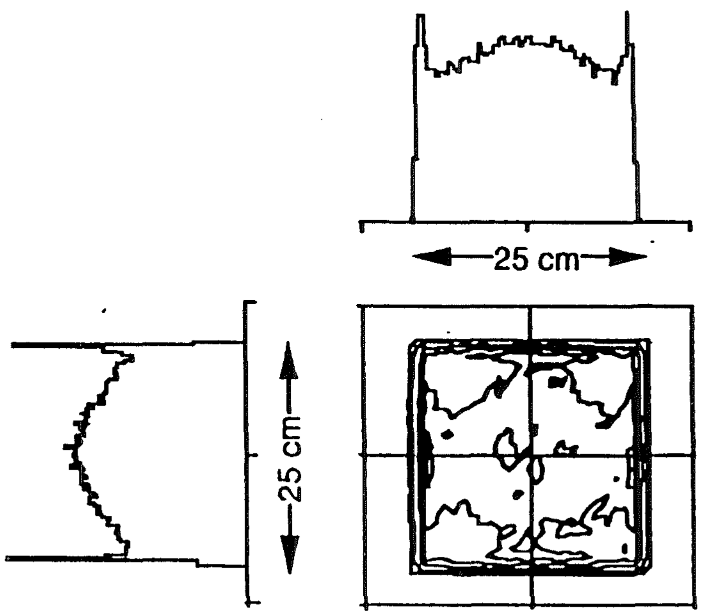
After drift

Non-Linear Beam Expander Transforms Gaussian Beam into Uniform Rectangular Distribution at ATW Target

At Entrance to Beam Expander



At Target Face



Los Alamos

INPUT BEAM TO HEBT

The input beam used to simulate the HEBT was the 10,000-particle output distribution of a PARMILA run for a superconducting IFMIF linac. The parameters of the beam at 35 MeV, given in the middle of the last quadrupole of the linac (a D-quad), are shown in Table I. At 20 MeV, the transverse lab emittances increase by 33%. With the remaining half D-quad and a 24.5-cm drift, the beam is extremely well matched into the achromatic bend.

Table I: Input Beam (rms, unnormalized, 35 MeV)
(Units: mm, mrad, keV, deg)

α_x=0	α_y=0	α_z=0
β_x=0.3845	β_y=1.4192	β_z=0.1496
ε_x=1.05π	ε_y=1.05π	ε_z=300π

PERFORMANCE AND SIMULATIONS

To simulate the ESNIT HEBT, we used the code PARMILA with the 10,000-particle distribution mentioned above. TRACE-3D and MARYLIE were both used for the design and fitting of the matching-section quadrupoles. Figures 2–5 show the beam-particle distributions on target in x,y space as well as horizontal and vertical profiles depicting the flatness of the distributions. The nominal tune has been achieved and is shown in Fig. 2. In Fig. 3, the current has been decreased from 100 mA to 50 mA with no adjustment of beamline elements. The flatness of the distribution is essentially maintained and appears to be insensitive to beam-current variations.

Comparing Figs. 2 and 4, one can see the difference in the distribution on target when there is a change in the beam energy from 35 MeV to 20 MeV. In this instance, all magnets are scaled by beam rigidity followed by optimization of the matching section. Although no simulations were performed outside of the 20–35 MeV range, it is clear the design is not limited to this range.

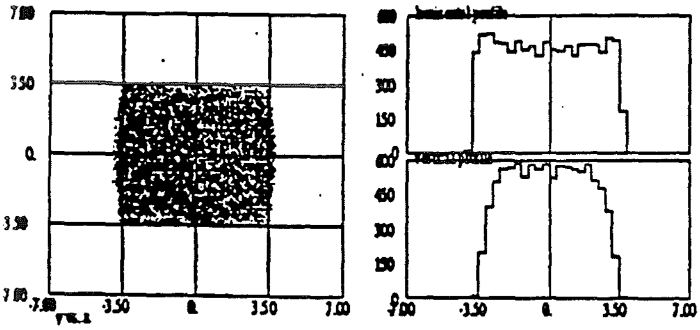


Fig. 2: 35 MeV, 100 mA, 7 cm x 7 cm, ±0.5 MeV

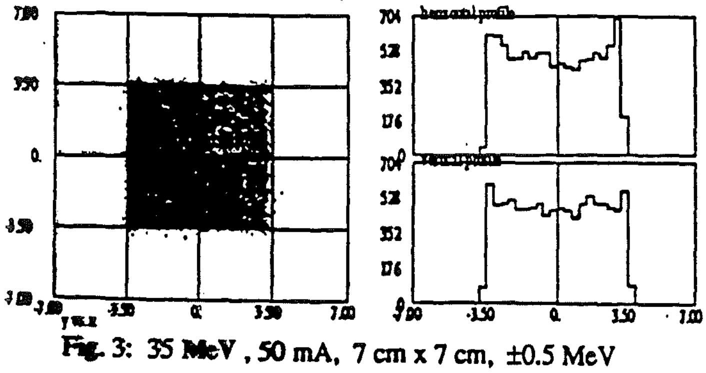


Fig. 3: 35 MeV, 50 mA, 7 cm x 7 cm, ±0.5 MeV

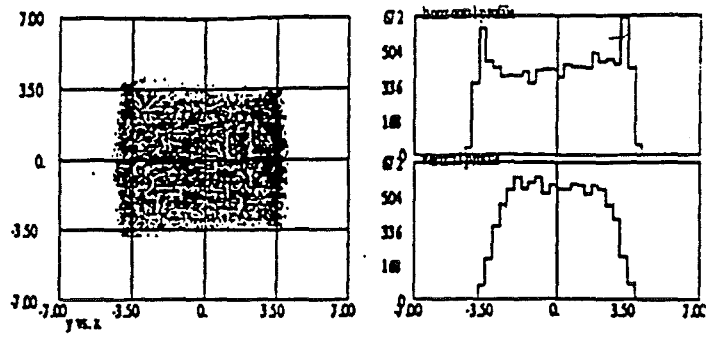


Fig. 4: 20 MeV, 100 mA, 7 cm x 7 cm, ±0.5 MeV

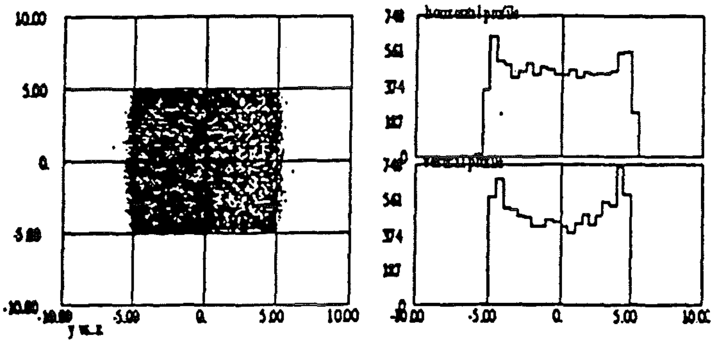


Fig. 5: 35 MeV, 100 mA, 10 cm x 10 cm, ±0.5 MeV

Finally, Figs. 2 and 5 illustrate the effect on the distribution uniformity when using the imager alone to adjust the spot size on target. Spot sizes of 5 cm x 5 cm, 7 cm x 7 cm, and 10 cm x 10 cm with uniform distribution were created on target.

Energy-Spread Variations. The final rf cavity increases the energy spread from ±0.25 MeV to ±0.5 MeV. It also produces a relatively flat distribution in energy spread in the x-plane (see Fig. 6a). The distribution exhibits a sharp peak on one end, resulting from a peak in the phase distribution of the beam out of the linac (which could be rephased). Figure 6b shows that the horizontal position is not correlated with the energy.

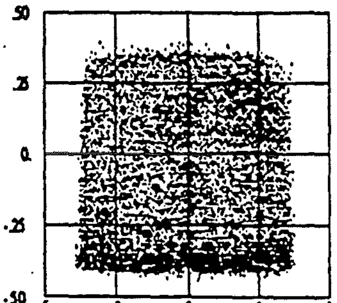


Fig. 6a: δE (MeV) vs. x (cm)

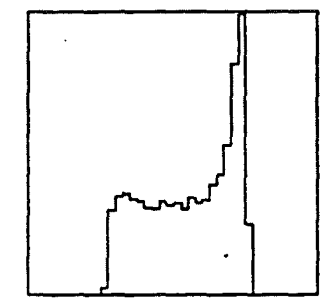


Fig. 6b: δE profile

APERTURE REQUIREMENTS

Beamline aperture is of concern because of the limitations in achieving the required field strength from large aperture multipole magnets. The beam is large in one plane in each octupole, and can get very large in the imager section depending on the beam spot size at the target. Figure 7 shows the beam envelope from the PARMILA simulation for 100%

Cost Estimate (1990 $M)

			250 mA	125 mA	500 mA
Accelerator					
Injector and LEBT	3.0				
RFQs					
Structures, vacuum, etc.	4.5				
RF Power ($2.0/W)	2.8				
Funnel & matching	3.5	13.8		–5.5	+8.4
Drift Tube Linac					
Structure, vacuum, etc.	24.0				
RF Power ($2.5/W)	28.5	52.5		–10.0	+38.1
High Energy Beam Transport					
Quads, dipoles, vacuum	5.0				
Nonlinear optics	0.8				
Energy disp. cavities	2.8				
Beam splitter	2.0				
Tuneup beam stop	1.0	11.6			–1.0
Beam Diagnostics					
Injector, LEBT, RFQ, funnel	1.5				
DTL	2.4				
HEBT	1.2	5.1		–0.5	+1.6
Controls (15% of above)		12.4		–2.4	+7.1
Accelerator Utilities					
Electric Power	2.5				
Water Cooling	2.5	5.0			+5.0
High Power Test Stand		5.0			
Beam Dynamics, Structures Dev.		3.0			
Installation (5% of equipment)		5.3		–1.0	+3.0
Total Accelerator		**113.7**		**94.3**	**175.9**
Balance of Plant		**100 - 200**			
Facility Total		**214 - 314**			

125 mA	1 accel. module (1 RFQ, no funnel, 1DTL); 2 beam lines
250 mA	1 accel. module (2 RFQs, funnel, 1 DTL, +RF); 2 beam lines
500 mA	2 accel. modules (4 RFQs, 2 funnels, 2 DTLs, +RF); 2 beam lines

Operating Cost Estimate
250 mA Facility

RF Power	12.4 MW	
AC Power for RF (e = 60%)	20.7 MW	
AC Power for BOP	6.0 MW	
AC Power Total	26.7 MW	
Annual Power Cost ($0.035/kWh, 7500 h/yr)		6.9 M$/yr
Operating Staff	50.0 FTE	
Annual Manpower Cost (170 K$/FTE)		8.5 M$/yr
Materials & Services		3.0 M$/yr
Target Servicing		1.5 M$/yr
Total Annual Operating Cost		19.9 M$/yr

FMIF R&D REQUIREMENTS — ACCELERATOR

OVERALL

- Prototyping

-- A RT accelerator design would be based on the FMIT work, which culminated in final construction drawings and prototyping of an injector, RFQ, RF system, and most of the components of the DTL and HEBT. Prototyping to 5-8 MeV would be prudent. The construction would be staged so engineering tests at full operational capability were performed in parallel on subsystems, and from the injector onward in the final installation, so that some iteration in critical components would be planned for, both in the schedule and as contingency costs.

-- A SC accelerator design has not been prototyped yet at the subsystem level for the intense beams needed for FMIF. Full-scale, integrated prototyping of the SC systems must be anticipated, including tests with beam, because there may be new effects stemming from residual beam losses, etc. that would affect a SC system differently than a RT system. Because the required development requires beam, the beam injection system must be built in order to do SC prototyping tests. A staged construction could again be planned, but the schedule and cost contingency would have to be considerably larger.

- Beam Loss Control

-- Detailed development of the beam-loss criteria and associated design, commissioning and operational procedures will require an on-going effort of several FTEs throughout the project.

FMIF R&D REQUIREMENTS — ACCELERATOR

INJECTORS

- Ion source prototype will be required
- Demonstrate delivery of output current with required emittance

RFQ

- A prototype should be built and tested with beam, for either RT or SC choice of technology. New design concepts will need to be tested for either.
- RF power feeds must be developed.
- The injector/RFQ interface introduces new complexities if the RFQ is SC, requiring full-scale tests.

BEAM FUNNEL

- The single one-sided funnel experiment to date indicated no rms emittance growth. However, the halo effects were not well characterized. This is a major transition point in the design; thus, if used, it should be prototyped along with the RFQ and DTL or ICL.

FMIF R&D REQUIREMENTS — ACCELERATOR

DRIFT TUBE LINAC (DTL or ICL)

- Full-scale prototyping to 5-8 MeV is necessary for a SC ICL, and would be prudent for a RT DTL. At minimum, a prototype module, including a transverse-focusing lattice element, instrumentation module, rf cavities, and associated peripherals, would be constructed and tested before placing orders for the full complement of modules.
- R&D may be required on the rf power feeds, depending on the rf amplifier sizing.
- R&D may be required on fabrication, measurement, and tuning methods for SC components. Considerable advantage is gained from techniques (e.g. beadpulls and quad alignment methods) developed in the SDI programs for cryogenic systems.

HIGH ENERY BEAM TRANSPORT (HEBT)

-

RF SYSTEM

- Tube development needed at lower rf frequency (nominal 175 MHz)
- Design of fault-recovery logic

INSTRUMENTATION

- R&D on necessary non-beam-interfering instruments in SC environment, including beam position, beam profile, emittance measurement, rf phase and amplitude tuning, beam current, radiation monitors, fast-protect system, personnel safety system.

Baseline Accelerator Concept for IFMIF
-JAERI Proposal-

M. Sugimoto

JAERI

Baseline accelerator concept for IFMIF
- JAERI proposal -

Masayoshi Sugimoto
Japan Atomic Energy Research Institute

IEA-Technical Workshop for an
International Fusion Materials Irradiation Facility

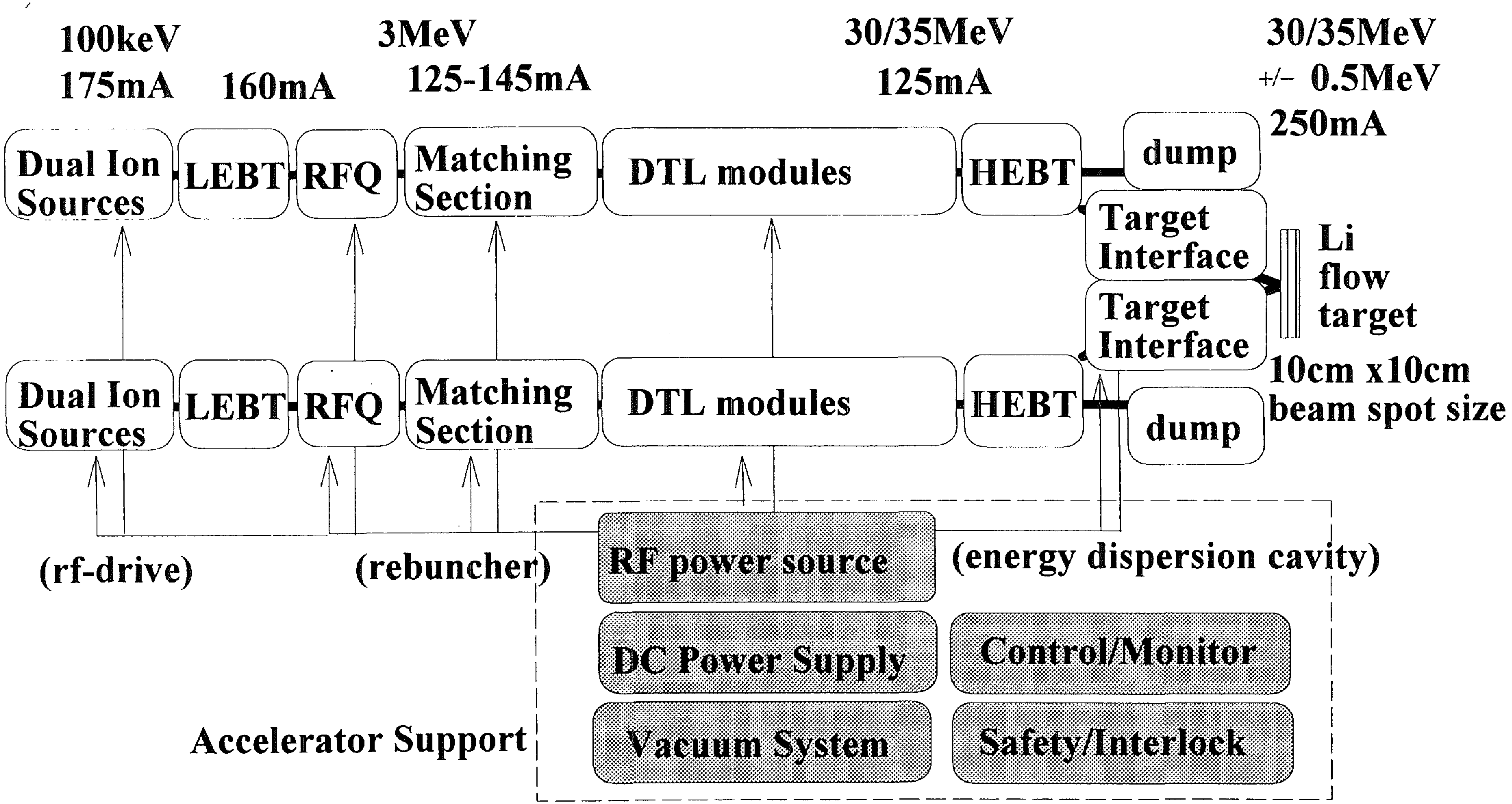
Karlsruhe, September 26-29, 1994

Design Approach:

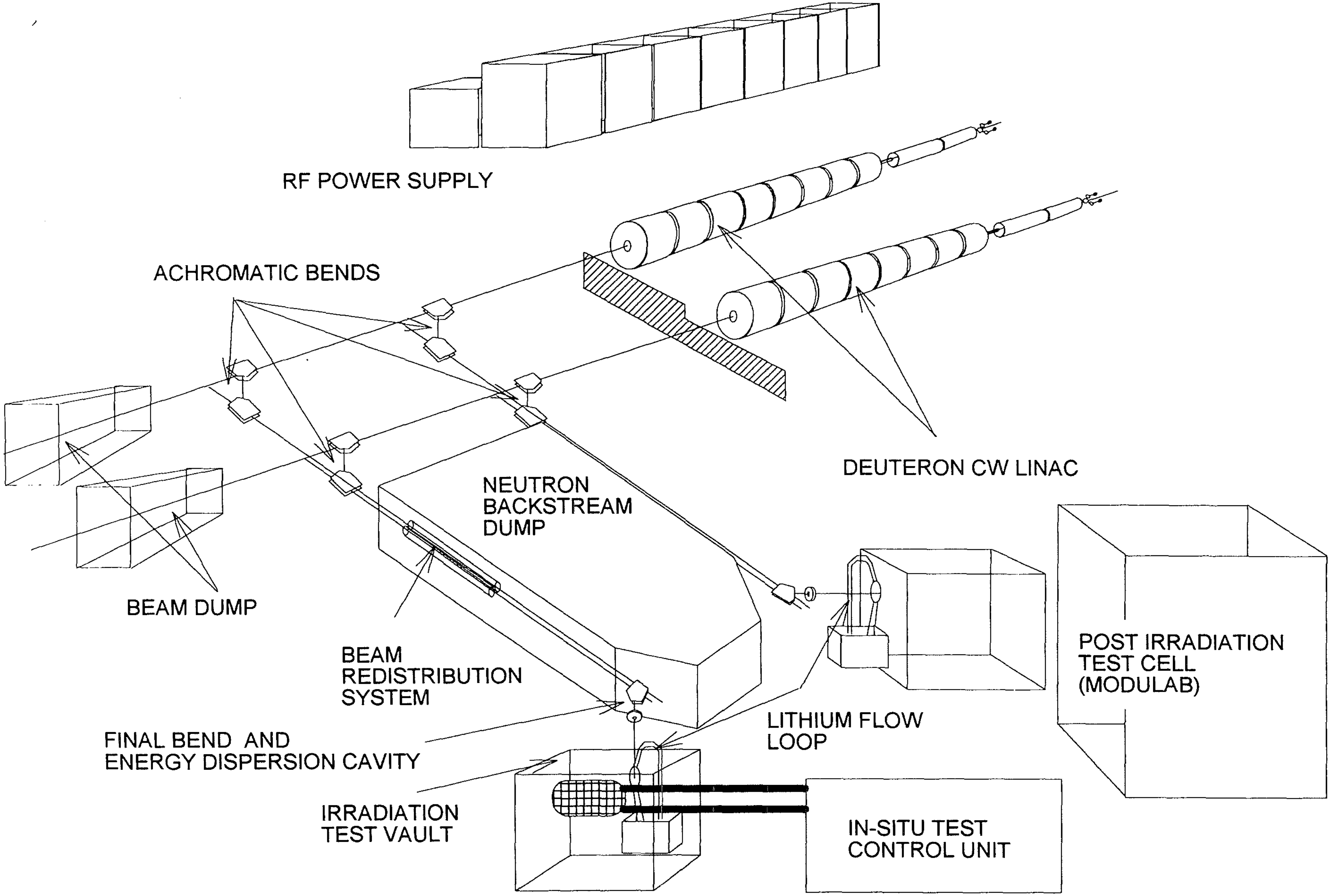
(1) Based on the currently available technologies
to avoid the time-consuming R&Ds

(2) Staged approach posing the intermediate milestones
to achieve the final specifications

(3) Top priority is the highest stability and availability



Layout of the Accelerator Subsystems



A conceptual view of IFMIF

Ion Source/Injector

Total current: > 175 mA dc = 125/0.9(atomic fraction)/0.8(overall transmission)
Transported current to RFQ: 145 - 160 mA

Extracted ions: D^+ , H_2^+

Atomic fraction: > 90 % (D^+ current > 160mA)

Emittance: < 1 π mm mr (full, normalized)

Extraction Volt.: 100 kV (lower limit 80 kV; upper limit 120 kV)

Plasma generator: Volume type with multicusp field (+ mirror field), rf-driven
(Plasma volume) / (Total loss area): as large as possible

Extractor: 2(or 3)-gap accel-deceleration electrodes
aperture diameter = electrodes distance = 14.1 mm (aspect ratio=0.5)

Number of sources per module: 2 (1 for back up)

Pulsing: long pulse (0.1 -1 msec), low duty mode (0.1 - 1 %)

Stability: better than 1 %

Injection line: focusing magnets (solenoid, quadrupole)
analyzing magnet, switching magnet
partial space charge neutralization is applied
beam diagnostics elements (current monitor, profile monitor)
focusing elements can be replaced by the electric potential lenses
(such as helical quads, einzel, or RFQ lens)

Specifications for single module of ion beam driver: (all figures are tentative ones and not optimized)

Pre Accelerator

RFQ — 4-vane, monolithic structure, q/m=1/2 (D^+ and H_2^+)

- Frequency: 120 MHz
- Duty factor: 100% (CW)
- Energy: input 0.1 MeV / output 3 MeV (or more),
- Current: input 145 - 160 mA / output 125 - 145 mA
- Transmission: > 90 %
- Peak surface field: 23.2 MV/m (1.9 x Kp)
- Dimensions: depend on the parameter optimization
  length 6 - 8 m, cavity diameter 0.5 m
- Required power also depends on the parameter optimization(wall loss)
  beam power 420 kW max

Matching section

- rebuncher
- magnetic quads
- beam diagnostics
- [funneling may be employed]

Specifications for single module of ion beam driver: (all figures are tentative ones and not optimized)

Main Accelerator

Frequency	120 MHz
Duty factor	100 % (CW)
Output	energies: around 30 and 35 MeV current: 125 mA
Accelerating Structure	Alvarez linac, Separated tank structure
Eacc,effective	1.5 MV/m
Focusing scheme	FODO with electro-magnets

RF source/components

Power source	120 MHz cw, 1.2 MW max/module for linac structure low power source required for ion source, rebuncher, and energy dispersion cavities
Transmission	Coaxial guide Circulator with dummy load
Control	phase < 1deg, amplitude < 1 %

Specifications for single module of ion beam driver: (all figures are tentative ones and not optimized)

High Energy Beam Transport

Target stations: 2

Transport line: 90-deg achromatic bends (2 branches)
Beam redistribution system using multipole fields
Final bend for target injection (and for avoiding the direct contamination of the sputtered lithium or the backstreaming neutron)
Opening angle between two beams within 20 deg

Beam dump: at the straight end of linac for beam tests/emergency

Beam Diagnostics/Control

Beam loss monitor
Nondestructive beam monitors: profile, current, position
Destructive beam monitors for beam tests/calibration
Neutron flux monitor
Accumurated radioactivity
Emergency interlock: beam loss, vacuum, component failure

Specifications for single module of ion beam driver: (all figures are tentative ones and not optimized)

FMIT Lithium Target Development and Application to IFMIF

J. A. Hassberger

LLNL

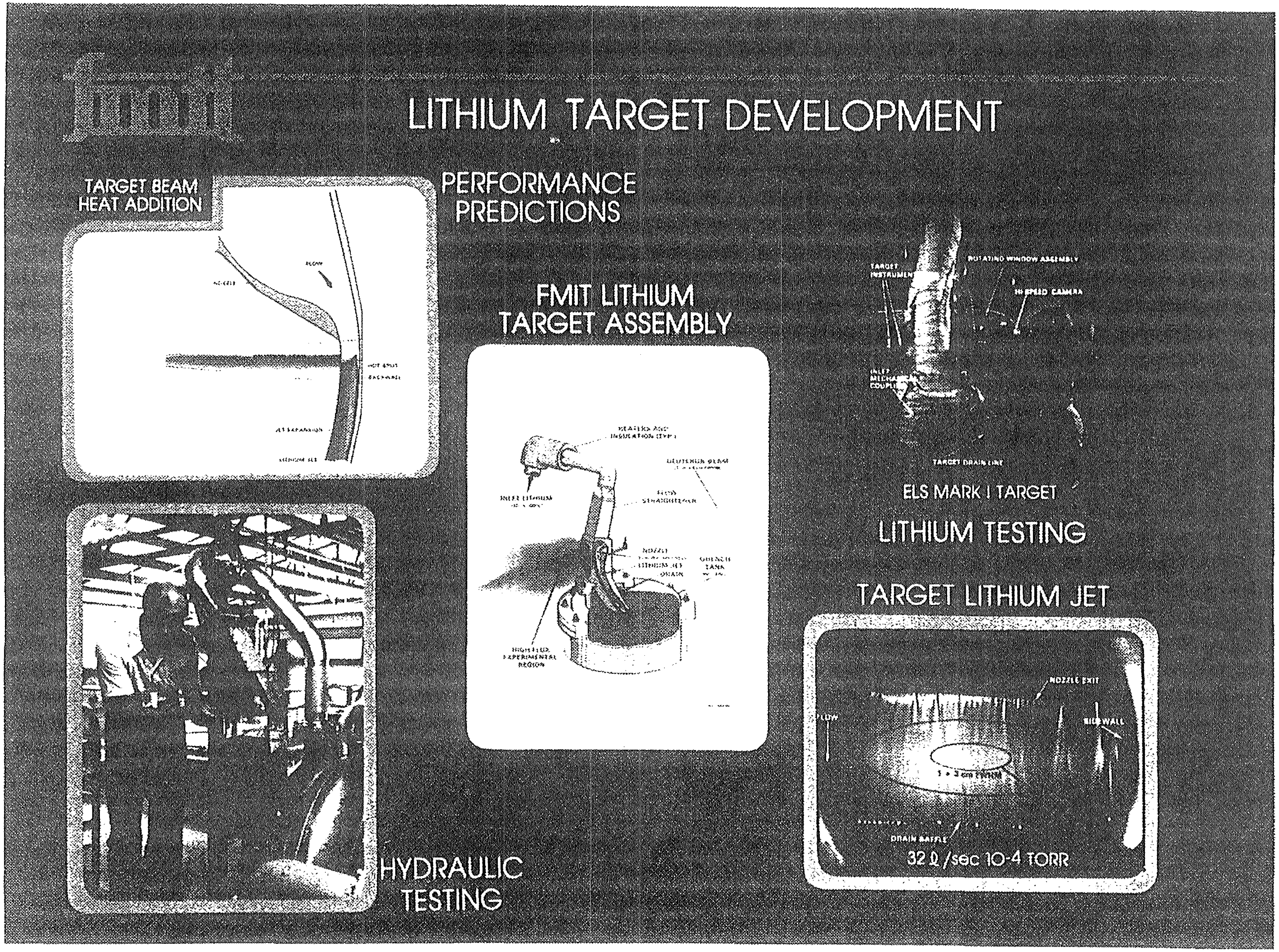
FMIT Lithium Target Development and Application to IFMIF

James A. Hassberger
Lawrence Livermore Natinonal Laboratory

Presented at
IEA - Technical Workshop for an
International Fusion Materials Irradiation Facility
Karlsruhe, September 26, 1994

Outline

- **Review of FMIT Target Development**
  - FMIT Target Design Philosophy
- **Target Interfaces**
- **FMIT/IFMIF Differences and Implications**


LITHIUM TARGET DEVELOPMENT
TARGET BEAM HEAT ADDITION
PERFORMANCE PREDICTIONS
FMIT LITHIUM TARGET ASSEMBLY
HYDRAULIC TESTING
ROTATING WINDOW ASSEMBLY
TARGET DRAIN LINE
ELS MARK I TARGET
LITHIUM TESTING
TARGET LITHIUM JET
NOZZLE EXIT
SIDEWALL
FLOW
DRAIN BAFFLE
32 ℓ/sec 10-4 TORR

FMIT Target Development Review

- Functional Criteria
- Target Design Philosophy
- Design Analysis
- Hydraulic Testing
- Lithium Testing

FMIT LITHIUM TARGET

THERMAL PERFORMANCE CRITERIA:

- PROHIBIT BOILING
  - HIGH VELOCITY
  - HIGH DEVELOPED PRESSURE
  - LOW IMPURITY BURDEN
  - MINIMIZE LOCAL HEATING

- MINIMIZE EVAPORATION
  - MINIMIZE EXPOSED SURFACE
  - HIGH VELOCITY
  - MINIMIZE LOCAL HEATING

HEDL 8005-270.11

FMIT LITHIUM TARGET

FUNCTIONAL REQUIREMENTS

- PROVIDE LITHIUM NUCLEI FOR NEUTRON PRODUCTION

  10^{15} NEUTRONS/SECOND IN 10 CC
  10^{14} NEUTRONS/SECOND IN 500 CC

- REMOVE BEAM HEAT

  3.5 MW
  CONTINUOUS
  2 MW/CC

HEDL 8005-270.2

FMIT LITHIUM TARGET

THERMAL PERFORMANCE CRITERIA:

- **PROHIBIT BOILING**
  - HIGH VELOCITY
  - HIGH DEVELOPED PRESSURE
  - LOW IMPURITY BURDEN
  - MINIMIZE LOCAL HEATING

- **MINIMIZE EVAPORATION**
  - MINIMIZE EXPOSED SURFACE
  - HIGH VELOCITY
  - MINIMIZE LOCAL HEATING

HEDL 8005-270.11

FMIT LITHIUM TARGET

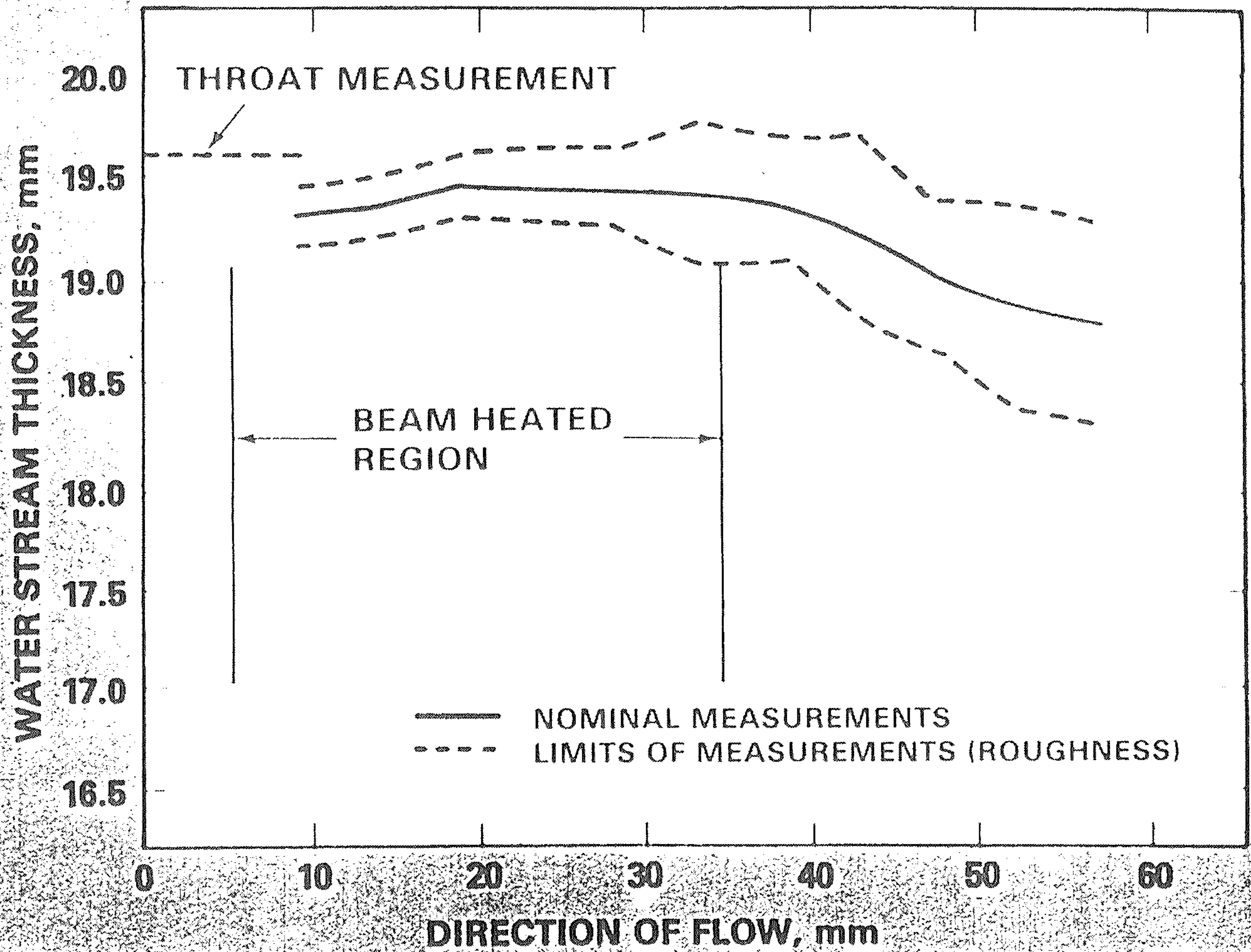
HYDRAULIC PERFORMANCE CRITERIA

- **SUFFICIENTLY THICK TO ABSORB THE BEAM**
  - DEUTERON PENETRATION CHARACTERISTICS
  - BOUNDARY LAYER DEVELOPMENT
  - JET THICKNESS DEVELOPMENT
  - SURFACE CONDITION
  - LITHIUM DENSITY DISTRIBUTION

- **SUFFICIENTLY THIN TO MAXIMIZE NEUTRON FLUX**
  - NEUTRON PRODUCTION CHARACTERISTICS

HEDL 8005-270.26

ULTRASONIC ELS JET PROFILE MEASUREMENTS
DOWN JET CENTERLINE



HEDL 8105-109.73

FMIT LITHIUM TARGET

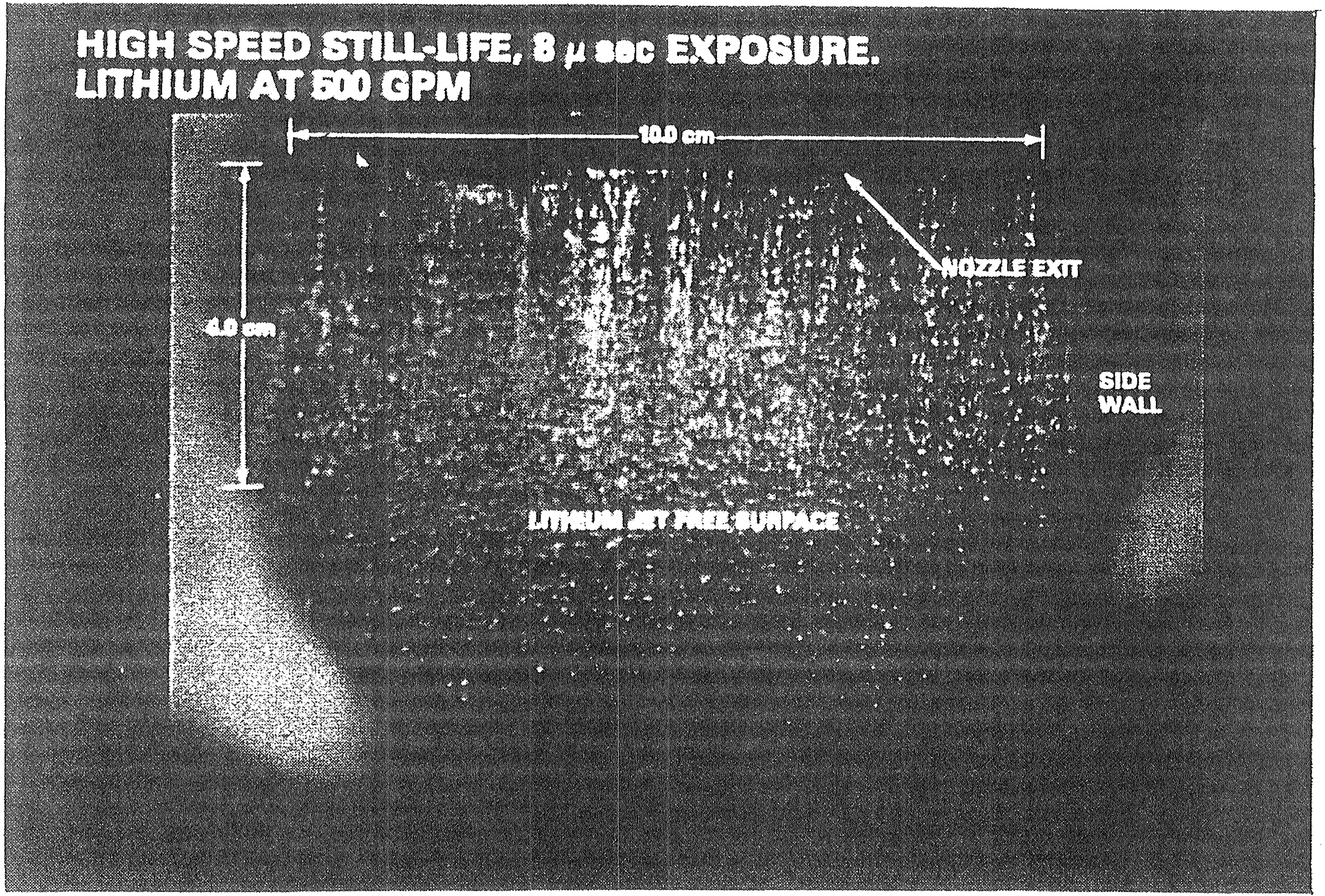
JET STABILITY PERFORMANCE CRITERIA

CONTINUOUS FILM
- PROHIBIT BOILING
- PROHIBIT VOIDING
- MITIGATE BUBBLE TRANSPORT

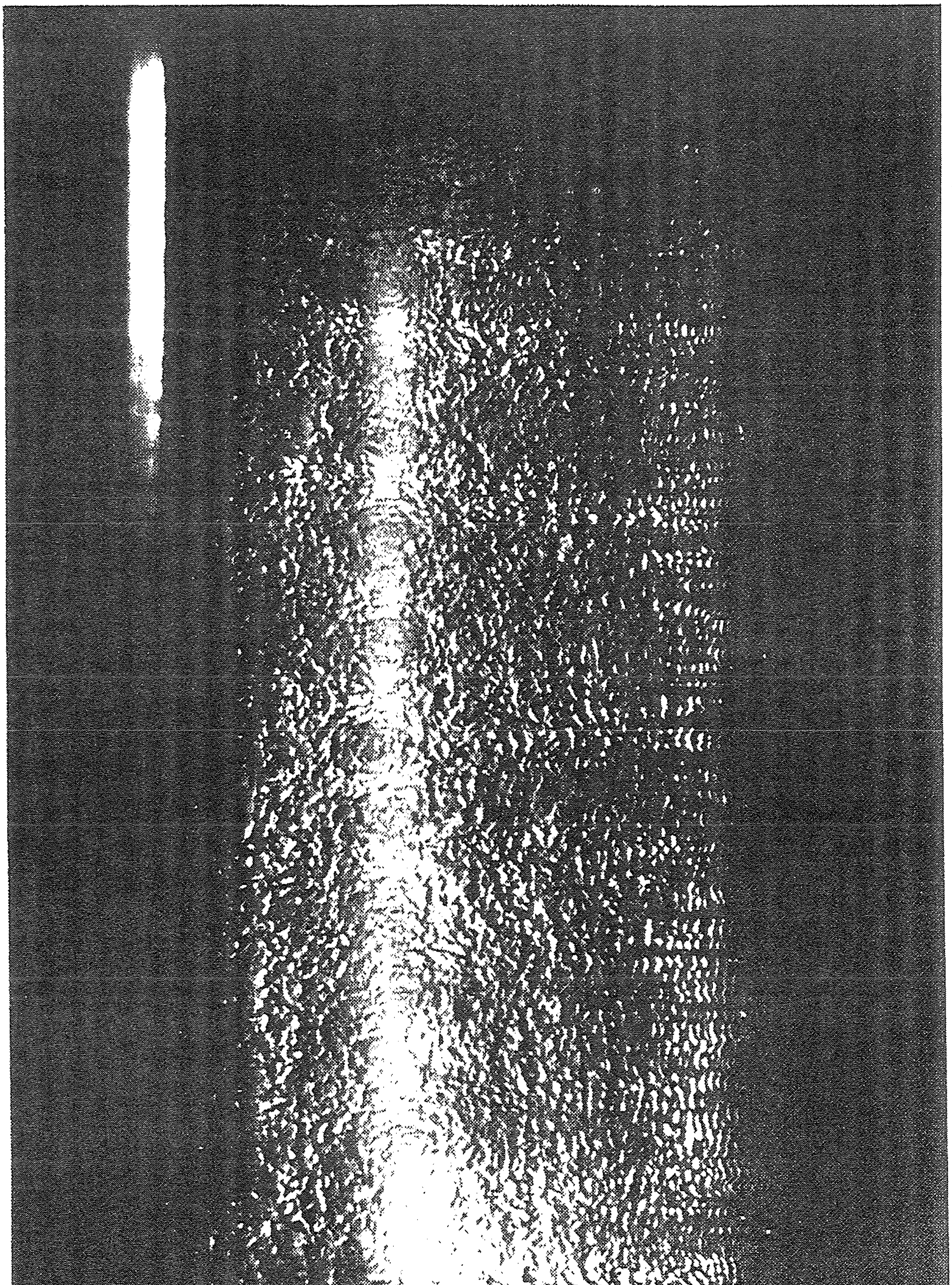
- GRAVITY DRAIN
  - PROHIBIT CHOKING
  - MINIMIZE PRESSURE DROP
  - ISOLATE DRAIN REGION

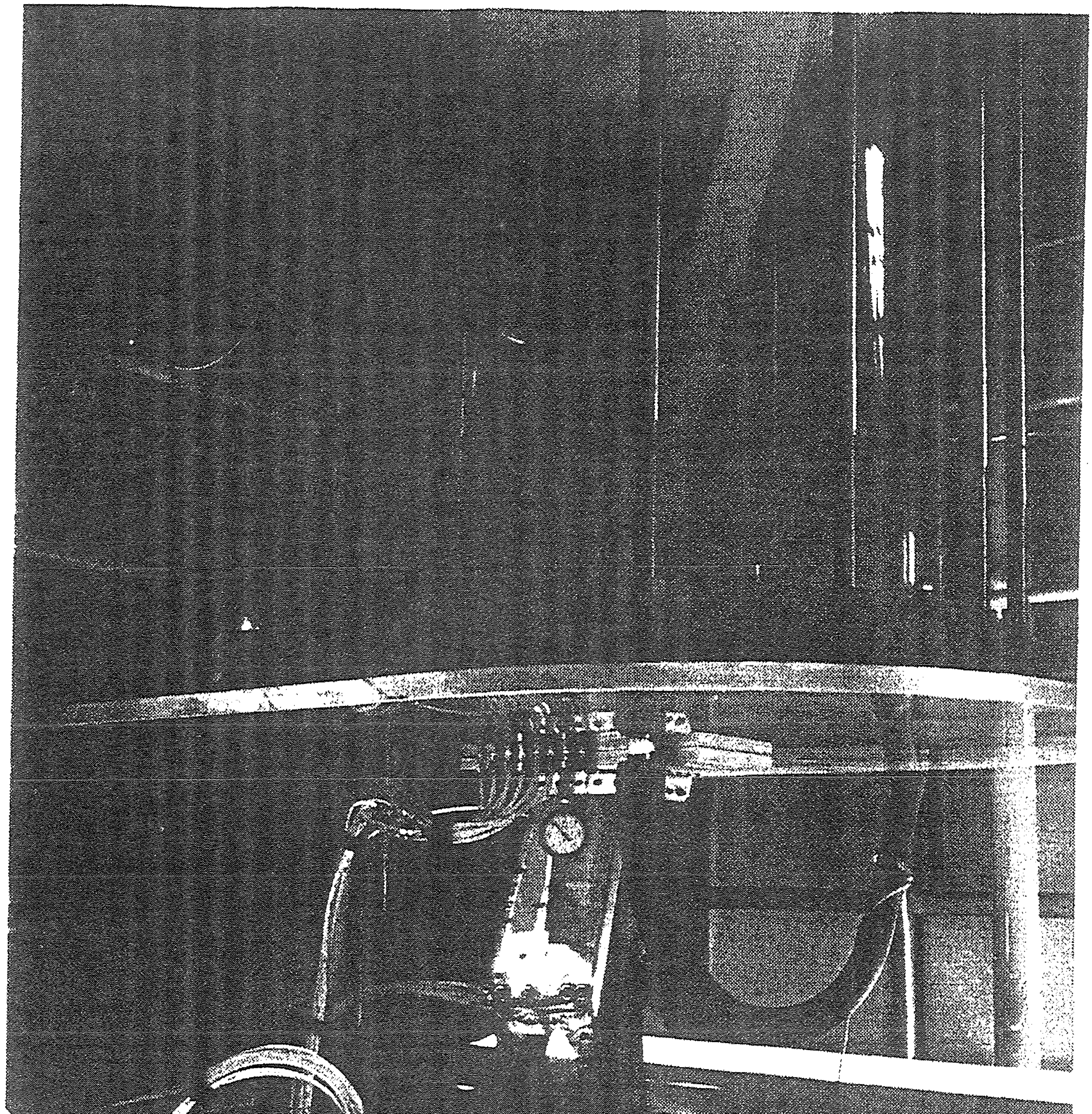
- MINIMIZE Li TRANSPORT TO BEAM
  - MINIMIZE DRAIN SPLASHING
  - MINIMIZE DROPLET FORMATION
  - MAINTAIN SURFACE STABILITY
  - MINIMIZE EVAPORATION

HEDL 8006-270.10



HIGH SPEED STILL-LIFE, 8 μ sec EXPOSURE.
LITHIUM AT 500 GPM
10.0 cm
4.0 cm
NOZZLE EXIT
SIDE WALL
LITHIUM JET FREE SURFACE





FMIT LITHIUM TARGET

STRUCTURAL CRITERIA

9 MONTH DESIGN LIFE

- IRRADIATION DAMAGE
- STRESS
- THERMAL

INTERFACE WITH PLANT AND EXPERIMENTAL SYSTEMS

- ACCELERATOR INTERFACE
- LITHIUM SYSTEM INTERFACE
- REMOTELY HANDLED
- TEST ASSEMBLY INTERFACES

HEDL 8005-270.12

FMIT LITHIUM TARGET

TRANSIENT PERFORMANCE CRITERIA:

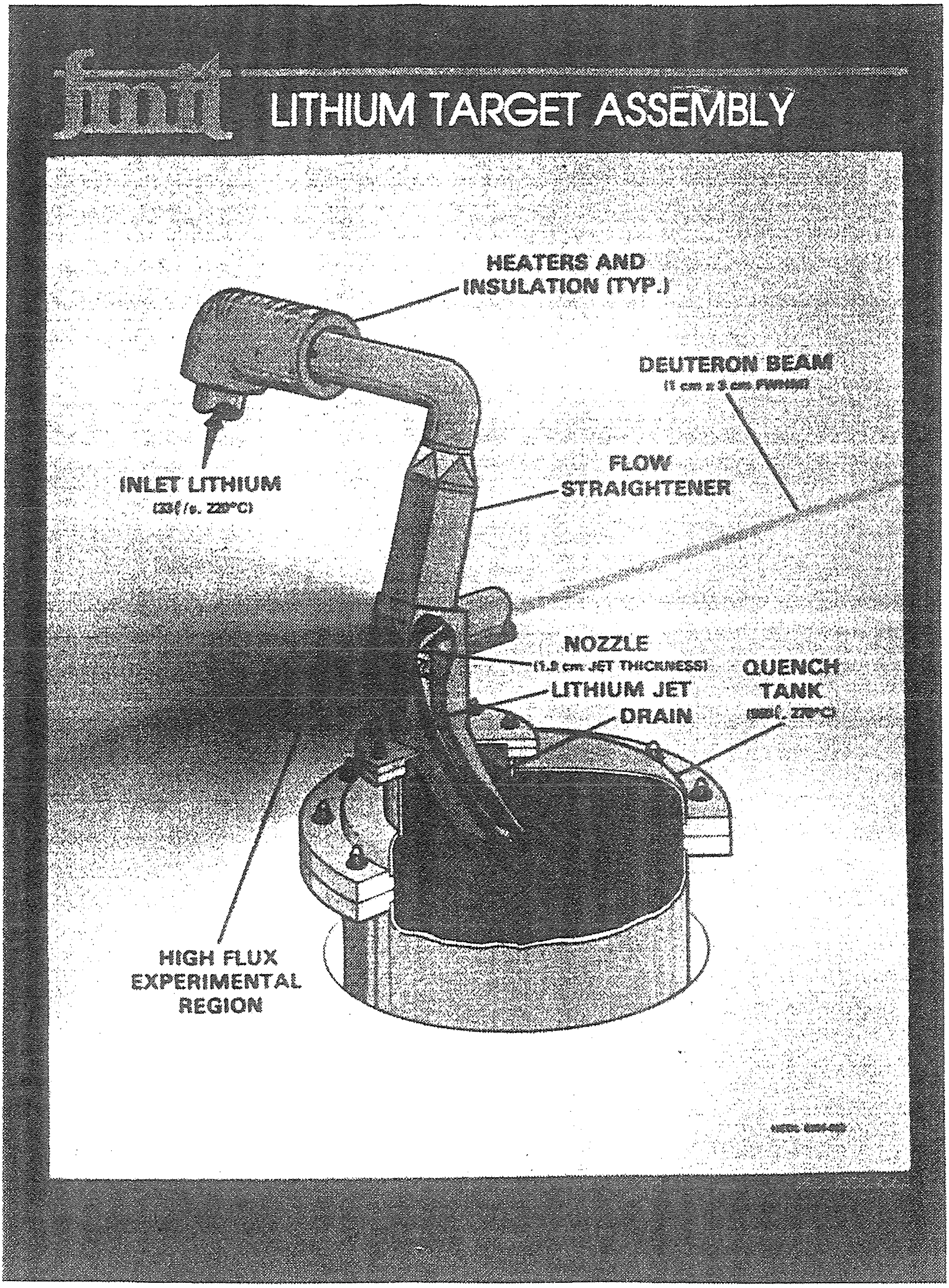
ACCOMMODATE RAPID TRANSIENTS

- BEAM EVENTS
- LITHIUM SYSTEM EVENTS
- STARTUP
- SHUTDOWN
- BUBBLE TRANSPORT
- PARTICULATE TRANSPORT

MITIGATE CONSEQUENCES OF MORE SEVERE EVENTS

- BEAM EVENTS
- LOSS OF FLOW
- TARGET FAILURES

HEDL 8006-270.3


LITHIUM TARGET ASSEMBLY
HEATERS AND INSULATION (TYP.)
DEUTERON BEAM
INLET LITHIUM
FLOW STRAIGHTENER
NOZZLE
(1.8 cm JET THICKNESS)
LITHIUM JET
DRAIN
QUENCH TANK
HIGH FLUX EXPERIMENTAL REGION

FMIT Target Design Philosophy

- Primary emphasis on "Understanding" target response
  - Based on simple analytic models
  - Supported by various numerical analyses
  - Confirmed by comprehensive hydraulic and lithium testing
- Defined degree of conservatism in design
  - "Boiling Margin" explicitly accounts for design uncertainties and errors
- Acknowledged potential for subsequent improvements

FMIT Hydraulic Testing

- 5 models tested
  - Straight-wall model
  - Curved wall hydraulic prototype
  - ELS Mark-I target
  - Asymmetric nozzle hydraulic prototype
  - ELS Mark-II target

FMIT/IFMIF Differences

- **Beam current**
  - Higher total current
  - Wider beam
  - Flat beam
  - Taller beam
- **Beam Energy**
  - Gaussian vs dual-peaked

Impact of Increased Beam Current

- **Little impact of increased beam current, Provided:**
  - Integrated (streamline) current <= FMIT (temperature limits)
  - Current (streamline) gradient <= FMIT (Pressure pulse)
- **Taller beam increases free-surface concerns**
  - Surface roughness grows with increased stream distance
  - May need to increase wall radius, may result in greater surface roughness
- **Taller x Wider beam increases surface evaporation**

Recommendations

- Special emphasis on surface stability with taller jet
- Geometric tailoring of backwall profile

Baseline Concept for the D-Li Target System in ESNIT

Y. Kato

JAERI

Baseline Concept for the D-Li Target System in ESNIT

Y. KATO
JAERI

IEA Technical Workshop on Planning IFMIF-CDA
Sept. 26-29, 1994
Karlsruhe, Germany

Main Frame Work in Preliminary Design Study of ESNIT Target System

I. Evaluation of Thermal and Fluid Dynamics of Li Target Flow.

- Under the requirement of deuteron beam energy selective(20-40 MeV, 50mA), the conditions of no boiling and stable flow are evaluated.
- As the option, some basic experiments by water have been done for no-backwall type system.

