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Proceedings of the IEA-Workshop on Intense Neutron Sources Karlsruhe, Germany, 21-23 September 1992

IEA-Implementing Agreement for a Programme of Research and Development on Fusion Materials Working Group Task - Annex II

K. Ehrlich, E. Daum (Eds.)
Institut für Materialforschung
Projekt Kernfusion
Association KfK-Euratom

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE

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

Working Group Task - Annex II

K. Ehrlich and E. Daum (Editors)

Kernforschungszentrum Karlsruhe GmbH, Karlsruhe

Kernforschungszentrum Karlsruhe GmbH
Postfach 3640, 76021 Karlsruhe

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Dedication

It is with deep regret that we have to announce the sudden passing of our respected colleague Dr. S. Cierjacks, who died on October 28th, 1992, after a long serious illness.

The members of the IEA Executive Committee - Annex Fusion Materials and the participants of the Workshop on Intense Neutron Sources dedicate the Workshop Proceedings to Dr. S. Cierjacks' memory.

Siegfried Cierjacks participated with a strong personal motivation in the revived discussions about the most promising way to build an Intense Neutron Source for the Fusion Materials Community. Since 1989 he has been an active and very energetic member of the IEA-Neutron Source Working Group, who successfully evaluated different propositions with regard to their suitability. He also proposed a design of his own, namely the so-called t-H_2O source, a very attracting alternative, which was acclaimed widely by his colleagues. Though already marked and weakened by his illness he, nevertheless, took an active part in our Workshop in September and presented his newest results on the technical feasibility of the t-H_2O source.

We will always be grateful to Dr. S. Cierjacks for the very vigorous part he took through contributions and other activities. He will be remembered by his partners as a very dedicated, always most likeable colleague.

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Session 3

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IEA-Workshop
Nuclear Research Center KfK Karlsruhe
Karlsruhe, Germany
September 21-23, 1992

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	- Necessary Material Developments for DEMO- and Commercial Fusion Reactors	E.E. Bloom T. Kondo K. Ehrlich
	- Fusion Energy and Intense Neutron Sources in China	J.P. Qian
	- The Role of Intense Neutron Sources and other Irradiation Facilities for the Material Development	P. Schiller S. Ishino W.F. Wiffen
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	- The T-H_2O-Neutron Source	S. Cierjacks
	- The Mirror-Type Beam Plasma Neutron Source	D. Ryutov
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IEA-Workshop Attendees

Everett Bloom
Oak Ridge National Laboratory
Martin Marietta Energy Systems, Inc.
P.O. Box 2008, Bldg. 4500-S
Oak Ridge, Tennessee 37831-6117
USA

Siegfried Cierjacks †
KfK
Institut für Materialforschung I
Postfach 3640
76021 Karlsruhe
Germany

Frederic H. Coensgen
Lawrence Livermore National Laboratory
P.O. Box 808, L-637
Livermore, CA 94550

Janos Darvas
Head of the Technology Division Commission of the European Communities
200, rue de la Loi
B-1049 Brüssel

Eric Daum
KfK
Institut für Materialforschung I
Postfach 3640
76021 Karlsruhe
Germany

Donald Doran
Washington State Univ. Tri-Cities
6012 W. Ridgecrest Dr.
Spokane, WA
USA 99208

Karl Ehrlich
KfK
Institut für Materialforschung I
Postfach 3640
76021 Karlsruhe
Germany

H.H. Hennies
KfK
Postfach 3640
76021 Karlsruhe
Germany

† Passed away in October 1992

Shiori Ishino
Dept. of Nuclear Engineering
University of Tokyo
Japan

H. John
KfK
IATF
Postfach 3640
76021 Karlsruhe
Germany

Takaya Kawabe
Institute of Physics
University of Tsukuba
Tsukuba, Ibaraki, 305
Japan

R. Klingelhöfer
KfK
Institut für Mikrostrukturtechnik
Postfach 3640
76921 Karlsruhe
Germany

Stefan Kelzenberg
KfK
Institut für Materialforschung I
Postfach 3640
76021 Karlsruhe
Germany

Tatsuo Kondo
JAERI - Tokai Research Establishment
Tokai-mura, Ibaraki-ken
Japan 319-11

Hermann Kumpf
Zentralinstitut für Kernforschung Rossendorf
Postfach 510119
01314 Dresden

S. Malang
KfK
IATF
Postfach 3640
76021 Karlsruhe
Germany

A. Miyahara
Teikyo University
Hachioji Tokyo, 192-03
Japan

Arthur W. Molvik
Lawrence Livermore National Laboratory
P.O. Box 808, L-637
Livermore, CA 94550

Stefano Monti
ENEA
Via dell' Arcoveggio 56/23
Bologna
Italy

Klaus Noack
Zentralinstitut für Kernforschung Rossendorf
Postfach 510119
01314 Dresden

Kenji Noda
JAERI - Tokai Research Establishment
Tokai-mura, Ibaraki-ken
Japan 319-11

Hideo Ohno
JAERI - Tokai Research Establishment
Tokai-mura, Ibaraki-ken
Japan 319-11

Jia Pu Qian
Head, Fusion Nuclear Technology Lab. SWIP
Southwestern Institute of Physics
Sichuan, P.R. China

R. Ryutov
Academy of Sciences
Institute of Nuclear Physics
Novosibirsk 90, GUS

Michael J. Saltmarsh
Oak Ridge National Laboratory
Martin Marietta Energy Systems, Inc.
P.O. Box 2009, Bldg. 9201-2
Oak Ridge, Tennessee, USA 37831-8070

Bob van den Schaaf
ECN Petten Netherlands
Westerduinweg 3
1755 LE Petten

Peter Schilling
CEC-Joint Research Centre
Materials Science Division
21020 Ispra (VA), Italy

Hans Ullmaier
Institut für Festkörperforschung
KFA Jülich
Postfach 1913
52428 Jülich

J. Vetter
KfK
Projekt für Kernfusion
Postfach 3640
76021 Karlsruhe
Germany

M. Victoria
Paul Scherrer Institute
Area Ost - Gbd. 21/2
CH-5232 Villigen PSI

F.W. Wiffen
US Department of Energy, ER-533
Washington, DC
USA 20585

WORKSHOP CONCLUSIONS

I). Introduction:

This workshop was convened in response to a recommendation of the IEA-Executive Committee/Implementing Agreement on Research and Development on Fusion Materials. It followed preceding meetings in San Diego (1989) and Tokyo (1991) and was initiated to deal with the following objectives:

1) To discuss the existing strategies for the development of materials for DEMO- and Commercial Fusion Reactors.

2) To review the needs of an Intense Neutron Source for a materials research and development programme and to explore it`s suitability for component testing.

3) To discuss the technical feasibility of the different neutron source candidates on the basis of existing or non-existing technical experience.

4) To compare the suitability of different concepts with regard to their specific atomic displacement and transmutation characteristics in dependence of their neutron spectrum.

5) To select an appropriate reference neutron source which fulfills the technical criteria and promises an early availability.

6) To identify the appropriate way for the implementation of the next steps towards the construction and the utilisation an Intense Neutron Source.

The workshop was attended by official delegates of the member countries of the European Community, Japan and the United States of America. In addition specialists from the non-member countries Russia and the People's Republic of China had been invited to the meeting. The list of attendees and the agenda of the workshop are listed above.

II). Summary conclusions of the meeting:

A total of 22 contributions was presented: In these papers new studies of various possible neutron source concepts and the results of comparison studies to evaluate the different candidates were reported. In addition the general strategies for the development of structural materials for future fusion reactors were discussed.
After extensive discussions the participants agreed to the following conclusions:

1) Since 1980 the need for a high energy neutron source for the development of fusion reactor materials has been discussed and endorsed by several national and international panels. (For example: Blue Ribbon Panel 1983; TW Party 1986; Amelinckx Panel 1986; Colombo Report 1991; U.S. FPAC 1990). Nevertheless, it was not possible in this period to reach a consensus on the urgent need to proceed with the construction of a high intensity, high energy neutron source.

2) The decision to start the ITER EDA process signals the intent of the different national programmes to enter the nuclear phase of fusion power development. Therefore the

development of materials adequate for the fusion nuclear environment must begin in earnest. An essential part of this development is the optimization and testing of new materials in an intense flux of high energy neutrons. This task will continue to use existing facilities such as fission reactors, but since the neutron spectra in these facilities differ substantially from those in a fusion reactor a separate high intensity neutron source is a key requirement.

Taking the proposed schedules for ITER and DEMO such a source should be operational not later than the year 2000. This conclusion is based on the experience of materials development for fission reactors where a lead time of 25 years for a fully characterized material was necessary. This high energy neutron source is required primarily for DEMO-related materials development. However, the ongoing work on materials for ITER would also greatly benefit from the existence of such a source. It would allow validation of the ITER relevant irradiation data obtained with the various simulation sources currently available, such as fission reactors and accelerators.

3) An IEA workshop on fusion neutron sources was organized in San Diego in early 1989. At that workshop various high energy neutron source concepts were discussed. These were spallation sources, D-Li stripping sources, a T-H_2O source and beam plasma target sources. The workshop participants developed a number of feasibility and suitability criteria and put in place a process to evaluate and compare the different concepts.

The conclusions drawn here were based on the report of the working group set up to compare the various sources and additional information presented on the current status of the different concepts. The focus of the working group was an evaluation of the effect of the different spectral characteristics of the various sources, as characterized by atomic displacement and transmutation rates in a number of materials. The comparison showed that the differences were not great enough to permit a selection on the basis of this criterion alone. Other criteria must be used, in particular the availability of the physics and technology required to construct and operate such a source by the year 2000.

4) The workshop concluded that a D-Li stripping source is the best choice. The size of the irradiation volume can be chosen within certain limits by increasing the total available beam current. Nevertheless the workshop recognized that the originally specified volume of 10 liters with a neutron flux corresponding to $2MW/m^2$ wall loading cannot easily be satisfied by the D-Li concept. Furthermore recent progress in small specimen test techniques reduces the volume requirement. For a realistic current of 250 to 500 mA a volume of 0.5 to 1.2 liter can be expected.

The workshop participants recommend that an international engineering design activity be started as soon as possible in preparation for the construction of a D-Li source for fusion materials development. The recommended goals for the first module are: 250mA beam current, some energy variability; operation by the year 2000; and a plant factor of 70%.

5) The workshop participants noted, that this source alone is not sufficient for a materials development programme for DEMO. Continued use of fission reactor irradiations will be required. However, the participants expressed their concern about the continued availability of these facilities during the whole development phase, i.e., up to the year 2025. The participants noted the potential of beam plasma sources to provide larger irradiation volumes in the longer term. They would favor the continuation of design and

development studies on these devices and encourage collaboration between the various interested groups.

III). Next step activities.

The participants decided to convey the elaborated summary conclusions to the IEA-Executive Committee/Implementing Agreement on Research and Development of Fusion Reactor Materials for further considerations. They strongly recommended further activities towards the Fusion Power Coordinating Committee (FPCC) of the IEA in order to implement the next step of a Conceptual Design Activity for the accelerator-driven d-Li neutron source and to continue predesign studies for beam plasma machines. The participants also encouraged to extend a collaboration in this very interesting field to interested groups of non-IEA-memmber countries.

K. Ehrlich , Chairman of the Workshop

The D-Li Approach to an International Fusion Materials Irradiation Facility (IFMIF)

Description of the D-Li Concept

The D-Li source concept for an IFMIF is based on the same general approach that was used for the (uncompleted) FMIT facility in the United States, and for the proposed Energy Selective Neutron Irradiation Test facility (ESNIT) project in Japan. As in FMIT, energetic (≈35-MeV) deuterons are used to generate a fusion-like neutron spectrum from the thick-target neutron yield of the Li(d,n) nuclear stripping reaction. The resultant neutron spectrum produces atomic displacements (dpa) and transmutation products, e.g., helium, in irradiated materials with ratios that approximately match the range expected in fusion reactor environments. Also, if the deuteron energy is adjustable, the He/dpa ratio can be tuned to evaluate possible spectrum-dependent effects, a point of emphasis for the ESNIT design.

The FMIT design involved a 100-mA beam incident on a 10 cm wide liquid lithium target flowing at 17 m/s. The useful test volume was relatively modest and steep neutron-flux gradients were a significant concern for materials experimenters. Before the project was terminated in 1984, FMIT firmly established the general technical feasibility of the D-Li source concept at the designed parameter values. The main accomplishments of the program included neutronics calculations to determine test-cell flux levels and volumes, thermal-hydraulic calculations to model the beam/target interaction, development and operation of a prototype lithium jet and circulation system, construction and cw operation of a prototype injector and radiofrequency quadrupole (RFQ), and a complete engineering design for the facility.

The IFMIF would take advantage of improvements in the technology of high-current ion accelerators that have occurred during the past decade. The current proposal is based on a single accelerator providing a 250 mA beam dispersed over a larger area (50 cm^2 - 100 cm^2) lithium target. This would provide a larger experimental volume and smaller flux gradients than FMIT. As in the ESNIT proposal the deuteron energy would be adjustable about the optimum of 35 MeV or so. The experimental volume available at a neutron flux equivalent to 20 dpa/year in iron (roughly 2 MW/m^2) is about 0.4 litres. At constant beam density on target the experimental volume available above a given minimum flux level scales as $I^{3/2}$, where I is the total beam current. Thus if required the facility could be upgraded by adding a second 250 mA accelerator module with the beam incident on either the same target or a separate target. The general features are shown in Figure 1.

In comparison with the FMIT the lithium target must accomodate the higher power dissipation resulting from the increased beam current. Using the proposed uniform dispersed beam intensity would produce a lower instantaneous peak temperature rise in the lithium (assuming the same flow velocity) as well as a lower peak rate of radiation damage to the back wall. However the dimensions of the target jet will be somewhat larger both perpendicular and parallel to the flow direction.