II. Preliminary Design of Lithium Circulation System.

- Over all system design for the primary loop, purification control system, intermediate cooling system and each component design have been made and the critical issues and engineering study issues were clarified.

Contents of the Main Flame Work

I. Thermal and Fluid Dynamics of Target Li Flow

-Boiling margin in the target Li flow were evaluated under the following parameters:

a) Deuteron beam energy(mono- and non-mono energetic) and beam profiles*

b) Li velocity

c) Backwall curvature.

-For the no backwall type free surface flow, the conditions of smooth flow down (no choking) were evaluated by water experiment (Osaka Univ.).

*** Beam conditions**

Beam intensity profile: **a) one dimensional Gaussian**

σ =10mm

beam area :30 x 30mm

peak current density= 15.7 mA/cm2

b) cylindrical uniform

diameter= 20mm

current density= 15.9 mA/cm2

Energy dispersion(non-mono energetic)

σ = 0.5 MeV

II. Li Circulation System

-Design Specification of primary loop, Li purification loop, intermediate loop and Components have been done(preliminary).

-In the Li purification loop, one cold trap and two hot traps are considered for trapping the impurity elements H(D,T), O, N and 7Be.

-To make constant temperature at the nozzle outlet(220℃) for each selected beam power(20-40MeV), the optimum design of intermediate cooling system was evaluated.

CONCLUSION

I. Thermal and Fluid Dynamics of Li Target Flow

a) Enough boiling margin is obtained at the peak temperature point in the Li flow.

b) Larger the beam energy, smaller the peak temperature in the Li flow..

c) Smaller the beam energy, larger the Li surface temperature.

In the simple estimation, boiling margin becomes negative at the free surface for the practical flow rate but still the boiling will not occur because of the effect of surface tension of Li.

d) Surface stability and boiling phenomena of the target flow can only be confirmed by the experiment.

II Design of Lithium Circulation System

If the selection of the structural and components materials including target backwall are adequate, there seems to be not so much difficulty in engineering design. Therefore, the planning of engineering feasibility tests and estimation of the safety counterplans will be the main issues of next phase.

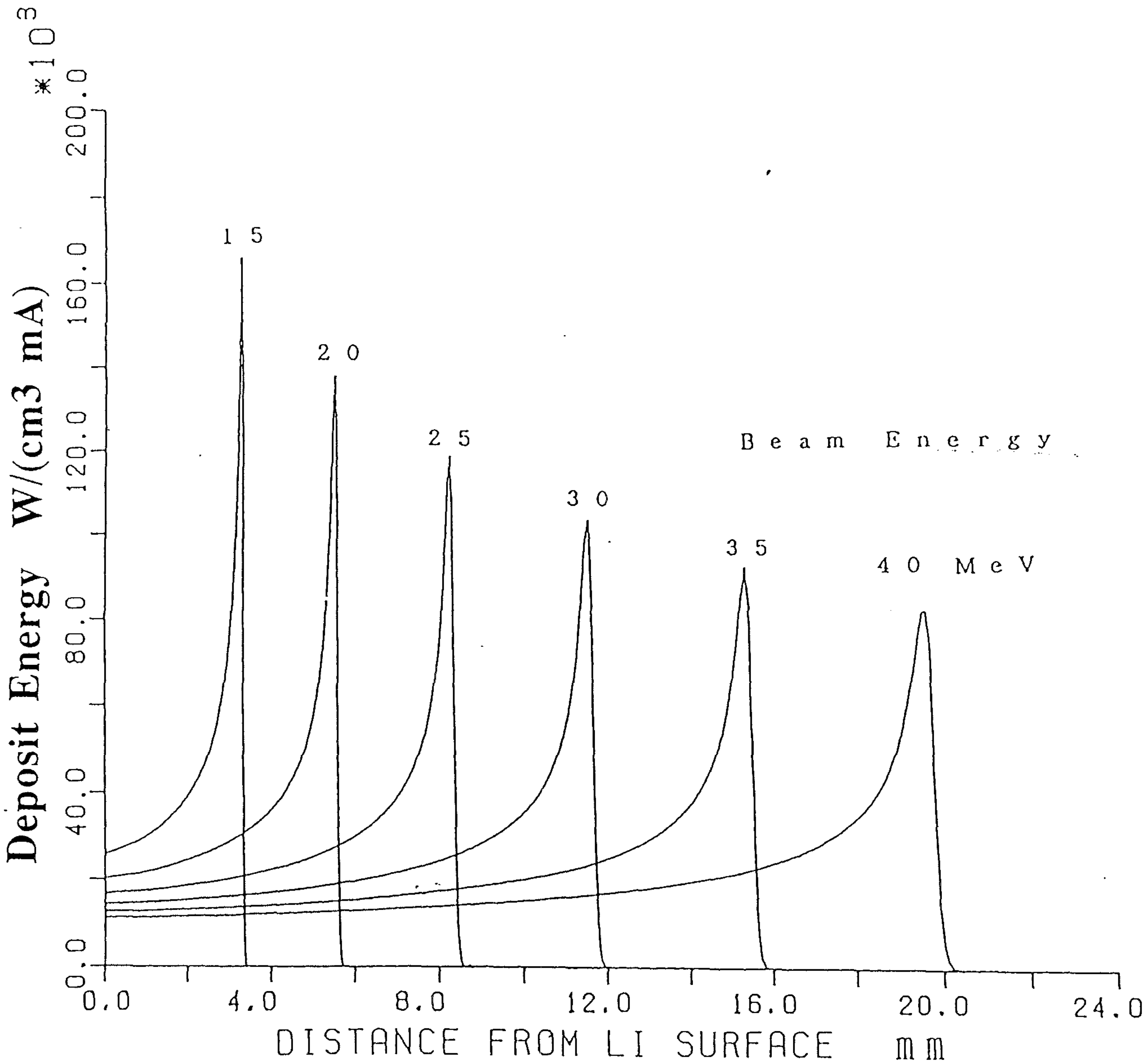


Fig. **Deposit Energy** (Mono energetic)

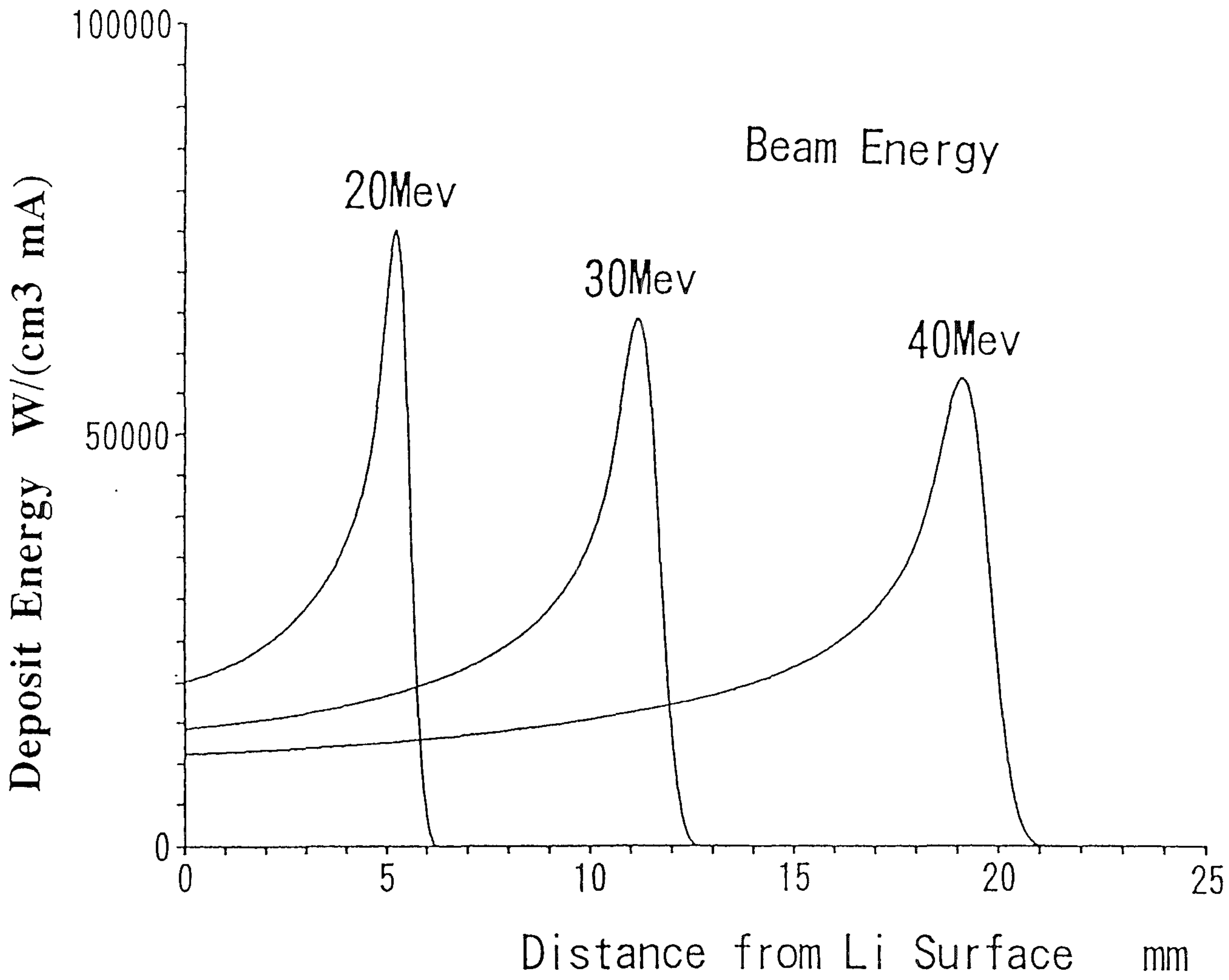


Fig. **Deposit Energy** (non-mono)

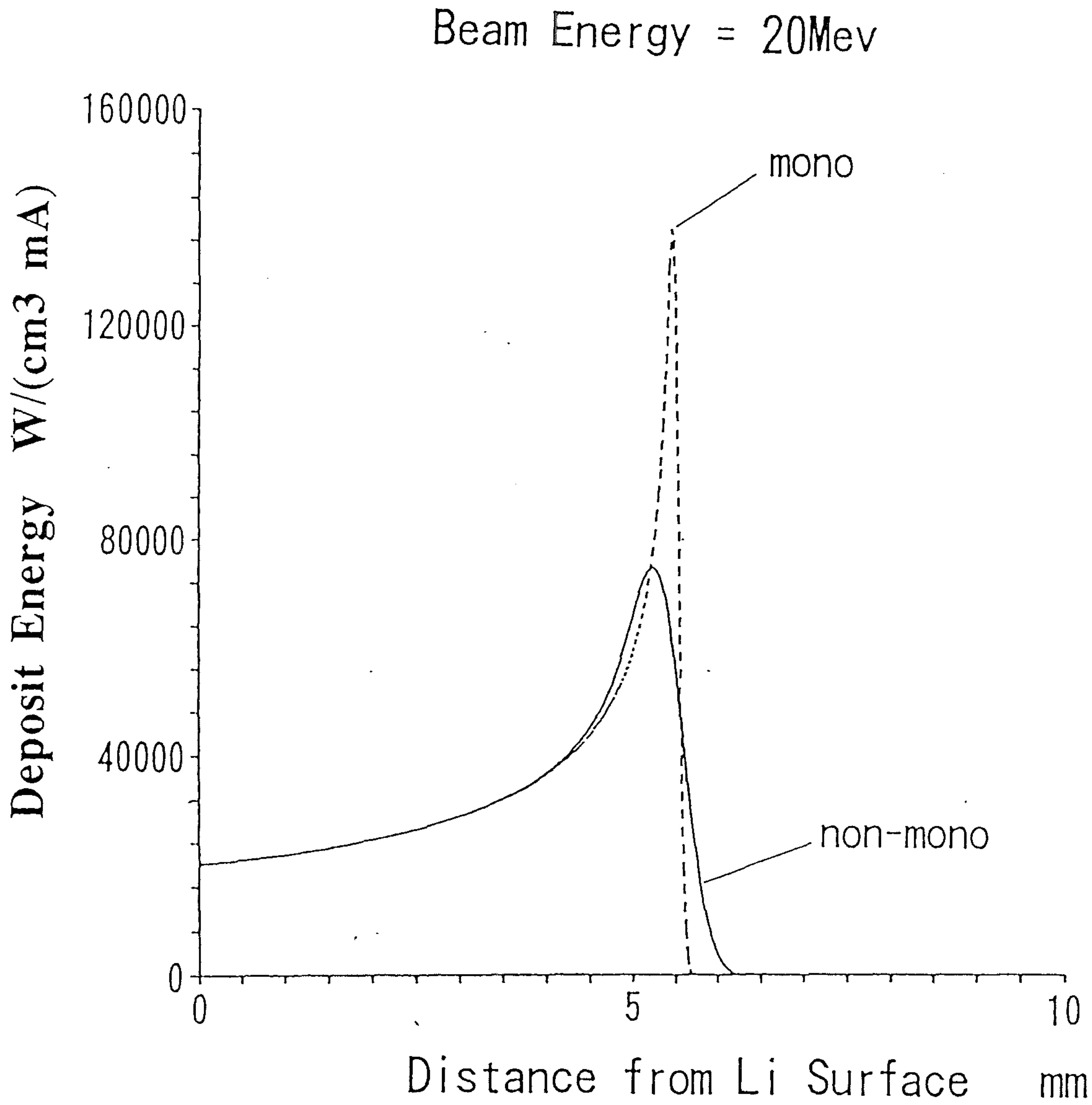


Fig. **Deposit Energy**

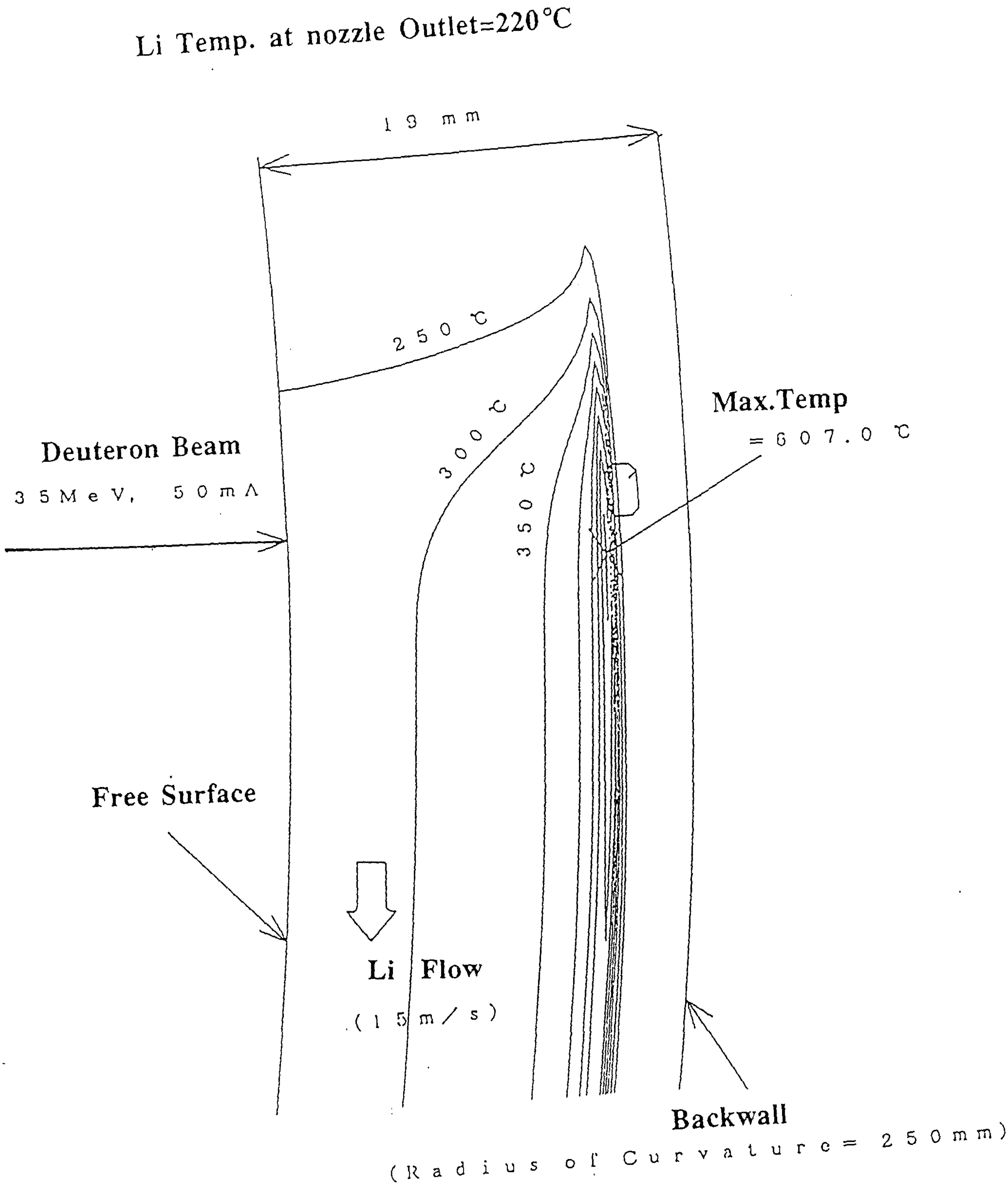


Fig. Temp. Distribution

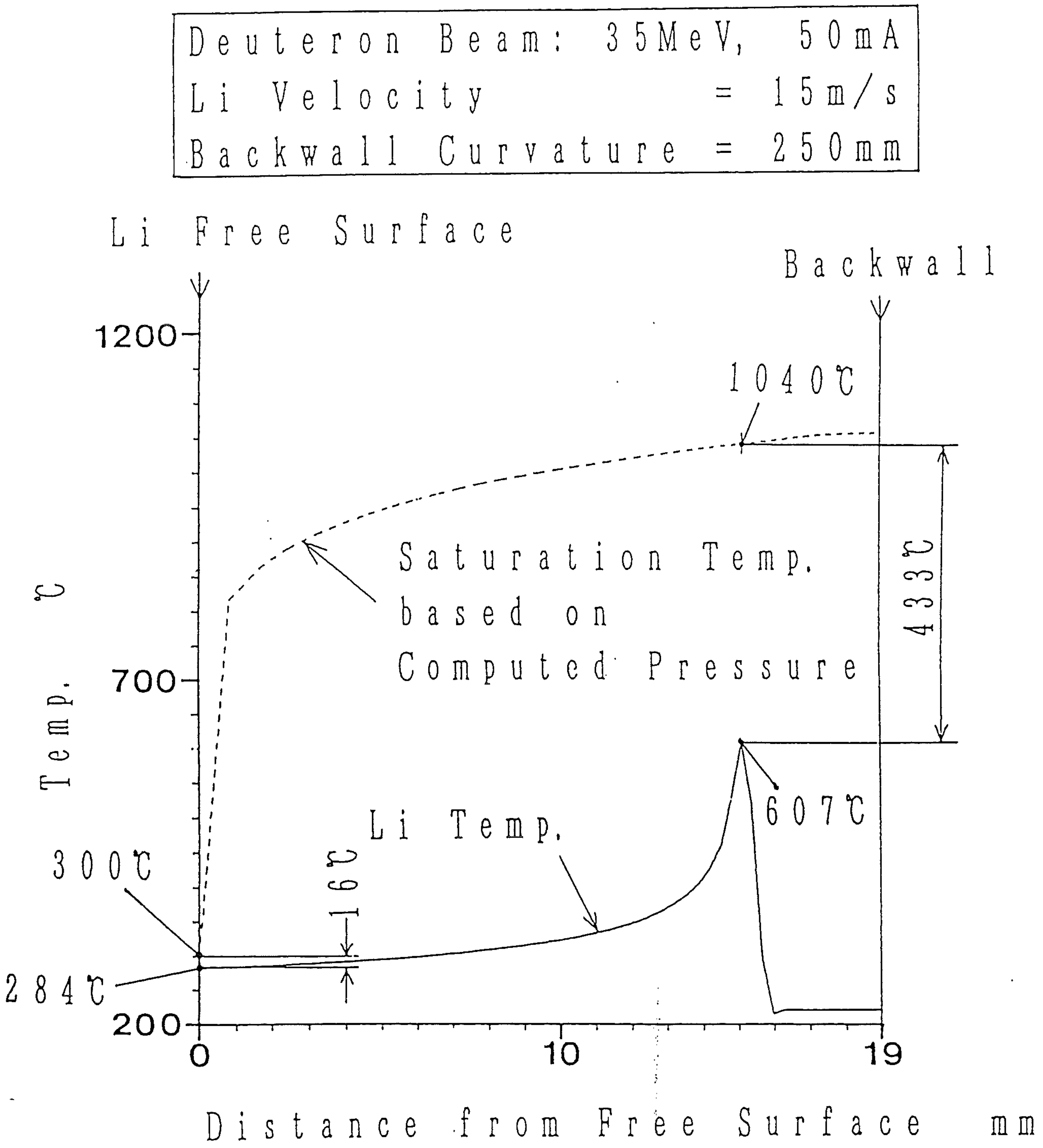


Fig. Li Temp. and Saturation Temp. Distribution in the cross section including Max.temp.

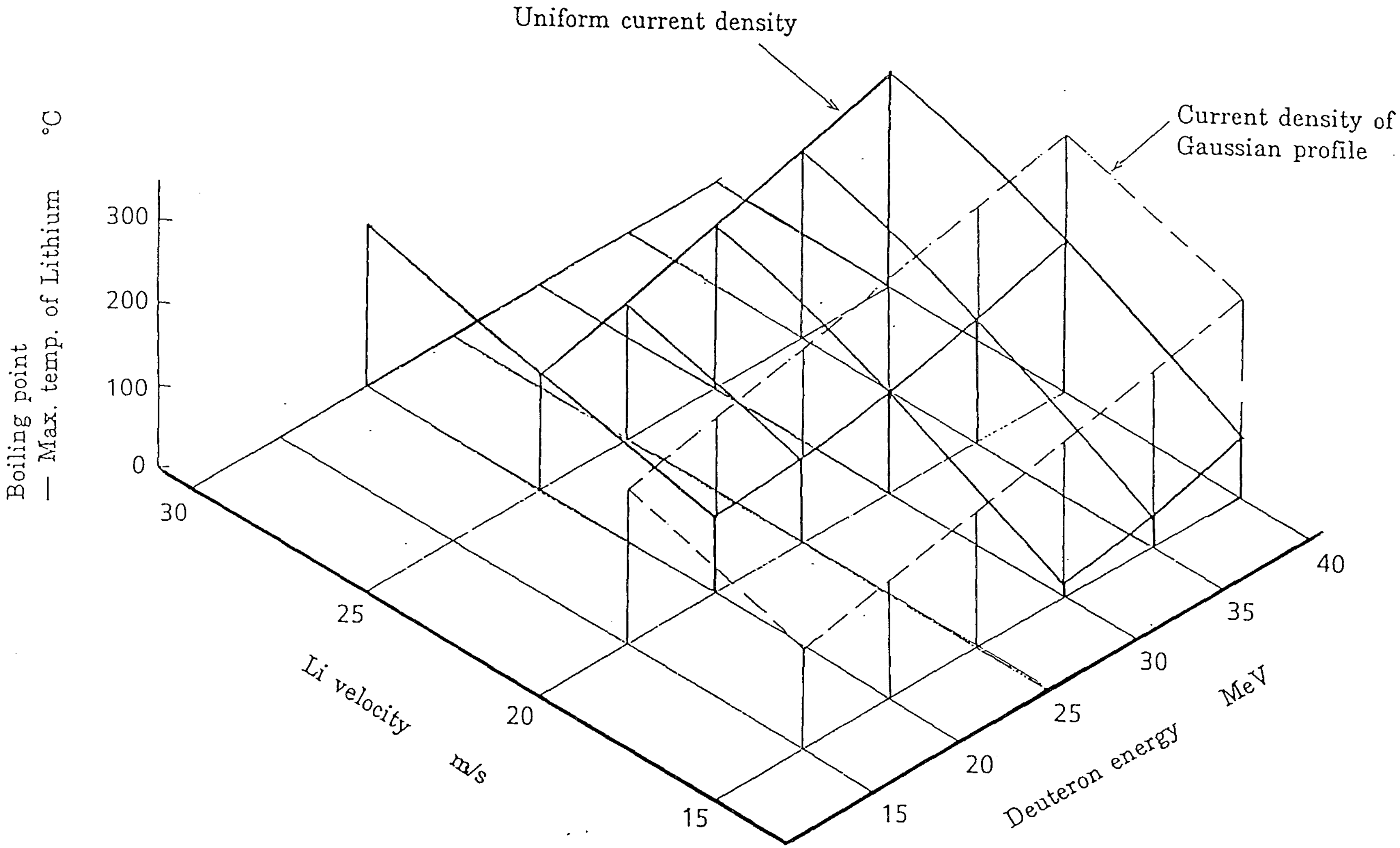


Fig. Boiling Margin at Max. Temp. Point

1.1 Design Conditions

1) Beam Power — 2MW

2) Lithium Flow Rate — 40 ℓ/s

3) Operating Temperature
   - a. Cold-leg Temperature — 220 ℃
   - b. Hot-leg Temperature — 243 ℃

4) Operating Pressure — 10^{-4}Pa (Quench Tank)

5) Design Temperature — 320 ℃

6) Design Pressure — 1.1MPa

7) Quench Tank Volume — 1.9 m^3

8) Dump Tank Volume — 6.4 m^3

1.2 Primary Lithium Circulation System

1.2.1 Design Specification of Primary Lithium Circulation System

1) Lithium Cooler
   - a. Lithium Inlet Temperature — 243 ℃
   - b. Lithium Outlet Temperature — 220 ℃
   - c. Lithium Flow Rate — 40 ℓ/s
   - d. Thermal Power — 2MW

2) Lithium EM Pump
   - a. Flow Rate — 40 ℓ/s
   - b. Pump Head — 0.36MPa

3) Piping
   - a. EMP Inlet Pipe — 6B
   - b. EMP Outlet Pipe — 4B

1.3 Lithium Purification System

1.3.1 Design Specification of Lithium Purification System

1) Target Value of Impurity Control
   - a. Target Value of FMIT Impurity Control
     - i) Nitrogen: <400ppm
     - ii) Hydrogen: < 60ppm
     - iii) Oxygen: < 10ppm
   - b. Impurity Limit of ESNIT
     - i) Nitrogen: ~10 ppm
     - ii) Hydrogen: ~8.4ppm
     - iii) Oxygen: ~10 ppm

2) Lithium Flow Rate
   - a. Cold Trap Flow Rate: 0.5 ℓ/s
   - b. Hot Trap (1) Flow Rate: 0.1 ℓ/s
   - c. Hot Trap (2) Flow Rate: 0.05 ℓ/s

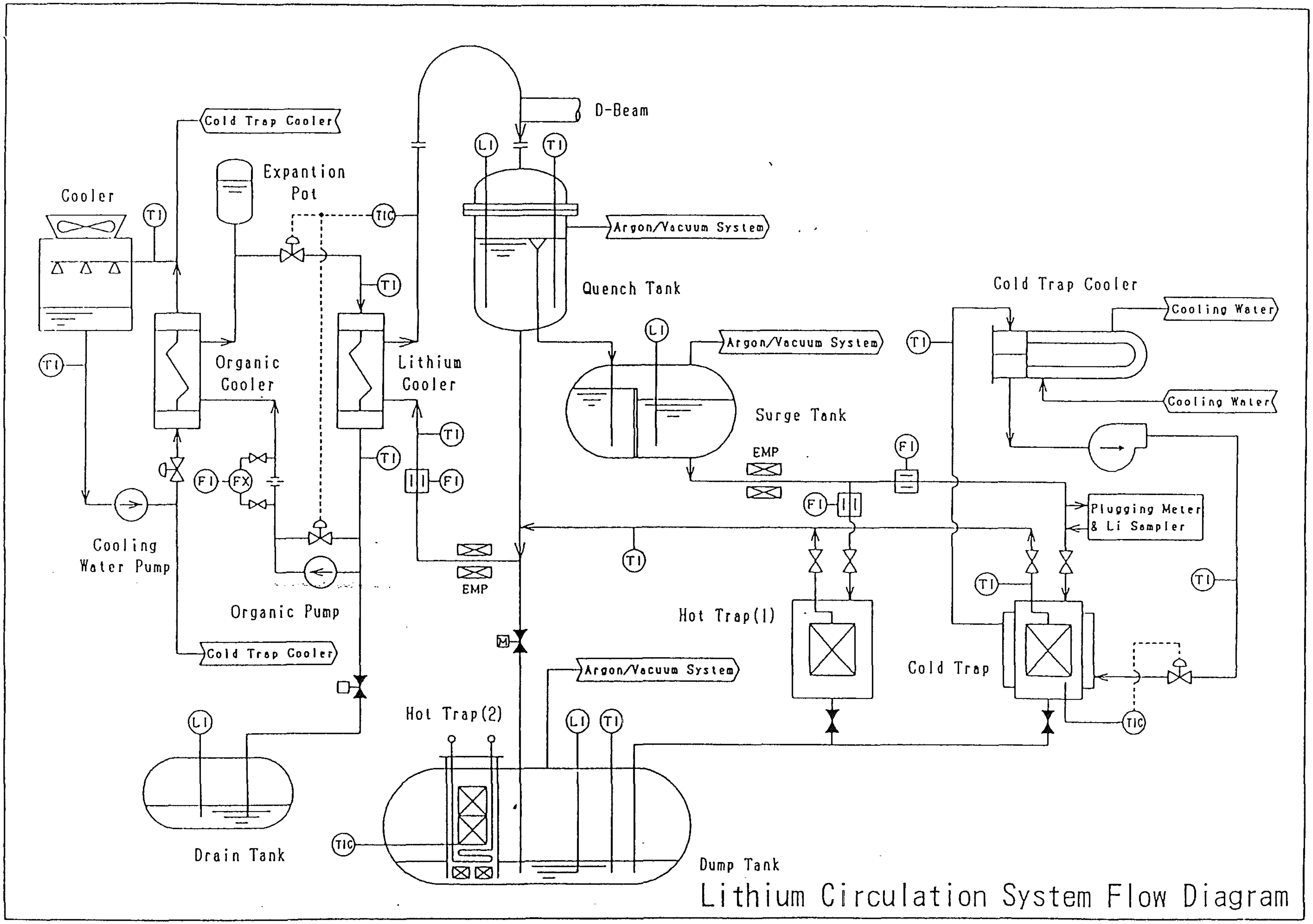
3) Trap Temperature
   - a. Cold Trap: 200 ℃
   - b. Hot Trap (1): 243 ℃
   - c. Hot Trap (2): 550 ℃

4) Lithium EM Pump
   - a. Flow Rate: 0.6 ℓ/s
   - b. Pump Head: 0.3MPa

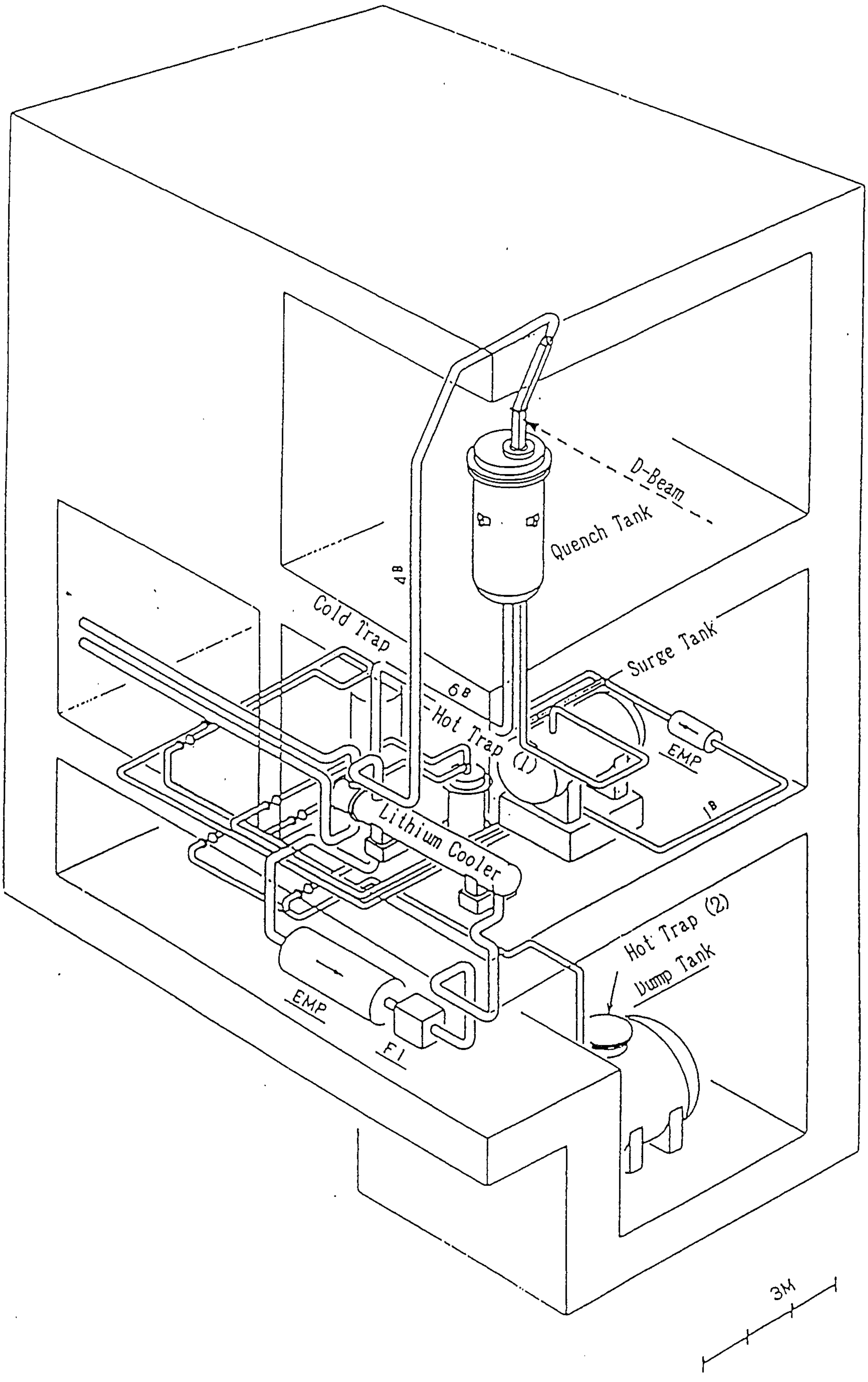
5) Cold Trap
   - a. Type: Forced Ar Gas Cooling Type
   - b. Number of Trap: 1
   - c. Mesh Volume: 120 ℓ

6) Hot Trap (1)
   - a. Type: Low-Temperature Getter
   - b. Number of Trap: 1
   - c. Getter Material: Yttrium Sponge
   - d. Getter Volume: 25 ℓ

7) Hot Trap (2)
   - a. Type: High Temperature Getter
   - b. Number of Trap: 1
   - c. Getter Material: Titanium Sponge
   - d. Getter Volume: 15 ℓ



Lithium Circulation System Flow Diagram



Perspective Sketch of Target System

IFMIF
Test Assembly

D. Smith

ANL

International Fusion Materials Irradiation Facility

Test Assembly

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Presented at

**International
Fusion Materials Irradiation Facility Meeting**

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Materials Test Cell

- Neutron Source Configuration
  - Single Beam (Beam Size)
  - Dual Beam
- Test Module Configuration
  - Flux Volume
  - Flux Gradient
  - Configuration Options
- Shielding Requirements
  - Reflectors
  - Cell Configuration
- Coolant System
  - Materials/Compatibility
  - Pump/Heat Rejection System
  - Chemistry Control
- Test Module
  - Structural Material
  - Geometry
  - Test Sample System
  - Insertion/Removal Scheme

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Neutronic Analysis of Target/Test Assembly

- Effect of Beam Energy on Neutron Production
- Effect of Beam Size/Shape on Nuclear Response Profile
- Flux Profile in Test Assembly
- DPA Profile for Selected Materials
- He Production Profile for Selected Materials
- Transmutation Rates of Selected Isotopes
- Incident Beam Angle on Nuclear Response
- Test Assembly Geometry

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Uncollided Neutron Flux

- MCNP code was used to transport the source neutrons and to perform the flux estimation throughout the test cell.
- Uncollided neutron flux distribution for a 3×1 cm beam size.
  - 3D plot
  - 2D plot along and perpendicular to the beam direction.

Comparison of Beam Configurations

Four types analyzed:

- One single beam.
- Two perpendicular beams on two separated jets.
- One beam incident on a curved jet.
- Two beams incident on the same jet at an angle.

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One Single Beam

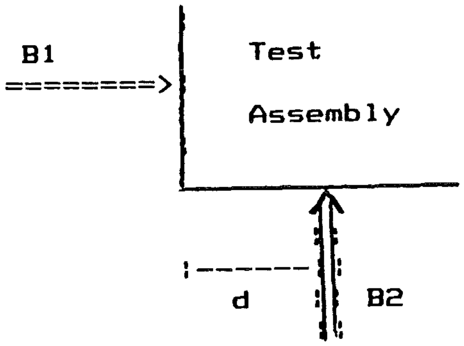
Varying the cross section of the beam it is possible to reduce energy deposition density, neutron flux gradient, etc...

- Comparison of the neutron flux gradient along the beam direction -- recommended maximum gradient = 1% per mm. (figure)

NOTE:

- The larger the beam cross sectional area the smaller the neutron flux gradient.
- The larger the beam cross sectional area the smaller the peak neutron flux value.

Two Perpendicular Beams



- d is a variable -- it affects the neutron flux distribution inside the test assembly region.
- Comparison of the neutron flux profile along the beam direction for two perpendicular beams using different "d" distances and the one single beam cases (plot).

NOTE:

- Reduces the gradient only inside a limited region of the test assembly.

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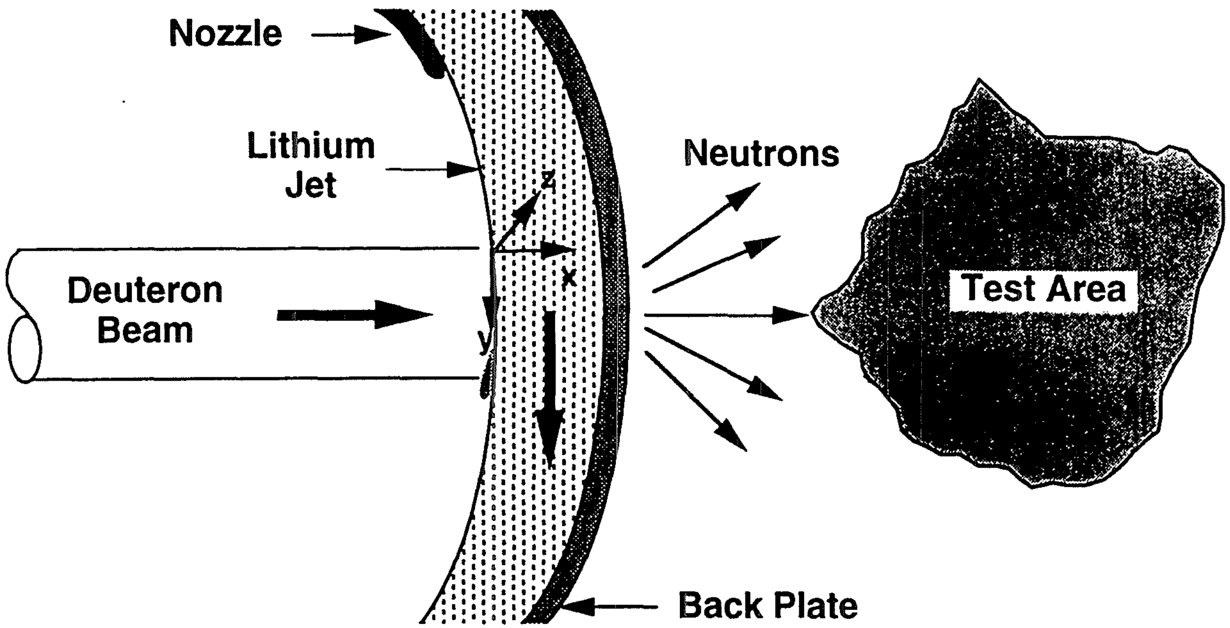
Schematic Illustration of Beam onTarget Interaction in a Neutron-Source Test Facility



Comparison between one and two target configurations

Beam current = 250 mA. Deuteron energy 35MeV. dpa calculations for Fe.