Although the FMIT experience would suggest that this will not pose a jet stability problem, the trade-off between target width, target height, and stability must be evaluated during engineering design.

Possible IFMIF D-Li Neutron Source Concept

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

Lightly drawn module suggests upgrade path to 500-mA system

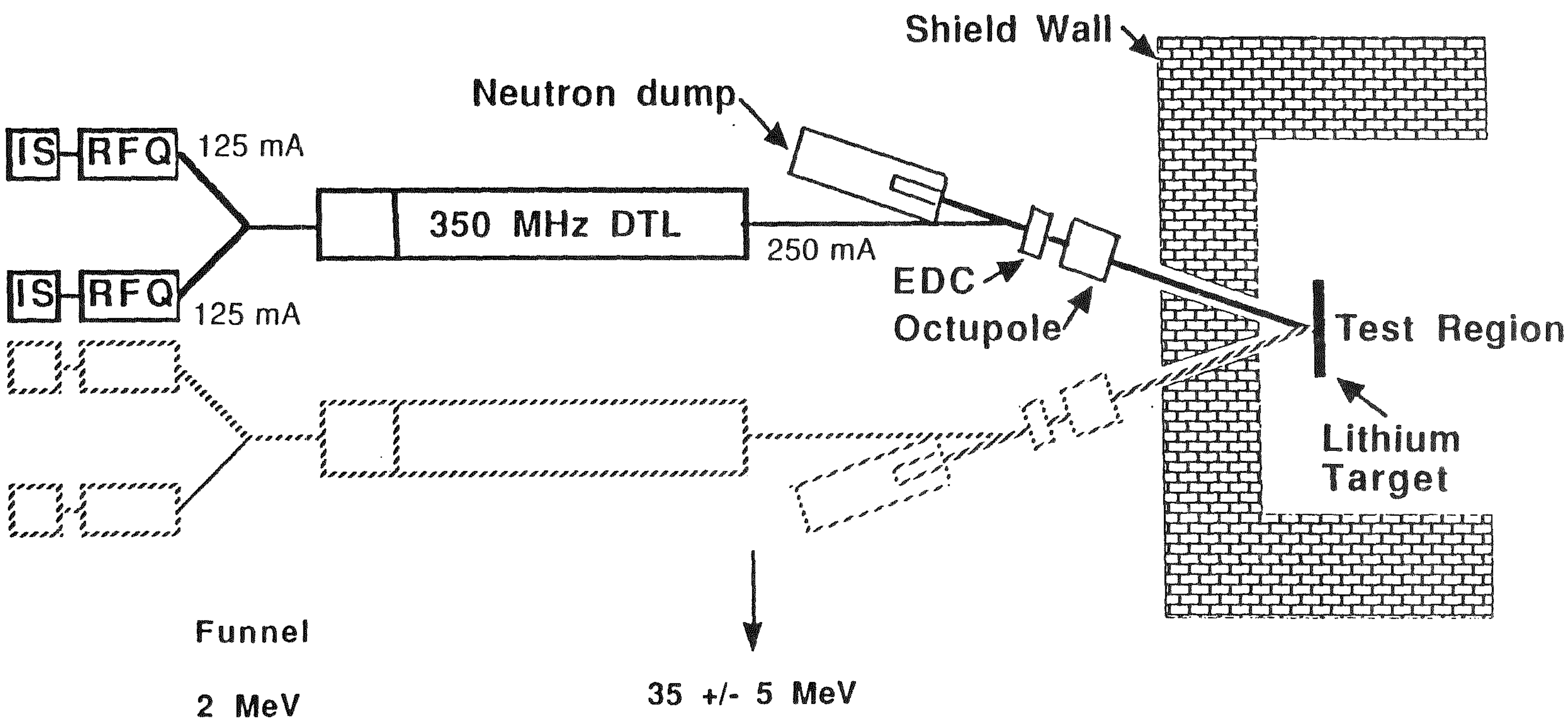


Figure 1

The accelerator module consists of two D^+ dc injectors, two RFQ's, a beam funnel, and a single drift-tube linac (DTL). Trade-off studies should be performed to choose between various design options, such as the use of normal or super conducting structures, and the optimum geometry for the beam-target configuration.

Justification of Beam Current Goal

Since the completion of the FMIT design, there have been significant advances in high-current ion-linac technology that will allow construction of a D-Li neutron source with higher performance. These advances include a comprehensive emittance-growth theory, better beam-dynamics simulation codes, development of the beam-funneling concept for current multiplication through rf frequency doubling, the use of high accelerating-structure frequencies plus permanent-magnet quadrupoles (PMQ) plus ramped accelerating gradients to control beam-emittance growth and halo growth, and the use of high-order optics in beam-transport systems to manipulate beam profiles. Preliminary beam dynamics simulations have been reported (G.P. Lawrence et al., Journal of Fusion Energy, Vol. 8, p. 201, 1989) for a configuration whose parameters are listed in Table 1, which is similar to those shown in Figure 1.

Because of beam loss inherent in the bunching process of the RFQ, about 140 mA of D^+ must be provided by the injector (at an energy ≈100 keV) to obtain 125 mA at the RFQ output. This requirement could be met by an ECR driven cusp field ion source. The selected RFQ frequency (175 MHz) is more than twice that of FMIT, allowing a large reduction in transverse structure dimensions. High-power (0.5-1.0 MW cw) tetrodes are commercially available to provide rf power for acceleration.

Mean aperture	1.2 cm
Tank diameter	36 cm
Structure length	5.4 m
Surface field (peak)	25 MV/m
Transmission	89.3 %
rf power (copper)	0.3 MW
rf power (beam)	0.4 MW
rf power (total)	0.7 MW
Output emittance (T)	0.27π mm-mrad
Output emittance (L)	0.46π mm-mrad

Table 1: RFQ Parameters

Beam behavior in the RFQ was simulated with the code PARMTEQ, using a 1000-super-particle input distribution that uniformly filled a four-dimensional transverse phase-space hyperellipsoid. The longitudinal input distribution was that of a continuous beam with zero energy spread. Table 1 lists various RFQ parameters. The transverse (T) and longitudinal (L) beam emittances shown are normalized rms values.

The output beams from the two RFQs are combined longitudinally at twice the RFQ frequency in a funnel. A one sided test of this concept at Los Alamos has demonstrated that essentially no emittance growth can be achieved with a beam having reasonably high space-charge forces.

The DTL consists of two 350-MHz tanks operating as 1 $\beta\lambda$ accelerating structures (β = matched particle speed as fraction of speed of light, λ = rf wavelength). The accelerating field in the first tank is ramped from 3 to 4 MV/m, while in the second the field is held constant at 4 MV/m. The frequency is more than four times that of FMIT, and the accelerating gradient is three to four times higher, resulting in a much more compact accelerator. Improved control of beam halos (and reduced beam loss) is expected with the higher frequency structure.

The simulation code PARMILA was run with 1000 super particles to examine the DTL beam dynamics at 250 mA. The input phase-space distribution is that of a uniformly filled six-dimensional hyper-ellipsoid whose rms emittances are obtained from the RFQ and funnel outputs. No particles from this distribution were lost from interception by the drift tubes. Table 2 lists DTL parameters for the case studied.

Tank diameter	50 cm
Number of drift tubes	128
Drift tube aperture	2.0 cm
Total length	13 m
Beam loading	71 %
rf power (copper)	3.3 MW
rf power (beam)	11.3 MW
rf power (total)	0.7 MW
Output emittance (T)	0.30π mm-mrad
Output emittance (L)	0.51π mm-mrad

Table 2: DTL Parameters

Reliability and Maintainability

The combination of the FMIT prototyping and advances in accelerator technology provide confidence that the specifications proposed for an IFMIF can be achieved.

However the high plant factor required will place high demands on the reliability and maintainability. During the design phase close attention must be paid to remote maintenance needs, and the schedule must allow for prototyping of critical components.

Session 1

Plan of New Stage Fusion R&D in Japan

T. Kondo

JAERI

Plan of New Stage Fusion R&D in Japan

- The 2nd stage plan (1975, JAEC) was revised.

- The 3rd stage plan (1992-, JAEC) is now authorized

- Implementing plans for each sector and field are being worked out.

Objectives of R&D for Experimental Reactor

- Self ignition (Q ~ 20)

- Long time burning (1000sec ~)

- Base technology formation for DEMO

Further Emphases

- International Collaboration

- Frequent and timely check & reviews

2.3 Fusion Technology

(1) R&D for scaling-up and improvement in performance of major components required for the development of an experimental reactor

(2) R&D to form the basis of fusion technology required for a prototype reactor in the next stage

(3) R&D on fusion technology which requires a long lead-time before it is realized, but are essential to the practical use of fusion energy

Fusion Technology Subject Areas

- Large, high intensity superconducting Magnets
- Remote maintainance and consistent reactor structure
- Plasma facing components for high heat load
- Devices for high power heating and current drive
- Tritium production, breading and handling
- Blanket technology
- Simplified, integrated major device elements
- **Materials for structure, blanket and instrumentation resistant to high fluence neutron irradiation**
- **Low activation materials**
- **Data for material performances in neutron environments**

U.S. Strategy for the Development of Fusion Reactors

F.W. Wiffen

U.S. DOE

U.S. STRATEGY FOR THE DEVELOPMENT OF FUSION REACTORS

Presentation to the

IEA Workshop on Intense Neutron Sources

F. W. Wiffen
Office of Fusion Energy
U.S. Department of Energy

KfK - Karlsruhe

September 21-23, 1992

FUSION MATERIALS PROGRAM

The Department of Energy's fusion policy supports the National Energy Strategy goals aimed at strengthening the foundations of future U.S. energy security, economic growth, and environmental progress.

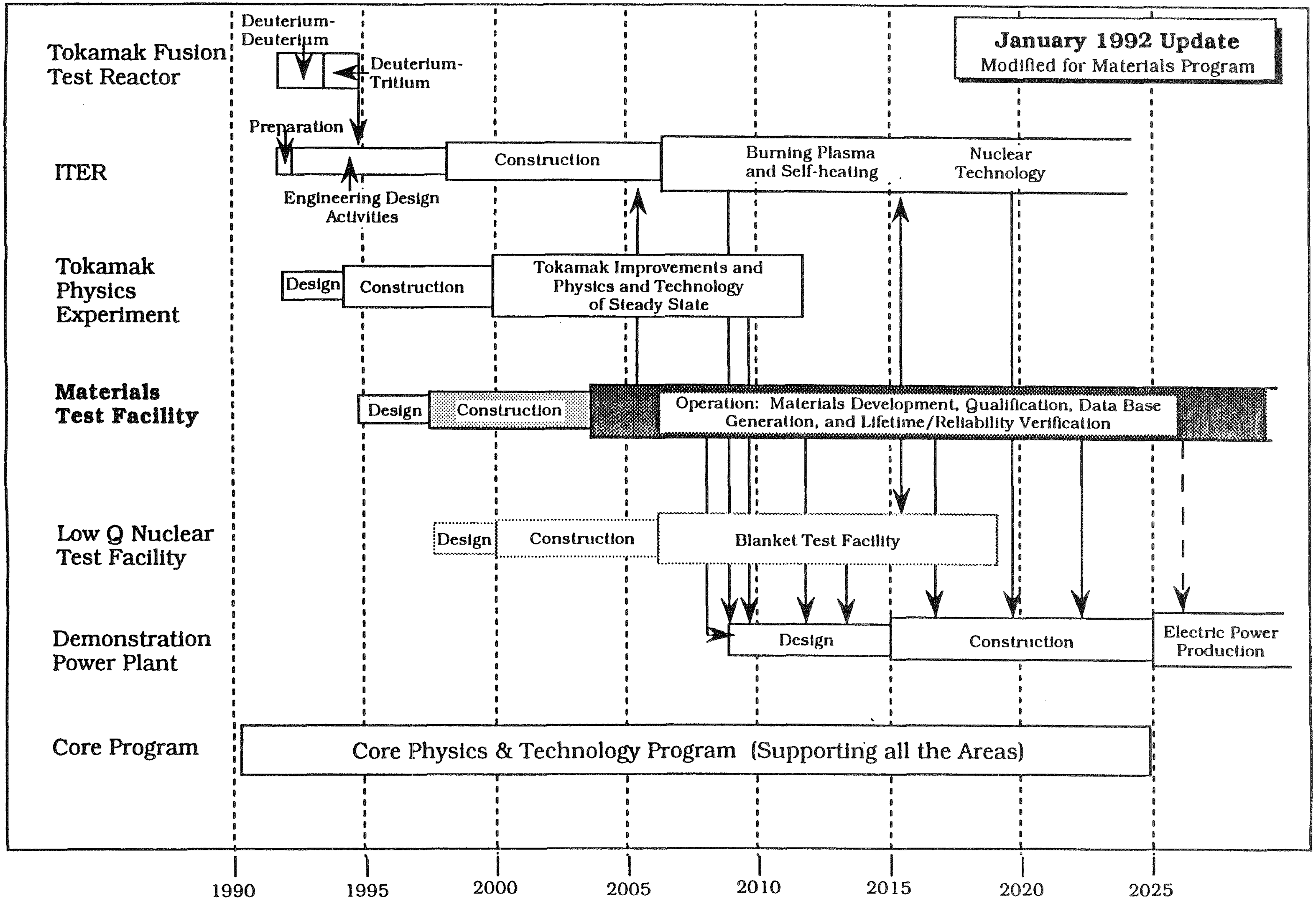
Fusion is a goal-oriented program with specific milestones.