Beam Size	# of Beams	10 dpa/yr Material	10 dpa/yr No Material	20 dpa/yr Material	20 dpa/yr No Material
3 x 1[1]	1	610	1000	245	370
	2	490	1050	190	275
7 x 7[2]	1	1000	1120	360	380
	2	840	1150	230	230
10 x 10[2]	1	1200	1200	370	350
	2	900	910	130	85
20 x 20[2]	1	640	520	0	0
	2	0	0	0	0

1 3 x 1 beam size - The material present inside the test cell is 100% dense stainless steel

2 The material present inside the test cell is stainless steel, 30% dense in the first 10cm, 100% dense from 10cm to 50 cm

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ANL data

Effect of Beam Size/Shape on Nuclear Response

- Volume above threshold value

- Uniformity of the flux/nuclear response inside the test assembly region

  Enlarging the beam cross sectional area produces a better uniformity both along the beam direction and perpendicular to the beam direction

- Helium to DPA ratio

  Helium to DPA ratio in the test assembly region is basically uniform and around 10 dpa ± 3 for the SS-316 with a 10 x 10 beam

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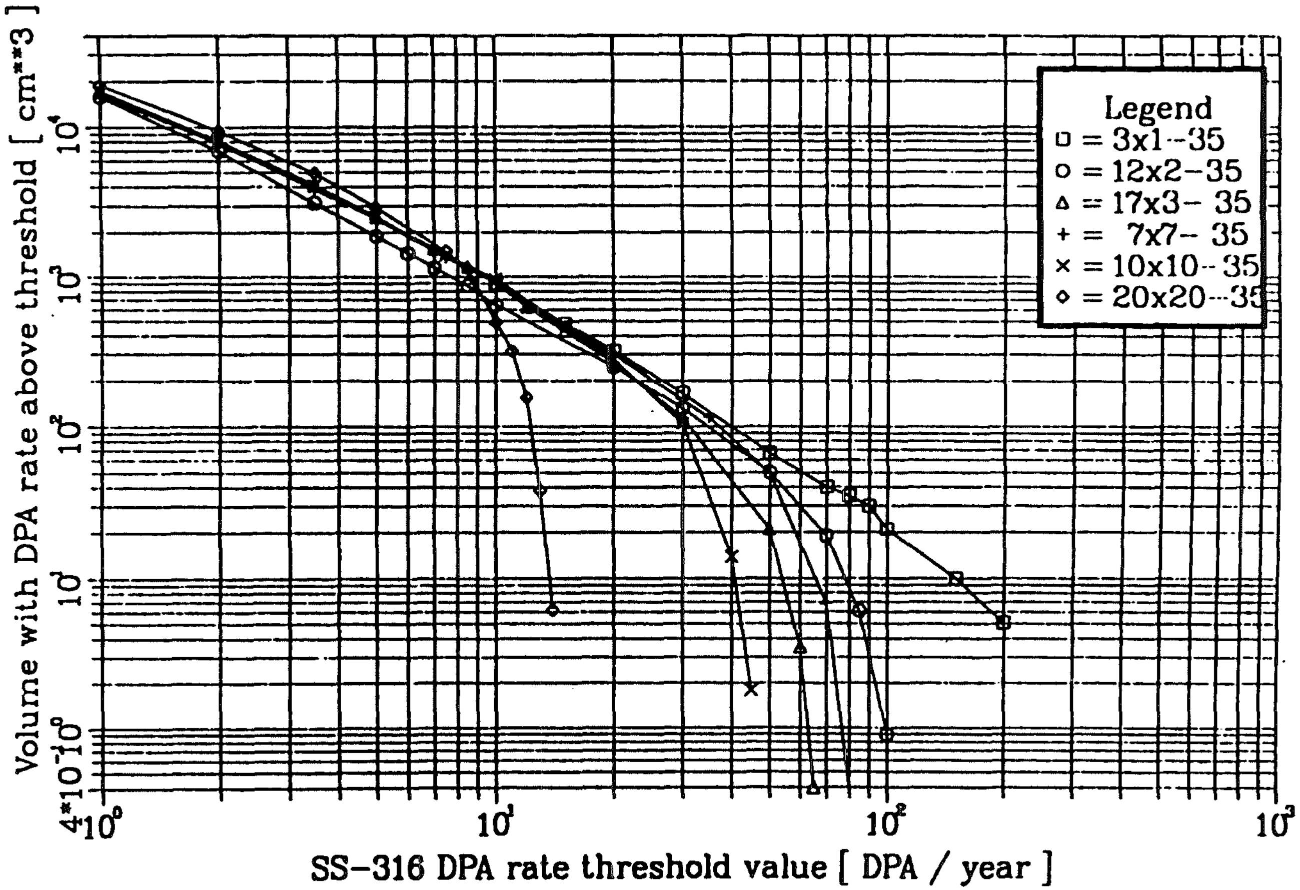


Figure 10 Volume above a threshold valve as a function of the threshold valve for 6 beams spot areas. Considering beams with 35 MeV deuterons and 250 mA of current.

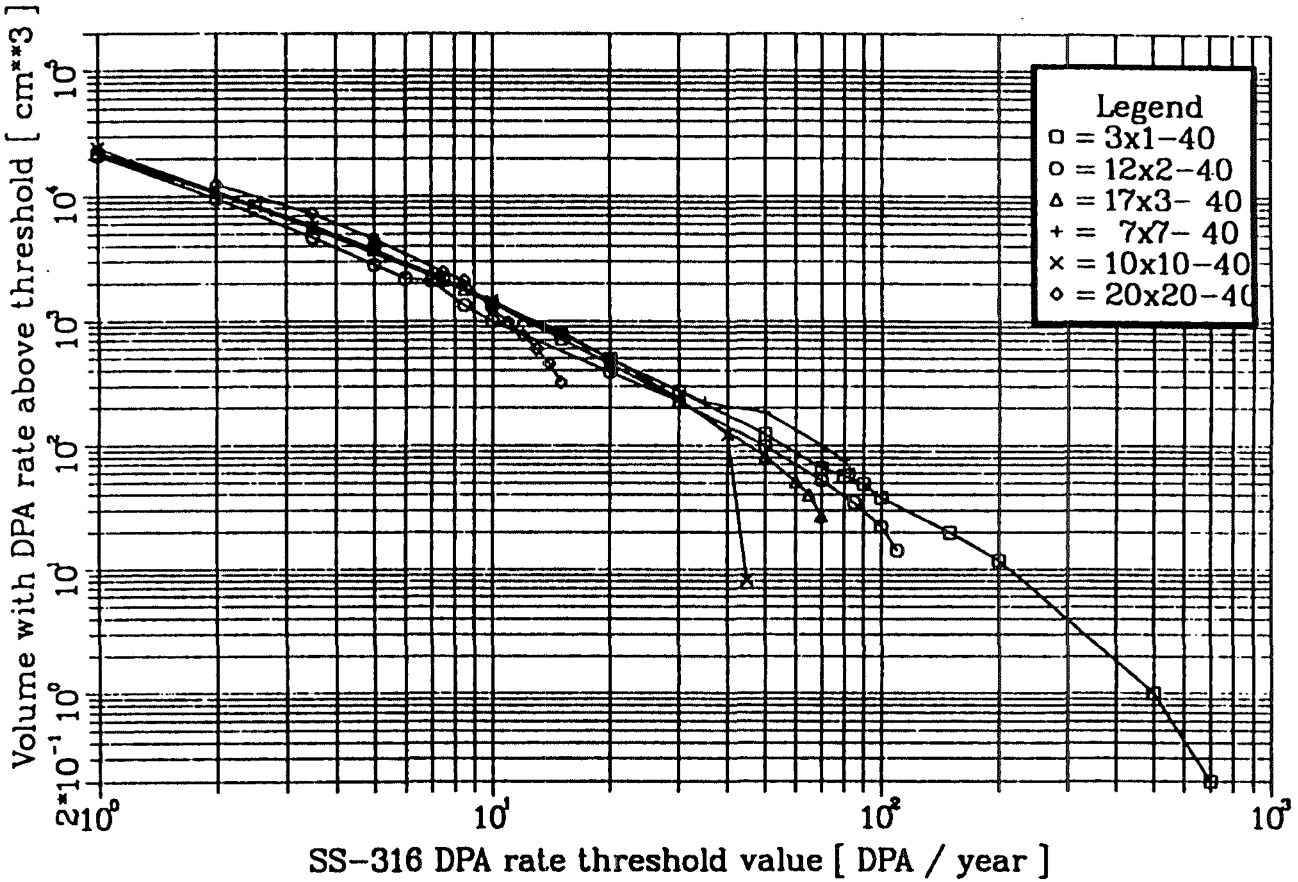


Figure 11 Volume above a threshold valve as a function of the threshold valve for 6 beam spot areas, considering beams with 40 MeV deuterons and 250 mA of current.

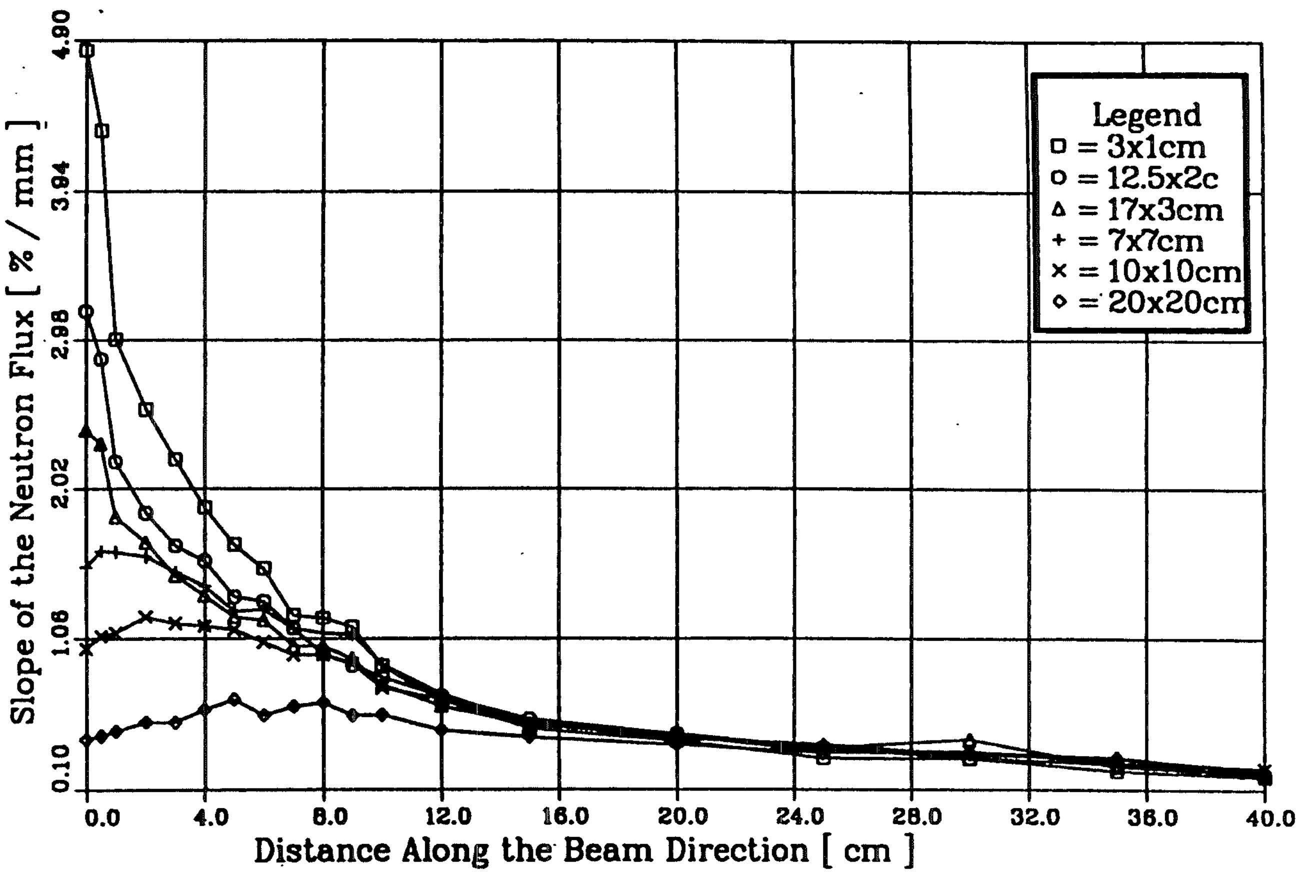
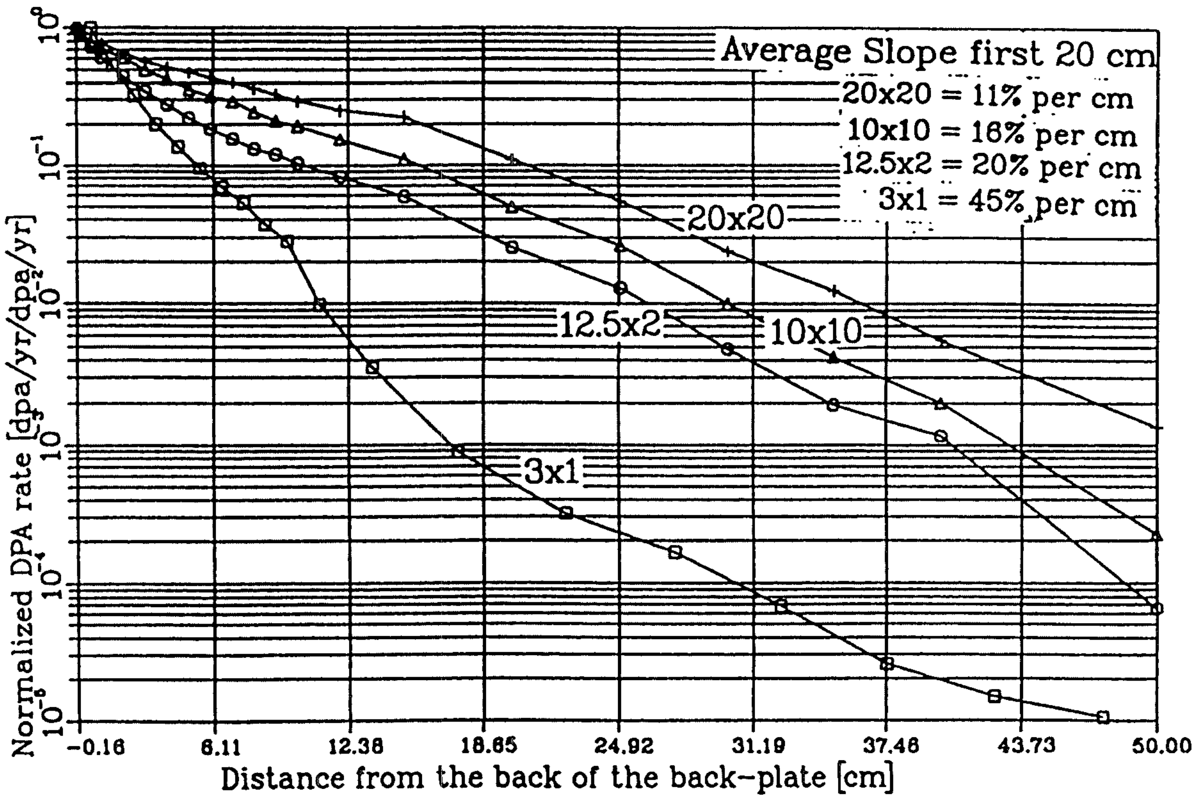


Figure 4. Uncollided neutron flux gradient in percentile per millimeter for six different beam cross sectional areas with the same 250 mA current, and same 35 MeV incident deuteron energy.

DPA rate Gradient for different beam spot areas

values normalized by the maximum value of each configurati



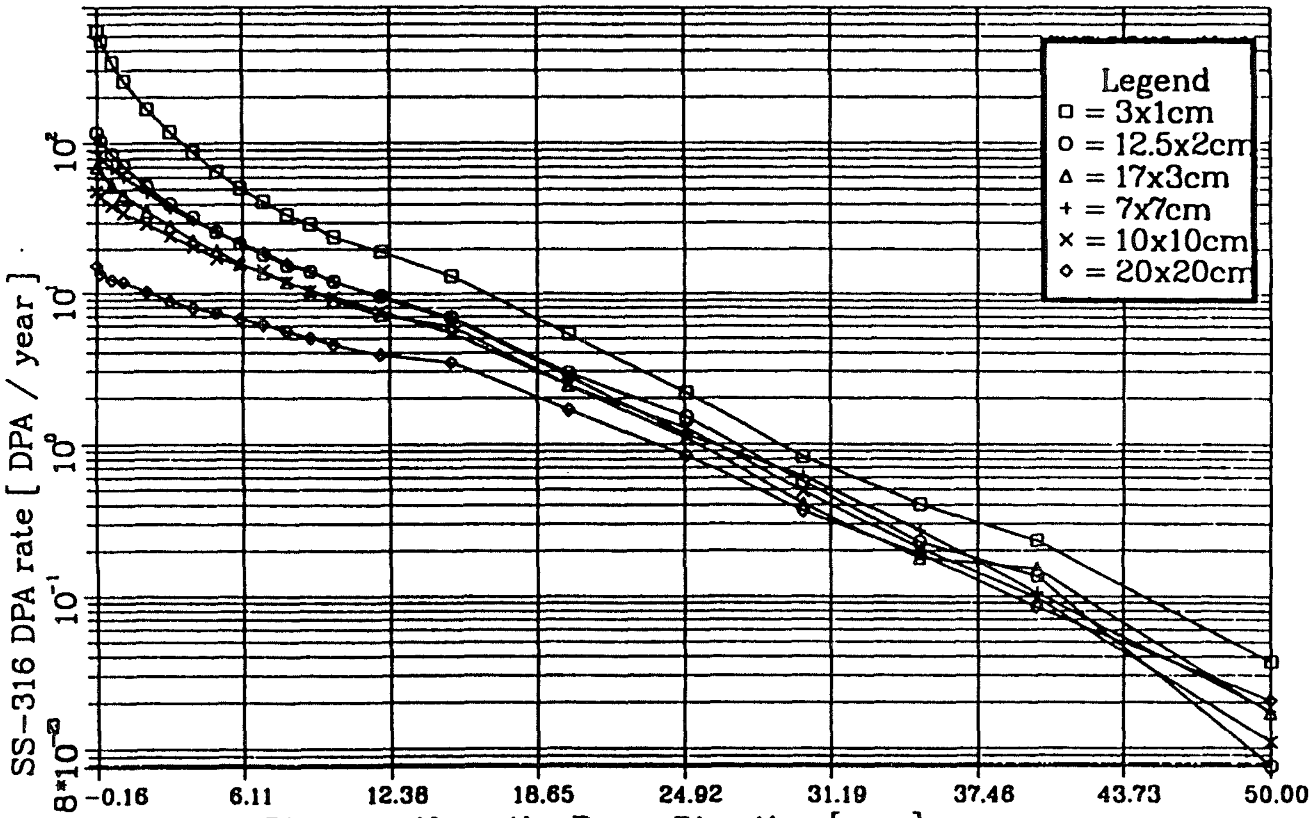


Figure 6 SS 316 DPA rate profile along the beam direction for four different beam cross sectional areas with 250 mA of current and 35 MeV deuteron energy.

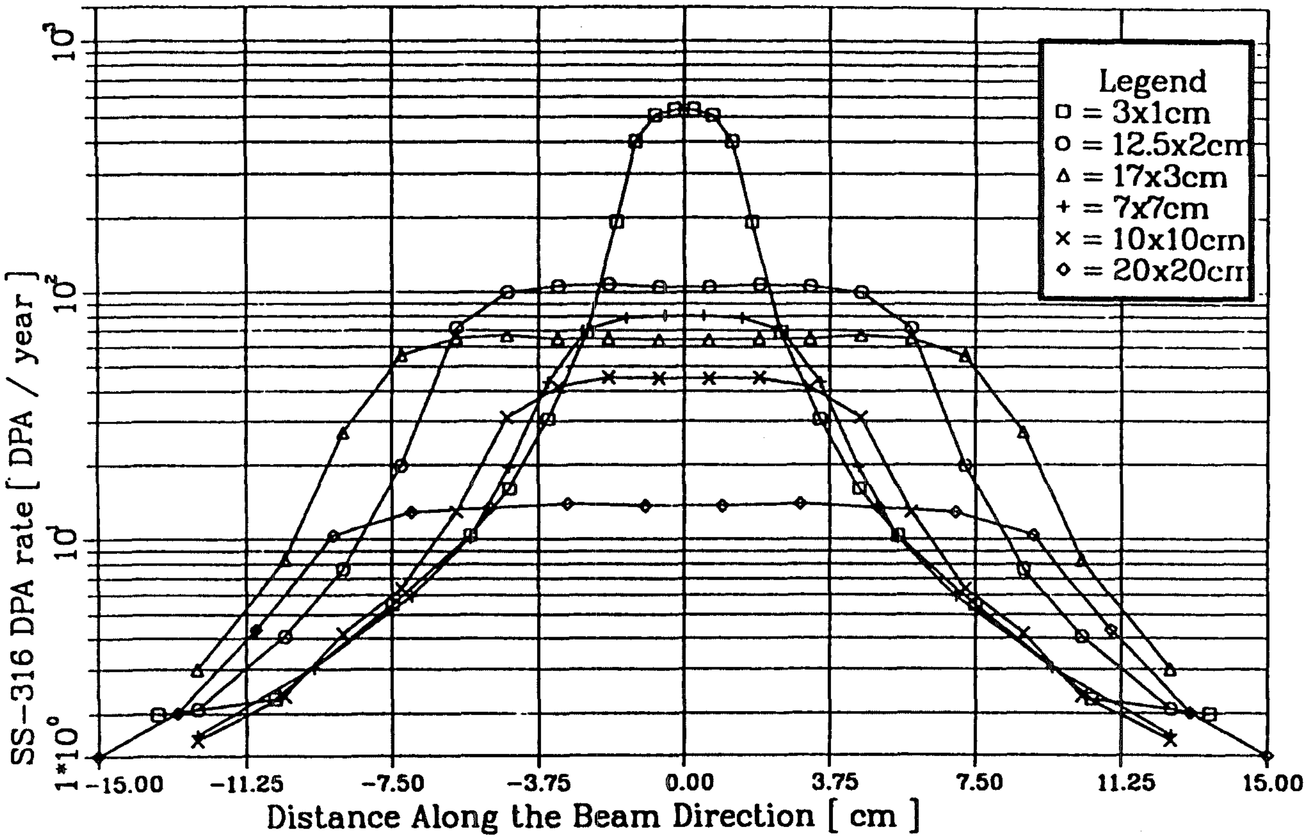


Figure 7 SS 316 DPA profile in the direction perpendicular to the beam and to the jet for four beam cross sectional areas with 250 mA of current and 35 MeV deuterons.

Deuteron Incident Energy

- Neutron Generation Increases with Increased Deuteron Energy (~5%/MeV)
  - Test Volume Increases

- Average Neutron Energy Increases with Increased Deuteron Energy

  30 MeV: 2.5% > 21 MeV

  35 MeV = 4.2% > 21 MeV

  40 MeV = 6.4% > 21 MeV

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Table 1
Comparison of Neutron Generation Rate, Average Energy, and Energy Distribution for Three Incident Deuteron Energies

	Deuteron Incident Energy		
	30 Mev	**35 MeV**	**40 MeV**
Percentage of Neutrons Born in Each Energy (MeV) Interval (%)			
from 0 to 15	91.94	88.12	84.33
from 15 to 21	5.51	7.63	9.28
from 21 to 32	2.12	3.54	5.39
from 32 to 43	0.42	0.66	0.90
from 43 to 50	0.0022	0.059	0.10
Total Neutron Generation rate for a 250 mA D-beam (neutrons/sec)	6.460e+16	8.364e+16	1.035e+17
Average Neutron Energy (MeV)	5.36	6.06	6.71

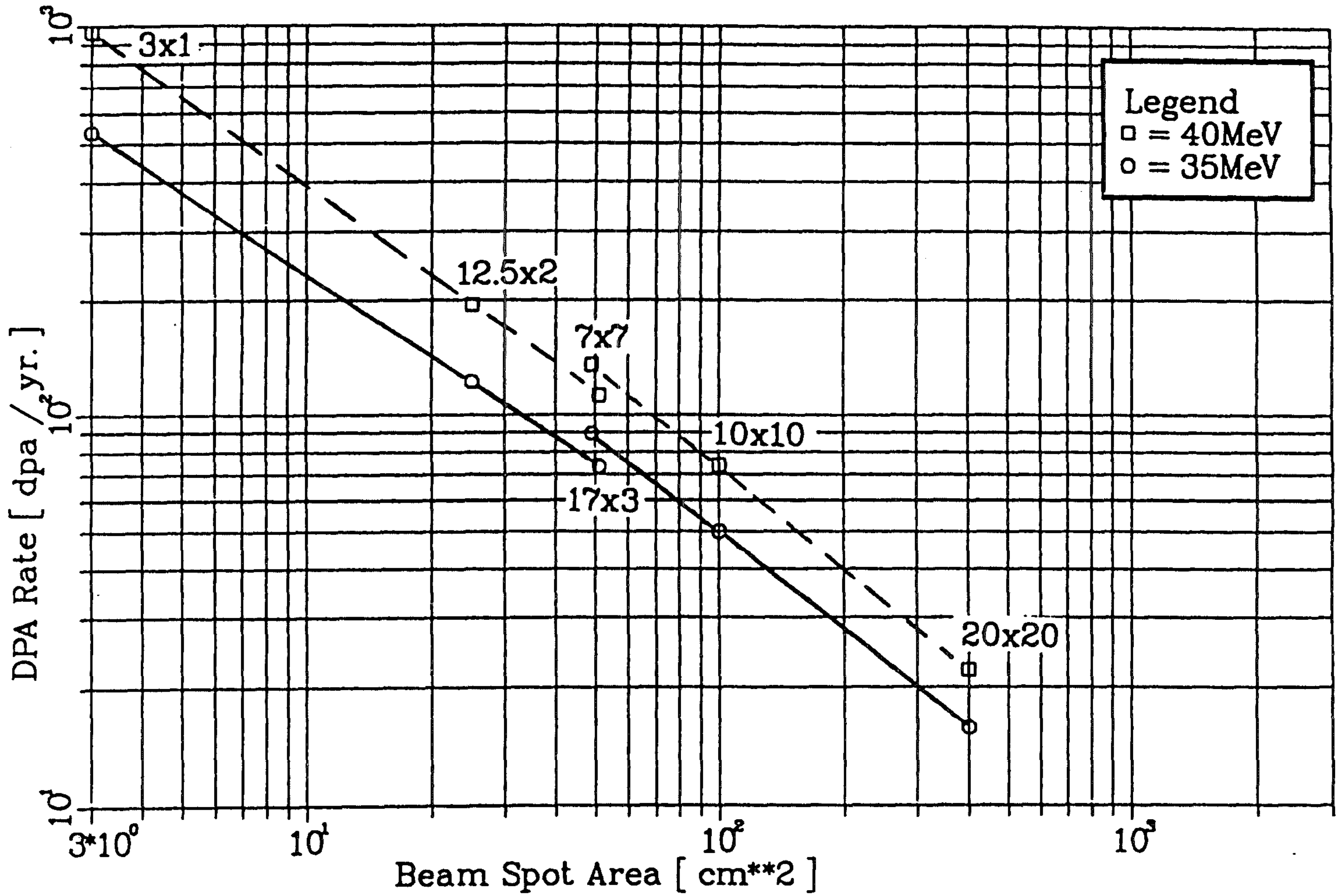

Figure 3 DPA rate at the backplate as a function of the beam cross sectional area for 35 MeV and 40 MeV deuterons with a beam current of 250 mA.

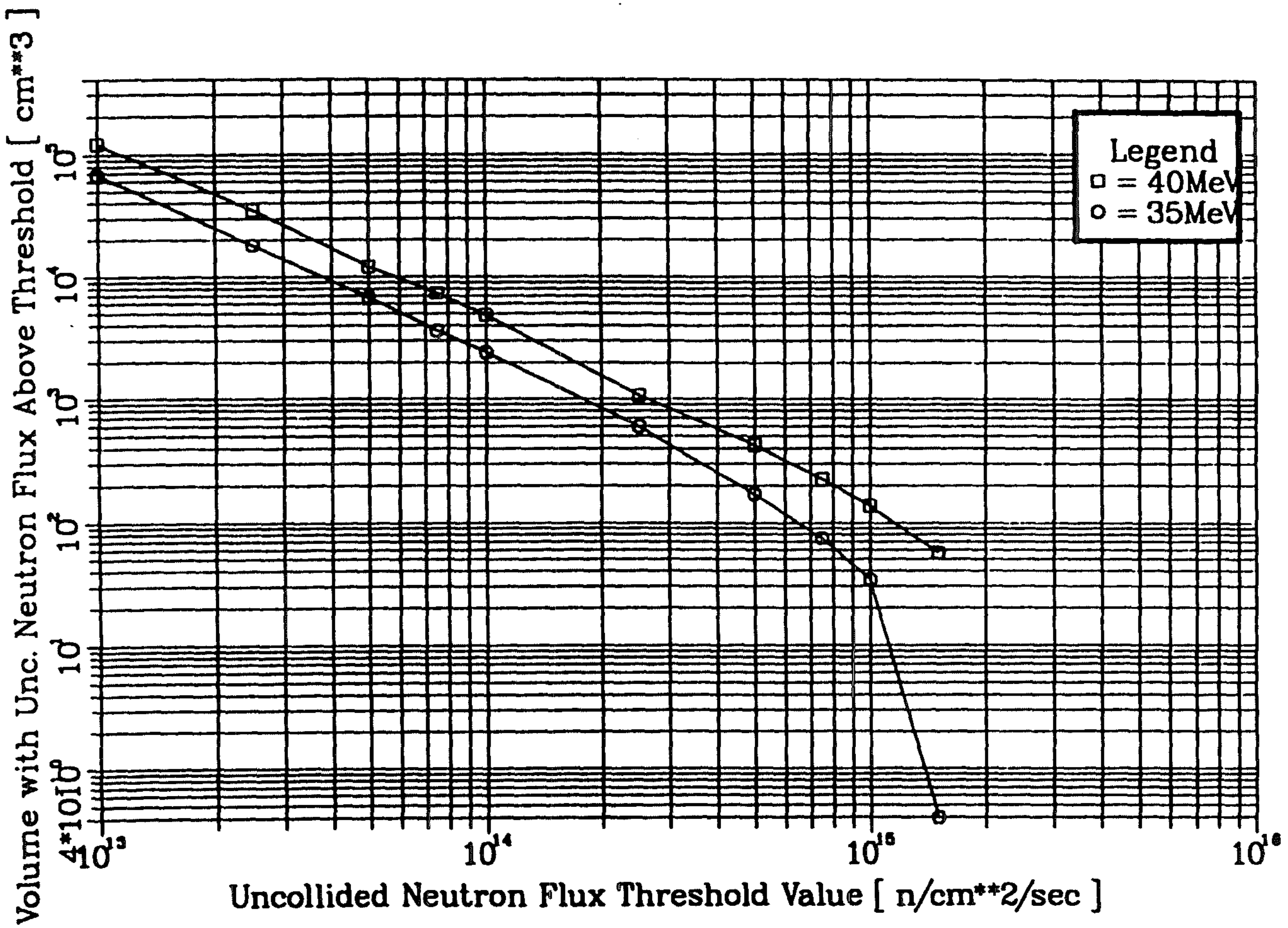

Figure 16. Volume with uncollided neutron flux above a specified threshold as a function of the threshold value for 35 MeV and 40 MeV deuteron energy, 7x7 beam cross sectional area and 250 mA of beam current.

Nuclear Response

- Damage rate (DPA)
- Helium production
- He/dpa ratio
- Nuclear heat deposition

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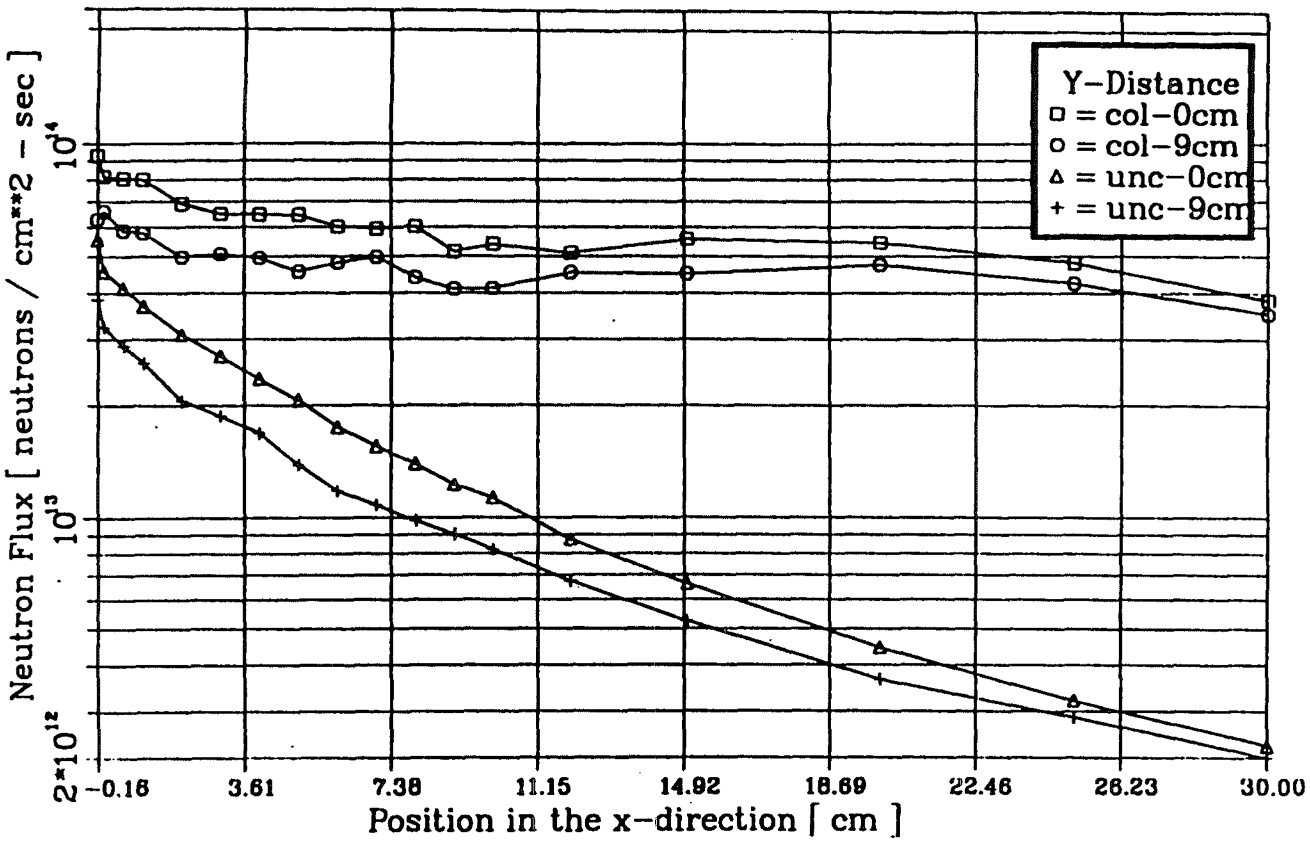

Figure 2 Comparison of the neutron flux distribution with and without material inside the test assembly for neutron energies below 1 MeV for a 20x20 cm^2 beam with 250 mA of current and 35 MeV deuteron energy.

Table 1. DPA rate per year for stainless steel, vanadium, niobium, and iron under D-Li neutron energy spectrum at different positions inside the test cell for a 35 MeV, 250 mA deuteron beam compared with the ITER first-wall DPA rate.

Material/ Beam Cross Section Area	DPA (dpa/year) Position Inside the Test Assembly Region					ITER
	(-.16,0,0)	(0,0,0)	(1,0,0)	(5,0,0)	(10,0,0)	1st-Wall
SS-316						
3x1 cm	535.	472.	256.	66.	24.	--
12.5x2 cm	119.	107.	73.	26.	12.	--
7x7 cm	89.	82.	62.	26.	12.	--
17x3 cm	72.	65.	47.	20.	9.	--
10x10 cm	50.	46.	36.	18.	10.	--
20x20 cm	16.	14.	12.	8.	5.	--
ITER	--	--	--	--	--	17.
Vanadium						
3x1 cm	534.	470.	252.	65.	24.	--
12.5x2 cm	120.	107.	73.	27.	12.	--
7x7 cm	91.	83.	62.	26.	12.	--
17x3 cm	74.	66.	47.	20.	9.	--
10x10 cm	51.	47.	36.	18.	10.	--
20x20 cm	16.	14.	13.	8.	5.	--
ITER	--	--	--	--	--	17.
Niobium						
3x1 cm	504.	446.	246.	64.	24.	--
12.5x2 cm	111.	100.	69.	25.	12.	--
7x7 cm	83.	76.	58.	25.	12.	--
17x3 cm	67.	61.	44.	19.	9.	--
10x10 cm	46.	42.	33.	17.	9.	--
20x20 cm	15.	13.	11.	7.	4.	--
ITER	--	--	--	--	--	16.
Iron						
3x1 cm	528.	465.	253.	65.	24.	--
12.5x2 cm	117.	105.	72.	26.	12.	--
7x7 cm	88.	80.	61.	26.	12.	--
17x3 cm	71.	64.	46.	20.	9.	--
10x10 cm	49.	44.	35.	17.	9.	--
20x20 cm	15.	14.	12.	7.	5.	--
ITER	--	--	--	--	--	17.

Table 3. DPA rate per year for stainless steel, vanadium, niobium, and iron under D-Li neutron energy spectrum at different positions inside the test cell for a 40 MeV, 250 mA deuteron beam compared with the ITER first-wall DPA rate.

Material/ Beam Cross Section Area	DPA rate (dpa/year) Position Inside the Test Assembly Region					ITER
	(-.16,0,0)	(0,0,0)	(1,0,0)	(5,0,0)	(10,0,0)	1st-Wall
SS-316						
3x1 cm	966.	788.	399.	100.	36.	--
12.5x2 cm	192.	163.	105.	38.	18.	--
7x7 cm	135.	118.	86.	38.	18.	--
17x3 cm	111.	94.	67.	27.	13.	--
10x10 cm	74.	65.	50.	25.	14.	--
20x20 cm	22.	20.	16.	10.	7.	--
ITER	--	--	--	--	--	17.
Vanadium						
3x1 cm	977.	789.	394.	98.	35.	--
12.5x2 cm	195.	164.	105.	38.	18.	--
7x7 cm	138.	120.	87.	38.	18.	--
17x3 cm	113.	95.	67.	27.	13.	--
10x10 cm	76.	66.	51.	25.	14.	--
20x20 cm	23.	20.	16.	10.	7.	--
ITER	--	--	--	--	--	17.
Niobium						
3x1 cm	909.	749.	388.	99.	35.	--
12.5x2 cm	180.	154.	100.	37.	18.	--
7x7 cm	126.	110.	82.	37.	17.	--
17x3 cm	103.	88.	64.	26.	13.	--
10x10 cm	68.	60.	47.	24.	13.	--
20x20 cm	20.	18.	15.	9.	6.	--
ITER	--	--	--	--	--	16.
Iron						
3x1 cm	952.	777.	395.	99.	35.	--
12.5x2 cm	189.	160.	104.	38.	18.	--
7x7 cm	133.	116.	85.	38.	18.	--
17x3 cm	109.	93.	66.	27.	13.	--
10x10 cm	73.	63.	49.	25.	13.	--
20x20 cm	22.	19.	15.	10.	6.	--
ITER	--	--	--	--	--	17.

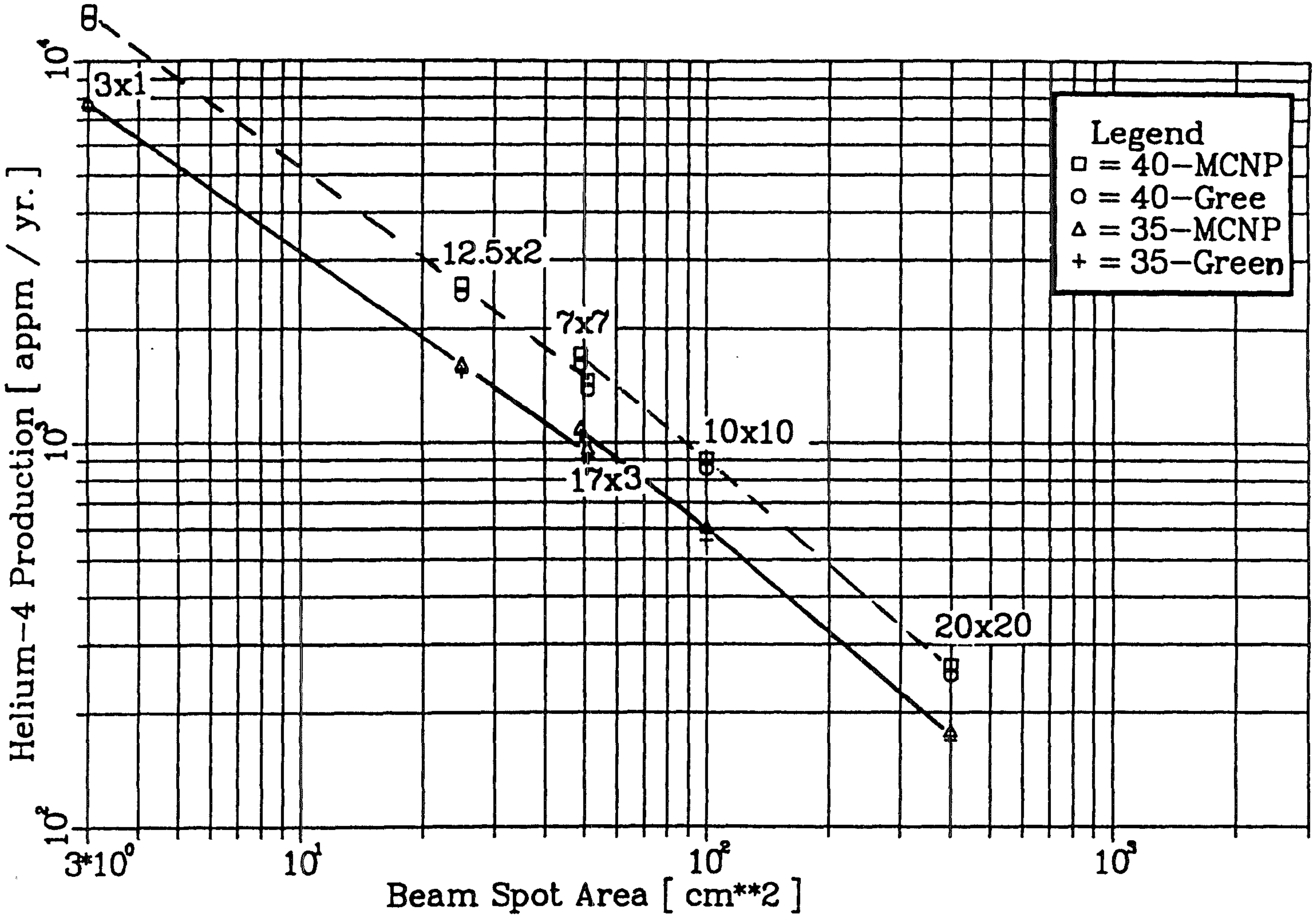

Figure 4 Helium-4 production rate at the backplate as a function of the beam cross sectional area for 35 and 40 MeV deuteron beams with 250 mA of current.

Table 2. Helium production for stainless steel, vanadium, niobium, and iron under D-Li neutron energy spectrum at different positions inside the test cell for a 35 MeV, 250 mA deuteron beam compared with the ITER first-wall helium production.

Material/ Beam Cross Section Area	Helium Production (appm/year) Position Inside the Test Assembly Region					ITER
	(-.16,0,0)	(0,0,0)	(1,0,0)	(5,0,0)	(10,0,0)	1st-Wall
SS-316						
3x1 cm	7414.	6657.	3966.	1072.	404.	--
12.5x2 cm	1508.	1395.	1010.	383.	187.	--
7x7 cm	1047.	992.	802.	389.	183.	--
17x3 cm	866.	800.	624.	275.	134.	--
10x10 cm	560.	532.	440.	245.	139.	--
20x20 cm	169.	152.	134.	88.	56.	--
ITER	--	--	--	--	--	240.
Vanadium						
3x1 cm	2262.	2045.	1280.	346.	127.	--
12.5x2 cm	441.	411.	313.	123.	65.	--
7x7 cm	306.	289.	238.	133.	62.	--
17x3 cm	245.	231.	188.	91.	48.	--
10x10 cm	156.	152.	129.	80.	47.	--
20x20 cm	46.	42.	38.	26.	18.	--
ITER	--	--	--	--	--	54.
Niobium						
3x1 cm	885.	797.	482.	134.	52.	--
12.5x2 cm	179.	166.	121.	47.	23.	--
7x7 cm	122.	116.	96.	46.	22.	--
17x3 cm	102.	94.	74.	33.	16.	--
10x10 cm	65.	62.	52.	29.	17.	--
20x20 cm	20.	18.	16.	10.	7.	--
ITER	--	--	--	--	--	38.
Iron						
3x1 cm	4834.	4347.	2624.	555.	24.	--
12.5x2 cm	974.	903.	661.	26.	12.	--
7x7 cm	670.	637.	520.	26.	12.	--
17x3 cm	555.	514.	406.	20.	9.	--
10x10 cm	356.	340.	284.	17.	9.	--
20x20 cm	107.	97.	86.	7.	5.	--
ITER	--	--	--	--	--	170.

Table 4. Helium production for stainless steel, vanadium, niobium, and iron under D-Li neutron energy spectrum at different positions inside the test cell for a 40 MeV, 250 mA deuteron beam compared with the ITER first-wall helium production.

Material/ Beam Cross Section Area	Helium Production (appm/year) Position Inside the Test Assembly Region					ITER
	(-.16,0,0)	(0,0,0)	(1,0,0)	(5,0,0)	(10,0,0)	1st-Wall
SS-316						
3x1 cm	12640.	11165.	6444.	1757.	638.	--
12.5x2 cm	2394.	2170.	1560.	600.	300.	--
7x7 cm	1603.	1491.	1186.	598.	281.	--
17x3 cm	1361.	1212.	946.	415.	204.	--
10x10 cm	860.	800.	648.	369.	210.	--
20x20 cm	250.	231.	190.	125.	84.	--
ITER	--	--	--	--	--	240.
Vanadium						
3x1 cm	4096.	3714.	2291.	639.	228.	--
12.5x2 cm	750.	697.	533.	218.	116.	--
7x7 cm	497.	473.	390.	223.	106.	--
17x3 cm	423.	387.	321.	152.	79.	--
10x10 cm	261.	251.	210.	131.	80.	--
20x20 cm	74.	70.	60.	42.	30.	--
ITER	--	--	--	--	--	54.
Niobium						
3x1 cm	1491.	1322.	776.	216.	81.	--
12.5x2 cm	281.	256.	186.	72.	36.	--
7x7 cm	186.	175.	141.	71.	34.	--
17x3 cm	158.	142.	112.	50.	24.	--
10x10 cm	100.	94.	76.	44.	25.	--
20x20 cm	29.	27.	22.	15.	10.	--
ITER	--	--	--	--	--	38.
Iron						
3x1 cm	8238.	7325.	4294.	1184.	432.	--
12.5x2 cm	1550.	1414.	1030.	400.	201.	--
7x7 cm	1032.	967.	777.	400.	188.	--
17x3 cm	877.	787.	622.	277.	137.	--
10x10 cm	552.	518.	422.	245.	141.	--
20x20 cm	159.	149.	123.	82.	55.	--
ITER	--	--	--	--	--	170.

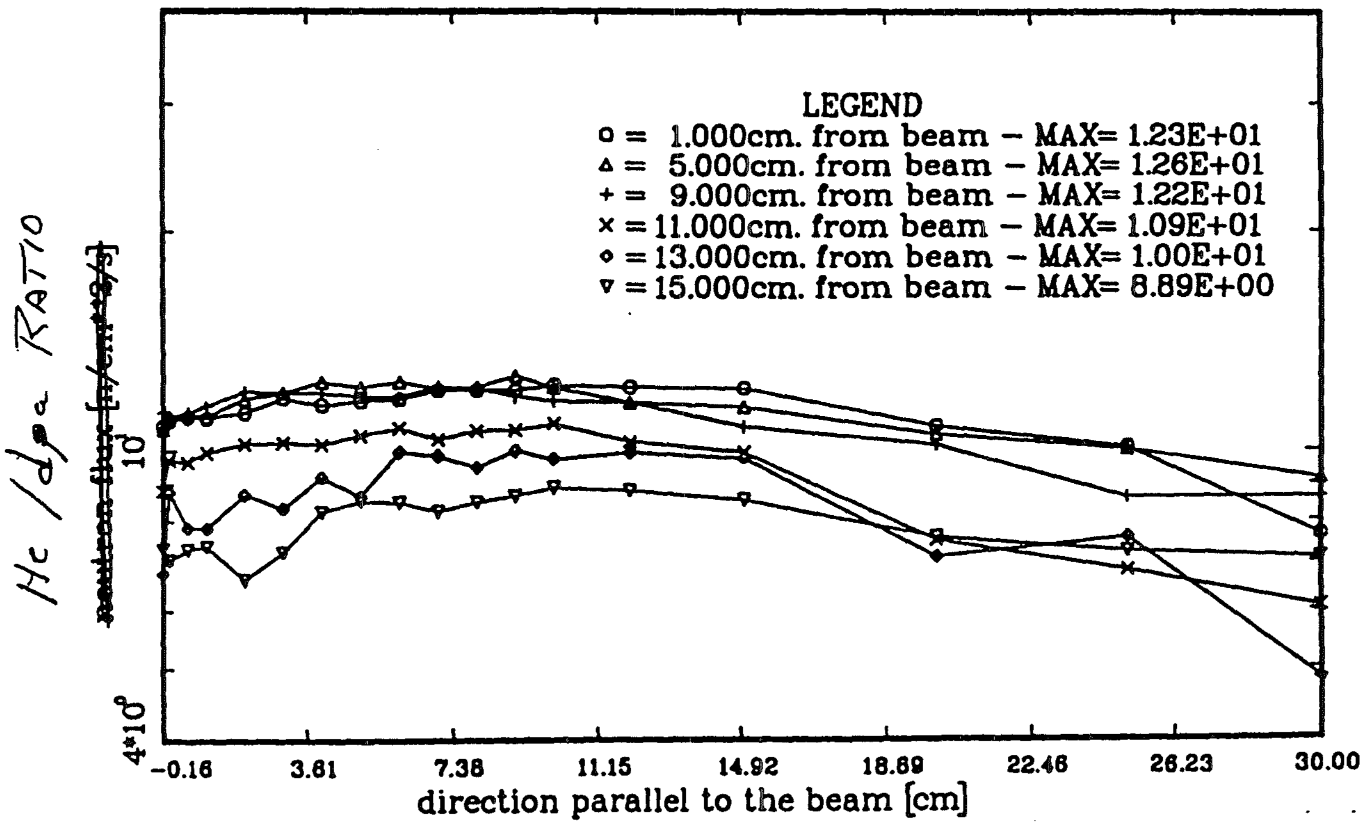

Figure 8 Helium production (appm/yr) to DPA rate (dpa/yr) ratio. Profile along the beam direction for a 250 mA, 35 MeV, 10 x 10 cm^2 deuteron beam.