Long-term goals are:

- An operating demonstration power plant by about 2025.

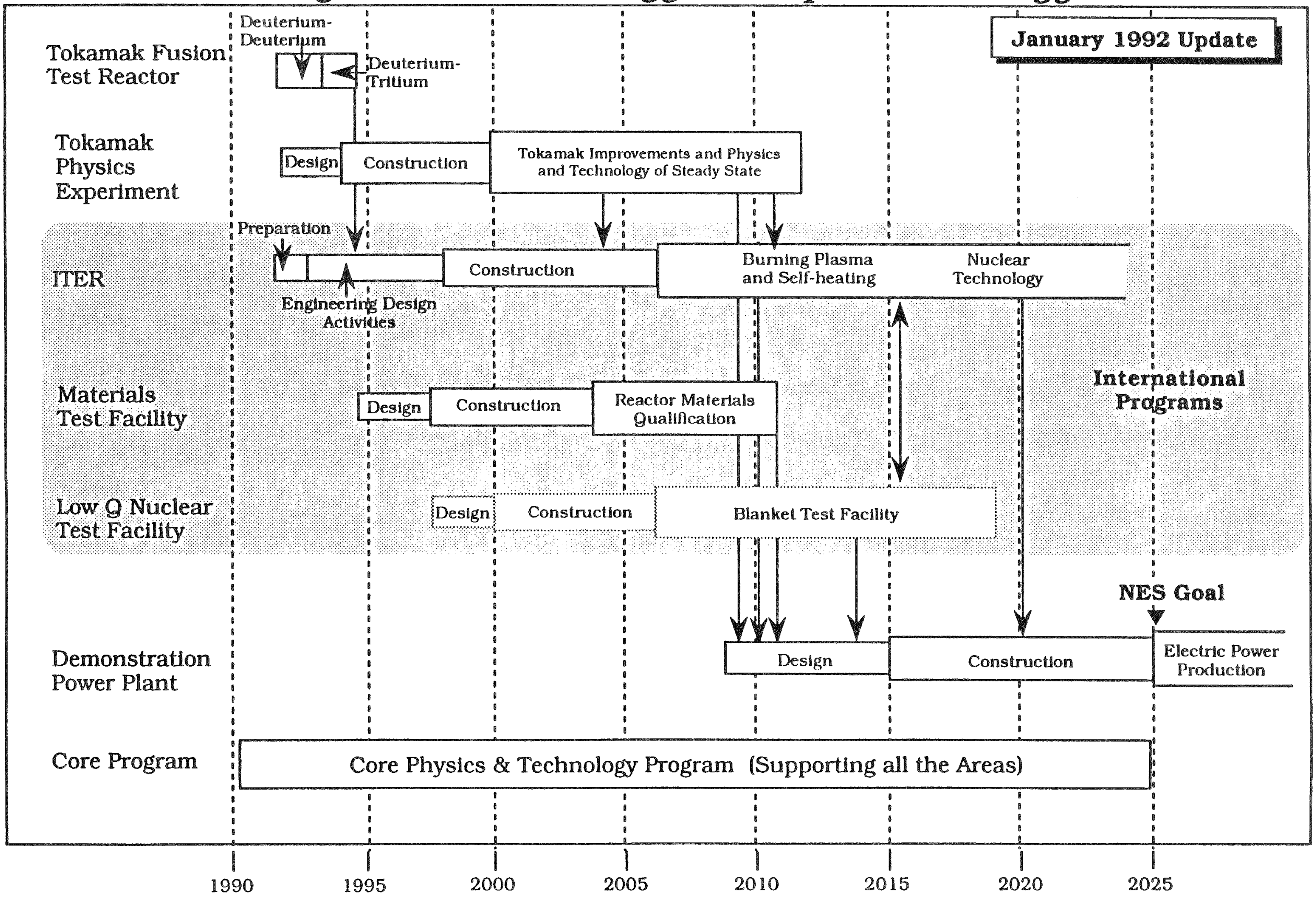
- An operating commercial power plant by about 2040.

Magnetic Fusion Energy Development Strategy



Note: Elements are drawn from recommendations of the Fusion Policy Advisory Committee, U.S. Department of Energy (September 1990). Schedule estimates are subject to uncertainty and will depend upon technical readiness, availability of funding, and international agreements.

Magnetic Fusion Energy Development Strategy



CONCEPTUAL DESIGN STUDIES HAVE EXPLORED A WIDE RANGE OF FUSION REACTOR OPTIONS

Completed Reactor Studies Included:

Starfire	--	Tokamak
Mars	--	Mirror
Titan	--	RFP

Specialized Studies:

BCSS -- Blanket Comparison and Selection Study
ESECOM -- Environmental, Safety, and Economic Aspects

Current Studies:

ARIES -- Advanced Tokamaks -- Innovative Engineering

Future Studies (under consideration):

Pulsed Tokamak, Stellerator
Demonstration Power Reactor

FUSION MATERIALS PROGRAM
THE REACTOR STUDIES HAVE INFLUENCED THE MATERIALS PROGRAM

- All conceptual studies have shown the materials data base to be inadequate for design.

- There are very strong feelings that DEMO and commercial reactors must use low activation materials.

- Water coolant is generally regarded as undesirable, due to safety issues.

- Materials limits have constrained the reactor performance envelope--through limits on operating conditions and limits on component lifetime.

FUSION MATERIALS PROGRAM

REACTOR STUDIES CANNOT BE THE ONLY GUIDE TO THE MATERIALS PROGRAM

- The history of the design studies is a progression of material choices.

- The materials program must maintain a range of options to meet the most probable design choices.

- When DEMO choices become firm, the materials programs must narrow down to meet the data base needs for DEMO.

FUSION MATERIAL PROGRAMS
HISTORY OF THE U.S. PROGRAM

- The structure and approach for the fusion materials program was established by task groups organized by K. M. Zwilsky in 1976.

- A major mid-course correction to include reduced activation materials occurred as a result of the low activation task force, the Conn Panel, established by R. J. Dowling in 1982.

- The FMIT Project of 1978-1985 established the technology needed for an accelerator-based D-Li neutron source. International interest did not develop in time to complete the project.

- The recent evolution of composite materials technology, the ESECOM Study, and the ARIES project have led to consideration of SiC/SiC composites for reactor structural components. This system is currently under limited evaluation.

- The goals of reduced activation materials development were examined by an IEA Workshop in 1991. The U.S. program is making adjustments as a result.

- The focus in structural materials development is on low activation compositions of ferritic/martensitic steels, vanadium alloys, and silicon carbide composites.

- Work on ceramic insulators is increasing rapidly.

SUMMARY

The Fusion Materials Program must develop reduced activation materials for use in DEMO by about 2025.

- o A much expanded effort is required to build from the base that has been established.

- o Expanded use of fission reactor irradiation is a requirement.

- o A high energy neutron source must be available by about 2000 for accelerated testing, neutron spectrum effects evaluation, design data validation, and generation of an engineering data base.