Table 5. Helium production (appm/yr) to DPA rate (dpa/yr) ratio for stainless steel, vanadium, niobium, and iron under D-Li neutron energy spectrum at different positions inside the test cell for a 35 MeV, 250 mA deuteron beam compared with the ITER first-wall helium to DPA ratio.

Material/ Beam Cross Section Area		Helium to DPA ratio (appm/dpa) Position Inside the Test Assembly Region				ITER
		(-.16,0,0)	(1,0,0)	(5,0,0)	(10,0,0)	1st-Wall
SS-316						
3x1 cm		13.8	15.5	16.3	16.7	--
12.5x2 cm		12.7	13.9	14.5	15.3	--
7x7 cm		11.7	13.0	14.7	14.9	--
17x3 cm		12.0	13.3	13.8	14.7	--
10x10 cm		11.2	12.4	13.8	14.4	--
20x20 cm		10.8	11.0	11.7	12.3	--
ITER	--	--	--	--	--	14.
Vanadium						
3x1 cm		4.2	5.1	5.4	5.4	--
12.5x2 cm		3.7	4.3	4.6	5.3	--
7x7 cm		3.4	3.8	5.0	5.0	--
17x3 cm		3.3	4.0	4.5	5.2	--
10x10 cm		3.1	3.6	4.5	4.8	--
20x20 cm		2.8	3.0	3.3	3.9	--
ITER	--	--	--	--	--	3.2
Niobium						
3x1 cm		1.8	2.0	2.1	2.2	--
12.5x2 cm		1.6	1.8	1.9	1.9	--
7x7 cm		1.5	1.7	1.8	1.9	--
17x3 cm		1.5	1.7	1.8	1.9	--
10x10 cm		1.4	1.6	1.7	1.8	--
20x20 cm		1.4	1.4	1.5	1.6	--
ITER	--	--	--	--	--	2.4
Iron						
3x1 cm		9.2	10.4	11.0	11.3	--
12.5x2 cm		8.3	9.2	9.7	10.4	--
7x7 cm		7.6	8.5	9.9	10.0	--
17x3 cm		7.8	8.8	9.3	10.0	--
10x10 cm		7.3	8.1	9.2	9.7	--
20x20 cm		7.0	7.2	7.7	8.2	--
ITER	--	--	--	--	--	10.

Table 6. Helium production (appm/year) to DPA rate (dpa/year) ratio for stainless steel, vanadium, niobium, and iron under D-Li neutron energy spectrum at different positions inside the test cell for a 40 MeV, 250 mA deuteron beam compared with the ITER first-wall helium to DPA ratio.

Material/ Beam Cross Section Area	Helium to DPA ratio (appm/dpa) Position Inside the Test Assembly Region				ITER
	(-.16,0,0)	(1,0,0)	(5,0,0)	(10,0,0)	1st-Wall
SS-316					
3x1 cm	13.0	16.2	17.6	18.0	--
12.5x2 cm	12.5	14.8	15.7	16.5	--
7x7 cm	11.9	13.8	16.0	16.1	--
17x3 cm	12.3	14.2	15.2	15.5	--
10x10 cm	11.6	13.0	14.6	15.3	--
20x20 cm	11.3	12.1	12.6	12.9	--
ITER	--	--	--	--	14.1
Vanadium					
3x1 cm	4.2	5.8	6.5	6.6	--
12.5x2 cm	3.9	5.1	5.7	6.4	--
7x7 cm	3.6	4.5	5.8	5.9	--
17x3 cm	3.8	4.8	5.5	6.0	--
10x10 cm	3.5	4.2	5.2	5.8	--
20x20 cm	3.3	3.7	4.1	4.5	--
ITER	--	--	--	--	3.2
Niobium					
3x1 cm	1.6	2.0	2.2	2.3	--
12.5x2 cm	1.6	1.8	2.0	2.0	--
7x7 cm	1.5	1.7	1.9	1.9	--
17x3 cm	1.5	1.8	1.9	1.9	--
10x10 cm	1.5	1.6	1.8	1.9	--
20x20 cm	1.4	1.5	1.6	1.6	--
ITER	--	--	--	--	2.4
Iron					
3x1 cm	8.7	10.9	12.0	12.2	--
12.5x2 cm	8.2	9.9	10.6	11.2	--
7x7 cm	7.8	9.2	10.6	10.7	--
17x3 cm	8.0	9.4	10.3	10.5	--
10x10 cm	7.6	8.6	9.8	10.4	--
20x20 cm	7.3	8.0	8.4	8.7	--
ITER	--	--	--	--	10.

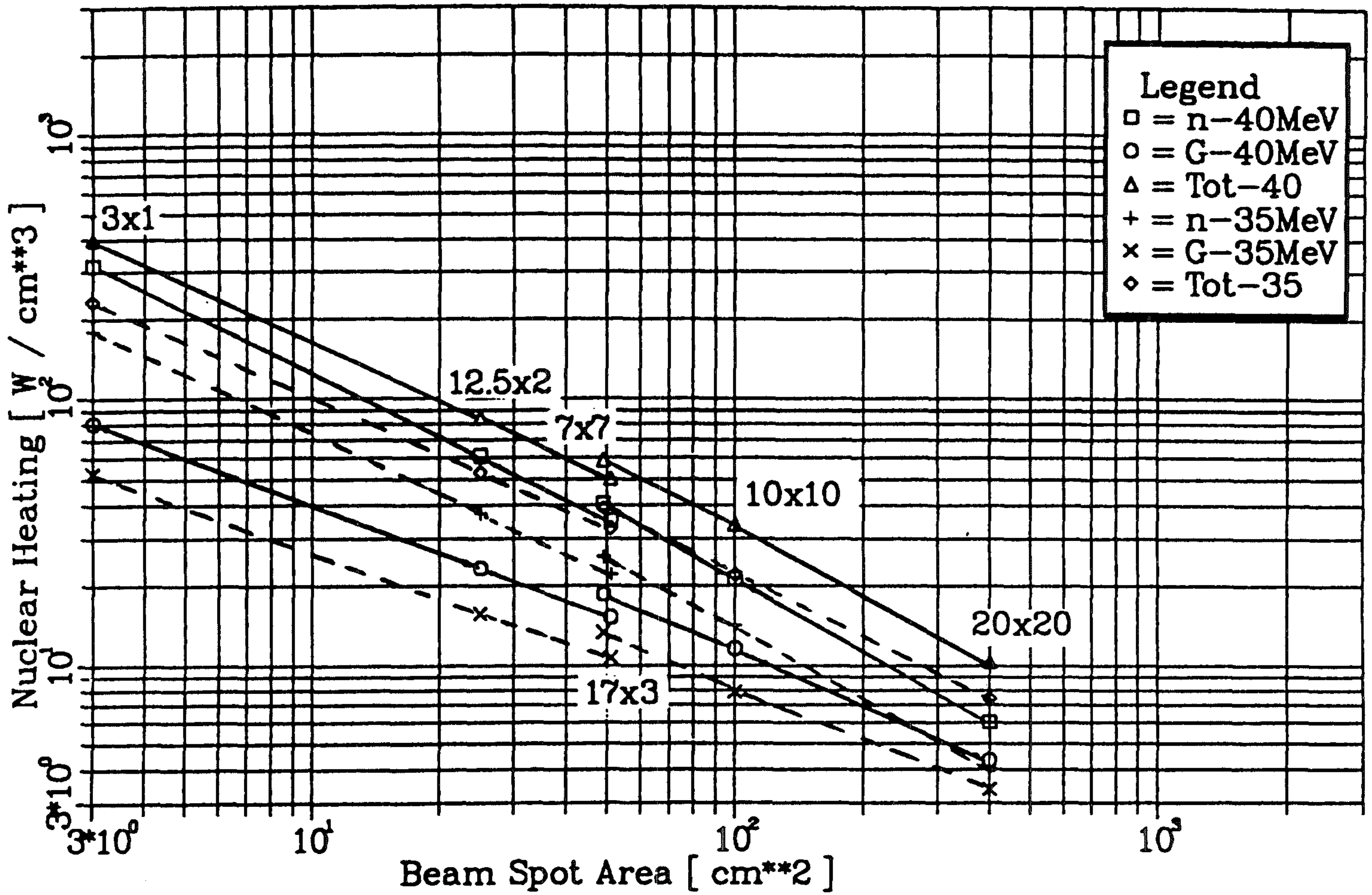

Figure 5 Nuclear heating due to neutrons and gamma-rays at the backplate as a function of the beam cross sectional area for a 35 and 40 MeV deuteron beams with 250 mA of current.

Beam Target Configuration

- Two separated beams (125 mA each) or four separated beams (125 mA each) incident on the same target is a viable option

- Beams incident at a convergent angle without overlapping their footprint on the target present a good performance when compared with other configurations

- Concerning uniformity, beams incident at an angle on the target present acceptable gradients as far as the angle between the beams is kept below 45°. Figures show some examples of the uncollided flux distribution profile for different angles of incidence of the beams relative to the normal to the jet surface.

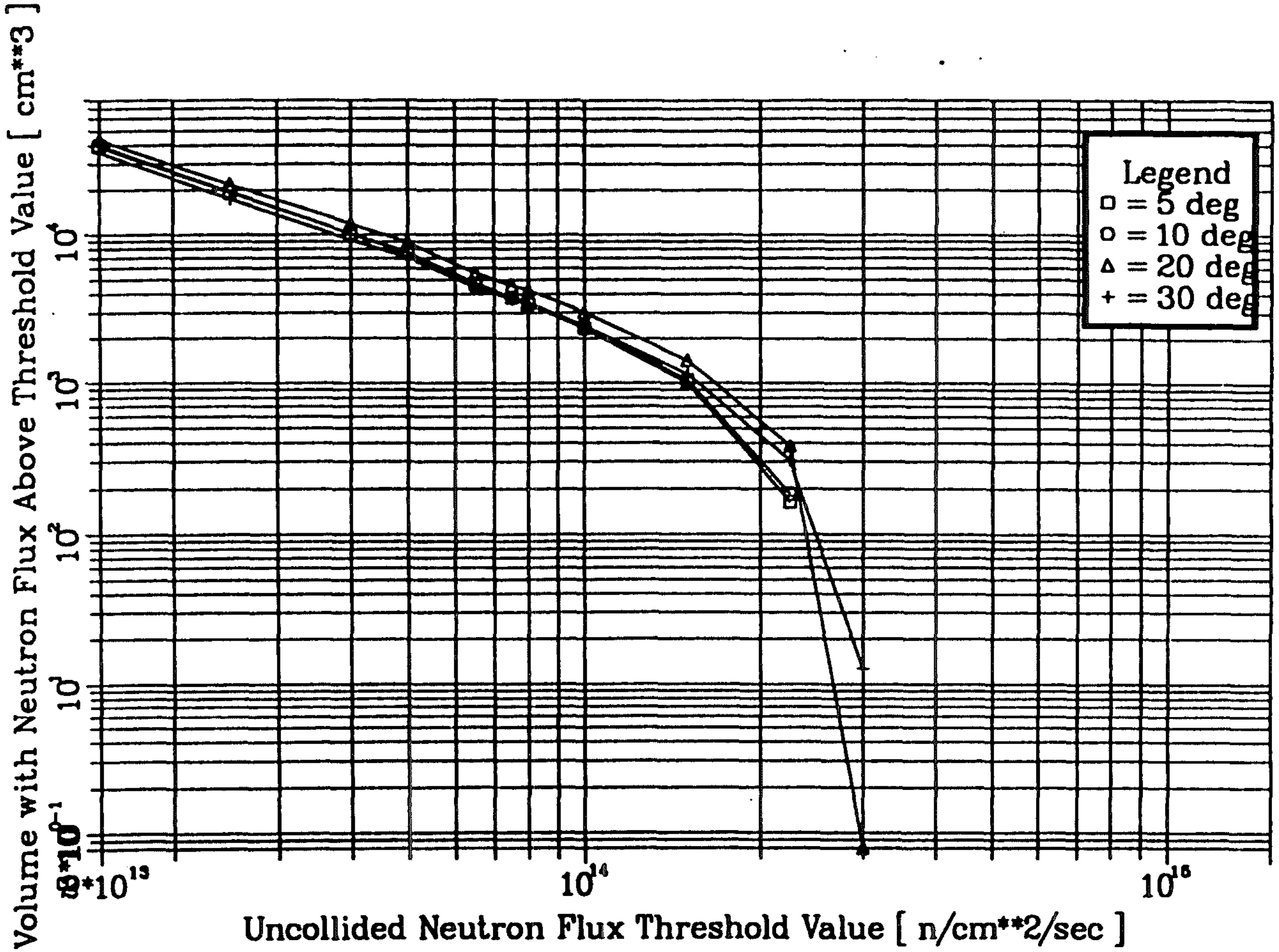

Figure 18. Volume with uncollided neutron flux above a specified threshold as a function of the threshold value for the two beams on the same target configuration for different angles between the beam direction and the normal to the target.

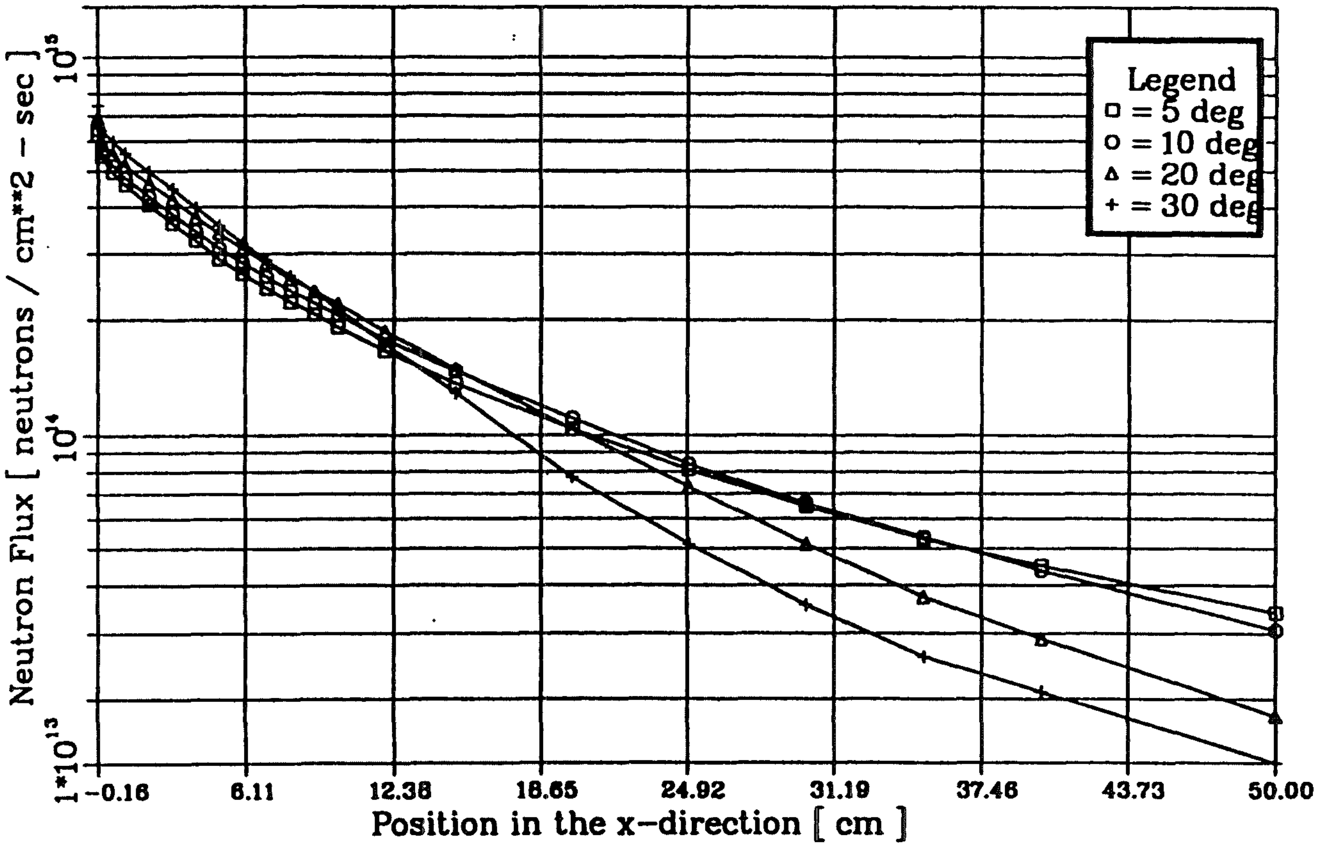

Figure 9. Uncollided neutron flux distribution for the two-beams on the same target configuration considering four different angles between the beam directions and the normal to the lithium jet. Distribution along the beam direction at the center of the beam spot area.

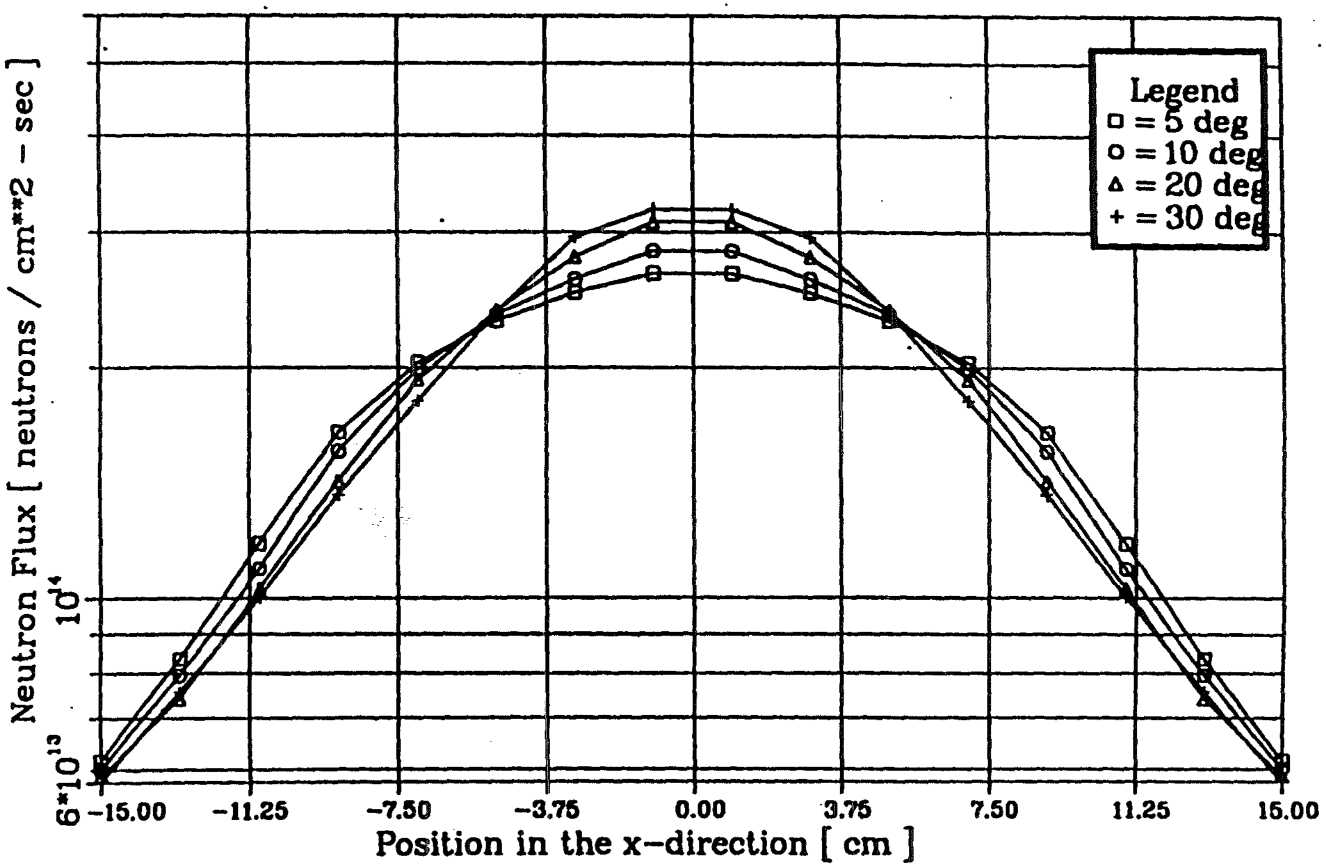

Figure 10. Uncollided neutron flux distribution for the two-beams on the same target configuration, considering four different angle between the beam directions. The curves show the profile in the direction perpendicular to the beam (Y-direction).

- Concerning the volume with nuclear responses/neutron flux above a threshold value beams incident at an angle present similar or better performance than other configurations with the same total beam cross sectional area.

- Preliminary analysis indicated that an angle to the normal to the jet around 10° to 20° present a good performance for both uniformity and volume.

- Figure 18 shows comparison of the available volume for different angles of incidence. Figure 19 shows a comparison of the volume produced with uncollided flux above a threshold value for different configuration.

Note: Label ⇒ 1 beam = 1 single beam 20 x 20

2b-90 deg = 2 beams of 20 x 20 incident on two separated jets

curved = convex jet facing the beam

2b-20 deg = 2 beams 10 x 20 on the same jet

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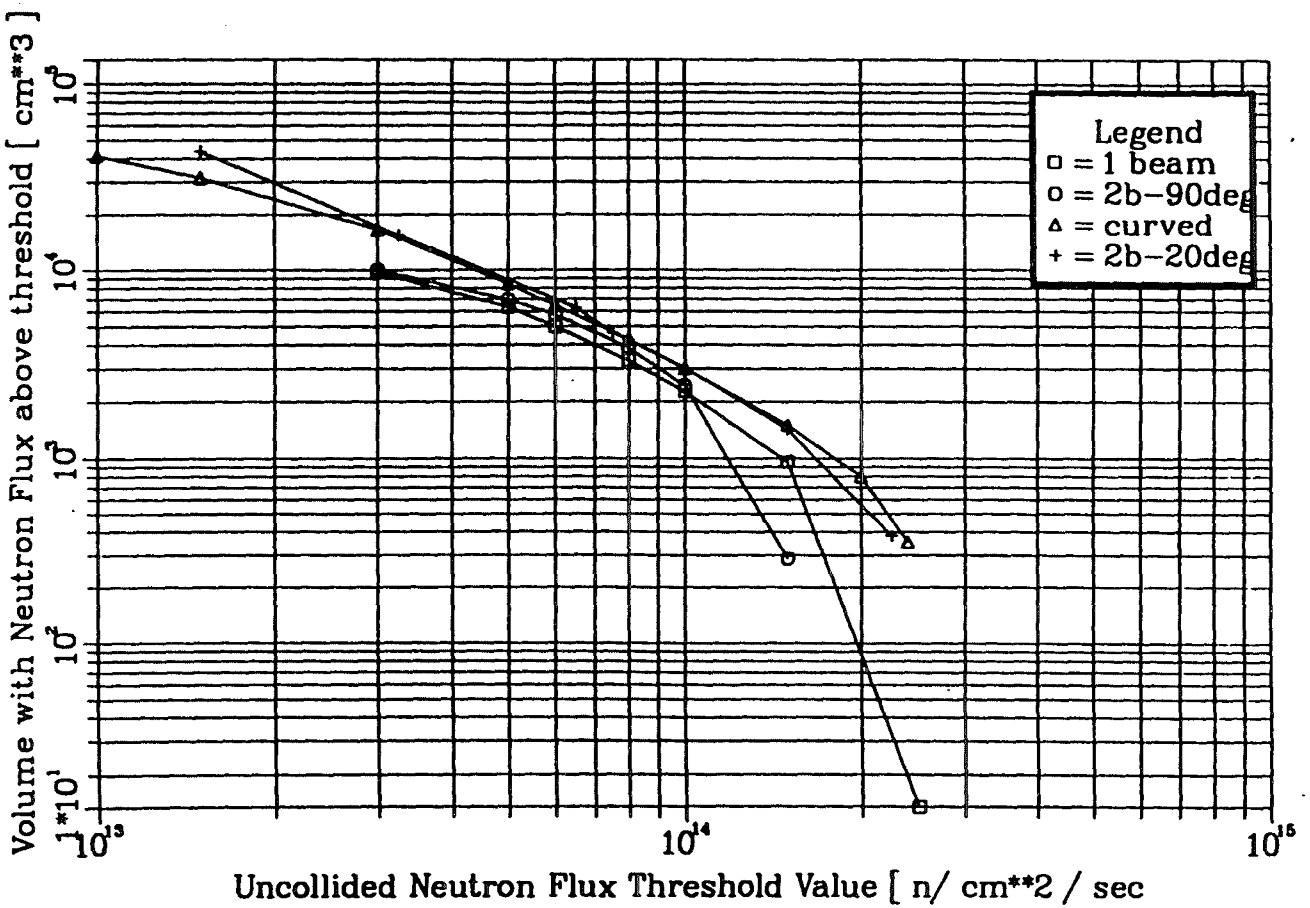

Figure 19. Volume with uncollided neutron flux above a specified threshold as a function of the threshold value for the four beam-target configurations analyzed.

Irradiation Modules Inside the Test Assembly Region

- Larger beams allow a larger area facing the jet at the high flux allowing the placement of different temperature irradiation modules at the high flux region.

- Preliminary calculations indicated that a thin layer of air between two modules would be enough to avoid significant heat transfer from a module to another.

- The placement of the sample modules can roughly follow the dpa contour lines. Figure shows that a 10 x 10 cm^2 beam size produces a very well suitable distribution for modules placement.

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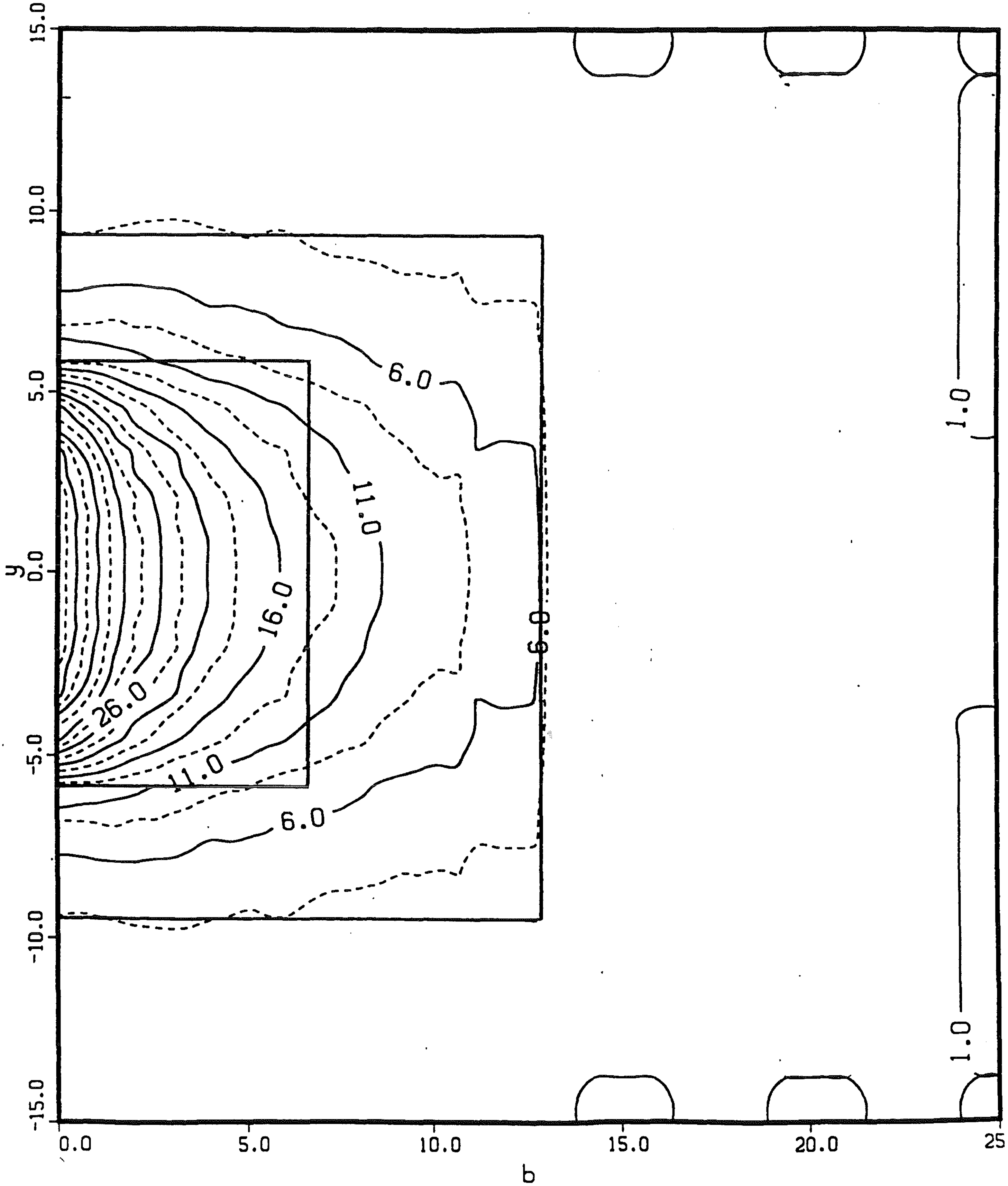
Collided Neutron Flux - 250 mA current



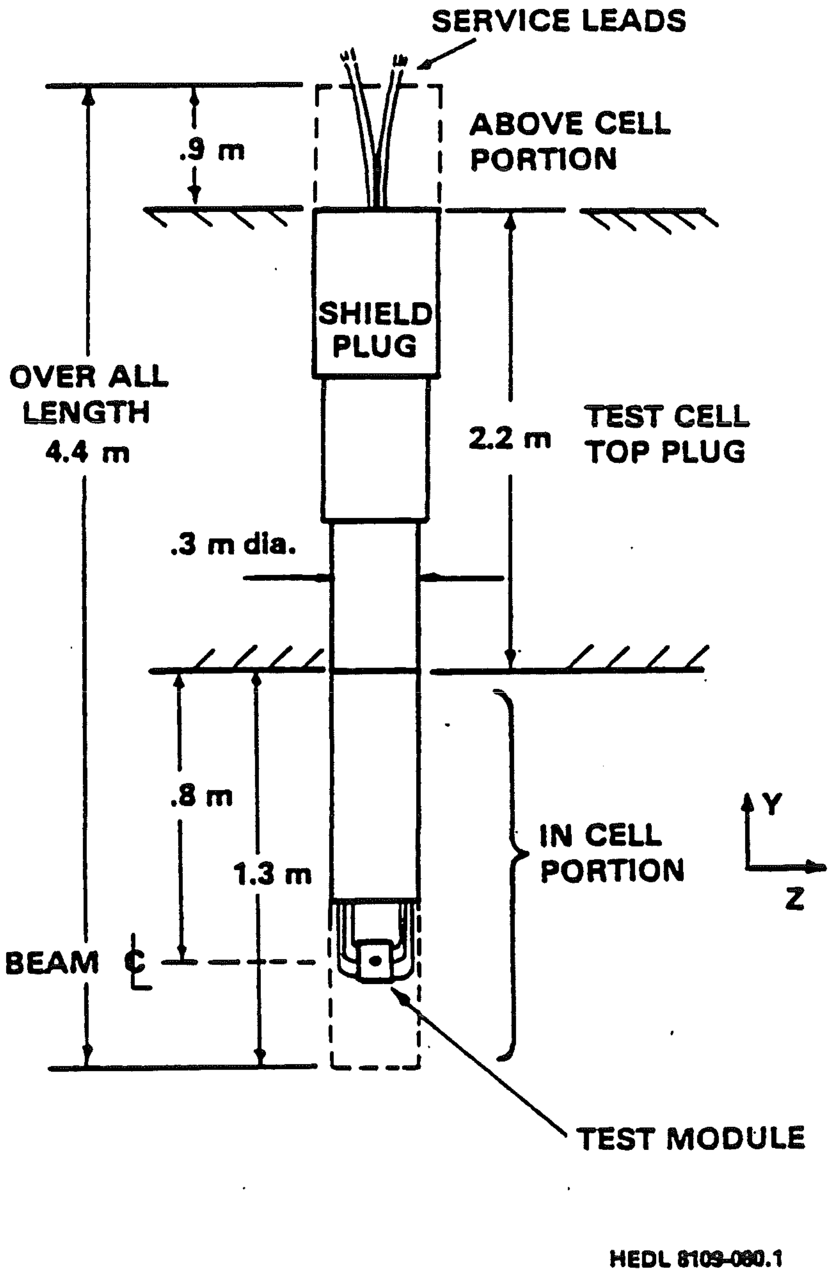


FIGURE 6. Vertical Test Assembly Located in Experiment Port.

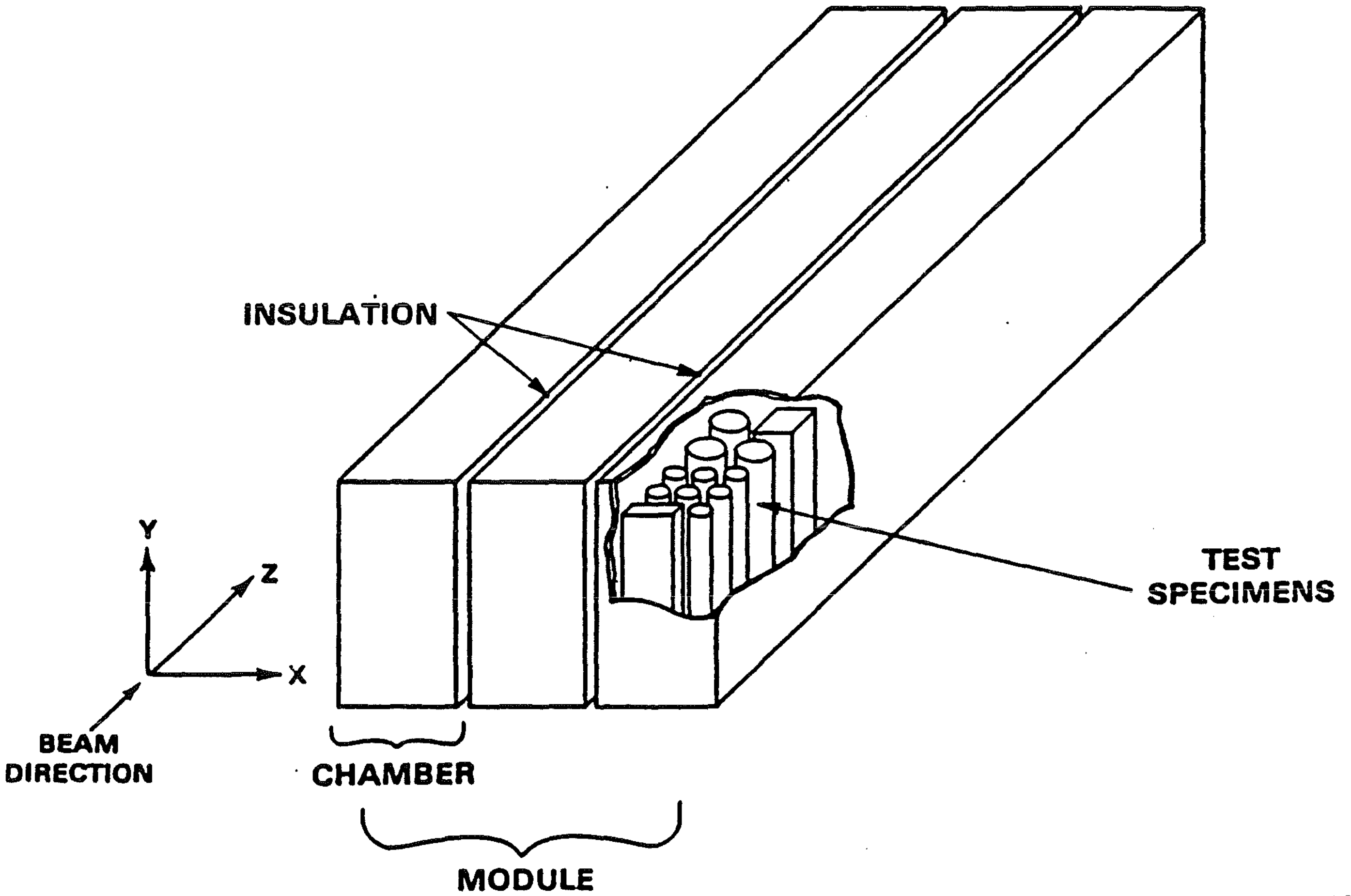


FIGURE 7. High Flux Test Module (VTA-1).

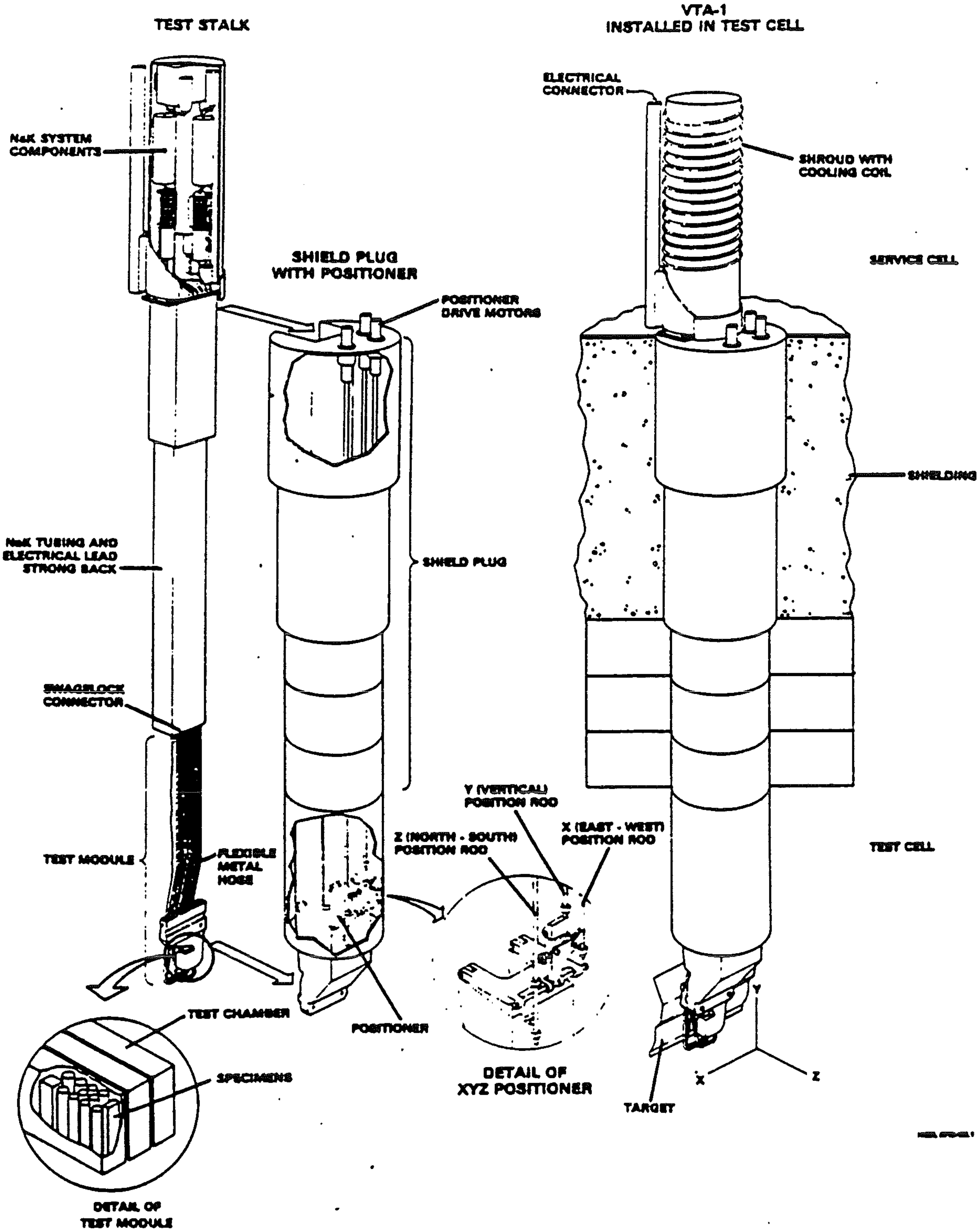


FIGURE 8. VTA-1 With Thermal Control System Located in Above-Cell Portion of Stalk.

TABLE 3

SPECIMEN SIZES USED IN HIGH FLUX TEST MATRIX
(Dimensions in Centimeters)

Packing containers	.37 dia x .33(ID) x 2 to 4
	1.1 dia x 1.0(ID) x 2 to 4
	2.5 dia x 2.3(ID) x 4 to 10
	1.0 x 1.0 x 6
TEM Disc	.30 dia x .030
Tensile	
Wire	.051 dia x 1.3 to 2
Flat (1)	.254 x .038 x 1.27 to 3.2
Flat (2)	.50 x .075 x 4.5
Pressurized Tube	.254 dia x 1.3
Beam or Stress Relaxation	.50 x .050 x 4
Charpy	1.0 x .50 x 5.5
Flux Cycling	Unspecified
Stress Cycling	Unspecified
Other Materials (Micro)	Unspecified
Other Materials (Post)	Unspecified

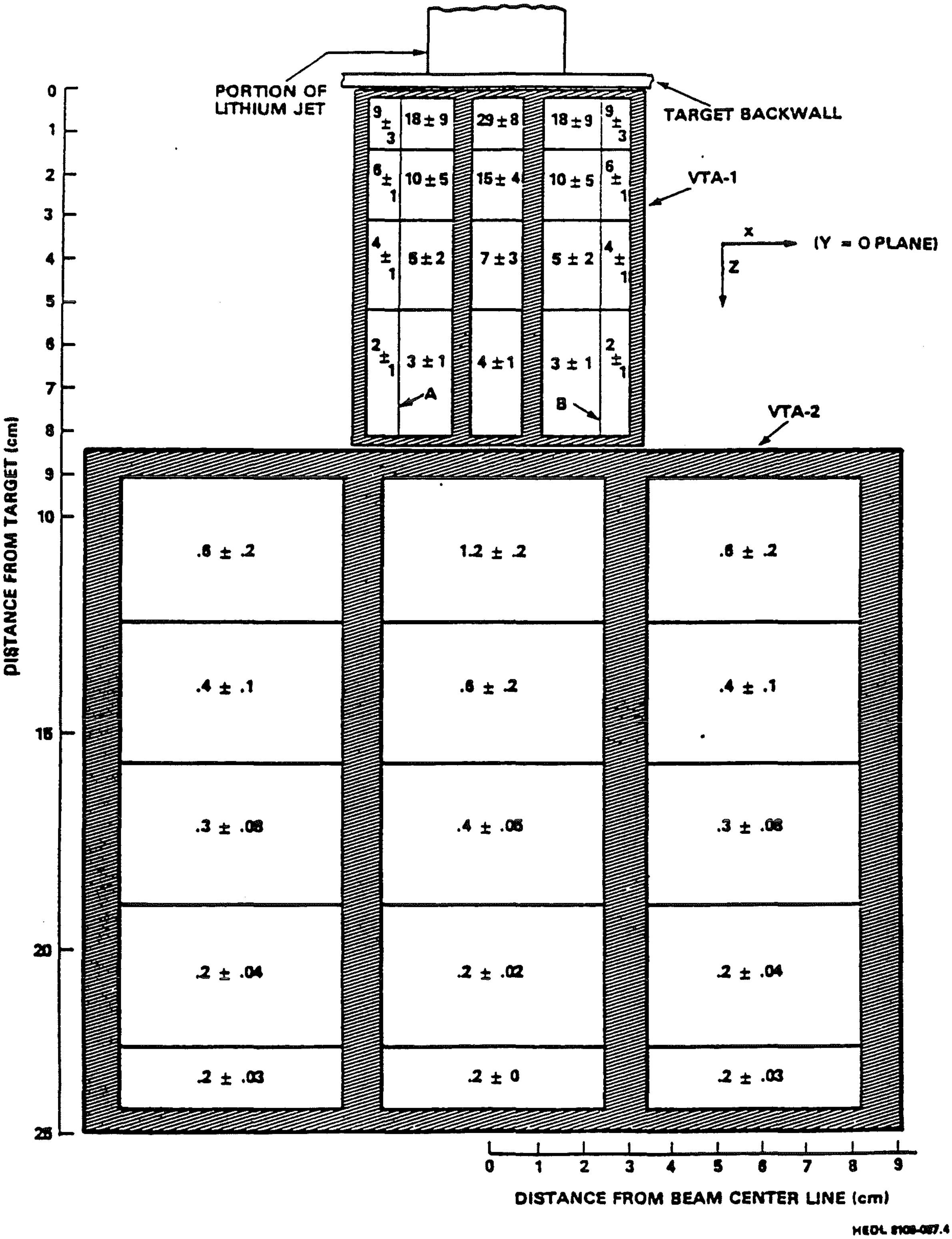


FIGURE 10. Plan View of Vertical Test Assemblies Module 1 and Module 2.
NOTE: Displacement per atom (dpa) values are shown for a volumetric module packing of 50% stainless steel and 50% NaK. Dpa values based on 90 full power days in stainless steel.

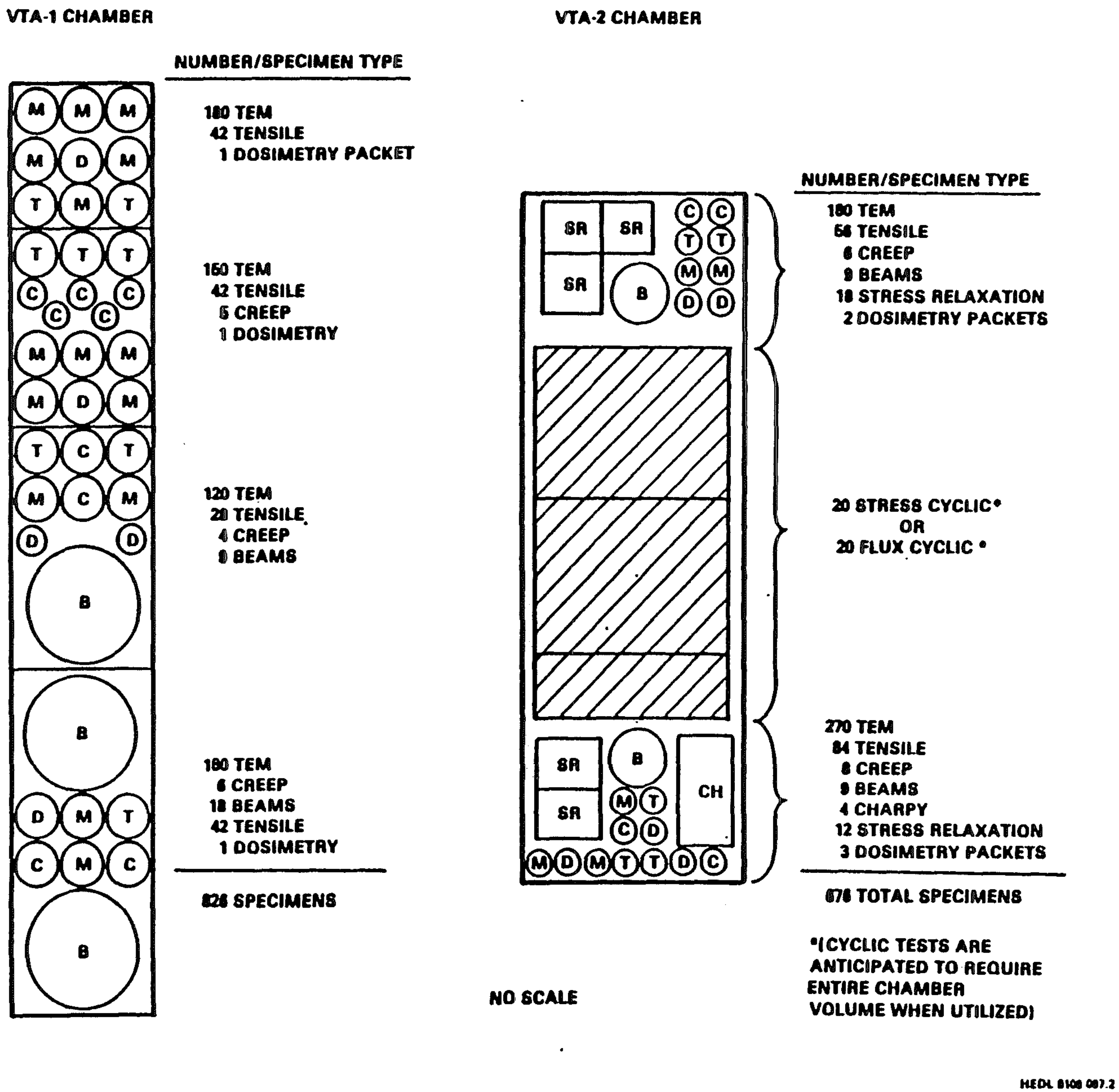


FIGURE 11. Specimen Packing Arrangement in VTA Module 1 and 2 Chambers.

Test Assembly Conclusions

- Large beam size (50-100cm^2) provides better neutronic performance
  - Larger test volume
  - Smaller flux gradients
  - Lower peak flux
  - Square beam, preferable to rectangular beam
  - Flat jet superior to curved jet for larger beam size
- Two beams incident at small angle (10-20°) on single target without overlapping of footprints is desirable
- Beam energy of 40 MeV (compared to 35 MeV) provides larger test volume/higher damage rate with only small penalty of increased fraction of high energy neutrons
- Uniform He/dpa ratio over large test volume for several materials with large beam size
- Multiple test regions with large beam size
  - High/medium/low flux regions
  - Multiple temperature regions
- Preliminary analyses indicate that the 3-4 m of shield is required for test cell

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IFMIF
Lithium Target and Loop System

D. Smith

ANL

International Fusion Materials Irradiation Facility

Lithium Target and Loop System

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Fusion Power Program

Presented at

International
Fusion Materials Irradiation Facility Meeting

Karlsruhe, Germany

September 24-29, 1994

Fusion Neutron Source

- <u>Lithium Target</u>
  - Analysis of beam-target interaction
    - Thermal response of Li jet
  - MHD stabilized Li jet
  - Material assessment of back plate
  - Evaluation of target size
  - Vaporization of Li jet
- <u>Lithium Loop/System</u>
  - Loop design
  - Corrosion issues
  - Purification system

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Fusion Power Program

Lithium Target Requirements

- Establishment of a stable lithium jet with specified geometry controlled with relatively high precision. The lithium target must be thick enough to absorb all of the deuteron energy but should not be thicker than necessary to minimize neutron losses.

- Deuteron energy deposition profile in the lithium target and neutron generation profile (number and energy) must be established.

- Lithium target flow rates must be provided to accommodate the energy deposited in the jet without excessive heating or destabilization of the jet.

- The vapor pressure of the lithium jet must be maintained sufficiently low so as to be compatible with vacuum requirements for the accelerator.

- Structural components required to provide a stable jet, e.g., nozzle and back plate, must meet certain performance and lifetime requirements to be specified.

- The lithium target system must be maintainable.

- Adequate shielding must be provided.

- Sufficient instrumentation must be provided to assure safe operation of the system.

- The target must interface geometrically and environmentally with the accelerator and test assembly.

Lithium Target System

- Lithium Jet Configuration/Stability
  - Geometry/size
  - Conventional jet with curved back plate
  - Free jet with no backplate

- Beam Target Interaction
  - Thermal hydraulic response
  - Vaporization rates
  - Nuclear response

- System Interfaces
  - Test cell interface
  - Accelerator interface
  - Lithium loop system
  - Shielding
  - Remote handling
  - Instrumentation/control

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Lithium Target System

- Stabilized Jet (Configuration)
  - Conventional Jet
    - Geometry (Size)
    - Backplate Integrity/Lifetime
  - Free Jet
    - MHD Stabilization
    - Lifetime/Integrity Components
- Beam Target Interaction
  - Nuclear Response
  - Thermal-Hydraulic Response
- Lithium Loop System
  - Pump/Heat Rejection System
  - Chemistry Control System
  - Instrumentation/Control
- System Interfaces
  - Test Cell Interface
  - Accelerator Interface
  - Remote Handling Interface
  - Vacuum Interface
  - Instrumentation/Control

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Lithium Target and Test Assembly

Current Focus of Activity

- Beam Target Interaction
  - Beam Profile
  - Considerations for Beam on Target Demonstration
- Li Jet
  - Stability of Free Flow Jet
  - Large Jet Cross-Section (Geometry)
  - Backplate and Nozzle Material Selection
- Test Module Configuration
  - Neutron Source Profile (Increased Size)
  - Single Versus Dual Beam Approaches
  - Optimized Test Module Geometry
    - Neutron Economy
    - Shield Optimization
- Shield Optimization
  - Reduce Backstreaming
  - Optimize Reflector/Shield
- Lithium Loop System
  - Chemistry Control System Requirements
  - Tritium Containment

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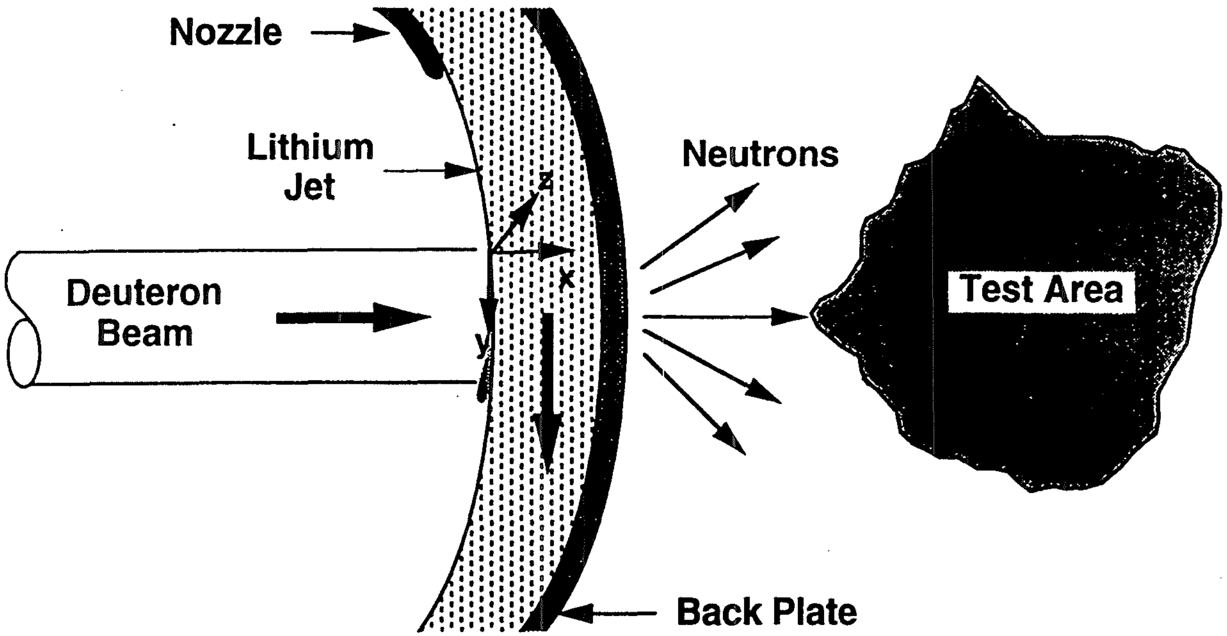
Analysis

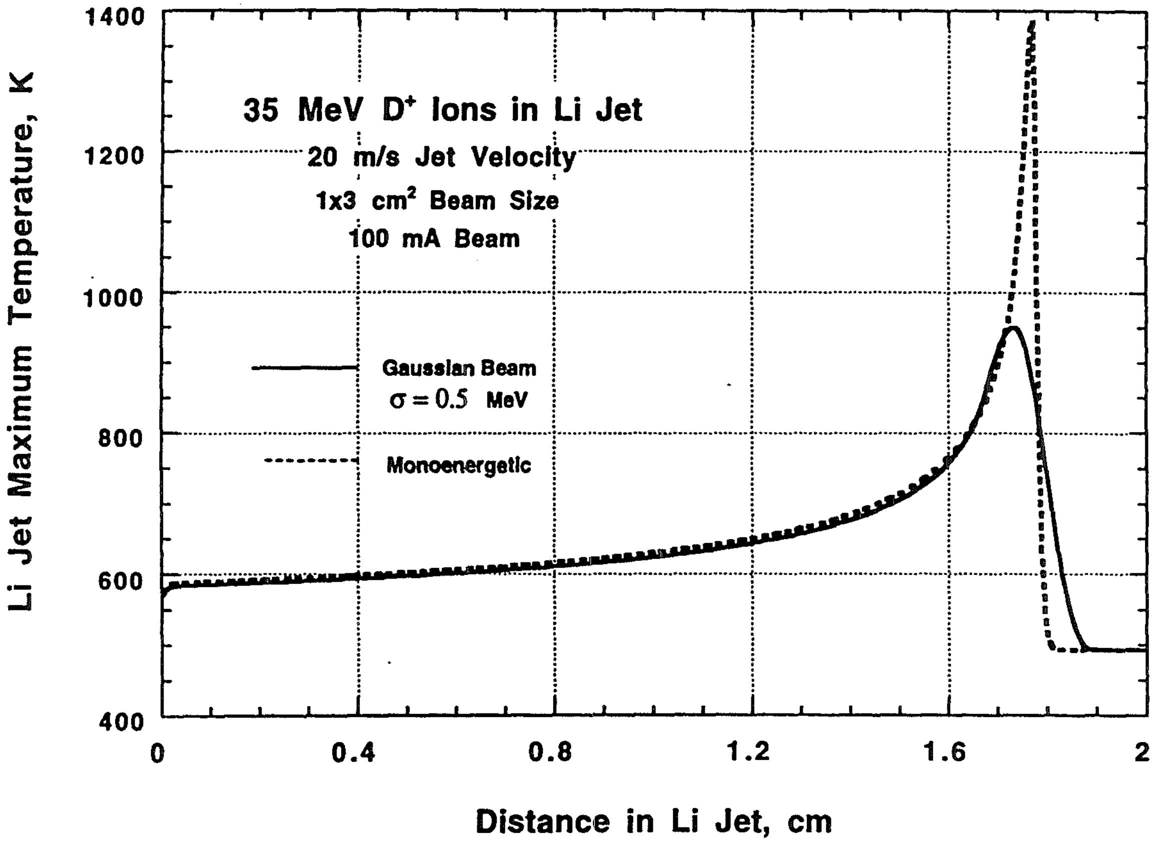
- The deposition and the response of lithium jet due to bombardment of high-energy deuterons are modeled with the A*THERMAL code.

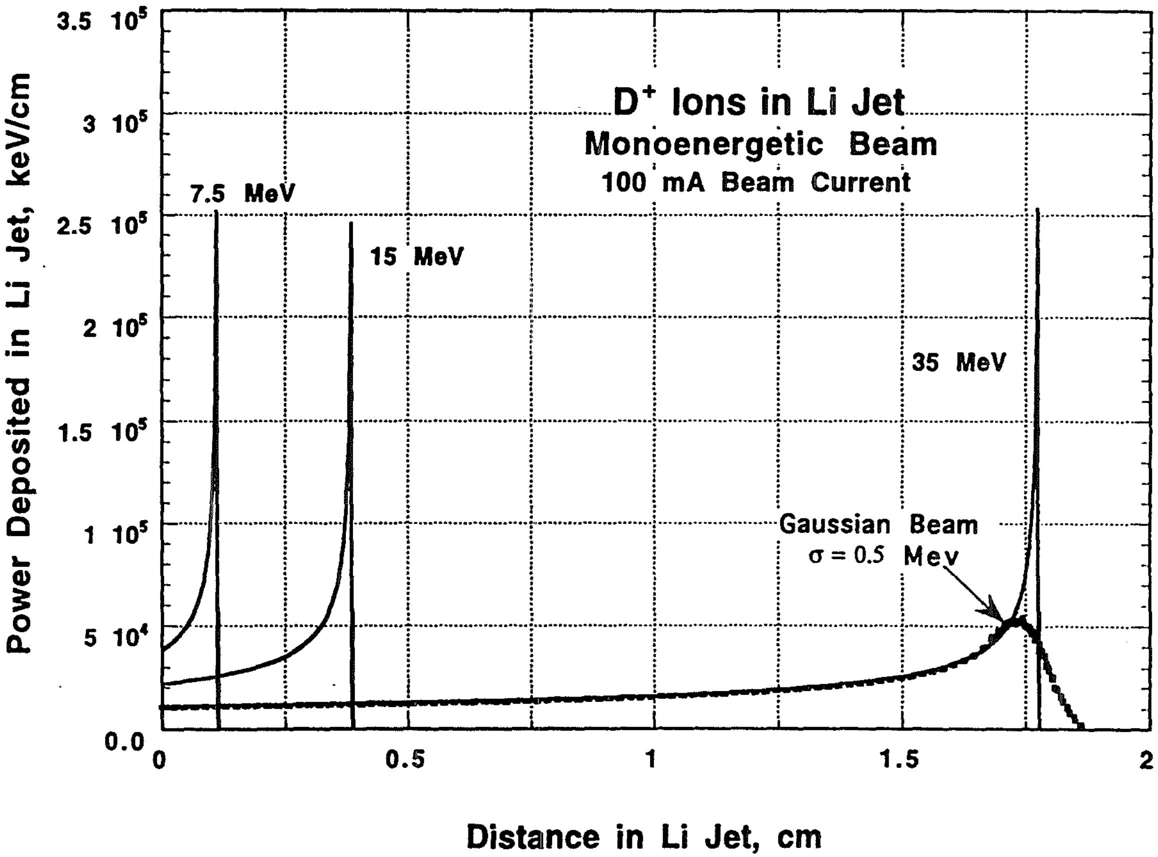
- The code uses several analytical models to calculate the energy loss of ion beam through both electronic and nuclear stopping powers.

- The code then calculates detailed thermal response of the jet and the supporting back plate using advanced and efficient numerical methods.

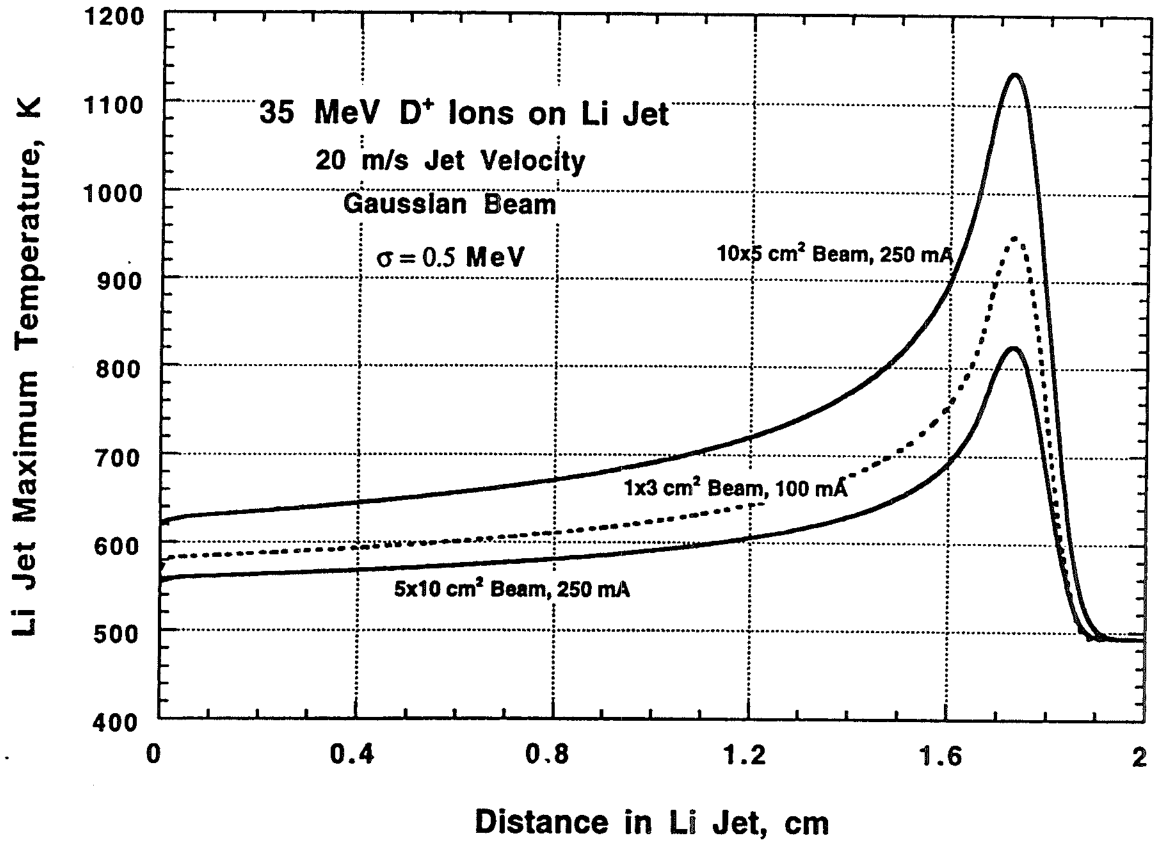
- Models to calculate net surface evaporation rate of the Li jet are also implemented in the code.

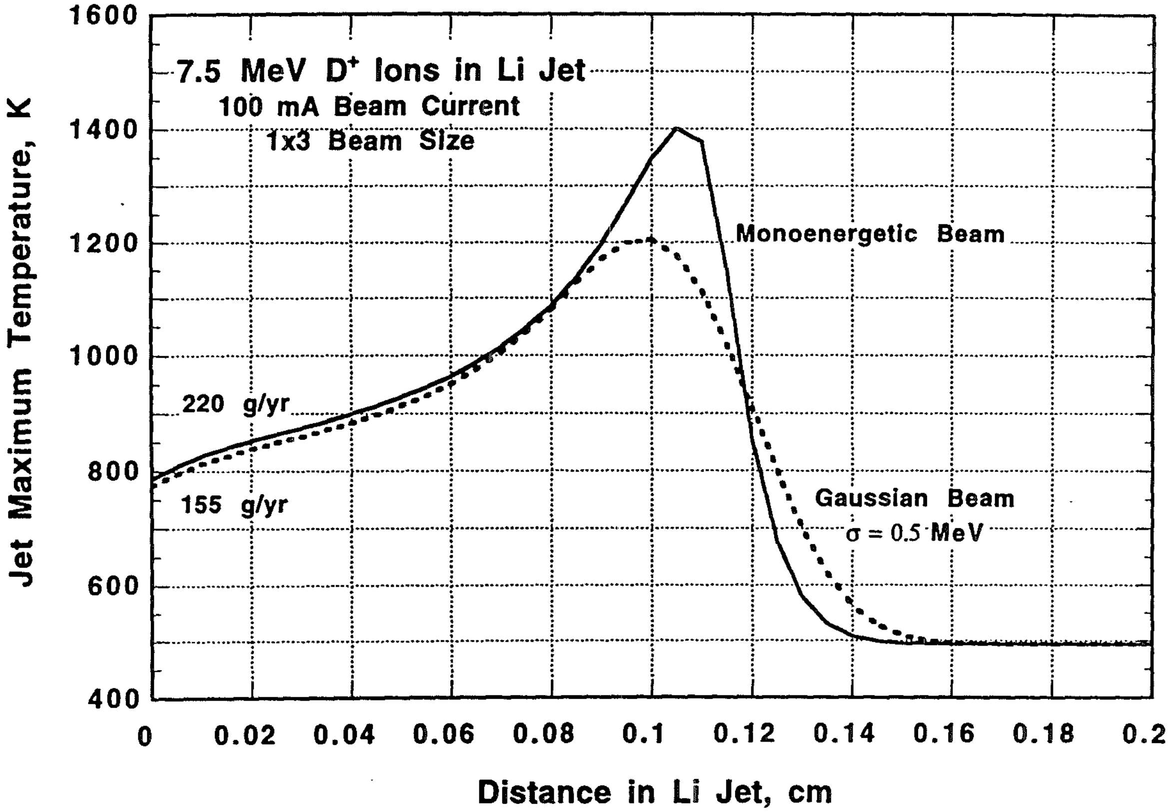

Nozzle
Lithium Jet
z
x
y
Deuteron Beam
Neutrons
Test Area
Back Plate

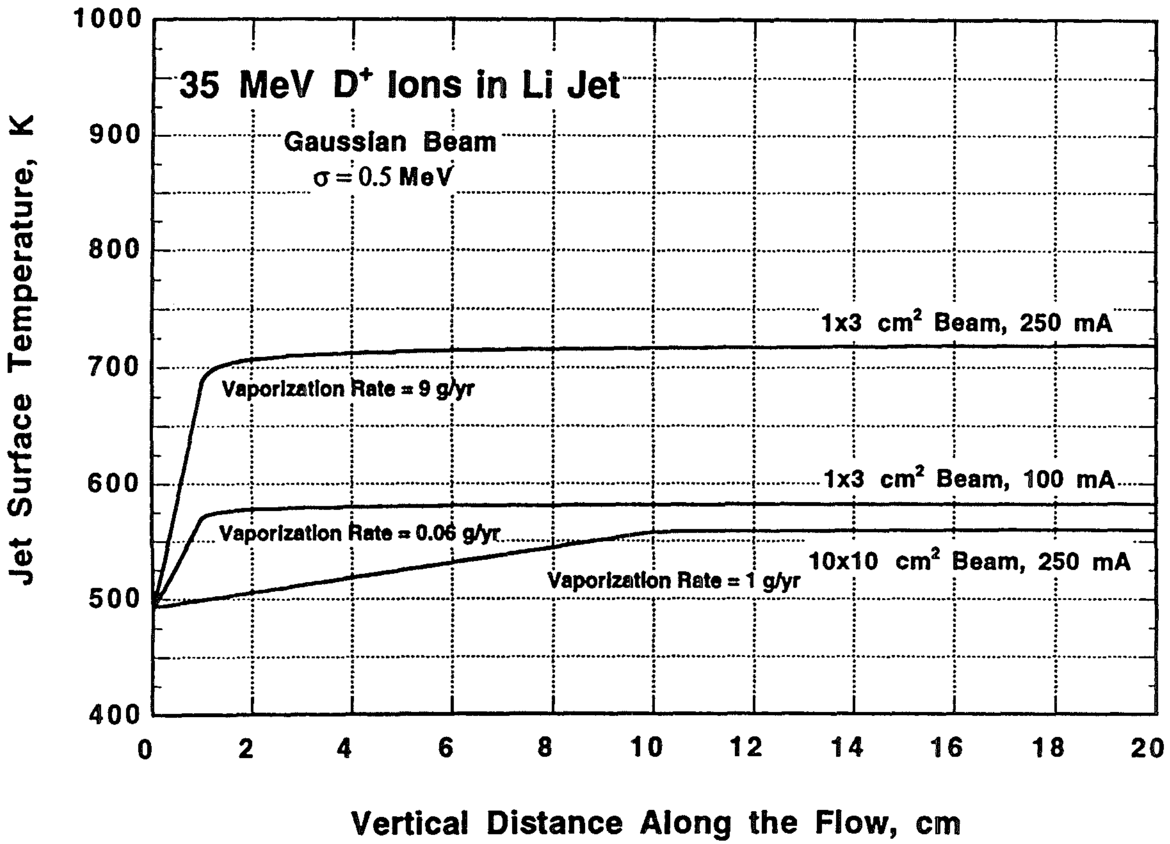

35 MeV D+ Ions in Li Jet
20 m/s Jet Velocity
1x3 cm² Beam Size
100 mA Beam
Gaussian Beam
σ = 0.5 MeV
Monoenergetic
Li Jet Maximum Temperature, K
Distance in Li Jet, cm
400
600
800
1000
1200
1400
0
0.4
0.8
1.2
1.6
2

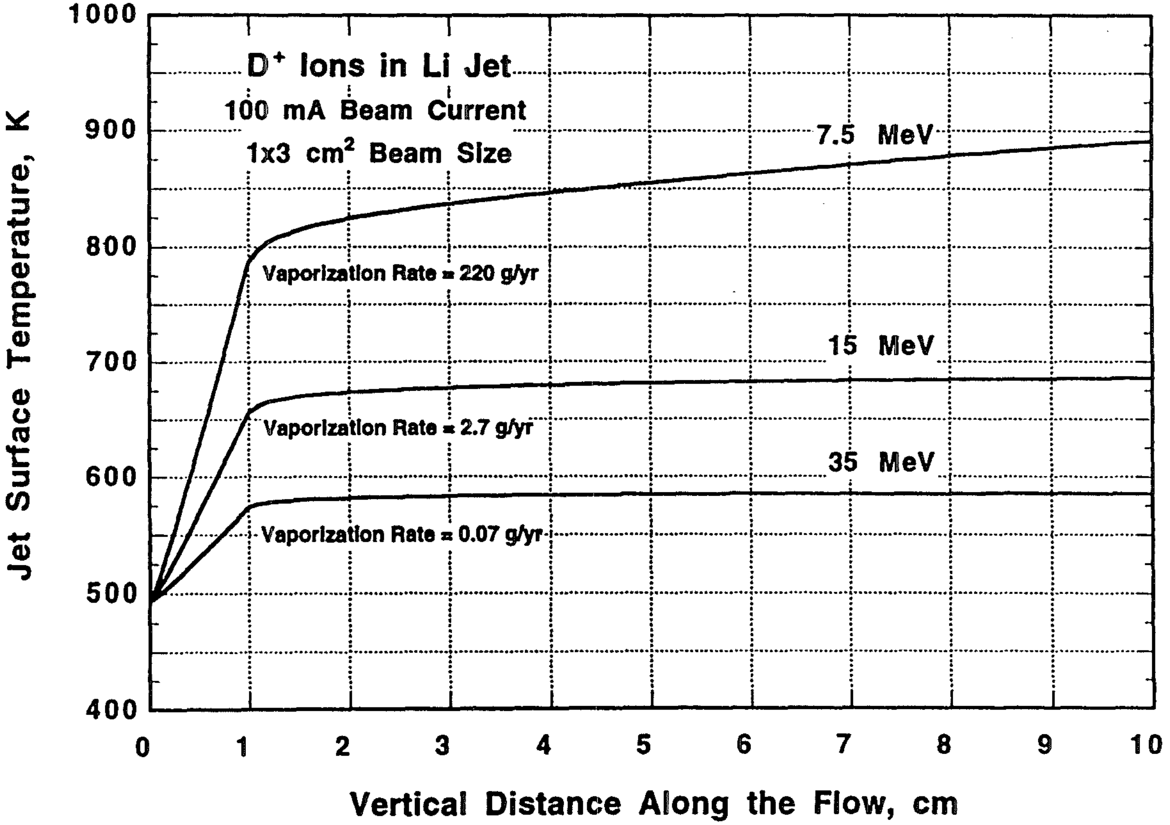


D+ Ions in Li Jet
Monoenergetic Beam
100 mA Beam Current
7.5 MeV
15 MeV
35 MeV
Gaussian Beam
σ = 0.5 Mev
Power Deposited in Li Jet, keV/cm
3.5 10^5
3 10^5
2.5 10^5
2 10^5
1.5 10^5
1 10^5
5 10^4
0.0
0
0.5
1
1.5
2
Distance in Li Jet, cm

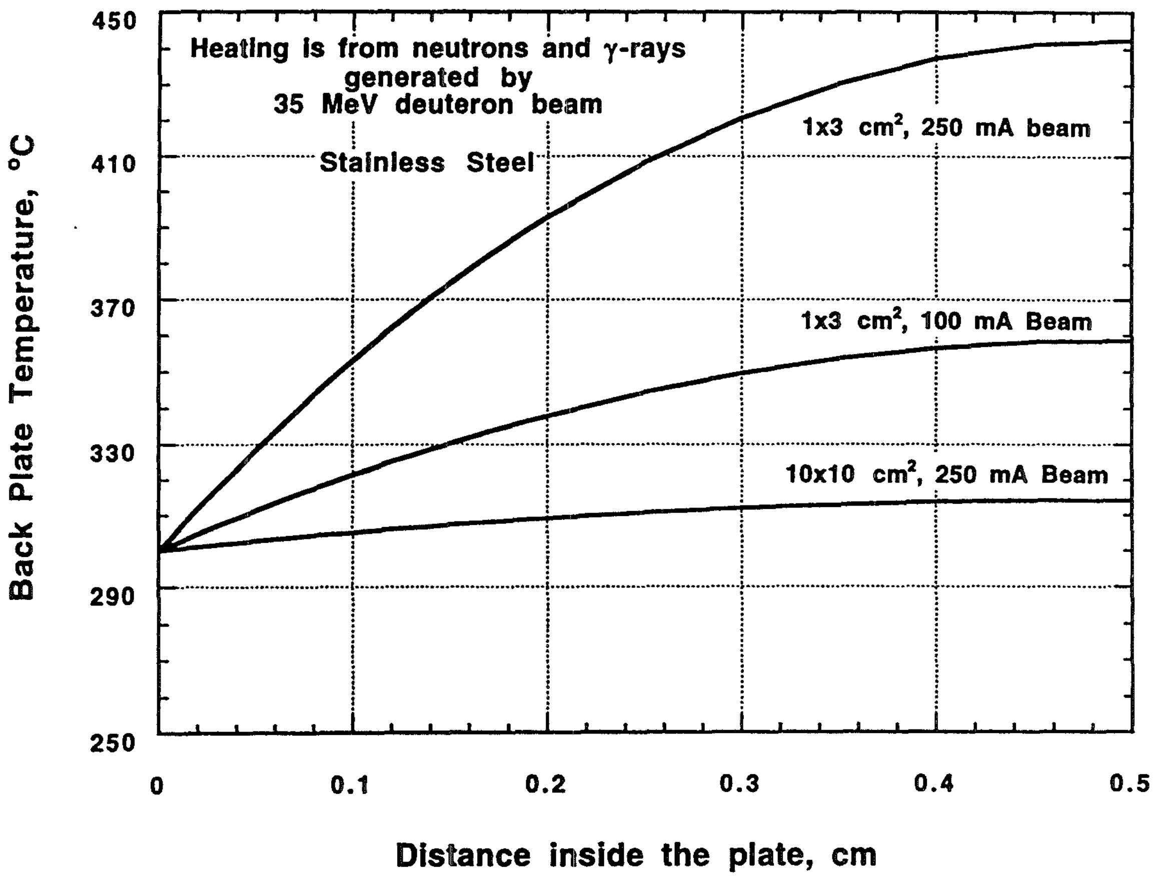

35 MeV D+ Ions on Li Jet
20 m/s Jet Velocity
Gaussian Beam
σ = 0.5 MeV
10x5 cm² Beam, 250 mA
1x3 cm² Beam, 100 mA
5x10 cm² Beam, 250 mA
Li Jet Maximum Temperature, K
Distance in Li Jet, cm
1200
1100
1000
900
800
700
600
500
400
0
0.4
0.8
1.2
1.6
2

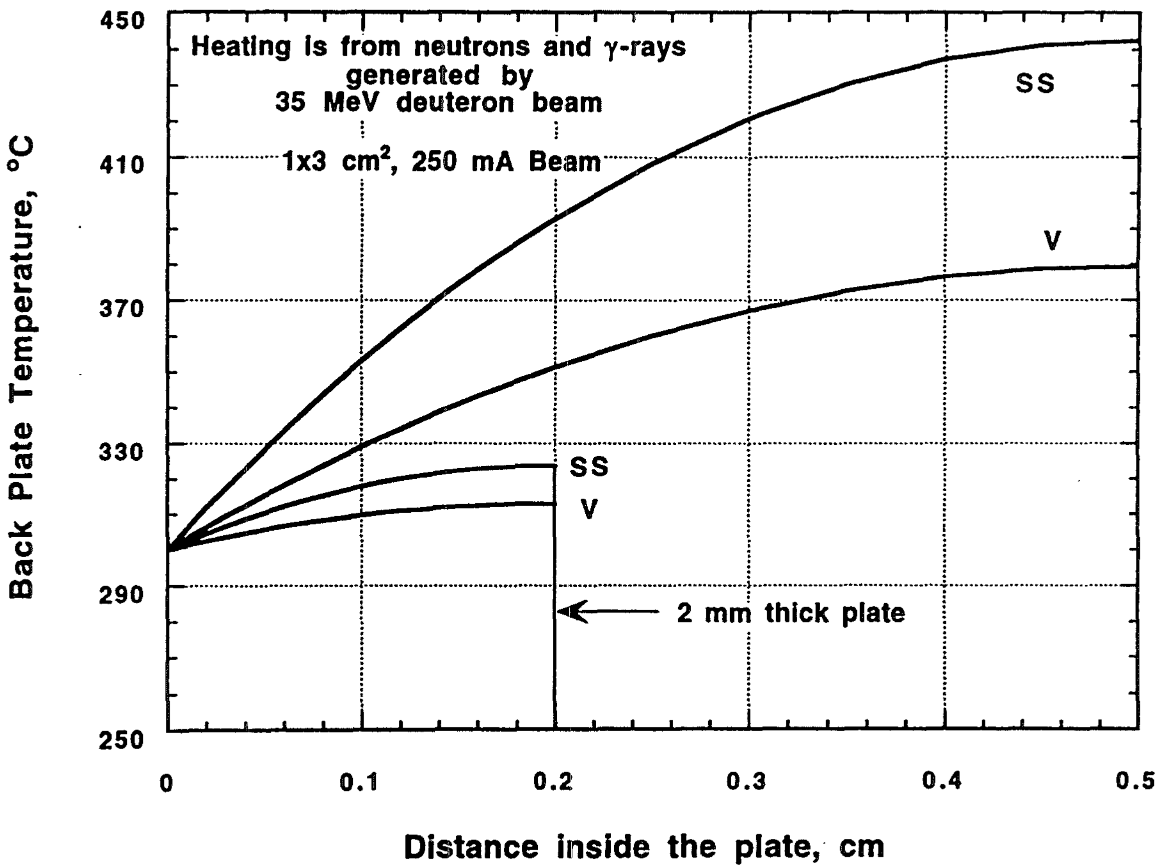

7.5 MeV D+ Ions in Li Jet
100 mA Beam Current
1x3 Beam Size
Monoenergetic Beam
Gaussian Beam
σ = 0.5 MeV
220 g/yr
155 g/yr
Jet Maximum Temperature, K
1600
1400
1200
1000
800
600
400
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Distance in Li Jet, cm


35 MeV D+ Ions in Li Jet
Gaussian Beam
σ = 0.5 MeV
1x3 cm2 Beam, 250 mA
Vaporization Rate = 9 g/yr
1x3 cm2 Beam, 100 mA
Vaporization Rate = 0.06 g/yr
10x10 cm2 Beam, 250 mA
Vaporization Rate = 1 g/yr
Jet Surface Temperature, K
1000
900
800
700
600
500
400
0
2
4
6
8
10
12
14
16
18
20
Vertical Distance Along the Flow, cm



D⁺ Ions in Li Jet
100 mA Beam Current
1x3 cm² Beam Size
7.5 MeV
15 MeV
35 MeV
Vaporization Rate = 220 g/yr
Vaporization Rate = 2.7 g/yr
Vaporization Rate = 0.07 g/yr
Jet Surface Temperature, K
Vertical Distance Along the Flow, cm
1000
900
800
700
600
500
400
0
1
2
3
4
5
6
7
8
9
10


Heating is from neutrons and γ-rays
generated by
35 MeV deuteron beam
Stainless Steel
1x3 cm², 250 mA beam
1x3 cm², 100 mA Beam
10x10 cm², 250 mA Beam
Back Plate Temperature, °C
450
410
370
330
290
250
0
0.1
0.2
0.3
0.4
0.5
Distance inside the plate, cm



Heating is from neutrons and γ-rays generated by 35 MeV deuteron beam
1x3 cm², 250 mA Beam
SS
V
SS
V
2 mm thick plate
450
410
370
330
290
250
0
0.1
0.2
0.3
0.4
0.5
Back Plate Temperature, °C
Distance inside the plate, cm

Conclusions

- Deuteron energy deposited and the resulting Li target heating calculations seem to be manageable for beam and jet parameters analyzed.

- Lithium jet surface evaporation depends on beam size, beam current, beam energy, and jet velocity.

- Larger beam sizes reduce thermal load inside the jet and increase available test volume.

- Thermal loads in the back plate are more tolerable with thinner plates.

- Other issues such as beam stability, erosion of structure by high velocity, flowing jet, and maximum allowable jet surface evaporation require study.

Lithium Jet Profile Stability

FMIT

- Use of curved backplate to profile/ stabilize jet
- Lifetime of backing plate is an issue
  - Irradiation damage
  - Corrosion/erosion

Proposed Modifications:

- Free jet (no backplate)
  - Lifetime issue for backplate
  - Maintenance/replacement of back- plate
  - Vacuum issue

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KEY ISSUES OF LITHIUM JETS

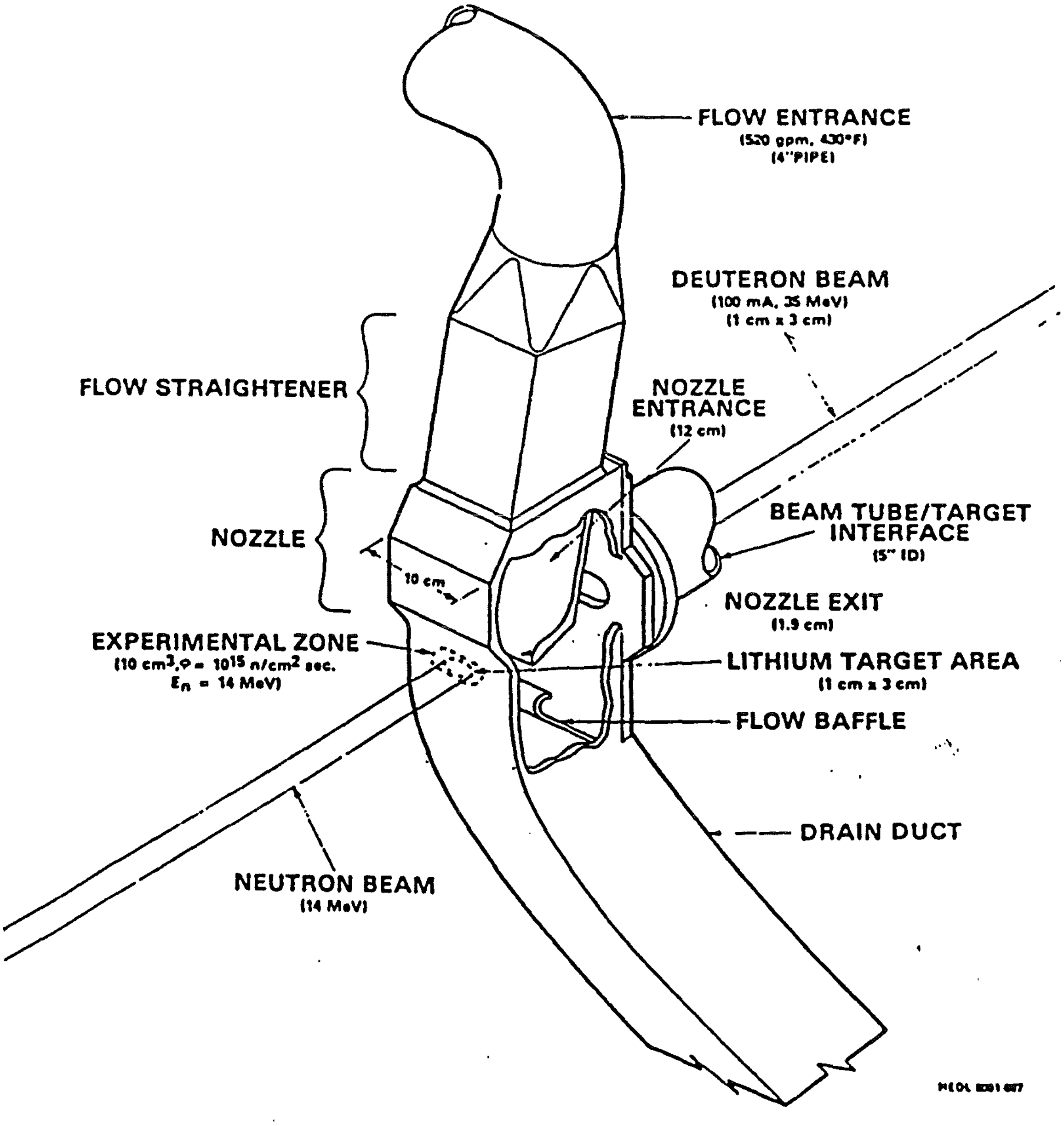
- Dynamic stability
  - stability for larger beam size
  - turbulence
  - ambient medium
  - velocity profile relaxation effect

- Thermodynamic stability
  - superheat in jet bulk fluid

- Beam/jet interaction
  - momentum of D^+ beam to jet

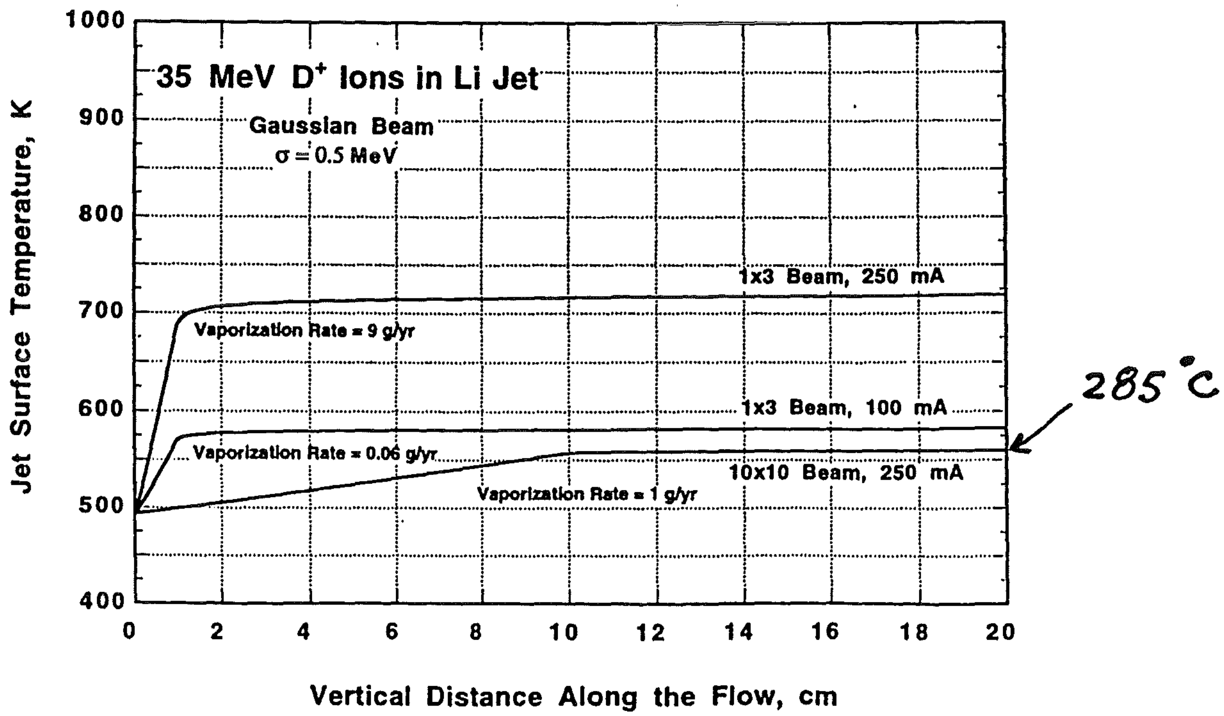
- Nozzle design
  - materials and geometry
  - calming section to enhance flow stabilization
  - isolation from noise and vibrations

FMIT LITHIUM TARGET



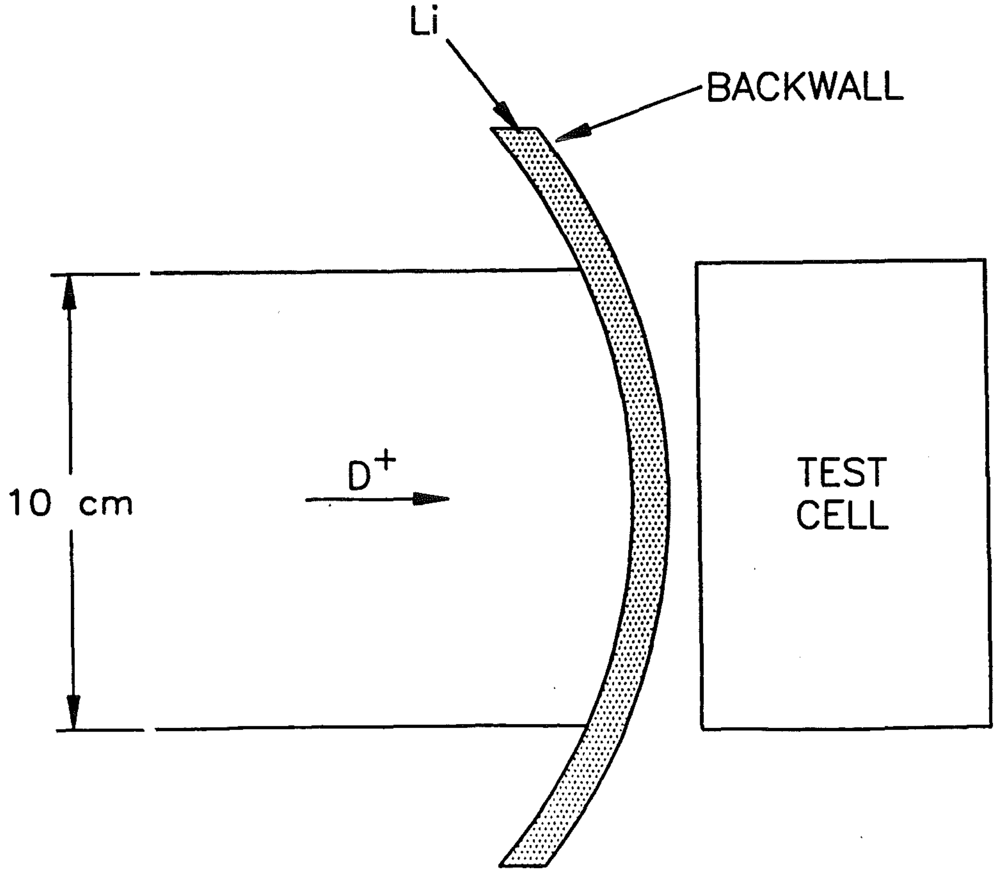
MOTIVATIONS FOR FREE JET CONCEPT

- Elimination of backwall lifetime issue
- More suitable for larger beam size proposed for IFMIF
- Larger beam size reduces power density to Li target by an order of magnitude. The amount of superheat in the jet is also reduced. Recent thermal analysis showed peak jet surface temperature below saturation temperature (310°C at 10^{-4} Pa). The computed evaporation rate was 1g/yr assuming 100% duty factor.



ISSUES CONCERNING CURVED BACKWALL CONCEPT FOR IFMIF

- Short lifetime (order of a few months)
- Frequent changeout of backwall/nozzle assembly is costly and adversely affects facility duty factor
- Wall curvature over the larger beam size (10cm x 10cm) results in lower neutron fluxes to the test section because of neutron attenuation through gap between the curved target and test section



STABILITY ANALYSIS FOR UNCONFINED JETS

- Jet stability is usually characterized through the coherent portion of the jet, or breakup length, as a function of jet velocity

- The stability of a jet may be influenced by ambient medium, turbulence in the nozzle, and velocity-profile relaxation

- As a starting point, stability analysis has been carried out for laminar Newtonian jets based on an extension of Weber's theory.