Fusion Programme Evaluation Board

J. Darvas

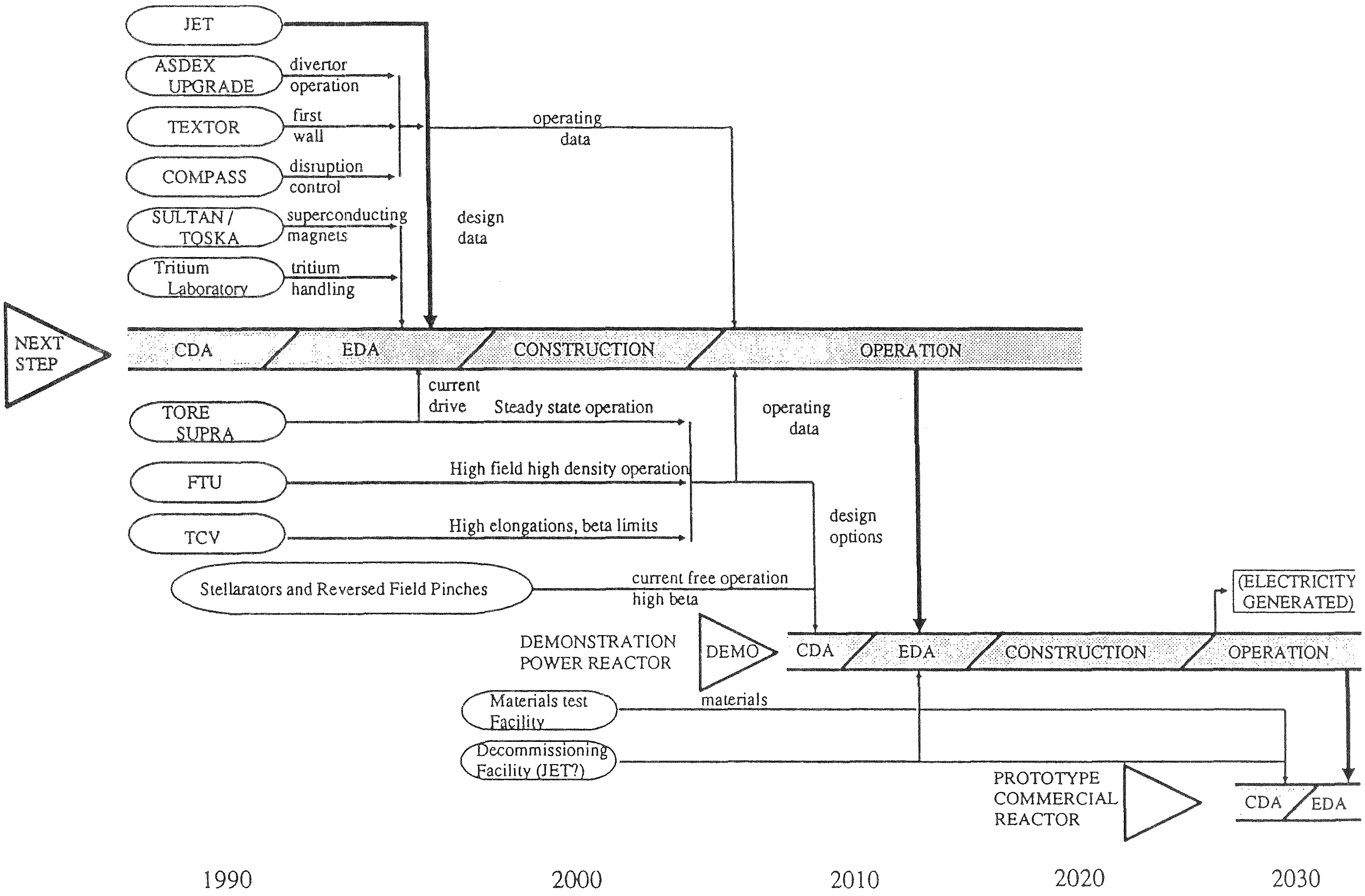
European Community

FUSION PROGRAMME EVALUATION BOARD

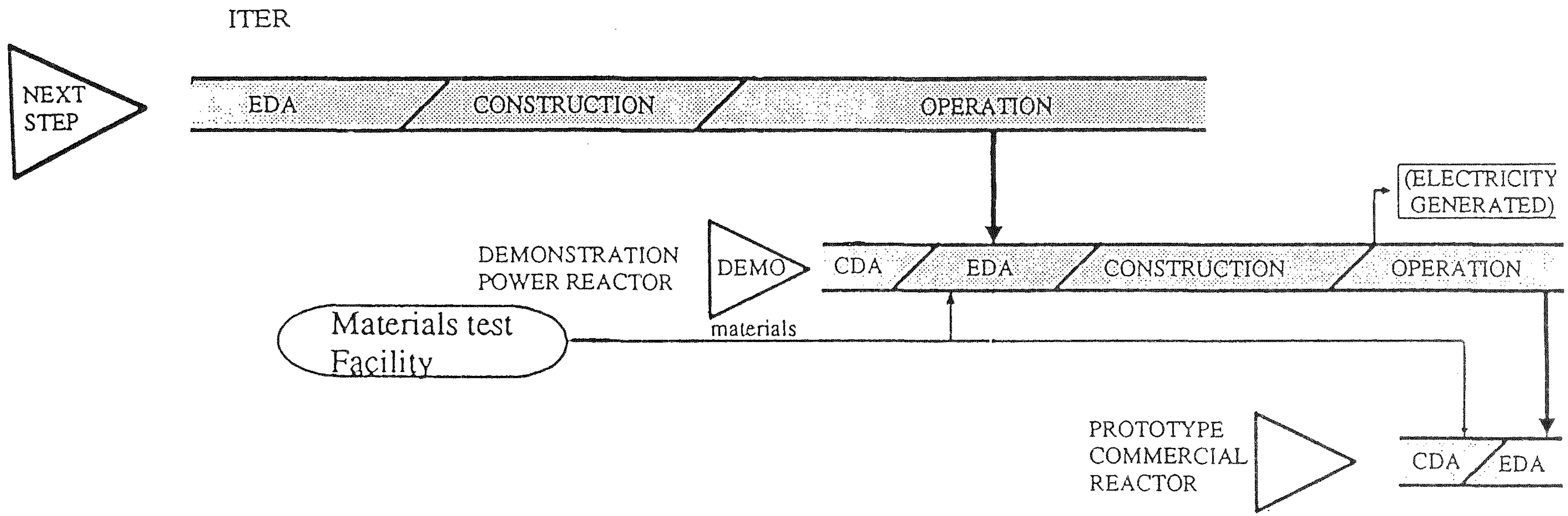
(Chairman U. Colombo, July 1990)

"The problem of the need for a powerful source of high energy neutrons for materials testing should be addressed with the utmost urgency. Such a source should be made an integral part of the ITER programme"

MAJOR FACILITIES PLANNING OF THE EUROPEAN FUSION PROGRAMME



PLANNING OF THE EUROPEAN FUSION PROGRAMME



POSSIBLE TIME SCALES

ITER

. EDA	1992-98
CONSTRUCTION	1998/99 - 2005/6 (assume no delays)
OPERATION	2006/7 - 2~~2~~026/27 (assume 20 y's)

DEMO

BEST GUESS	CD	≥ 2 - 4 y's
	ED	≥ 6 y's
	CONSTR.	≥ 8 y's
	OP	≥ 20 y's

MATERIALS CHOICE FOR DEMO: at beginning of DEMO-ED, 2010

MATERIALS TEST PROGRAMME IN DEMO: ≥ 2025

n - SOURCES

STRATEGIC MISSION:

- to allow choice of materials for DEMO (at the beginning of ED, $\geq$ 2010

- to support the development of low-activation materials (to be tested in DEMO)

IN CONCLUSION THE TASKS AHEAD ARE:

- to define the technical objectives of a n-source which fulfill the strategic mission
- to find a concept which promises to reach those objectives
- to reach international consensus on the above issues

Materials Development for DEMO and Commercial Fusion Reactors

E. Bloom

ORNL

MATERIALS DEVELOPMENT FOR DEMO AND COMMERCIAL FUSION REACTORS

IEA Workshop on Intense Neutron Sources

September 21—23, 1992

Kernforschungszentrum Karlsruhe
Karlsruhe, Germany

E. E. Bloom

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6117

ORNL WSZ-19614

Development of Materials for Fusion Reactors is a Greater Challenge Than for Any Other Energy System

Operating Environment	Material Response/Issue
● Radiation Damage – Displacement – Transmutations	Swelling Irradiation Creep Degradation of Physical and Mechanical Properties
● Chemical Compatibility – Coolants – Tritium Breeders	Corrosion - Mass Transfer Degradation of Mechanical Properties Hydrogen Embrittlement
● Elevated Temperatures	Time Dependent Deformation (Creep)
● Mechanical Stresses – Primary – Secondary (Thermal) – Cyclic – High Loading Rates (Disruptions)	Many Mechanical Properties Critical in Design Tensile Fatigue Crack Growth Fracture Toughness
● Complex Structure	Fabricability Welding/Joining Maintenance

Long-Term Goal

Develop materials that will contribute to the realization of fusion as an economically competitive, safe, and environmentally acceptable energy source

Commercially Available Materials Will Not Satisfy the Long-Term Fusion Goal

Economically Competitive

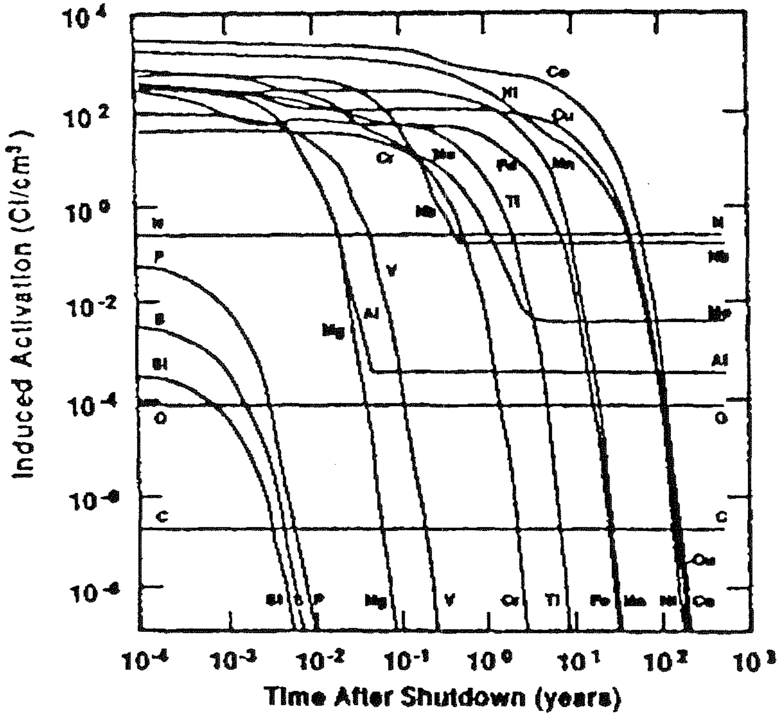
- We must develop materials that have acceptable
  - Lifetime
  - Temperature capability
  - Maintainability

The Unique Characteristics of Fusion Permit Us to Design Materials that Will Enhance Safety and Environmental Attractiveness

- The primary sources of afterheat, dispersible radioactivity, are the reactor structural materials
- The source of long half-life radioactivity is the reactor structural material

ORNL-DWG 92Z-94

Radioactive Decay And Basic Material Characteristics Reduce To Four The Number Of Candidate Reduced Activation Systems



Severely Restricted:
Ni Mo Nb N Cu

Unrestricted:
Mn W Cr Ta Fe Si Ti V

Alloy Systems	RA Alloy	Commercial Analog
Vanadium Alloys	V-Cr-Ti, V-Si-Ti	
Ferritic Stainless Steels	Fe-Cr-W-V	Fe-Cr-Mo
Austenitic Stainless Steels	Fe-Cr-Mn	Fe-Cr-N
Silicon Carbide	SiC/SiC	

ORNL-DWG 92Z-9410

.The First Step In Developing a Material System Is To Establish Feasibility

- Design study to show potential
- Basic properties and response to operating environment
  - Radiation
  - Chemical
  - Physical properties
  - Mechanical properties
- Synthesis, fabrication, joining
- Consideration of unique characteristics
- Effects of structure/chemistry on response

- Positive (or negative) assessment
- Identification of properties that limit performance
- Approaches to improvements

In the Materials Development Step the Composition and Microstructure are Tailored to Achieve the Desired Properties

- Composition and microstructure variations to obtain acceptable performance for limiting properties
- Estimates of end-of-life properties
- Technology for fabrication, joining, NDE
- Definition of chemical compatibility issues for design