SUMMARY OF ANALYSIS

- A surface disturbance may be written as a Fourier series including terms of the form

$$\bar{\delta} = \bar{\delta}_o \, e^{\alpha\tau + ikx}$$

- The characteristic equation for α, the disturbance growth rate, is

$$\alpha^2\left[\frac{\xi I_o(\xi)}{2I_1(\xi)} + \frac{\hat{\rho}\xi K_o(\xi)}{2\rho K_1(\xi)}\right] + \alpha\left\{\frac{\mu\xi^2}{\rho a^2}\left[2\xi\frac{I_o(\xi)}{I_1(\xi)} - 1\right]\right\}$$

$$= \frac{\sigma}{2\rho a^3}\left(1-\xi^2\right)\xi^2 + \frac{v^2\hat{\rho}\xi^3 K_o(\xi)}{2a^2\rho K_1(\xi)} \qquad (1)$$

where:

ξ	= ka, wave number
a	= radius of nozzle
δ	= surface tension
ρ	= density of jet fluid
$\hat{\rho}$	= ambient density
μ	= viscosity of jet
v	= jet mean velocity
I_o, I_1	= modified Bessel functions of the first kind
Ko, K_1	= modified Bessel functions of the second kind

- The largest growth rate, α^*, from eq. (1) will eventually dominate the jet breakup.

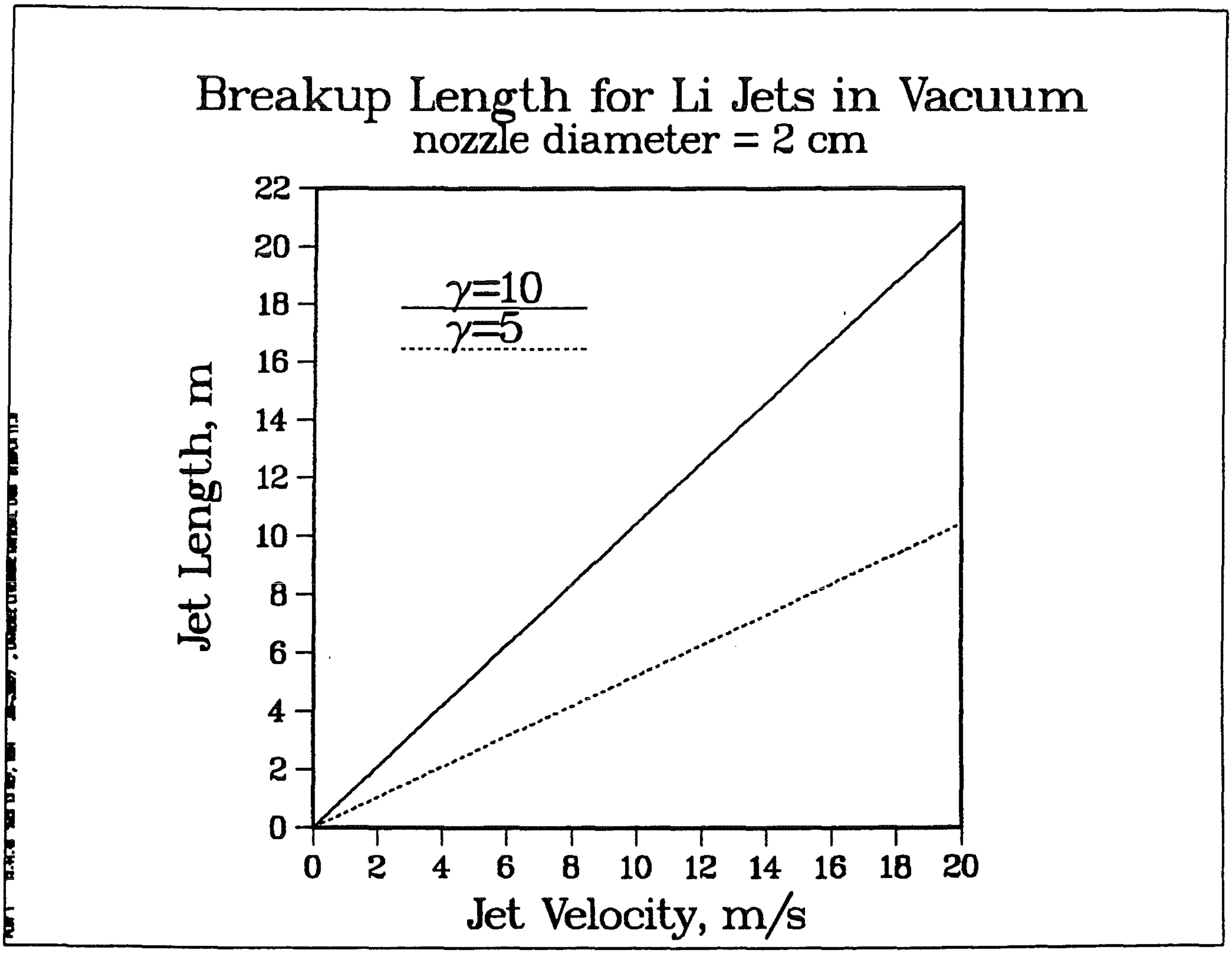
- If the initial disturbance has amplitude $\bar{\delta}_o$, and grows to magnitude "a" in time t* , then

$$t^* = \frac{1}{\alpha^*} \, ln \left(\frac{a}{\bar{\delta}_o} \right)$$

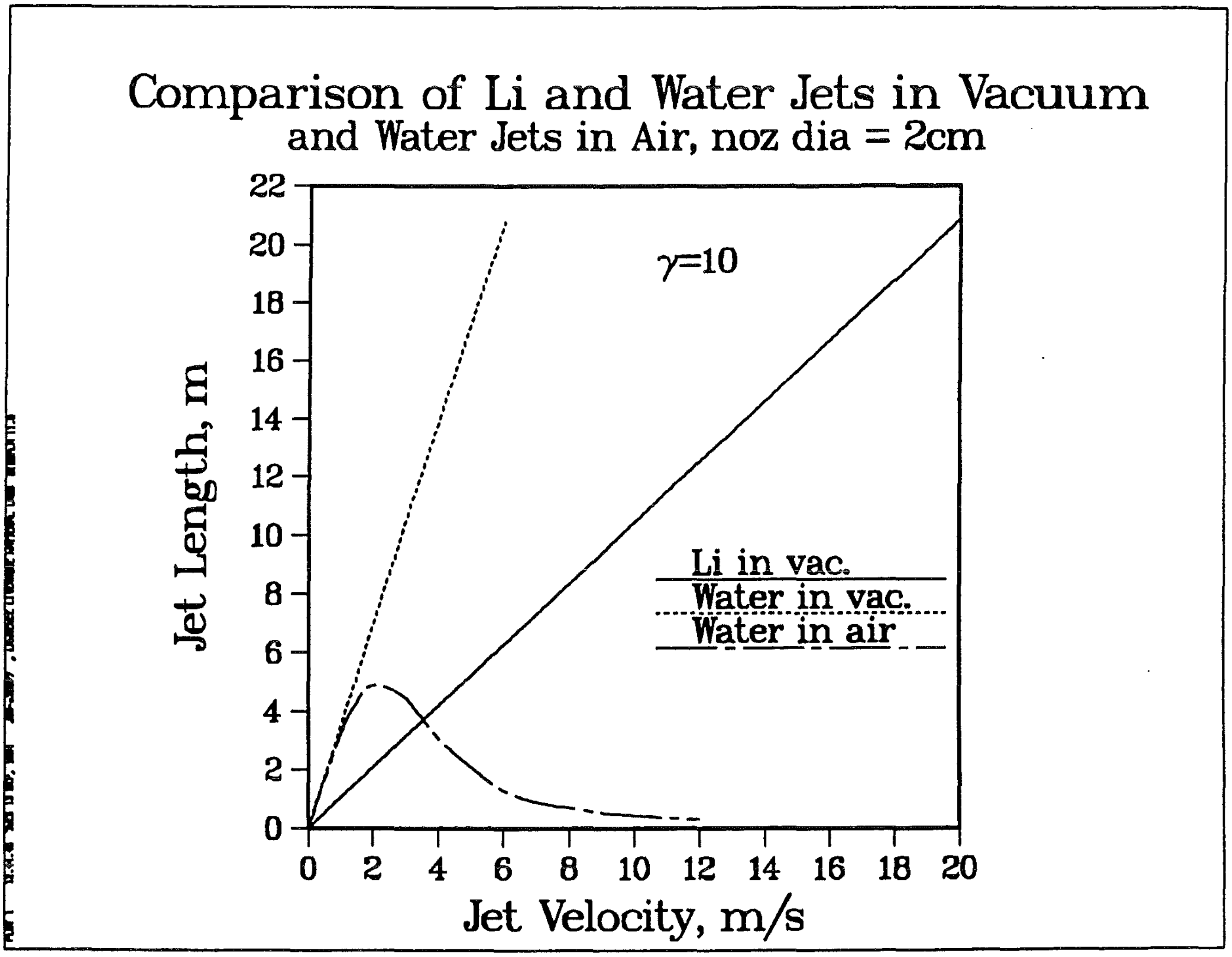
The jet length will be:

$$L = vt^* = \frac{v}{\alpha^*} \, ln \left(\frac{a}{\bar{\delta}_o} \right)$$

- The value for $\gamma = ln \left(\frac{a}{\bar{\delta}_o} \right)$ depends upon the vibration and noise and the extent to which the apparatus is isolated from such disturbances.
- Previous experiments have found $\gamma = \mathbf{10 - 14}$.



$$\gamma = \ln\left(\frac{a}{\bar{\delta}_0}\right)$$



Comparison of Li and Water Jets in Vacuum
and Water Jets in Air, noz dia = 2cm
γ=10
Li in vac.
Water in vac.
Water in air
Jet Length, m
Jet Velocity, m/s
0
2
4
6
8
10
12
14
16
18
20
22

EFFECT OF D+ BEAM MOMENTUM ON JET

- Pressure from D+ beam on Li jet:

$$\mathbf{P = m_D v_D \Phi}, \qquad \mathbf{\Phi = D^+ \text{ flux}}$$

- Force on jet:

$$\mathbf{F = \frac{P}{A,}} \qquad \mathbf{A = \text{beam area}}$$

- Acceleration of jet in beam direction:

$$\omega = \frac{\mathbf{F}}{\mathbf{Ad\rho}}, \qquad \mathbf{d = \text{jet thickness}}$$

- Displacement of jet in beam direction:

$$\Delta Z = \omega \left(\frac{\mathbf{L_B}}{\mathbf{v}} \right)^2, \qquad \mathbf{L_B = \text{beam length}}, \quad \mathbf{v = \text{jet velocity}}$$

- For 35MeV D+ beams with total current of 250 mA, beam area A= 0.1x0.1 m ^{2}, jet thickness d=2 cm and velocity v=20 m/s:

$$P = 30 \text{ Pa}$$
$$\Delta Z = 0.1 \text{ mm}$$

PRELIMINARY CONCLUSIONS

- Present analysis shows a Li jet length which is two orders of magnitude longer than that required for the IFMIF target. However, turbulence is expected to shorten this length. Experiments will be needed to characterize the jet stability under flow conditions and nozzle design for IFMIF

- High velocity jets are significantly more stable in vacuum than in air. Therefore jet simulation experiments should be conducted in vacuum conditions.

- Effect of velocity profile development in the nozzle will also influence jet stability. The extent of such effect is dependent on the nozzle design.

- Effect of D^+ beam momentum to the Li jet was found to be small

- Further analysis are in progress to determine thermodynamic stability of the jet as a result of possible boiling

FUTURE WORK

- Continue thermodynamic stability analysis
- Extend dynamic stability analysis to larger rectangular jet cross section
- Investigate effects of velocity profile relaxation in nozzle
- Nozzle design
- Jet flow profile for detail thermal analysis
- Considerations for laboratory demonstration of jet stability and beam/jet interaction

- Transmutations in the lithium jet

  - Preliminary analyses indicate that the amount of tritium produced in the lithium jet will be in the order of 10 g per fpy.

  - Beryllium production was estimated to be about 1 g/fpy.

  - Further detailed analysis is required.

LITHIUM LOOP SYSTEM

- Lithium loop design
- Purification system

  * Stringent ES&H requirements in tritium containment and handling

  * Recent advances in ITER blanket R&D and design favor the cold trap method for tritium recovery and processing

  * Beryllium handling
- Chemistry control system
- Pump and heat rejection system
- Quench tank
- Instrumentation and diagnostics

Preliminary Test Cell Design for IFMIF

L. Green

Westinghouse

Preliminary Test Cell Design for FMIF

INS Workshop

September 26-30, Karlsruhe

Westinghouse
Science & Technology Center

- Based on FMIT design
- Scaled up for FMIF Conditions
- Design Detail for layout and costing purposes

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Science & Technology Center

Test Cell Functions

- Provides cavity for lithium loop/target components and test assemblies
- Provides entry for beam flight tube(s)
- Biological shield
- Removal of heat generated by neutrons
- Removal of heat from loop and test assemblies
- Provide for insertion and removal of test assemblies
- Services required for test assemblies
- Contains beam and target diagnostics

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FMIF Test Cell

- Two design concepts considered
  - horizontal access/loading of test assemblies
  - vertical access/loading of test assemblies

- Vertical access configuration is recommended
  - Ease of test assembly handling/alignment
  - Improved remote handling equipment interfacing
  - Utilizes controlled access areas (service cell) for experiment handling/storage operations
  - Reduces test cell congestion
  - Improves operational flexibility/reliability

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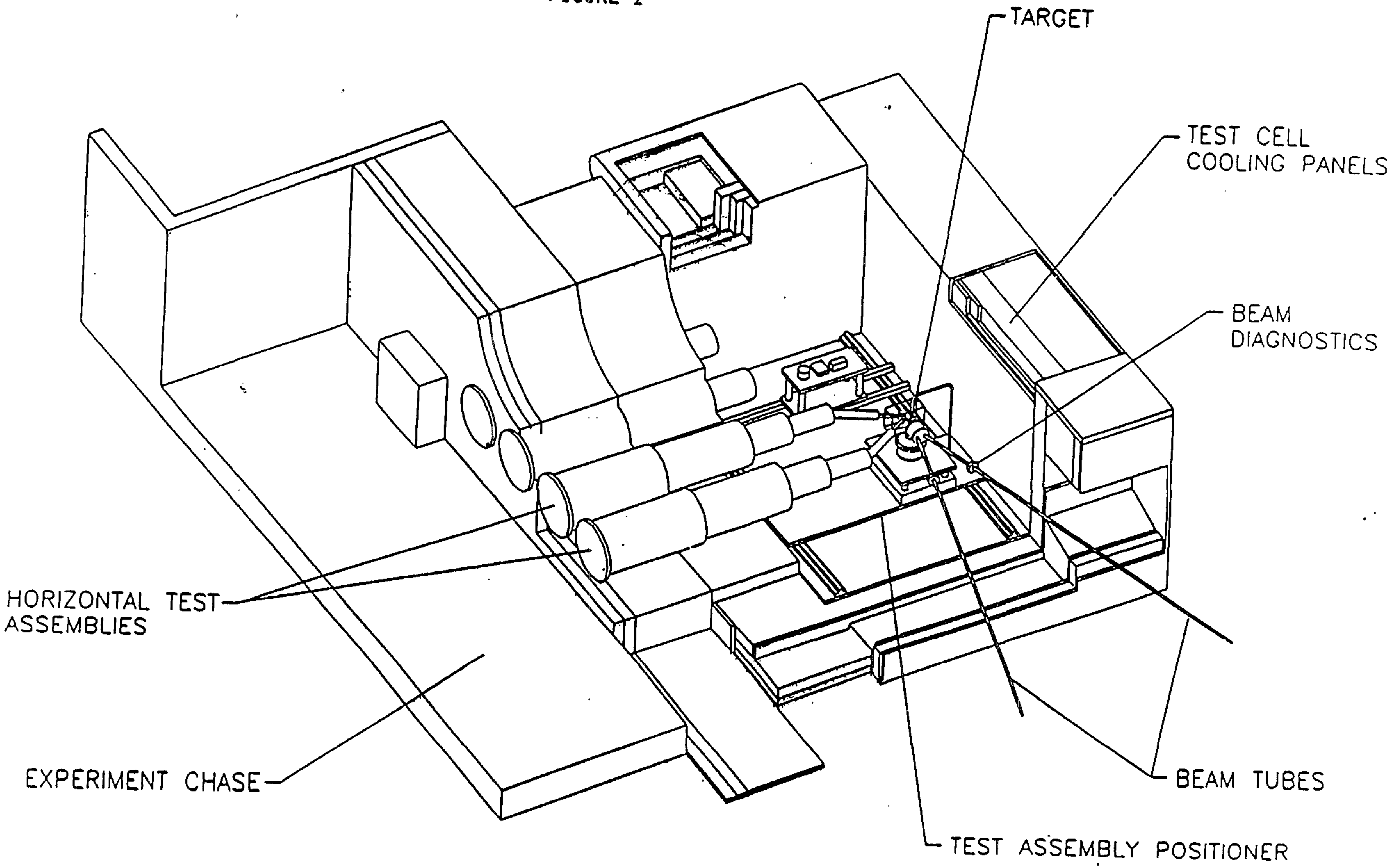
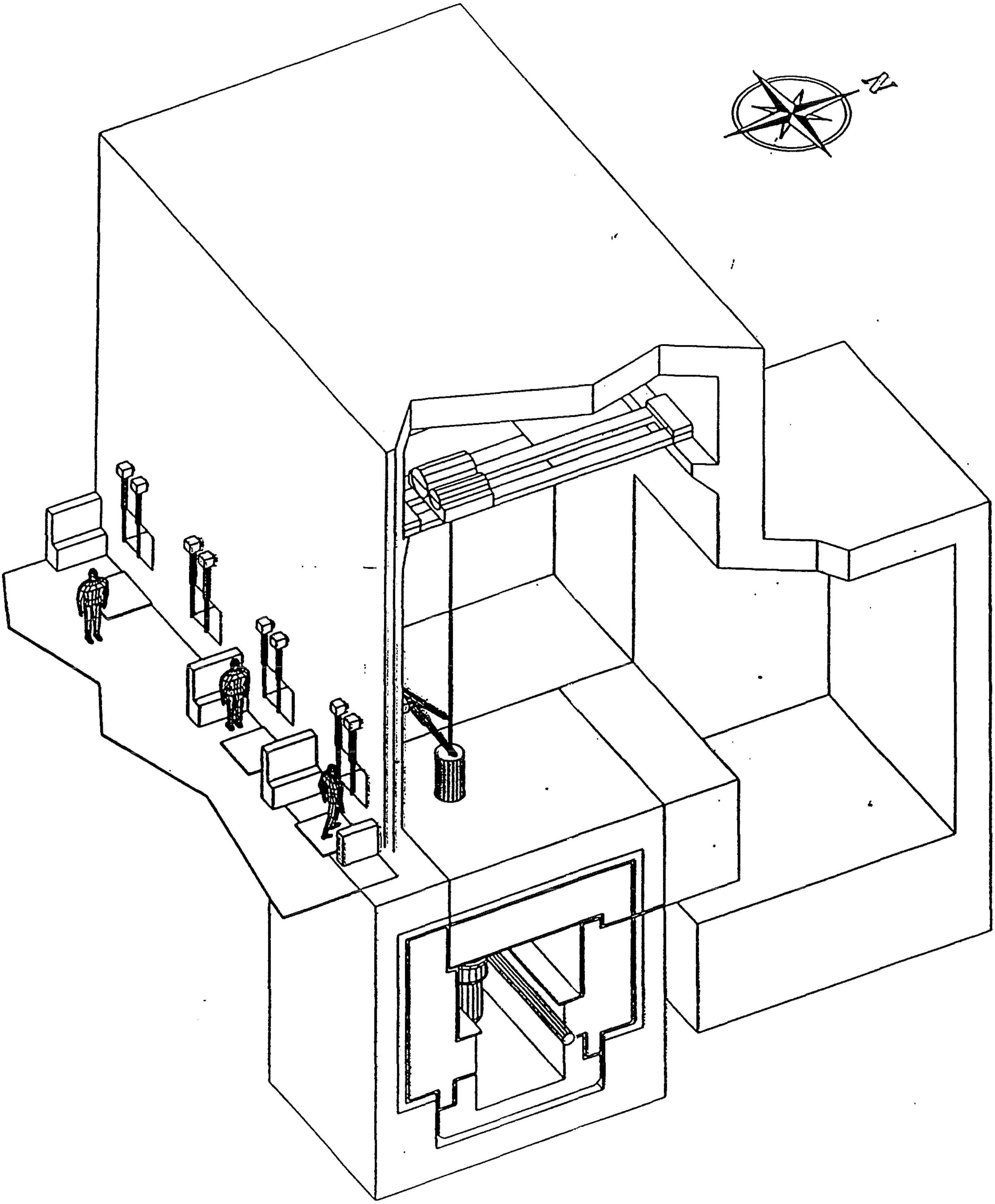
FIGURE 1



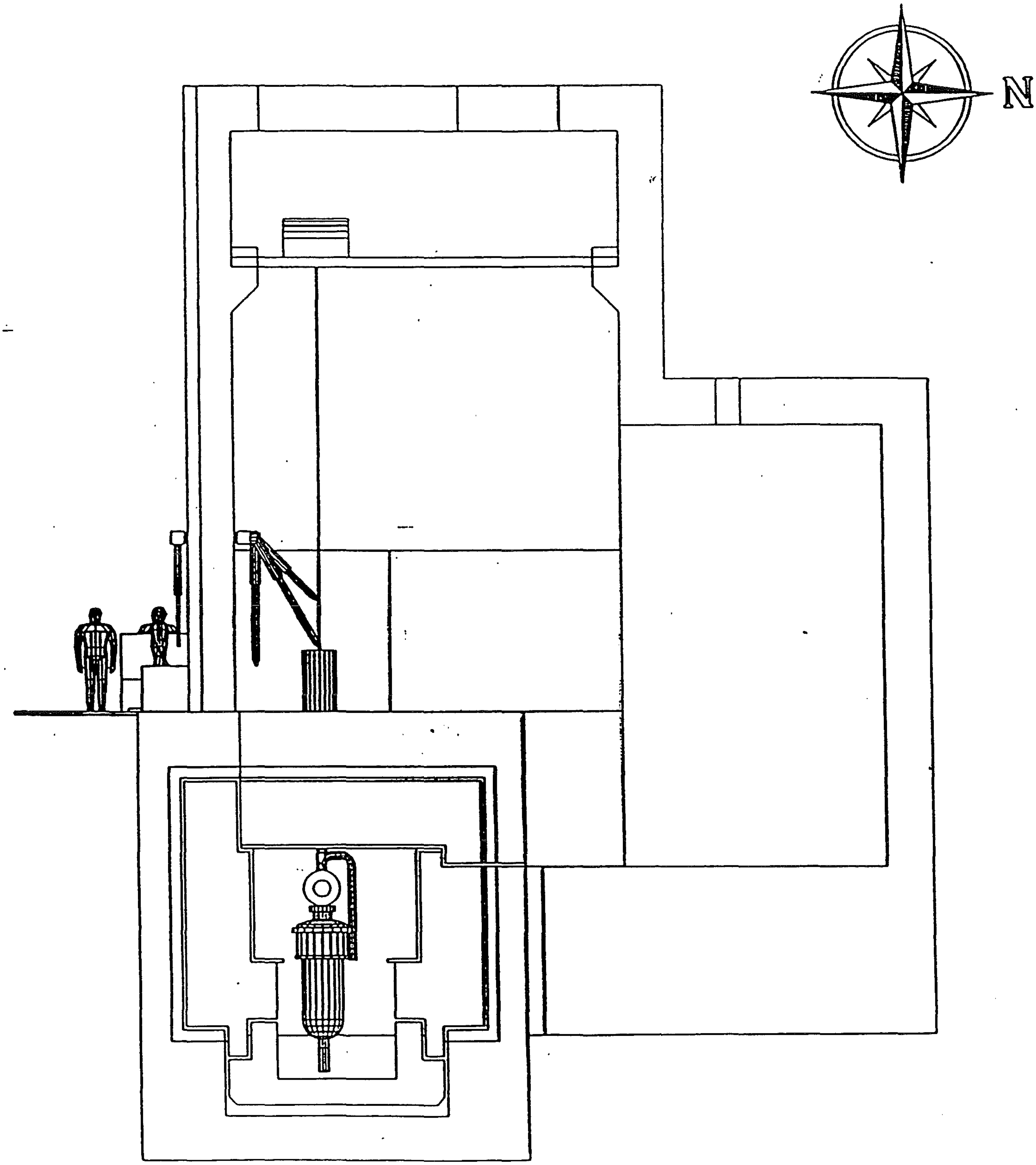
FUSION MATERIAL RADIATION
FACILITY TEST CELL

FIGURE 2



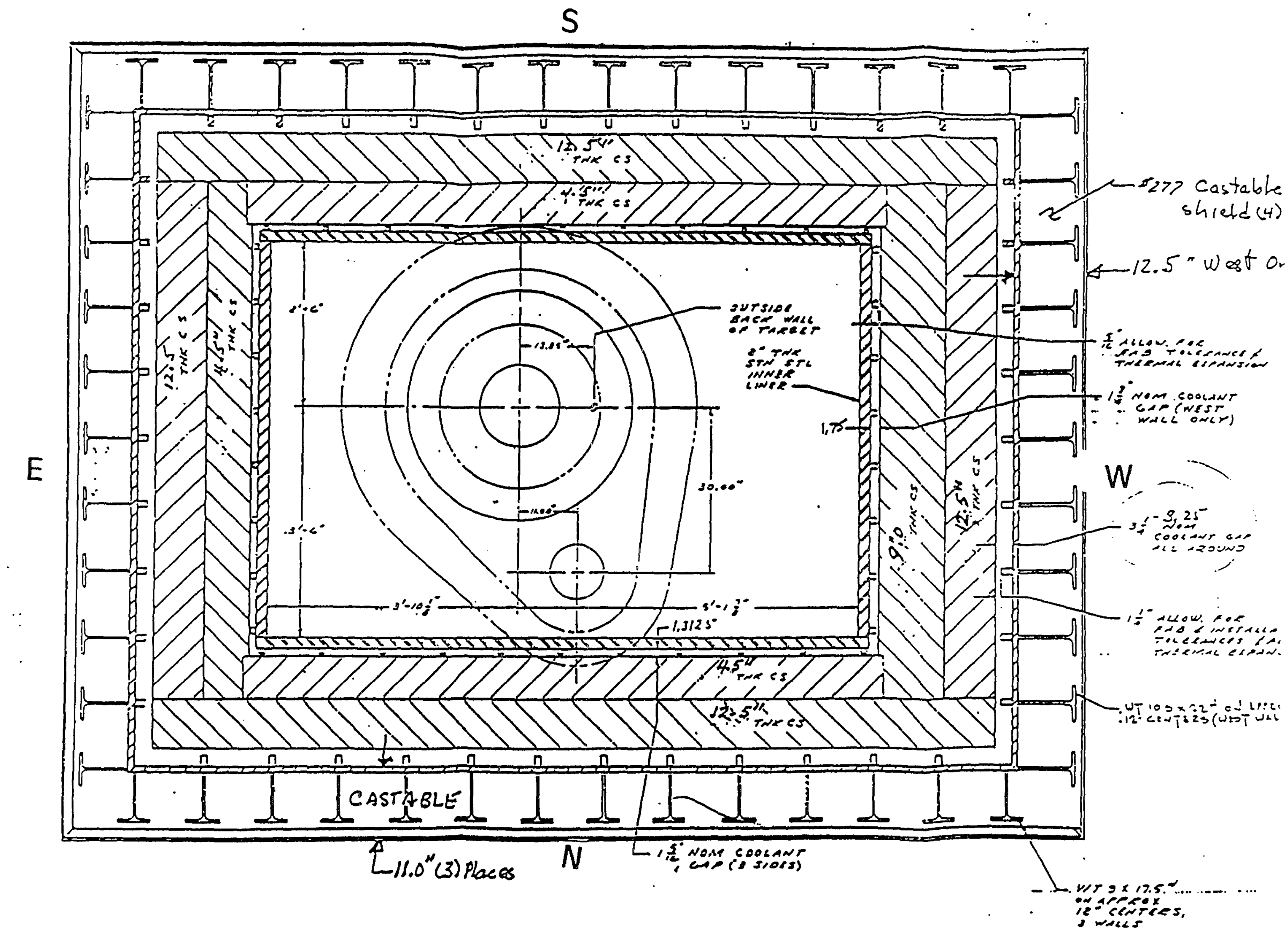
PROPOSED FMIF TEST CELL

FIGURE 3



PROPOSED FMIF TEST CELL

FMIT Test Cell Cooling Panel - Mid Elevation



FMIT Test Cell Design Power

Source	Quantity (kW)
Shielding system with empty test cell	77
Beam pipe with attached components	1.4
Test assembly nuclear	15
Test assembly electrical power	3
Lithium components	4.6
Total	101 kW

FMIF Test Cell

- Cell size - 2.9 m (W) x 4.4 m (L) x 1.8 m (H)
- Materials - Concrete (outer enclosure)
  Carbon steel panels (inner primary shielding structure)
  Castable refractory (carbon - steel interface)
  Stainless steel (inner cell liner)
- Forced nitrogen gas cooling
- Inerted w/nitrogen gas during operation
- Peak temperature ~ 260°F (castable wall opposite beam)
- Sliding top plug

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Test Cell Issues

- Preliminary design has estimated 260°F peak temperature in castable material
  - increase N_2 flow rate
  - intermediate coolant passage
  - replace castable material
- Confirm shielding requirements
- Detailed cell design concept
  - interfaces to service cell
  - interfaces to test assemblies
- Detailed test assembly designs
- In cell monitoring/diagnostic instrumentation
- Remote handling/viewing/maintenance systems
- Safety/cleanup systems

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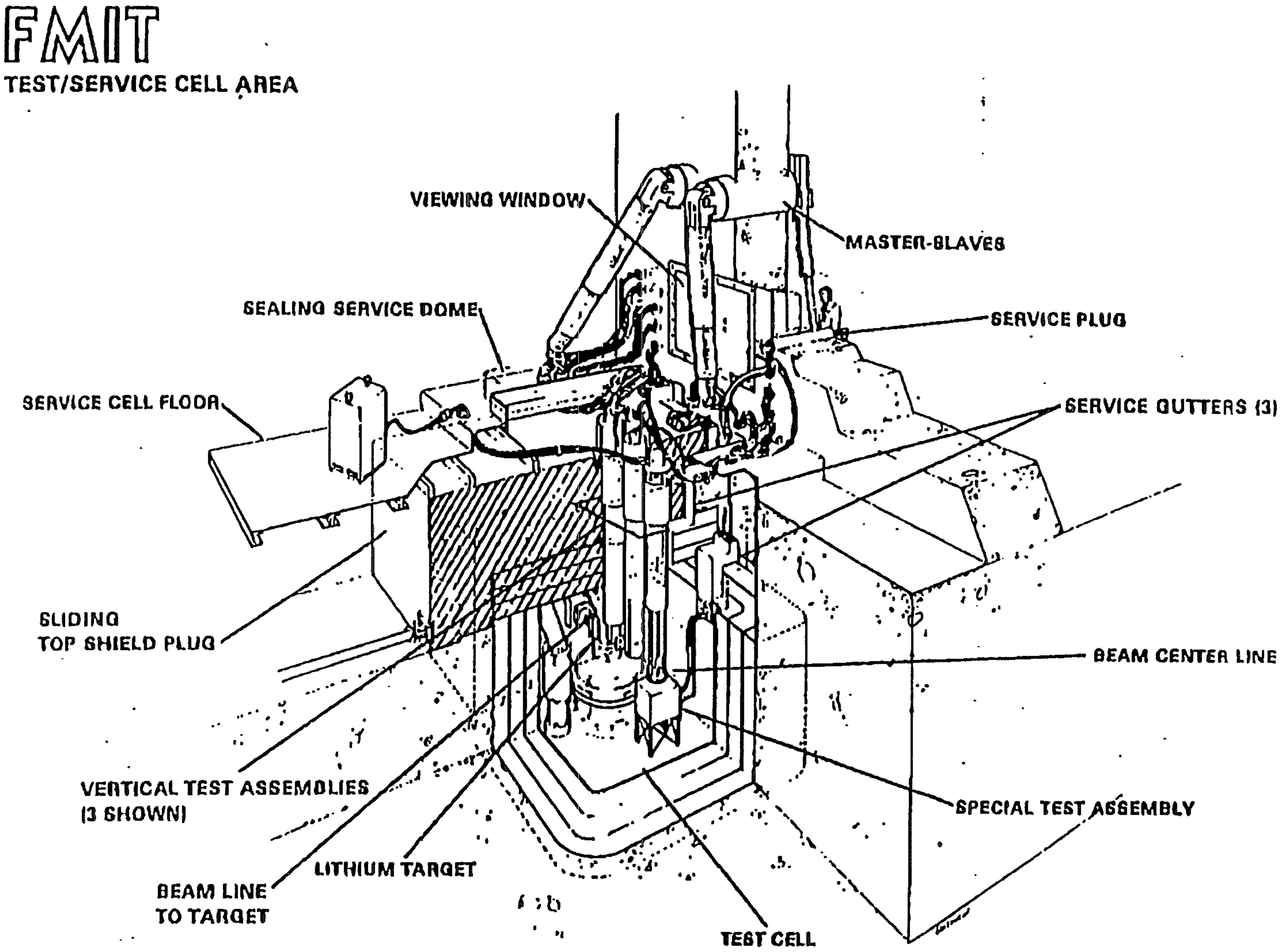
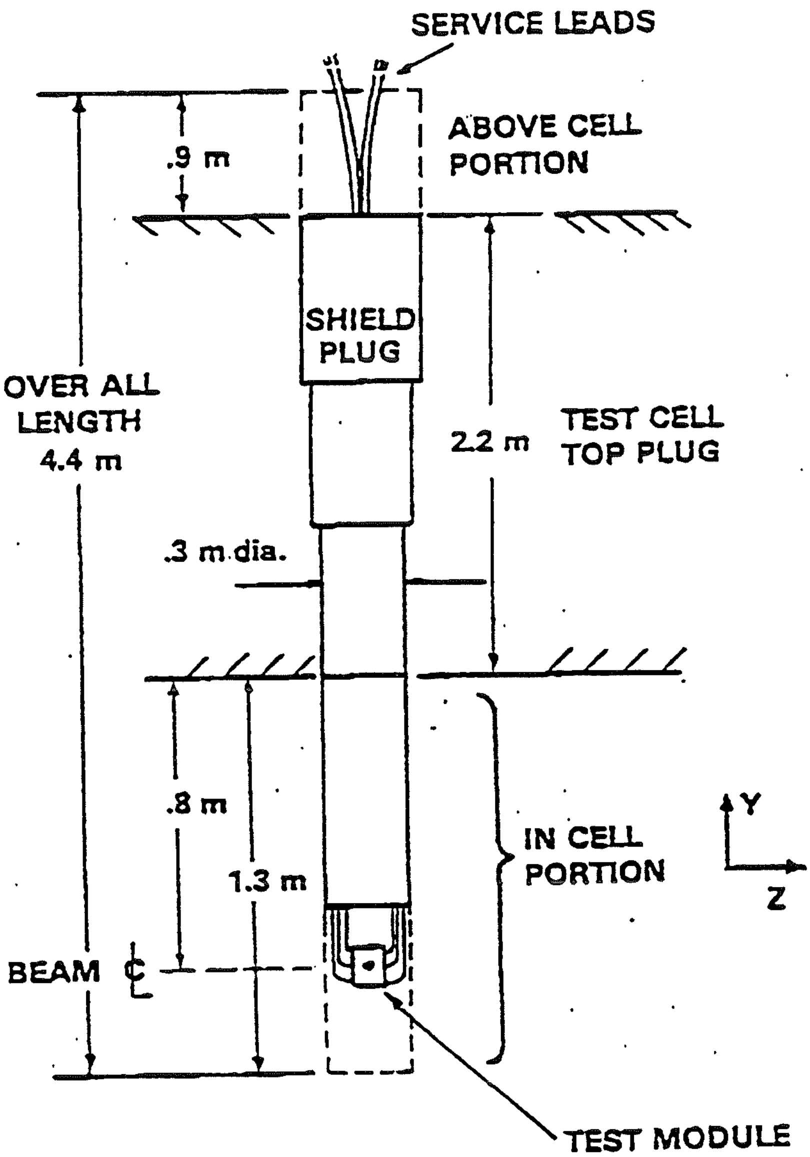


The FMIT Test Cell Arrangement Showing Vertical and Special Test Assemblies

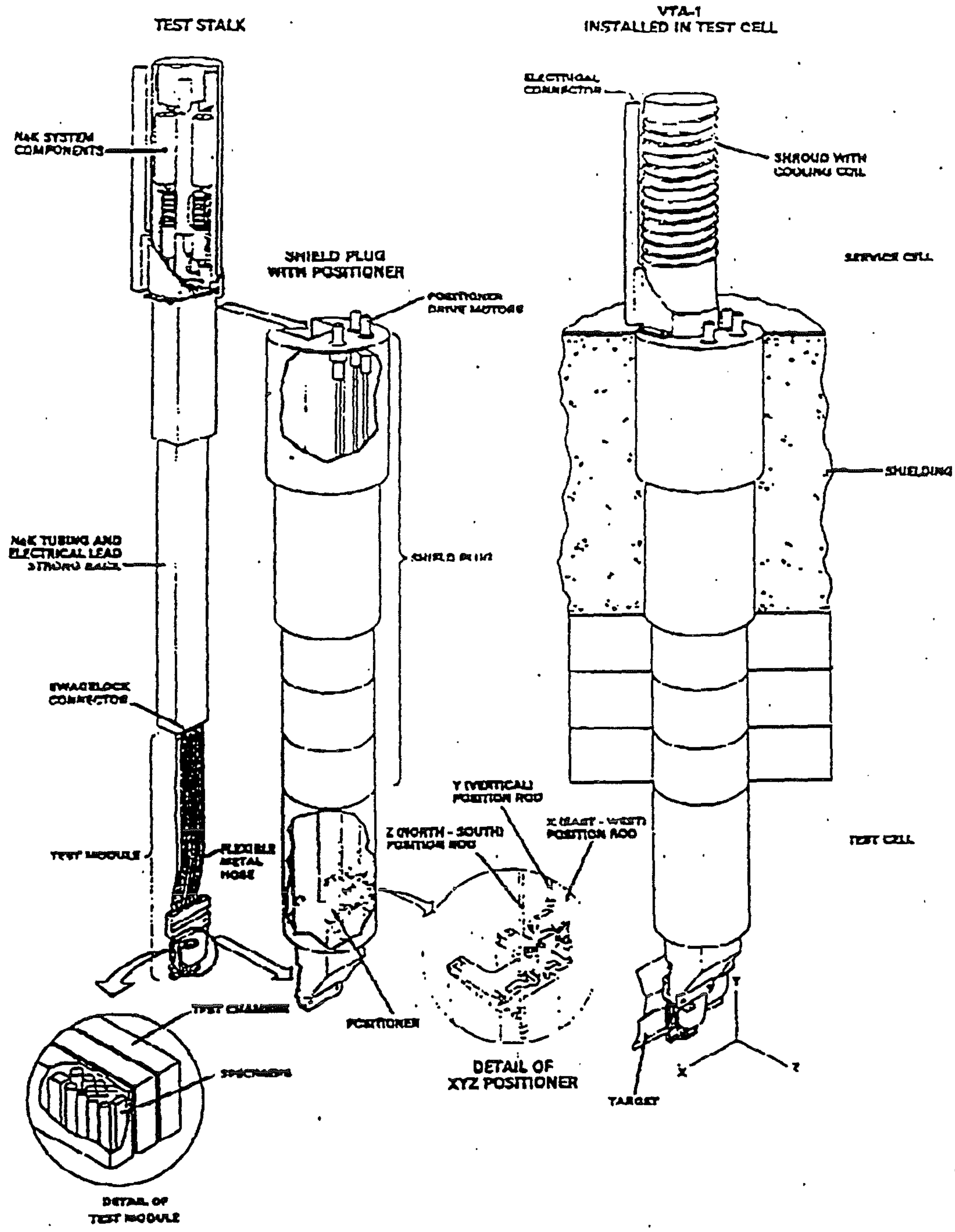


Vertical Test Assembly Located in Experiment Port

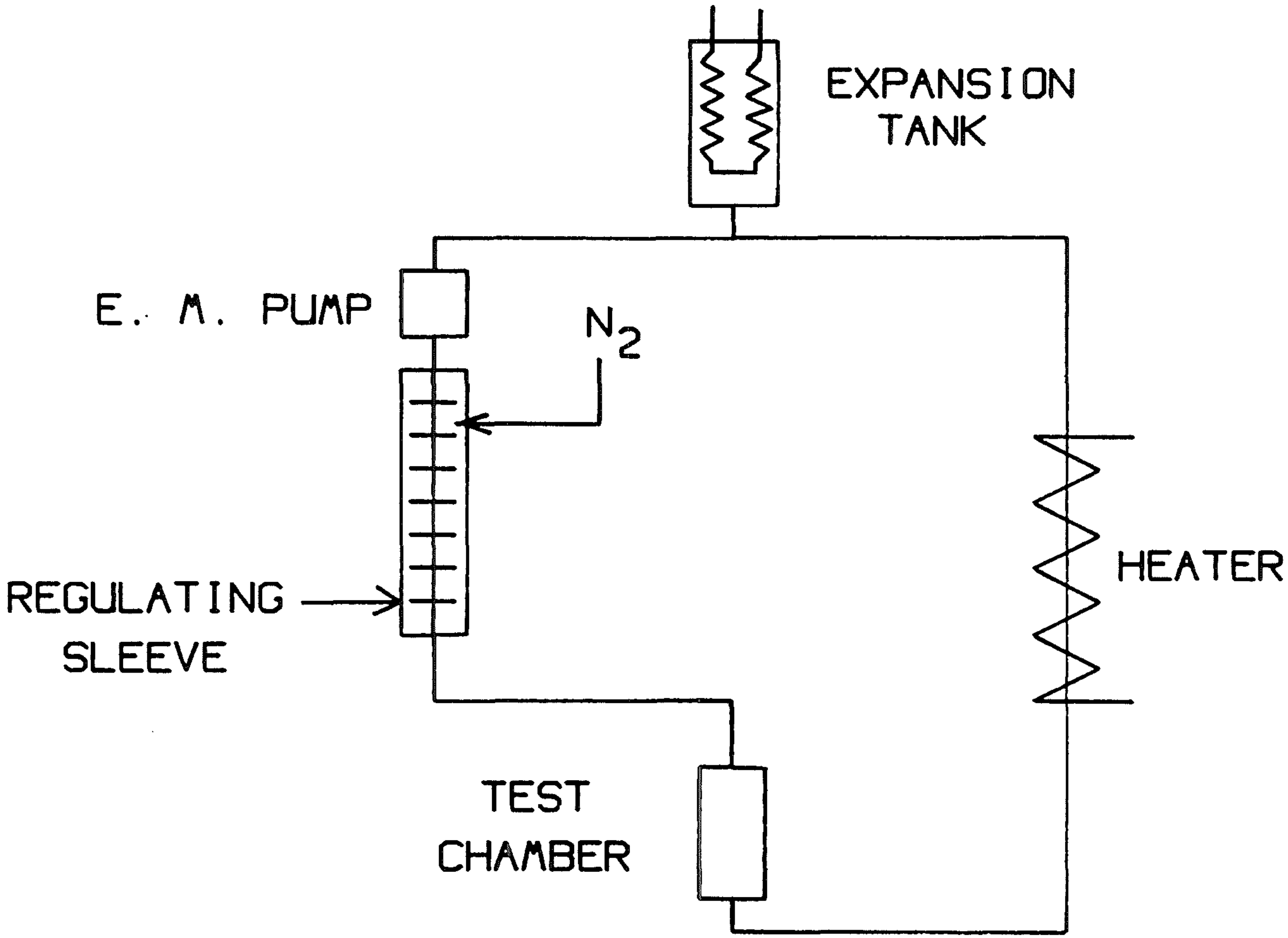
Vertical Test Assemblies

- Test assembly stalk
  - temperature control system
  - structural frame
  - test module

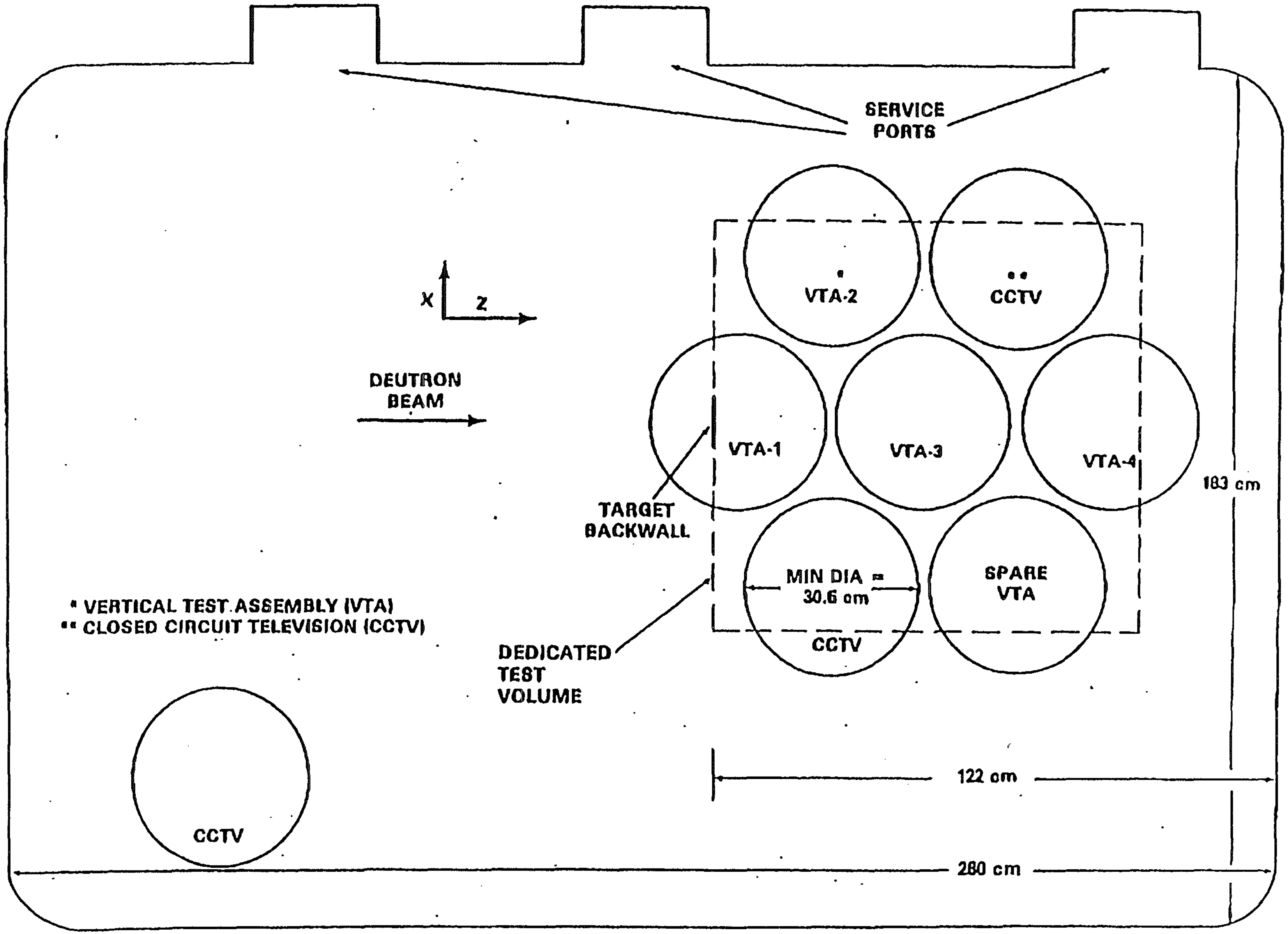
- Shield plug
  - positioner



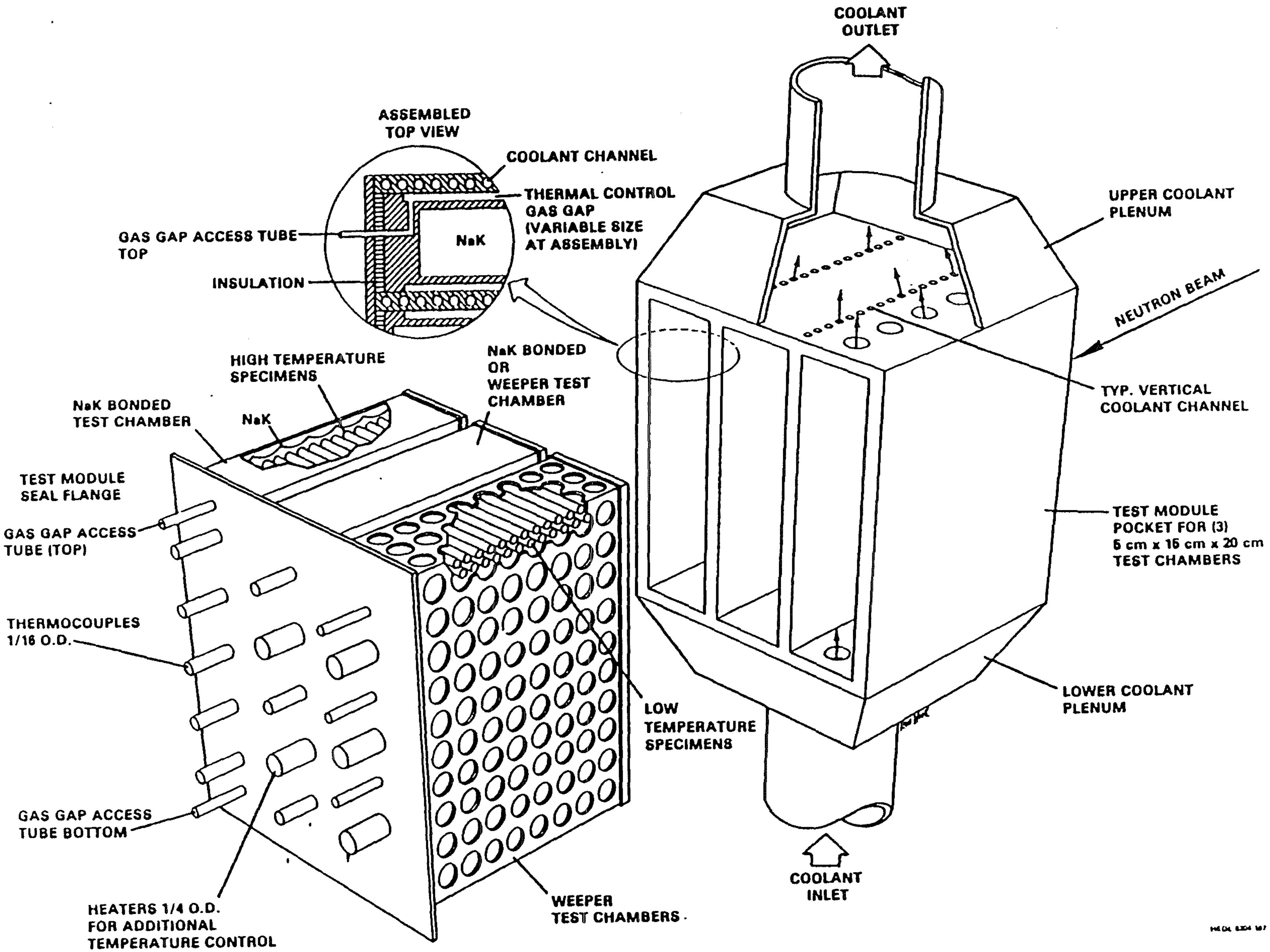
VTA-1 with Thermal Control System Located in Above-Cell Portion of Stalk



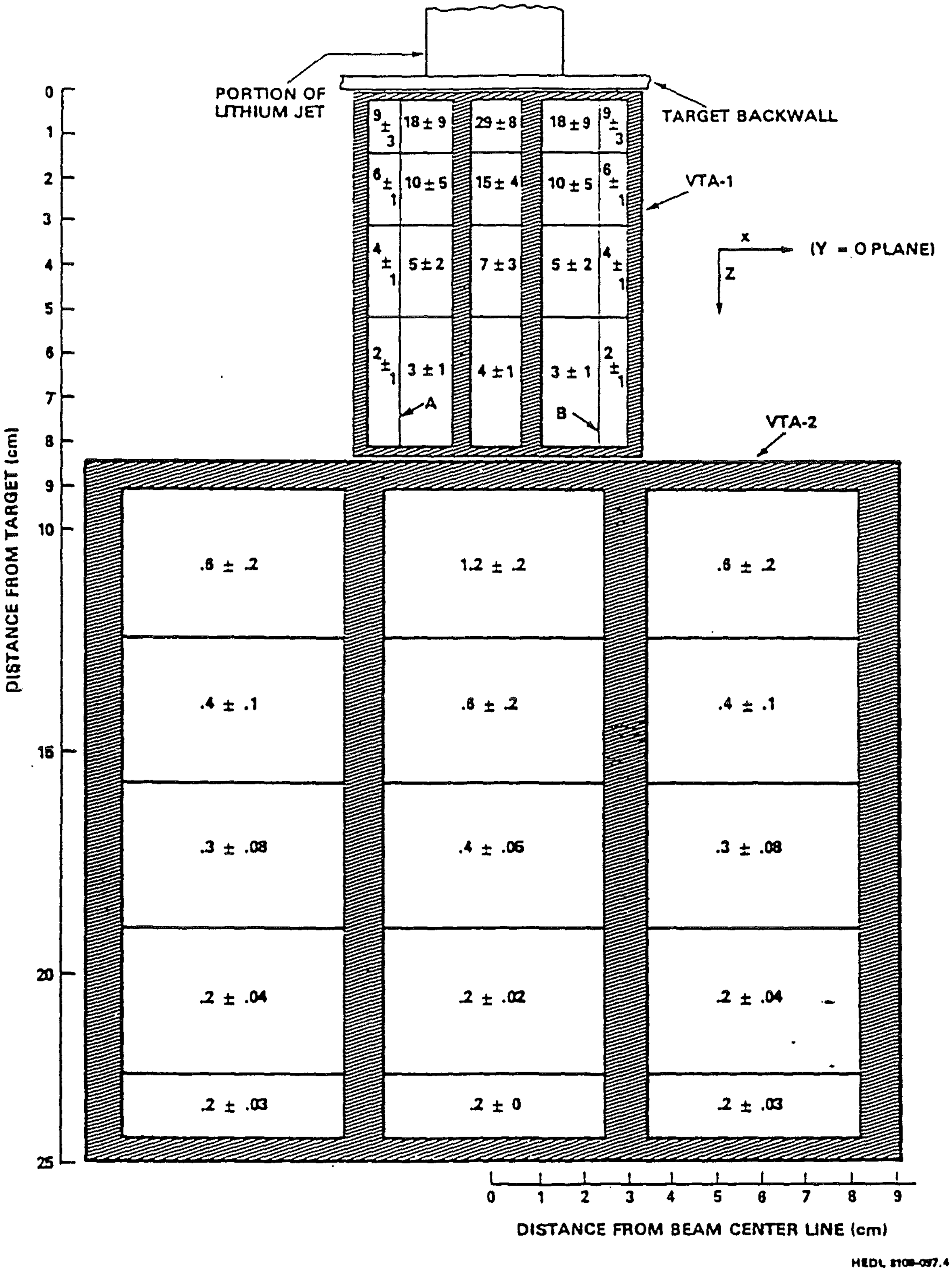
VTA-1 Thermal Control Schematics



Plan View of Test Cell Showing Arrangement of Access Ports



VTA-2 Test Module.



Plan View of Vertical Test Assemblies Module 1 and Module 2.
NOTE: Displacement per atom (dpa) values are shown for a volumetric module packing of 50% stainless steel and 50% NaK. Dpa values based on 90 full power days in stainless steel.

Specifications for Various Test Assemblies Placed in FMIT Test Cell

Test Assembly	In-Cell Spatial Envelope (cm)	Est. Volume for Specimens (cm^3)	Approximate Changeout Time (days)
VTA-1	30 dia x 127 long	~ 150	1 to 2
VTA-2	30 dia x 127 long	>1 x 10^3	1 to 2
VTA-3,4	30 dia x 127 long	>1 x 10^4	1 to 2
Special Test Assembly	60 deep 91 high 91 wide	Variable	7 to 14

Westinghouse
Science & Technology Center

Neutronics Study for IFMIF

Y. Oyama

JAERI

Neutronics Study for IFMIF

Y. Oyama

Japan Atomic Energy Research Institute

IEA Techinical Meeting
for
IFMIF/CDA Planning
KfK, Germany
Sept. 26-29, 1994

Neutron Field Evaluation for IFMIF

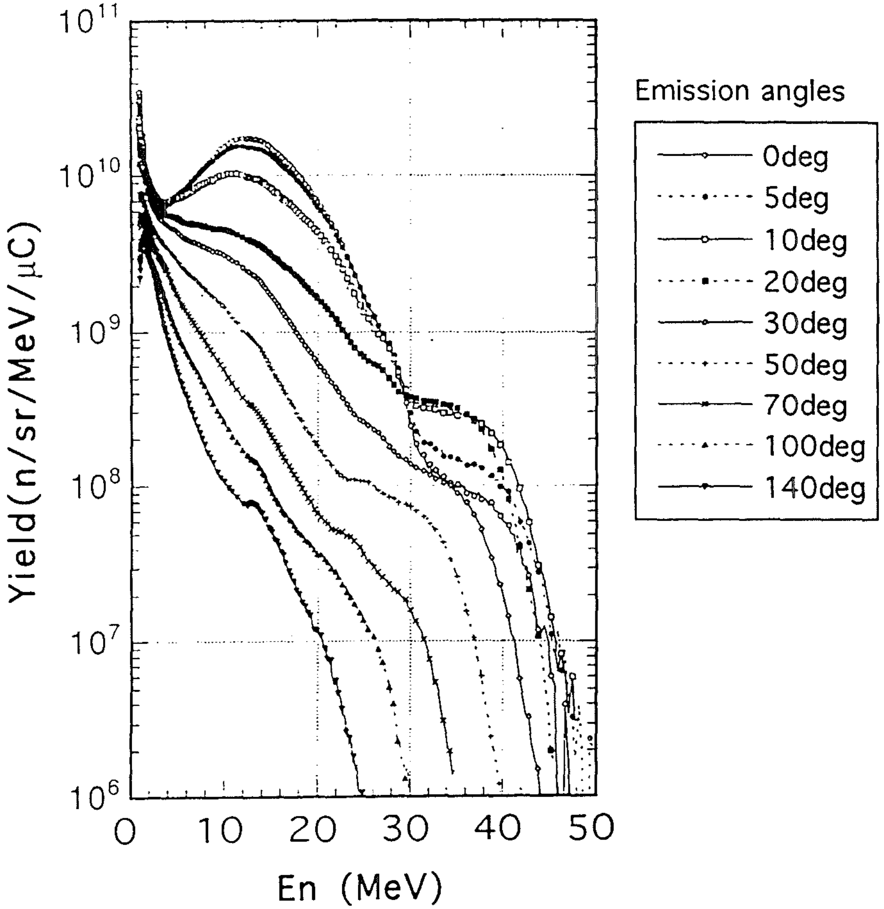
1. **Deuteron slowing-down model in lithium**
   - reaction energies of deuterons are distributed from incident energy down to a few MeV over deuteron range of 17 mm for 35 MeV-d^+ beam

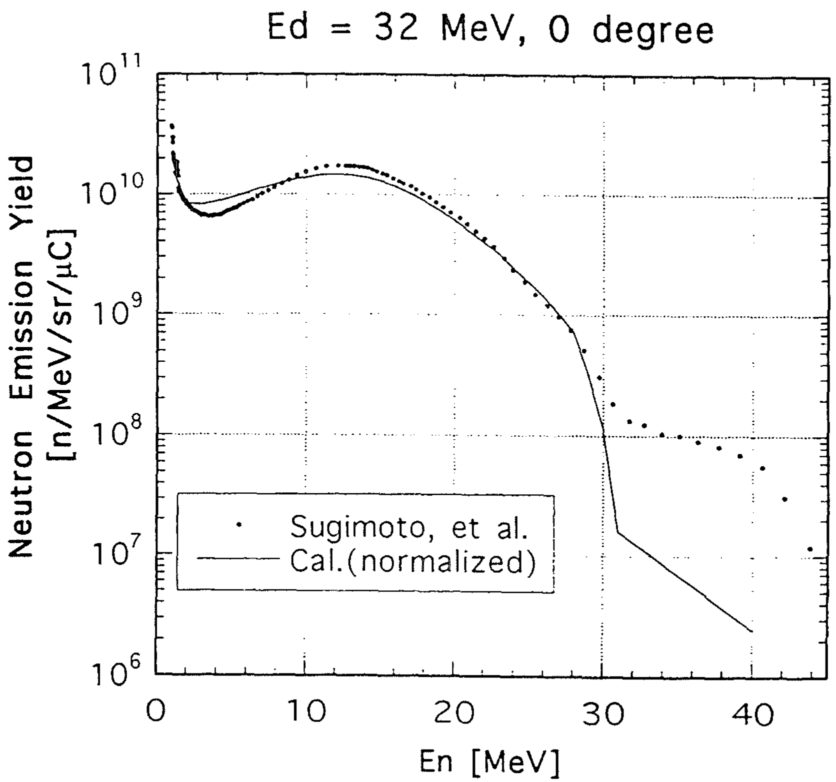
2. **Neutron production reaction model**
   - combination of d-Li stripping reaction and evaporation models
   - forward emission yield was normalized to the experiment
   - agreement with the JAERI experiment is within 10-30 % for forward spectrum, except in lower than 1 MeV and higher than 30 MeV

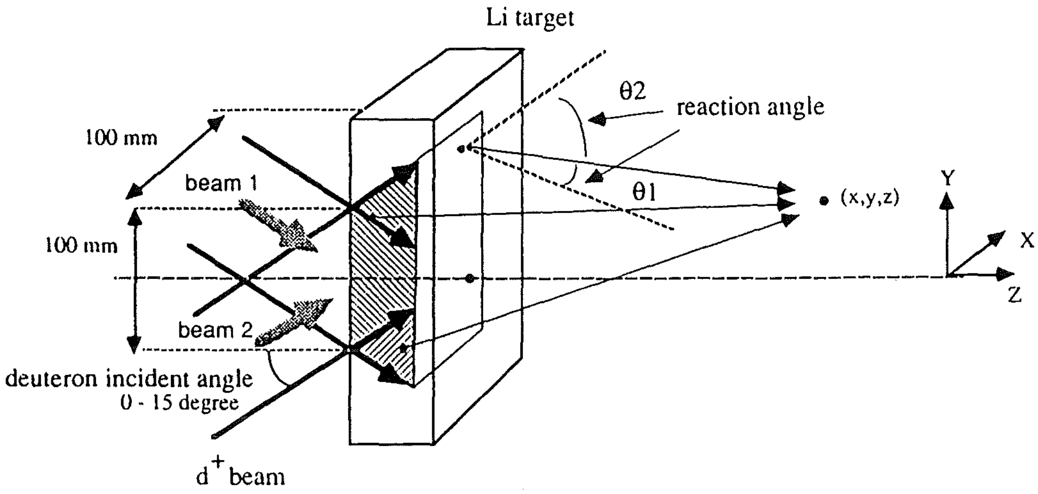
3. **Two beam geometry**
   - two deuteron beams are taken account of incident angles of 0, 5 and 15 degrees
   - three dimensional model in x,y and z coordinates

4. **Target dimension and beam current**
   - 100 x 100 mm square and 20 mm in thick
   - 125 mA for each beam with square profile and flat distribution

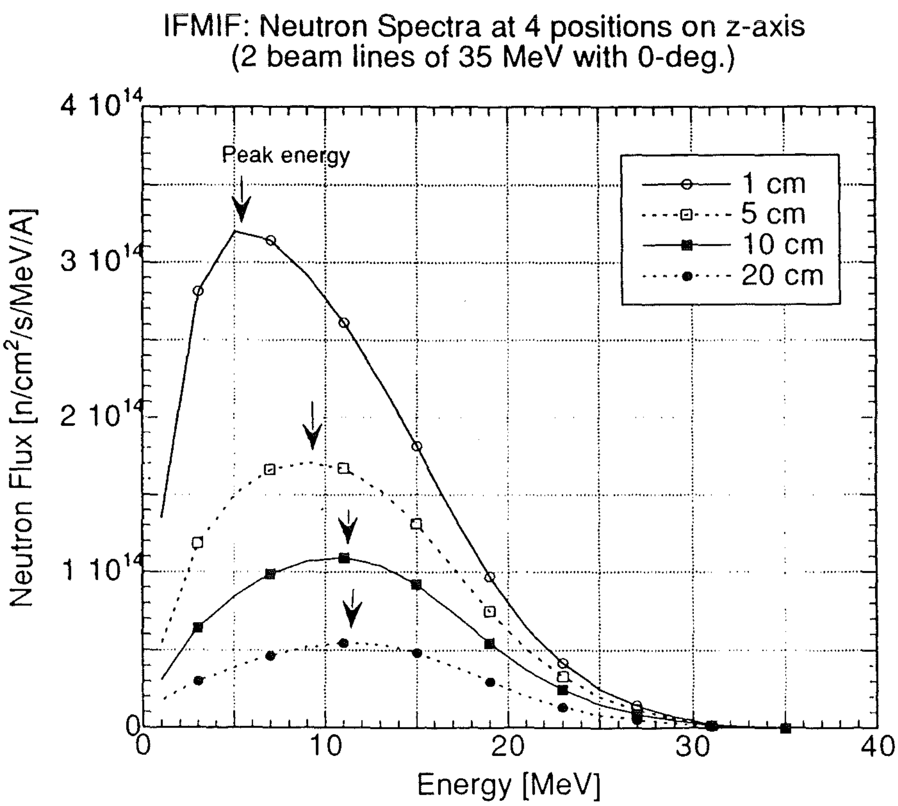
32 MeV d-Li Experiment (M. Sugimoto, et al)

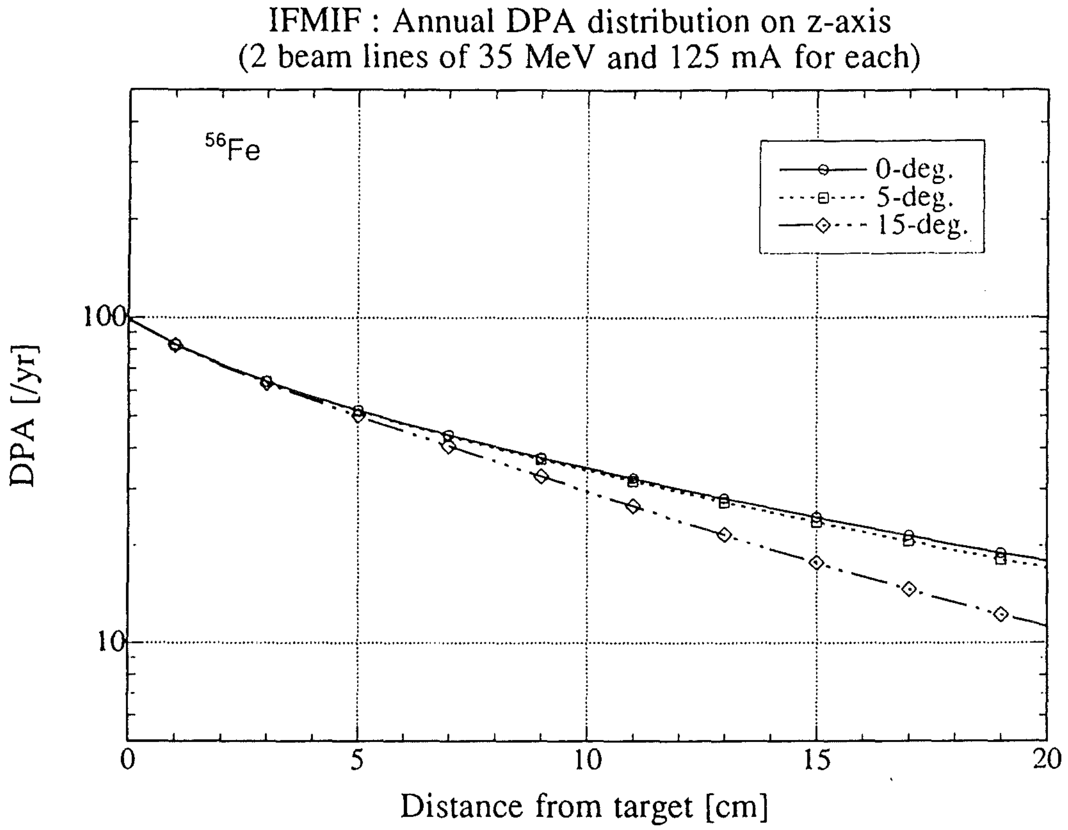




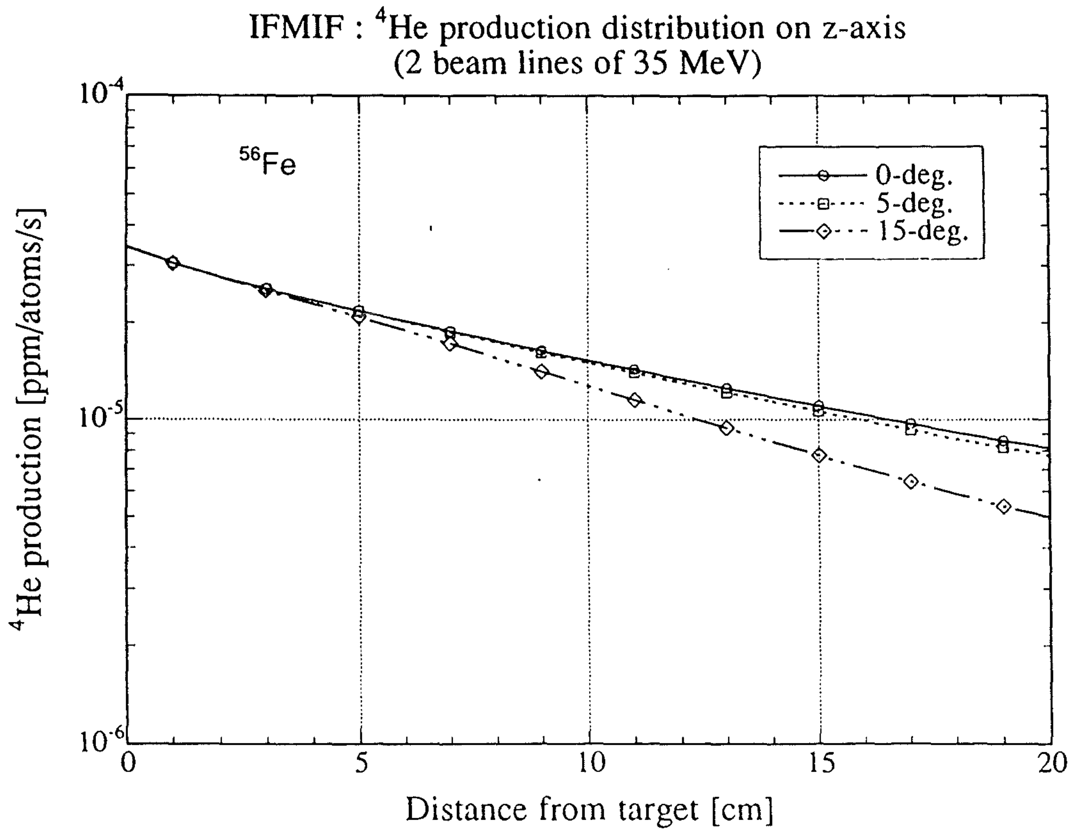


Neutron Flux and Spectrum Calculation Model at Positions in Irradiation Field

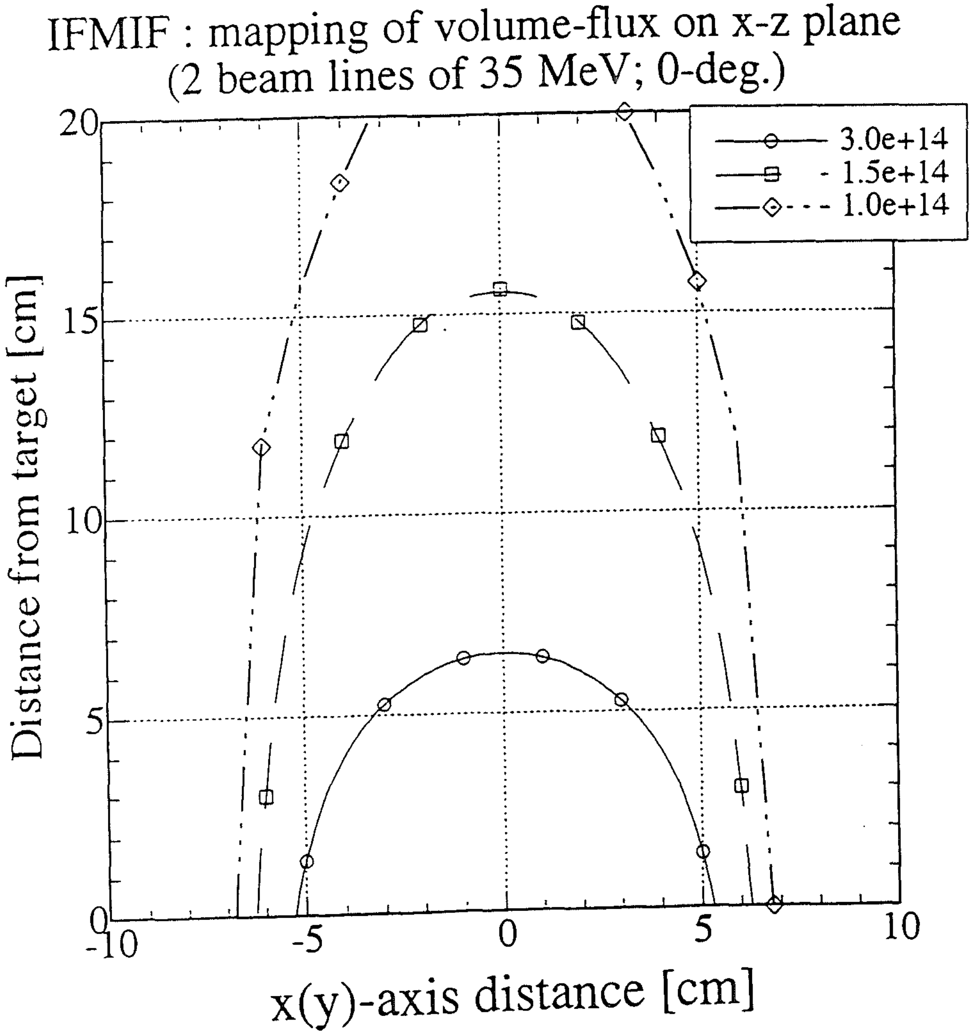


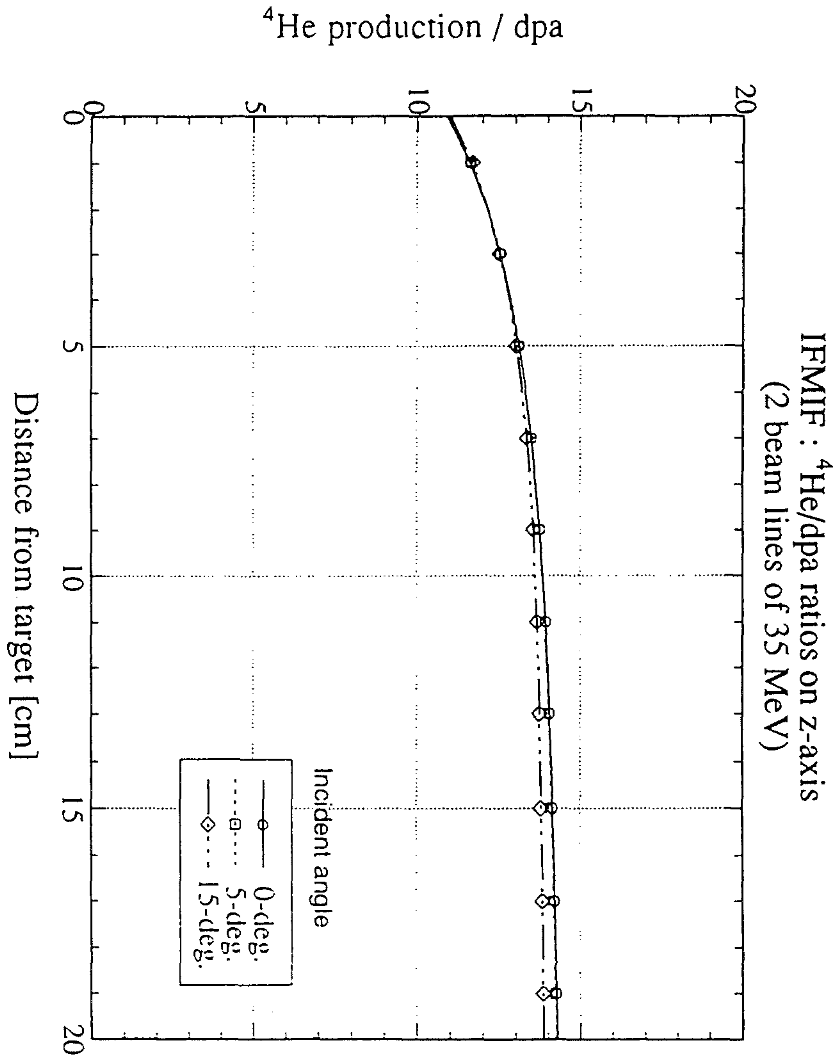


IFMIF : Annual DPA distribution on z-axis
(2 beam lines of 35 MeV and 125 mA for each)
56Fe
0-deg.
5-deg.
15-deg.
DPA [/yr]
100
10
0
5
10
15
20
Distance from target [cm]

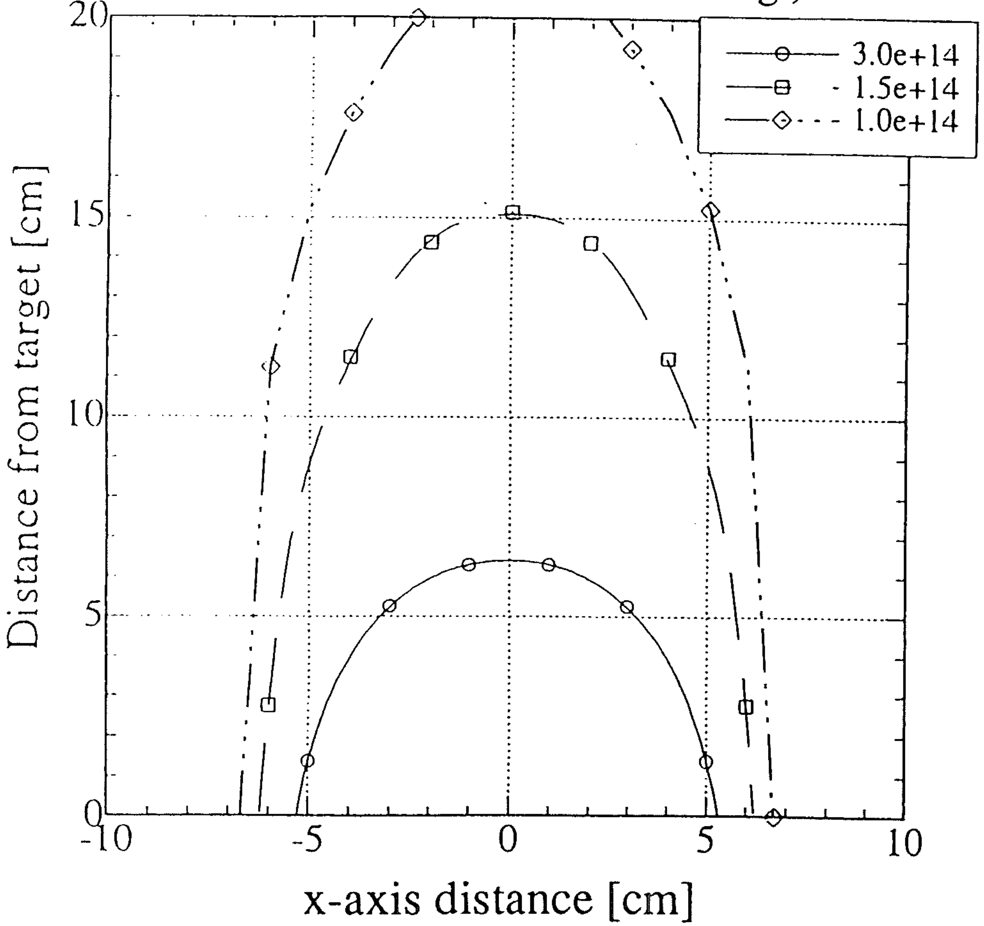


IFMIF : 4He production distribution on z-axis
(2 beam lines of 35 MeV)
56Fe
0-deg.
5-deg.
15-deg.
4He production [ppm/atoms/s]
10-4
10-5
10-6
0
5
10
15
20
Distance from target [cm]

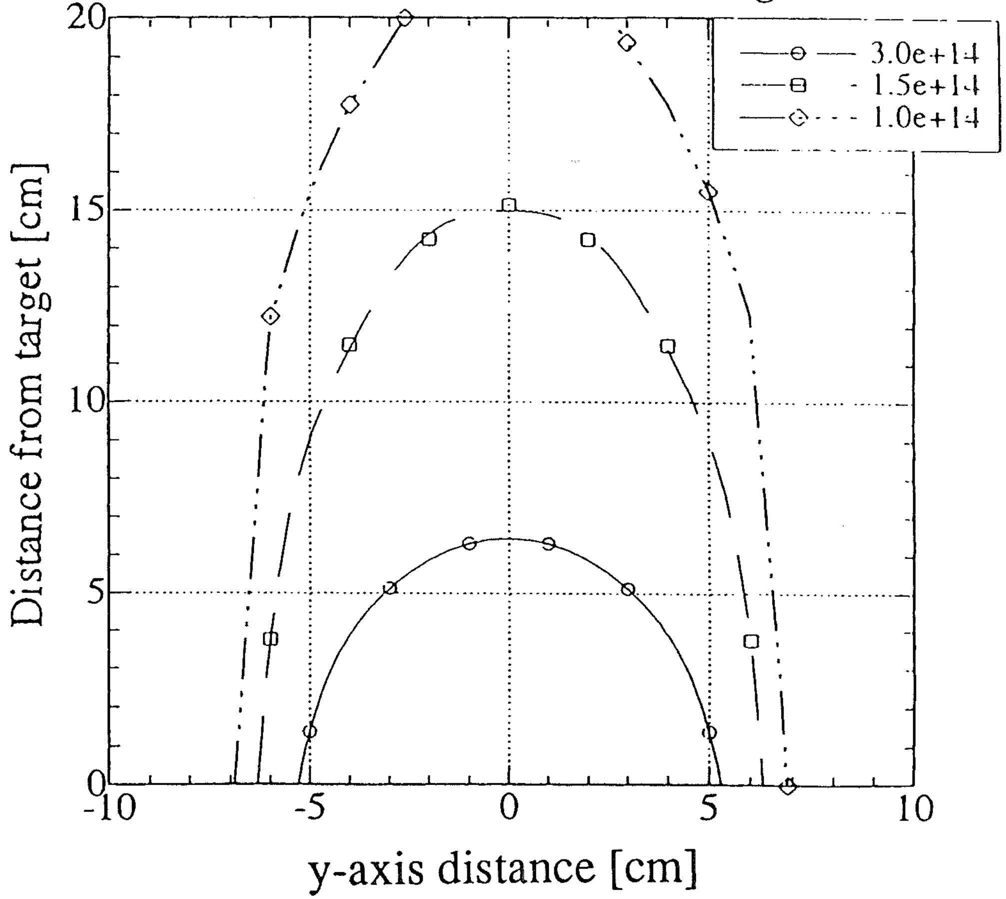

IFMIF : mapping of volume-flux on x-z plane
(2 beam lines of 35 MeV; 0-deg.)
3.0e+14
1.5e+14
1.0e+14
Distance from target [cm]
x(y)-axis distance [cm]
0
5
10
15
20
-10
-5
0
5
10


IFMIF : 4He/dpa ratios on z-axis
(2 beam lines of 35 MeV)
4He production / dpa
Distance from target [cm]
Incident angle
0-deg.
5-deg.
15-deg.
0
5
10
15
20

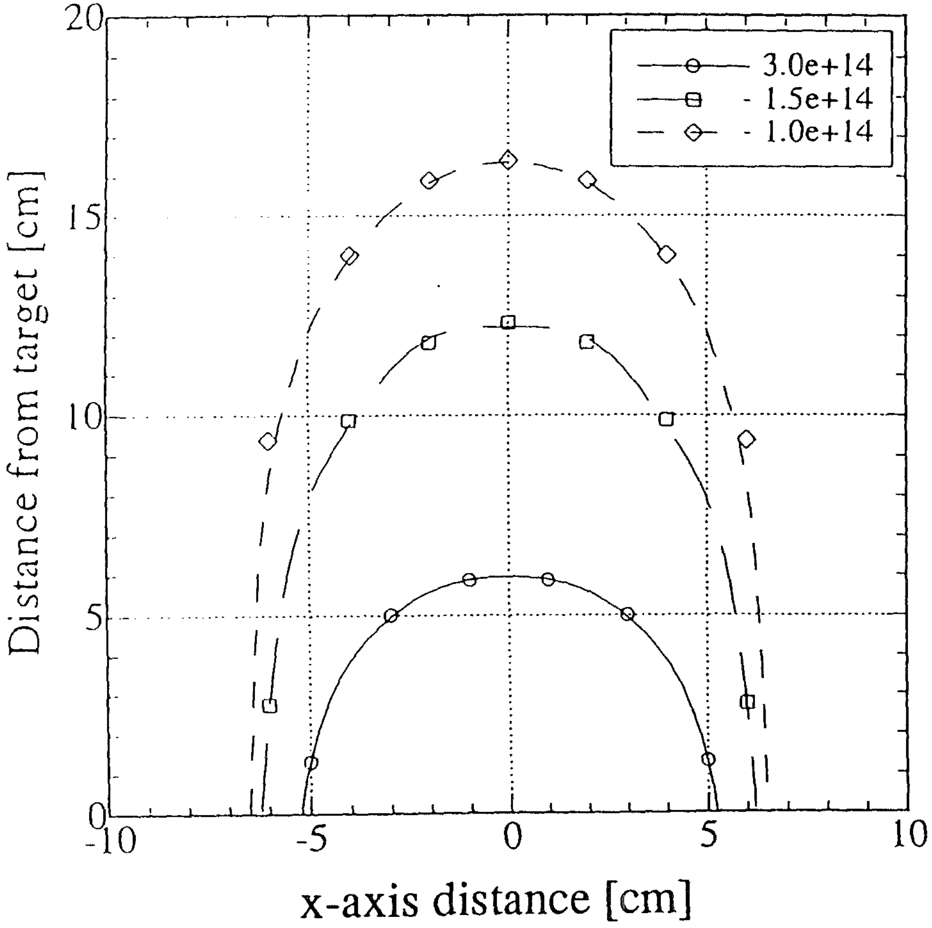
IFMIF : mapping of volume-flux on x-z plane
(2 beam lines of 35 MeV; 5-deg.)



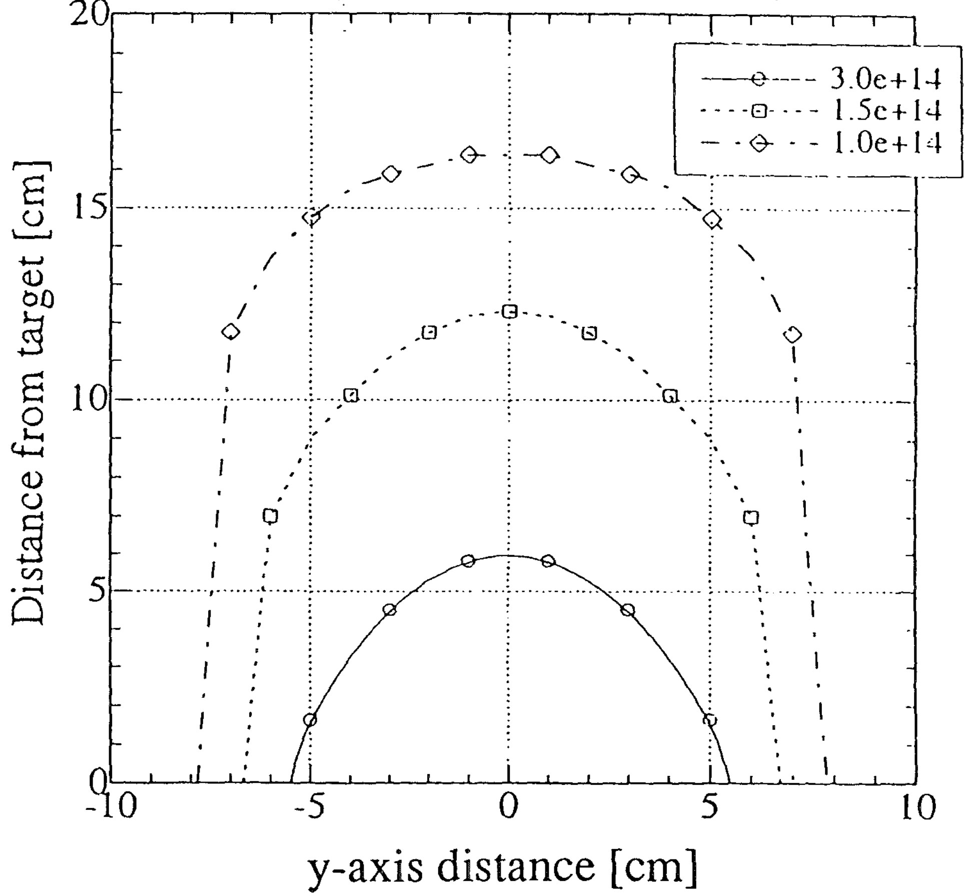
IFMIF : mapping of volume-flux on y-z plane
(2 beam lines of 35 MeV; 5-deg.)



IFMIF : mapping of volume-flux on x-z plane
(2 beam lines of 35 MeV; 15-deg.)



IFMIF : mapping of volume-flux on y-z plane
(2 beam lines of 35 MeV; 15-deg.)



Summary of IFMIF Neutron Field

1. Energy Spectrum

- Peak energy of neutrons is ~ 13 MeV for 35 MeV deuterons
- But, spectra at very close position, less than 50 mm, show peak energy shift to lower
- Spectrum with large incident angle shows a little energy shift (~ 1MeV) at far positions on z axis

2. He/DPA Ratio for uncollided flux

- He/DPA ratio is ~ 14 (close to DT source of 13)
  Lower ratio is obtained near the target region than at far positions

Summary of IFMIF Neutron Field (continued)

3. Effect of incident angle

- Flux gradient increases with increase of angle
  Beam incident angle should be less than 15 degree
- Increasing angle, high-flux regions decrease,
  but low flux regions increase

Lower limit flux [n/cm^2/s]	DPA [/yr]	Irradiation Volume [cm^3] Incident Angle 0 deg.	5 deg.	15 deg.
5.0e+14	38	90.0	86.0	86.0
3.0e+14	23	417	413	372
1.5e+14	12	1330	1320	1220
1.0e+14	8	2400	2360	2230
5.0e+13	4	4890	4950	5380

Baseline Concept of Test Cell, Remote Handling and PIE facility for IFMIF

K. Noda

JAERI

Baseline Concept of Test Cell, Remote Handling and PIE Facility for IFMIF

Presented by K. Noda
Japan Atomic Energy Research Institute

IEA Technical Workshop on IFMIF-CDA Planning
September 26-29, 1994

KfK Karlsruhe Germany

Proposal of Baseline Concept of Test Cell

R&D and technical studies on test cells for high energy intense neutron irradiation facilities have not been carried out since cancellation of FMIT project.

To develop baseline concept of IFMIF test cell, concept based on FMIT test cell should be improved to meet users' requirements for IFMIF test cell.

Proposal of Baseline Concept of Test Cell

(1) Test Assembly

*FMIT Test Assembly Concept:
- -Vertical test assemblies (VTA) for irradiation of specimens for PIE and in-situ tests.
- -Special Test Assembly (STA) for large in-situ test apparatus etc.

*IFMIF Test Assembly Concept:
- -Vertical access of VTA and STA to test cell is suitable.
- -Horizontal access should be also taken into account for heavy test module or large in-situ apparatus from standpoint of positioning.

Proposal of Baseline Concept of Test Cell

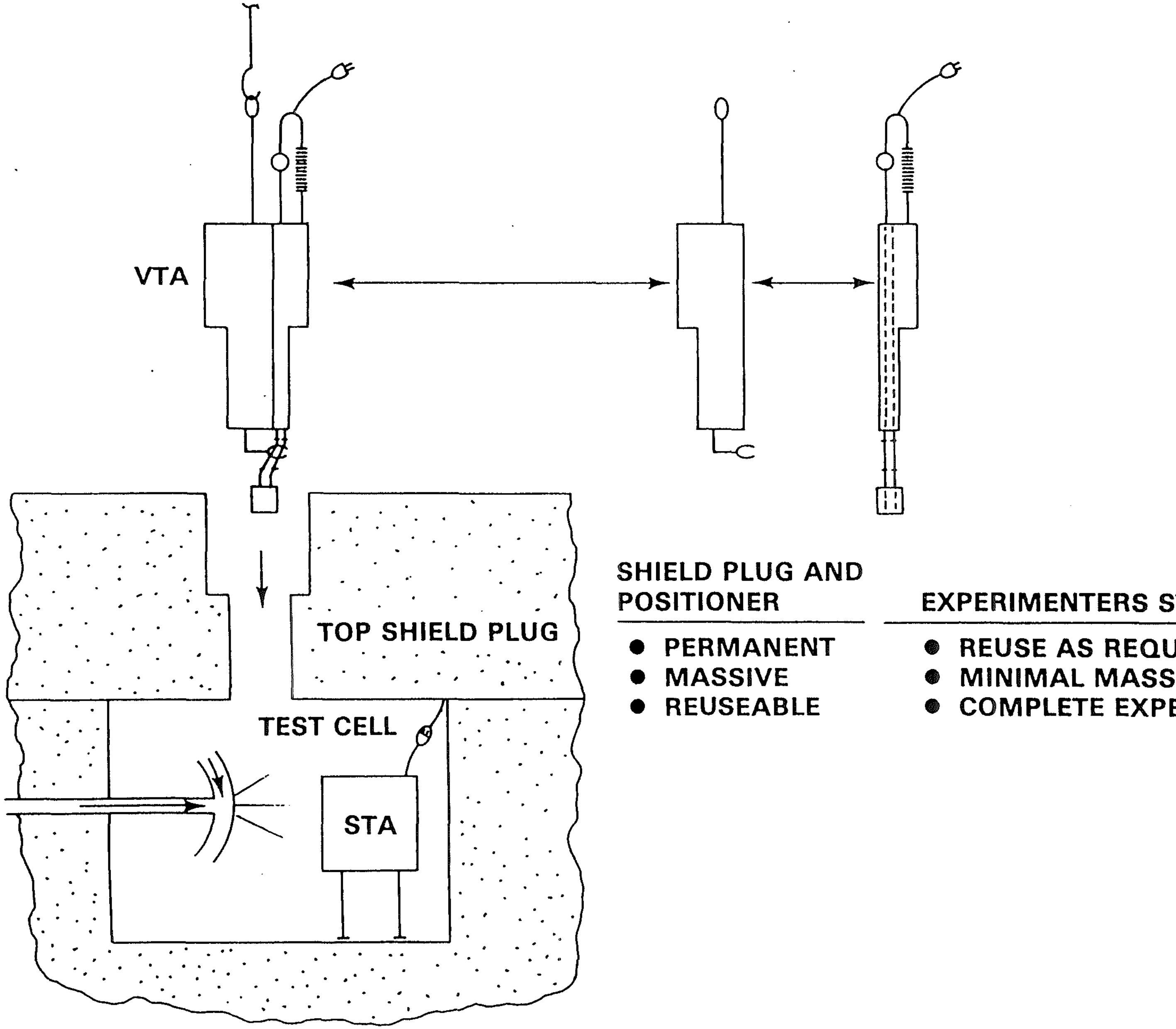
(2) Specimen Temperature Control System

*FMIT Temp. Control Concept
- -NaK bonded specimen chamber with gas gap temp. control (Coolant: NaK or gas (N_2, He)).
- -Weeper specimen chamber (Coolant: NaK).

*IFMIF Temp. Control Concept
- -The same as FMIT concept for high flux region.
- -He cooling should be studied especially for ceramic specimen from standpoint of compatibility.
- -Cryogenic irradiation for low flux region.

METHODS OF TESTING

Vertical Test Assembly of FMIT



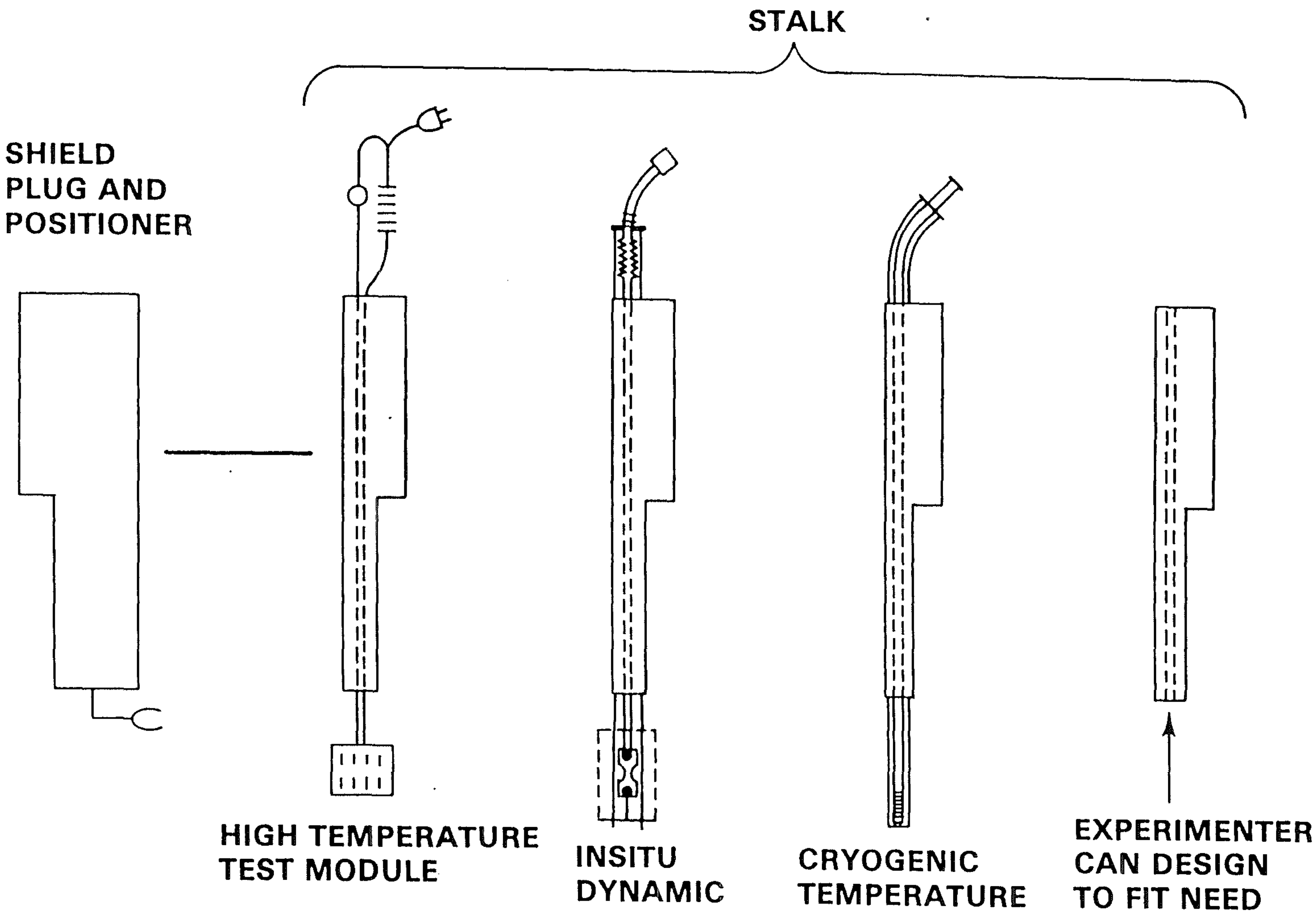
SHIELD PLUG AND POSITIONER

- PERMANENT
- MASSIVE
- REUSEABLE

EXPERIMENTERS STALK

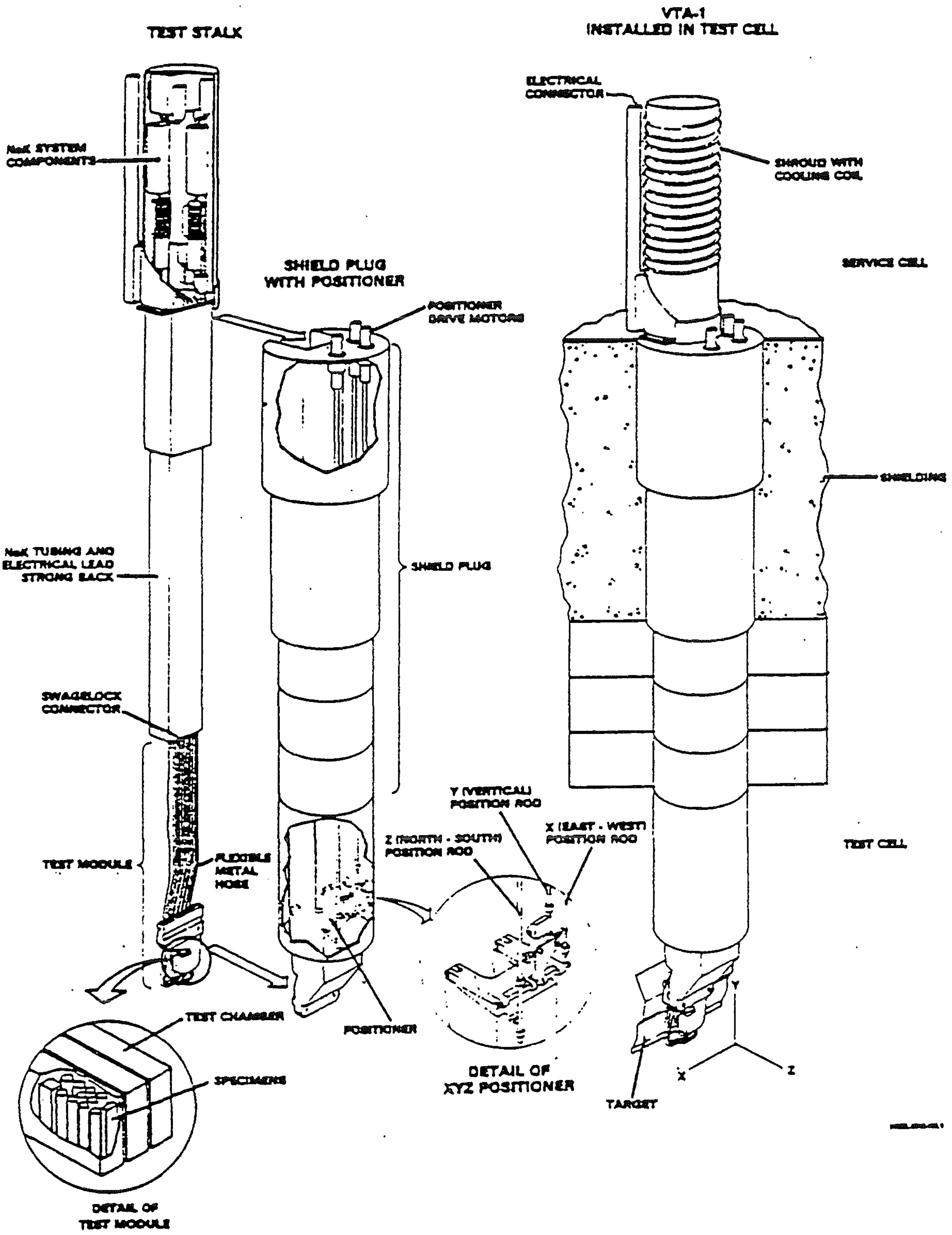
- REUSE AS REQUIRED
- MINIMAL MASS
- COMPLETE EXPERIMENT

HEDL 8311-210.6



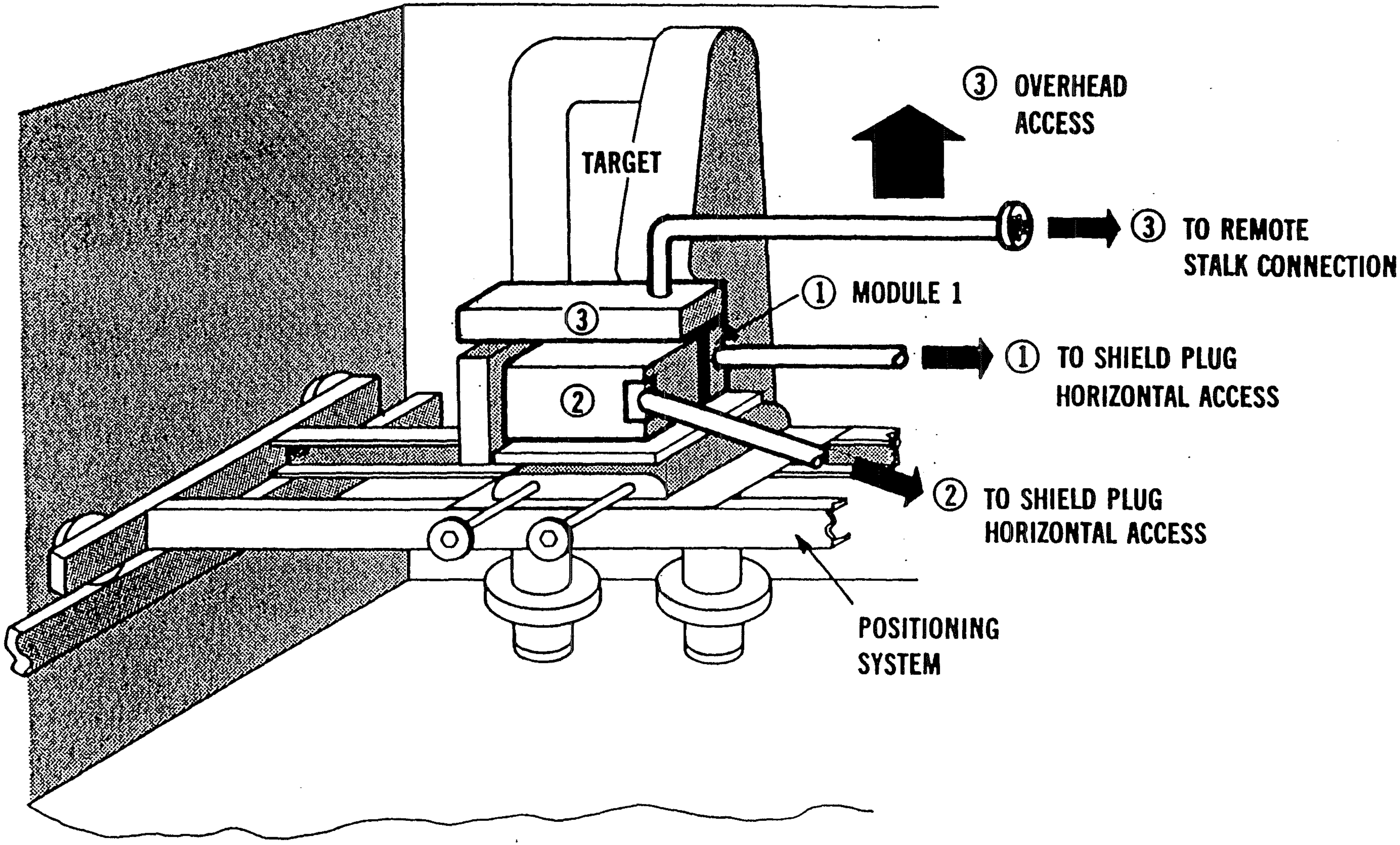
THE STALK IS DESIGNED TO BE SMALL IN MASS YET INCLUDE ALL MAJOR EXPERIMENT HARDWARE

Vertical Test Assembly of FMIT

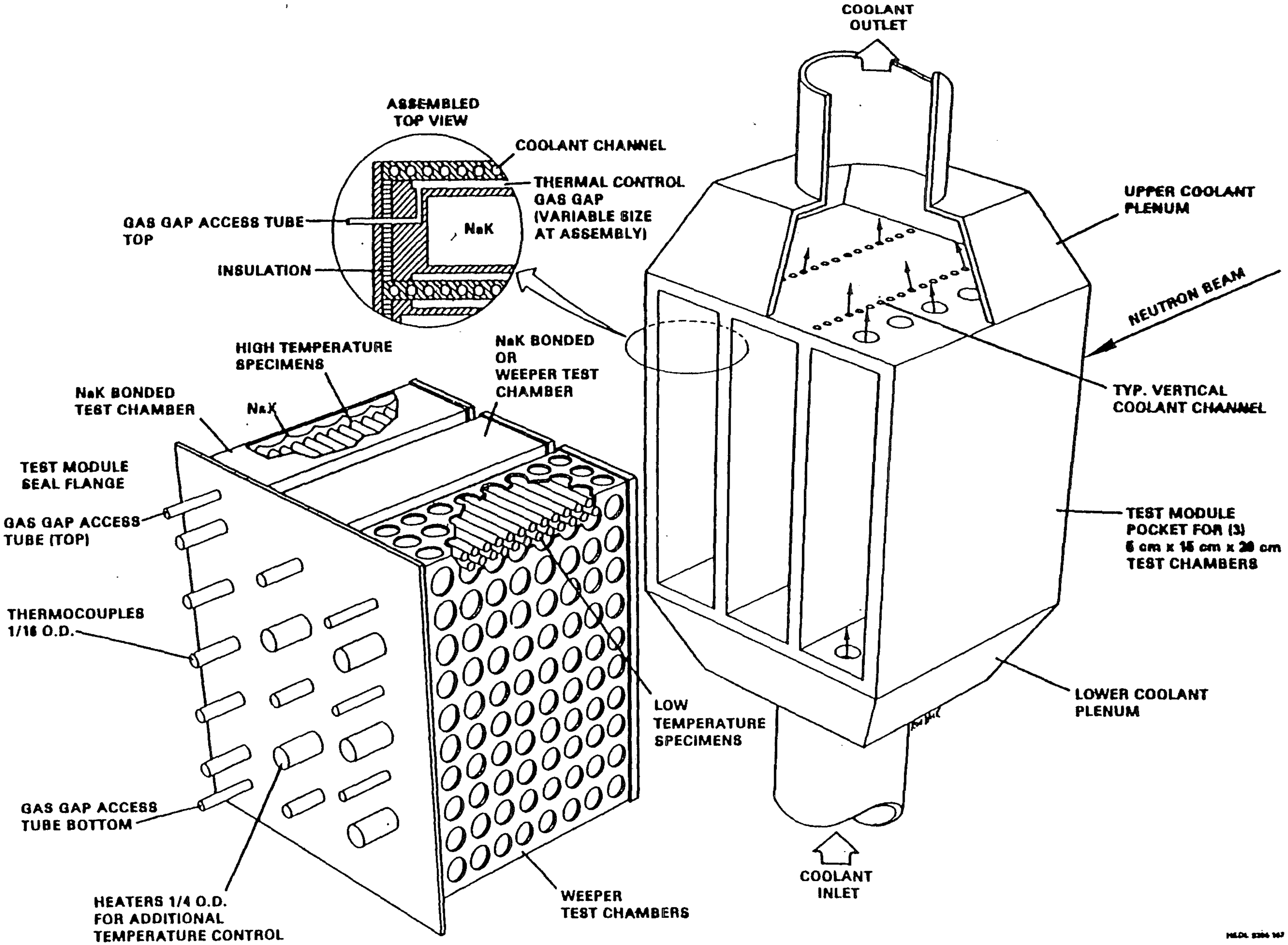


VTA-1 With Thermal Control System Located in Above-Cell Portion of Stalk.

Vertical Test Assembly of FMIT



Various Access of Test Assembly

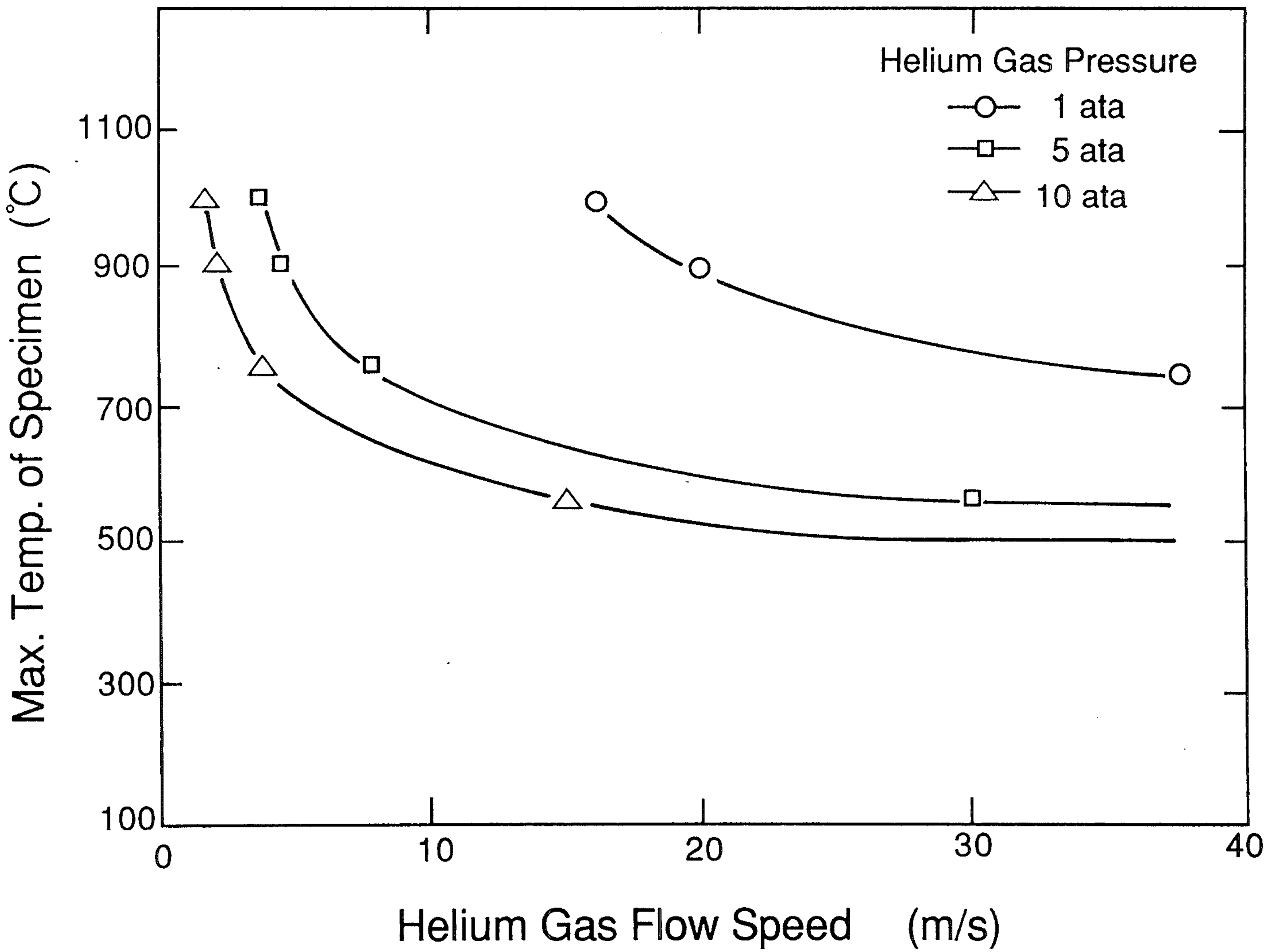


Specimen Temperature Control System of FMIT

Preliminary Evaluation of He Gas Specimen Temp. Control System

Calculation Coditions

- Specimen Size : 5 mm in diameter (Endless Length)
- Material : Iron
- Deuteron Energy : 35 MeV
- Peak Energy of Neutron Spectrum : 14 MeV
- Neutron Flux : 3×10^{14} n/cm^2 s
- Heat Generation Density in Iron Specimen : 22 W/cm^3
- Helium Gas Coolant Temp. : 500 ℃


Helium Gas Pressure
1 ata
5 ata
10 ata
Max. Temp. of Specimen (℃)
1100
900
700
500
300
100
0
10
20
30
40
Helium Gas Flow Speed (m/s)

Preliminary Evaluation Results

Maximum specimen temperatures are only higher than He gas temperature by a few tens degree, in case of He gas speed of 20 m/s and pressure of 10 ata.

Preliminary evaluation shows that helium gas specimen temperature control system can be applied for IFMIF

Proposal of Baseline Concept of Remote Handling

Baseline concept of IFMIF remote handling system should be also based on concept of FMIT remote handling system.

Recently, remote handling technology and robotics made great progress. Baseline concept of IFMIF remote handling system should include such high technology.

Technology of maintenance system for ITER is presented as one of typical examples of current remote handling technology.

Proposal of Baseline Concept of PIE Facility

Small size test technique (SSTT) will be extensively used for IFMIF irradiation tests.

A PIE facility for SSTT at high efficiency is necessary on-site. JAERI carried out technical evaluation of module type PIE facility for SSTT.

Remote Handling Technology Development in ITER-EDA

Rail-mounted vehicle type maintenance system

(1) Configuration

a. Articulated rail inserted through ports into vessel
b. Formed into toroidal rail configuration with supports
c. Several vehicles working with manipulators/end-effectors

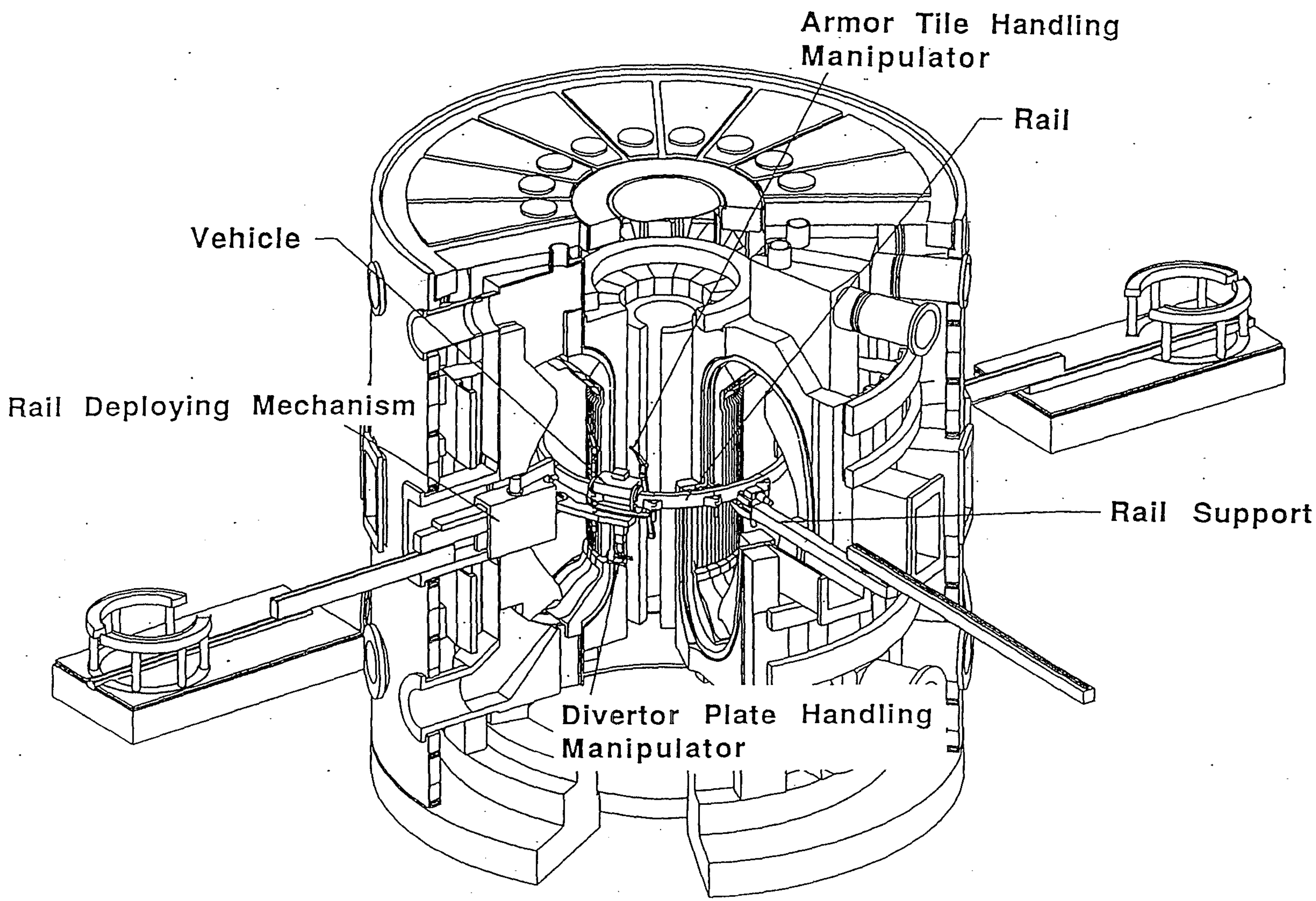
(2) Features

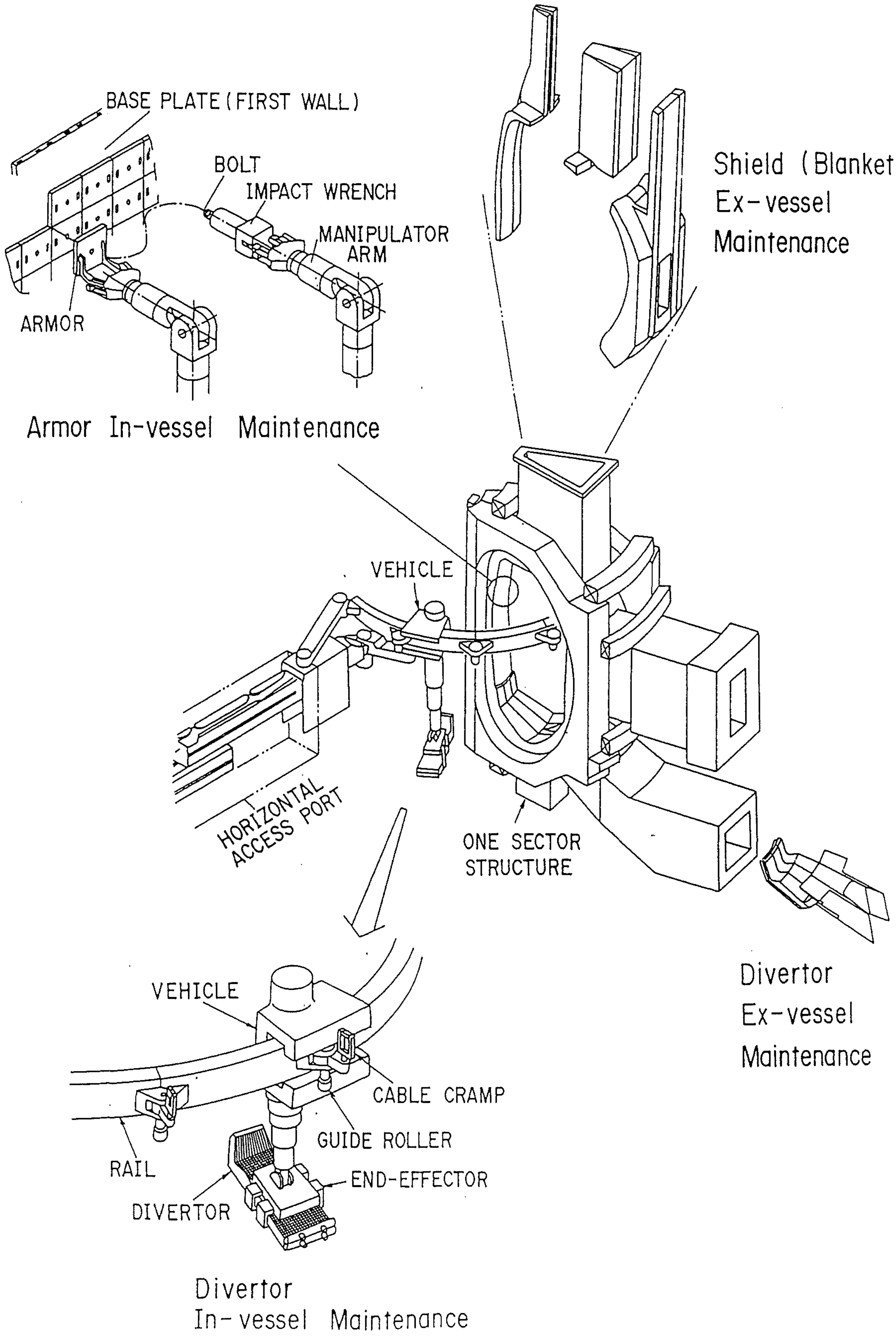
a. Stable operation for handling heavy component
b. Reliable transporter without weak elements
c. Effective operation due to common transporter with several vehicles, manipulators and end-effectors
d. Compact cask space

(3) Present status

a. A 1/5-scaled model tests
Basic feasibility (rail deployment, vehicle operation)
Structural integrity under various loading conditions
Accessibility with rotating mechanism around rail

b. A 1/1-scaled model tests
Mechanical behavior under loading/unloading
Position feedback control to compensate deformation
Integrated operations using mock-up structures


Armor Tile Handling Manipulator
Rail
Vehicle
Rail Deploying Mechanism
Rail Support
Divertor Plate Handling Manipulator



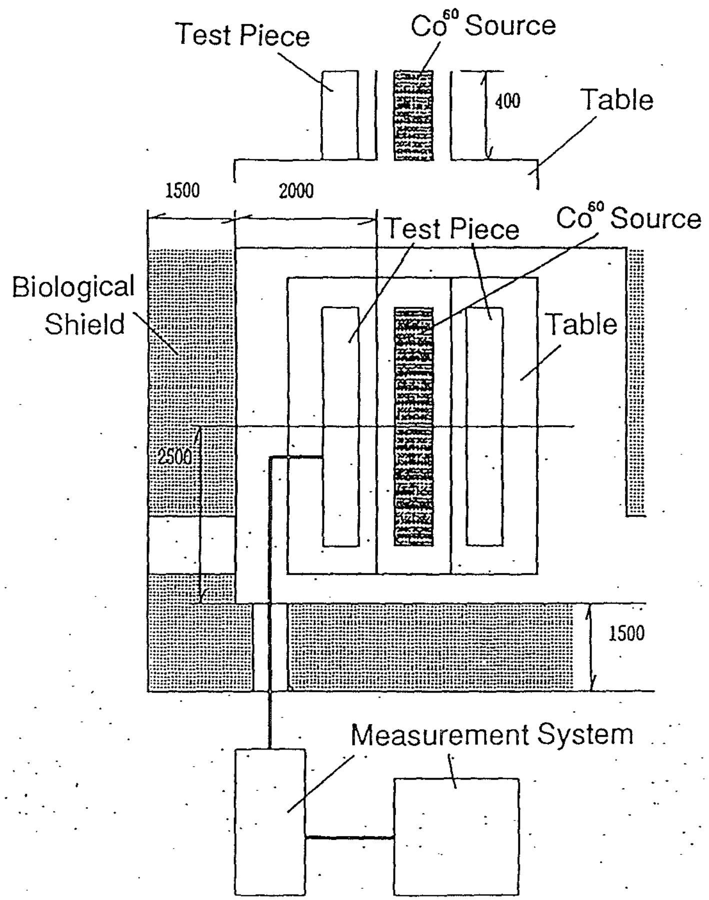
BASE PLATE (FIRST WALL)
BOLT
IMPACT WRENCH
MANIPULATOR ARM
ARMOR
Armor In-vessel Maintenance
Shield (Blanket Ex-vessel Maintenance
VEHICLE
HORIZONTAL ACCESS PORT
ONE SECTOR STRUCTURE
Divertor Ex-vessel Maintenance
VEHICLE
CABLE CRAMP
GUIDE ROLLER
RAIL
END-EFFECTOR
DIVERTOR
Divertor In-vessel Maintenance

Main Specs. of Rail-Mounted In-Vessel Maintenance System (1/5 scale model)

	Dimensions	Weight	Load Capacity	Maximum Speed at the Tip	Degrees of Freedom	Control
Vehicle System	Rail radius : 900mm Cross section Height : 100mm Width : 50mm Thickness : 2.5mm	Vehicle : 25kg Rail : 34kg	Vehicle Travelling force : 45kgf	50mm/sec	13 accessible range : 180° (Toroidal direction)	Teaching playback
Divertor Handling Manipulator	Length : 540mm Width of telescopic mast: 40 × 40mm(min.) 100 × 100mm(max.)	7.5kg	15kgf (Divertor grasping force : 4kgf)	150mm/sec	5 Accessible range :R1020mm	Teaching playback
Armor Tile Handling Manipulator	Length : 1145mm Width : 215mm(min.) 292mm(max.)	13kg	0.5kgf	300mm/sec	8 Accessible range : R995mm	Teaching playback

Gamma ray irradiation test facility in JAERI

Type of cell	: water pool type
Gamma ray source	: Co^{60}
Configuration of Co^{60} source	: 2 m × 0.4 m × 0.1 m
Temperature	: room temperature
Dose rate	: 1×10^{6} R/h max.



Irradiation test

(1) Development of radiation proof components for remote handling system
- Motor
- Optical sensors
- Electrical sensors
- Camera
- Lens
- Lubricant
- Electrical break

(2) Others
- Concrete
- Seal materials

Preliminary Proposal of the Concept on Modular Type Multi Function Hot Laboratories (MODULAB)

-Objective-

- Extensive use of small specimen test technique (SSTT), because of the limited test volume of IFMIF.

- Establishment of the concept of a completely new type of hot cell for automatized test of small specimens.

Preliminary Proposal of the Concept on Modular Type Multi Function Hot Laboratories (MODULAB)

-Characteristics of the MODULAB-

(1) Removable boxes having no window are installed in modular type cell systems.

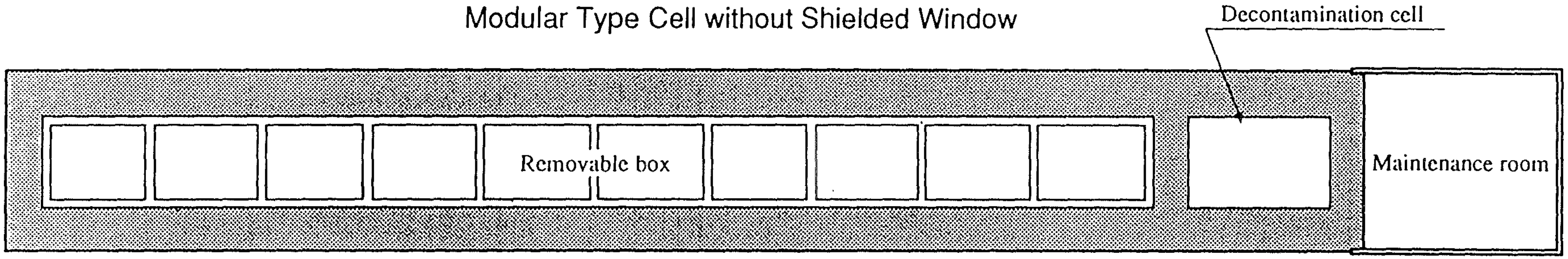
(2) Removable boxes contain an equipment for various materials testing.

(3) Removable box exchange system enables rapid exchange of testing equipments for different materials test and quick maintenance/repair of testing equipments.

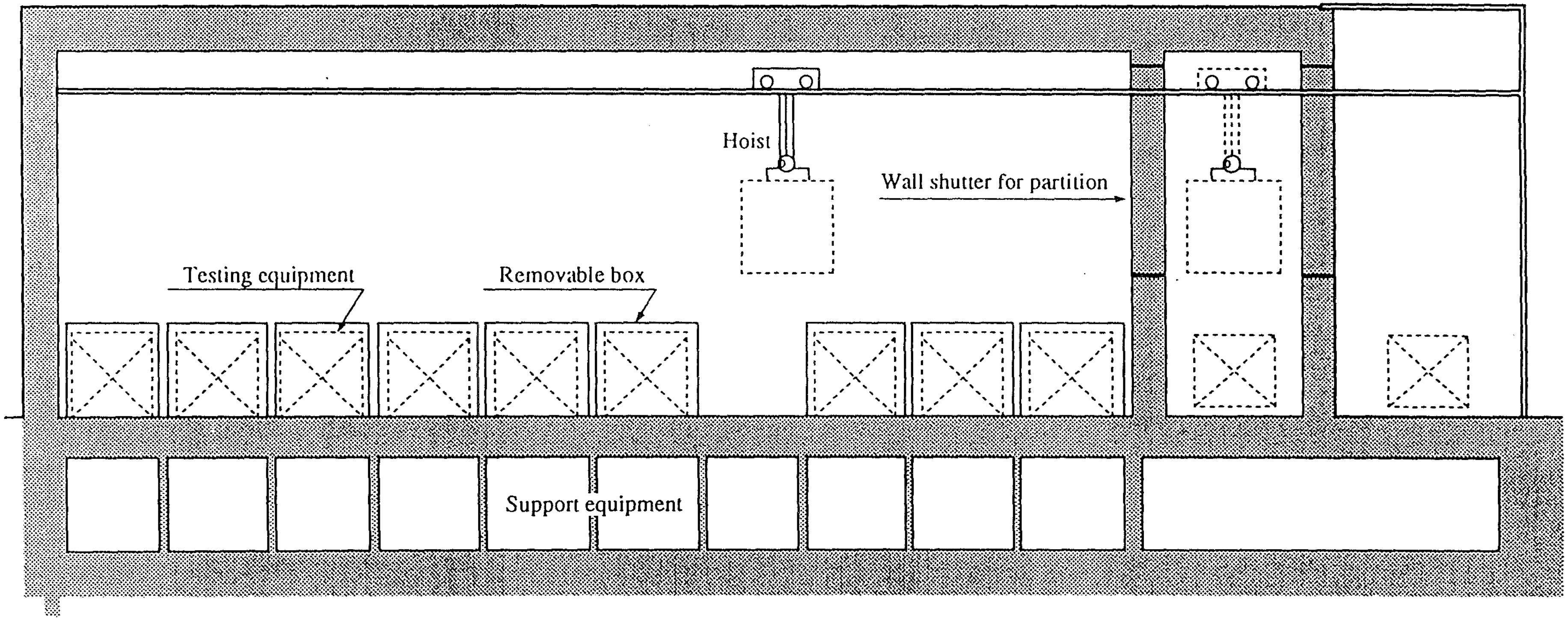
This is essential for fully automatized testing equipments for SSTT and leads high efficiency of hot cells.

(4) Higher safety and efficiency using decontamination cells for removable boxes.

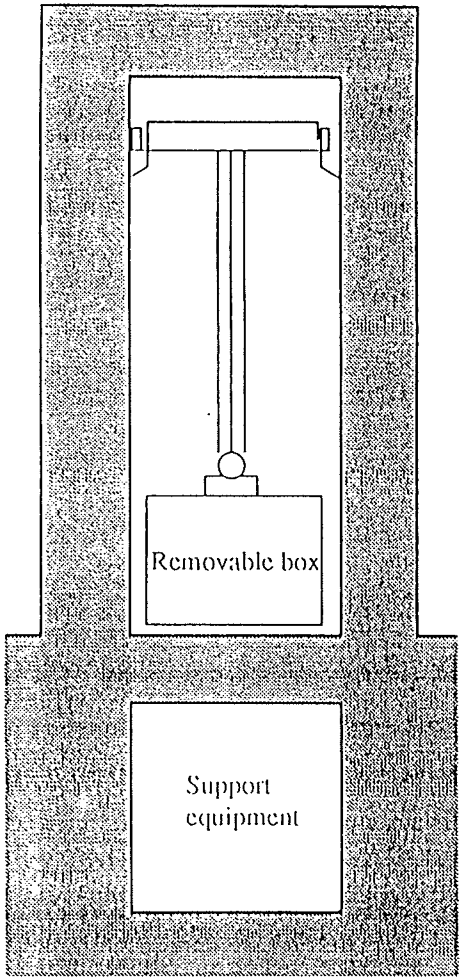
Modular Type Cell without Shielded Window



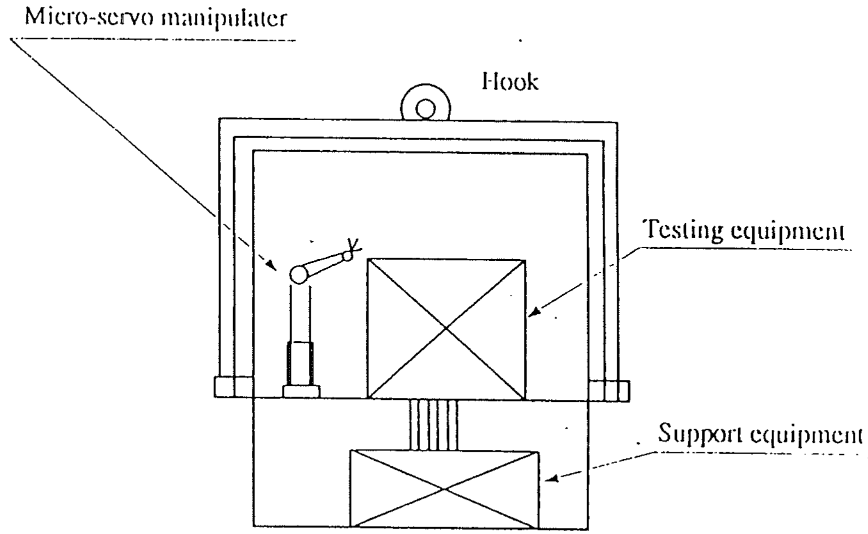
Plane view of cell line



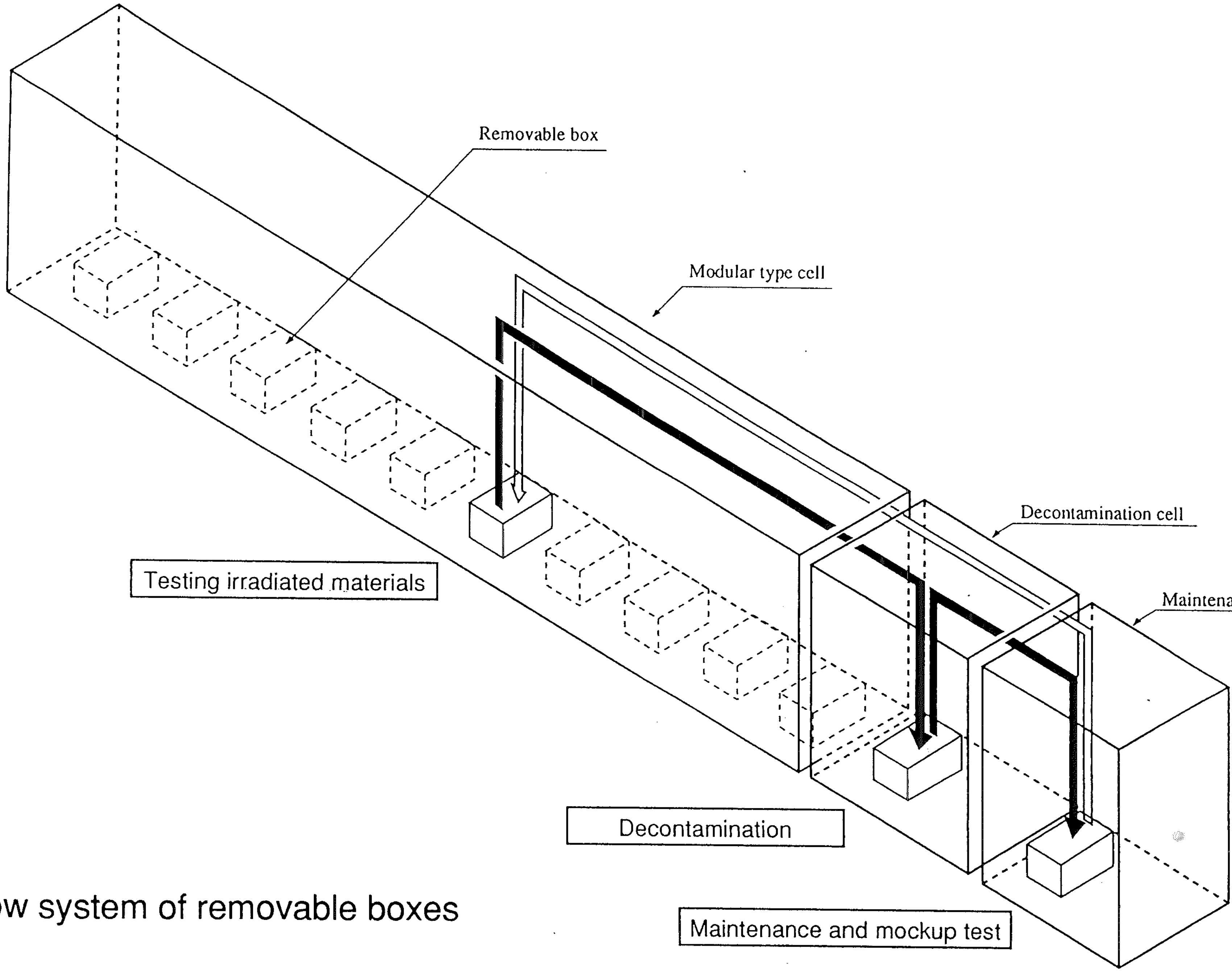
Front view of cell line



Side view of cell



Side view of removable box



Flow system of removable boxes

Conclusions from the IEA International Symposium on Miniaturized Specimens

A. Möslang

KfK

SUMMARY

G.E. Lucas, UCSB
S. Jitsukawa, JAERI
A. Möslang, KfK

IEA-International Symposium on

Miniaturized Specimens for Testing of Irradiated Materials

- 22-23 September 1994, Jülich • Germany
- H. Ullmaier, P. Jung - Organizers; A. Hishinuma, G.E. Lucas - program committee
- Participants: 45
  Presentations/papers: 26

  3 Discussions
  - ITER needs
  - mechanical properties
  - INS parameters

- 4th; Albuquerque '83; Tokyo '87, New Orleans '92

- **Highlights (SSTT)**
  - Multiplicity of - tests - properties - objectives

    Objectives: Screening tests
    Fundamental studies
    Surveillance
    flux gradients
    <u>design data</u>

    Tests/properties: tensile (punch)
    fracture
    impact
    creep, fatigue, creep-fatigue

    Experiments: postirradiation:

short-time tests (ms - 10^3 s)
tensile, fracture, impact

In-situ experiments:
long-term tests (>10^4 s)
creep, fatigue, creep-fatigue
stress corrosion

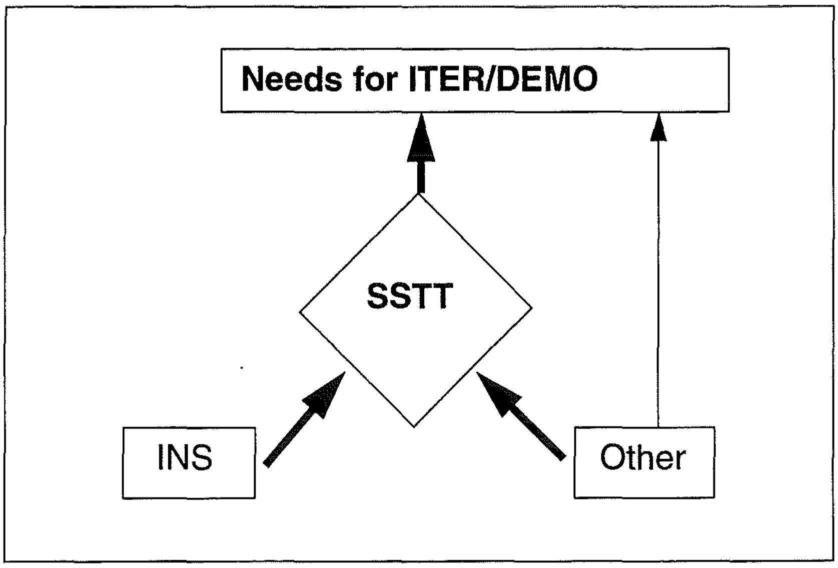
- ❍ Progress in applying SSTT to meet objectives

  goal: to derive "full sized specimen" data from "small sized specimens"

- ❍ Progress in combining theory and experimental results from miniaturized specimens

- ● **Discussion on**
  - ITER/DEMO needs
  - Mechanical properties
  - INS parameters

- ❍ Design criteria will drive data needs
- ❍ Mechanical properties



- For a nuclear power plant the structural integrity is the final goal

  → SSTT in combination with INS are central tools

  →- SSTT important to identify failure modes (fast fracture, inelastic analysis)

- Success require formal interaction between

- INS

  - Beam stability is critical in materials testing
  - Nominal irradiation volumes (high Ø ~ 0.5 l, med Ø ~ 3-4 l, low Ø >10 l) seems to be satisfactory to SSTT community
  - Availability (≥ 70%)
  - Large number of operational issues: Resolution requires ongoing formal interaction between INS effort & SSTT community