- Structural material with composition and structure optimized for fusion

ORNL-DWG 92Z-9412

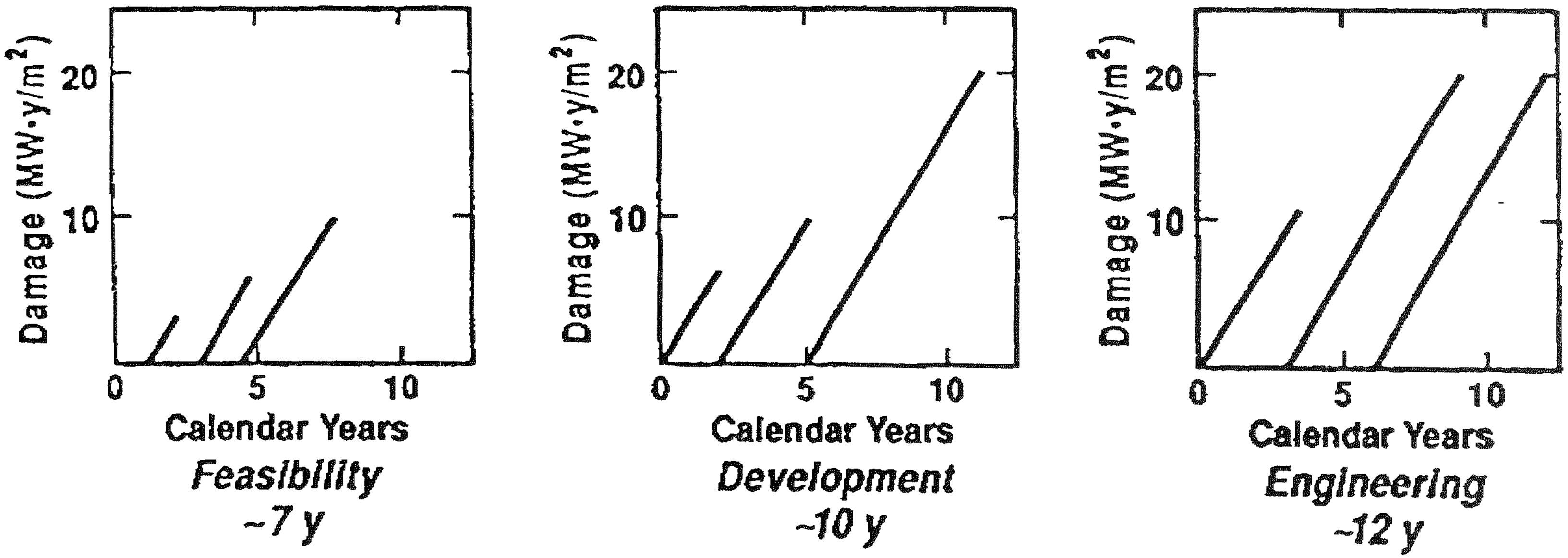
The Third Step - Materials Engineering - Develops the Technology Required to Utilize the New Material

- Production scale-up (verification of properties)
- Properties of product forms, welds/brazes, etc.
- Compatibility/mass transfer data for design
- Mechanical properties and radiation effects design data base
- Synergistic effects, design specific issues

- A structural material qualified for design and licensing

The Rate Controlling Step In the Materials Development Process Is Investigation of Radiation Effects

- Multiple and sequential irradiation experiments are generally required
- Below is an approximate time scale to develop a material capable of 20 MWy/m^2 using fission and fusion sources producing damage at a rate of 3MWy/m^2



- Most material options drop out in the feasibility step or early in the development step
- Only one or two would be carried through engineering

ORNL WSZ-19622

Development of Ferritic/Martensitic Steels

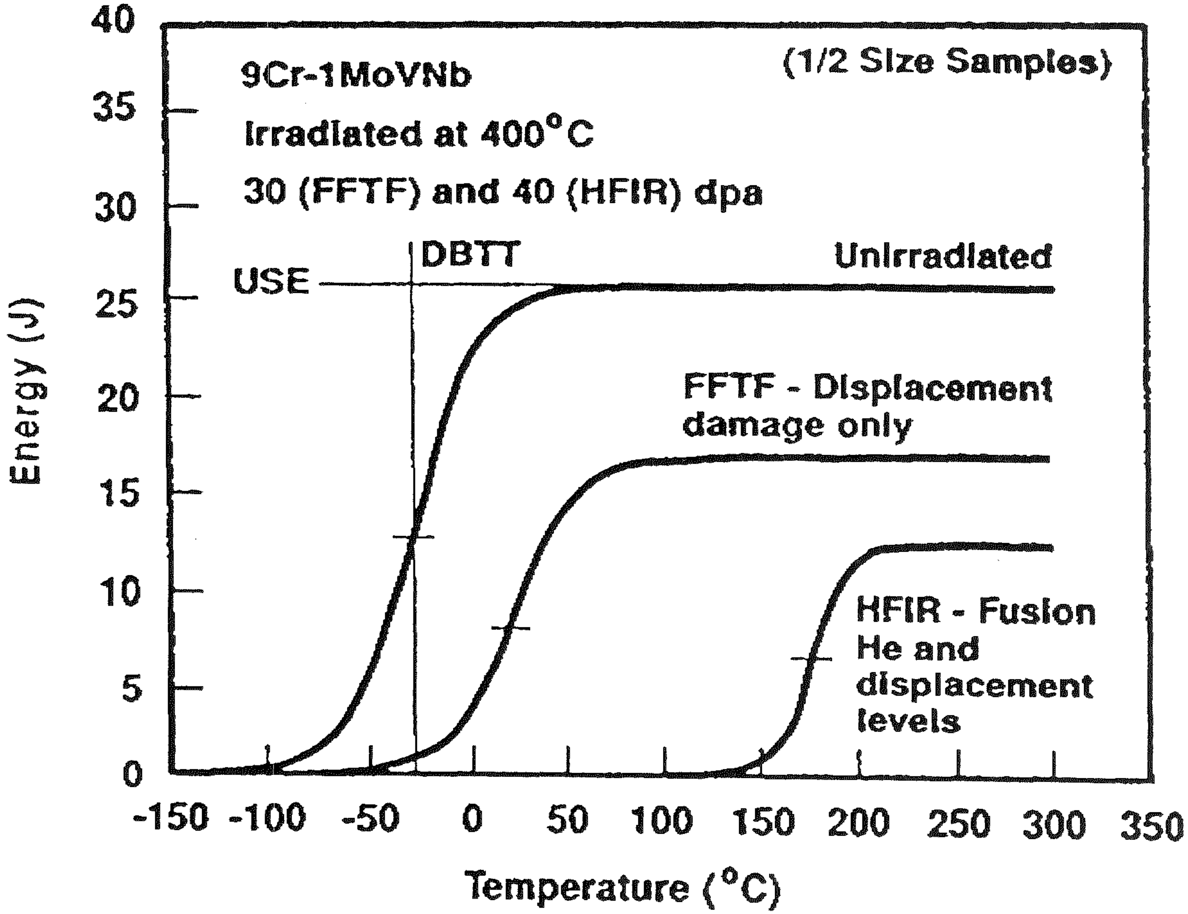
Evaluation of feasibility of using F/M steels began in 1978

Critical issues identified by DOE working group

- Interactions of the ferromagnetic structure and the magnetic field
  - Concluded that additional loads were manageable
  - Effect of ferromagnetic structure on fields and operation is manageable
- Need for post-weld heat treatment during fabrication
  - Required for higher Cr alloys (9-12 Cr) possibly can be eliminated for 2-3 Cr alloys
- Effect of increased helium generation on irradiation response
  - Results to date show F/M steels to be very resistant to swelling and He embrittlement at fusion He/dpa levels
- Effects of fusion neutron damage levels on fracture properties
  - Shown to be a critical issue on which alloy development focused

ORNL-DWG 92Z-9400

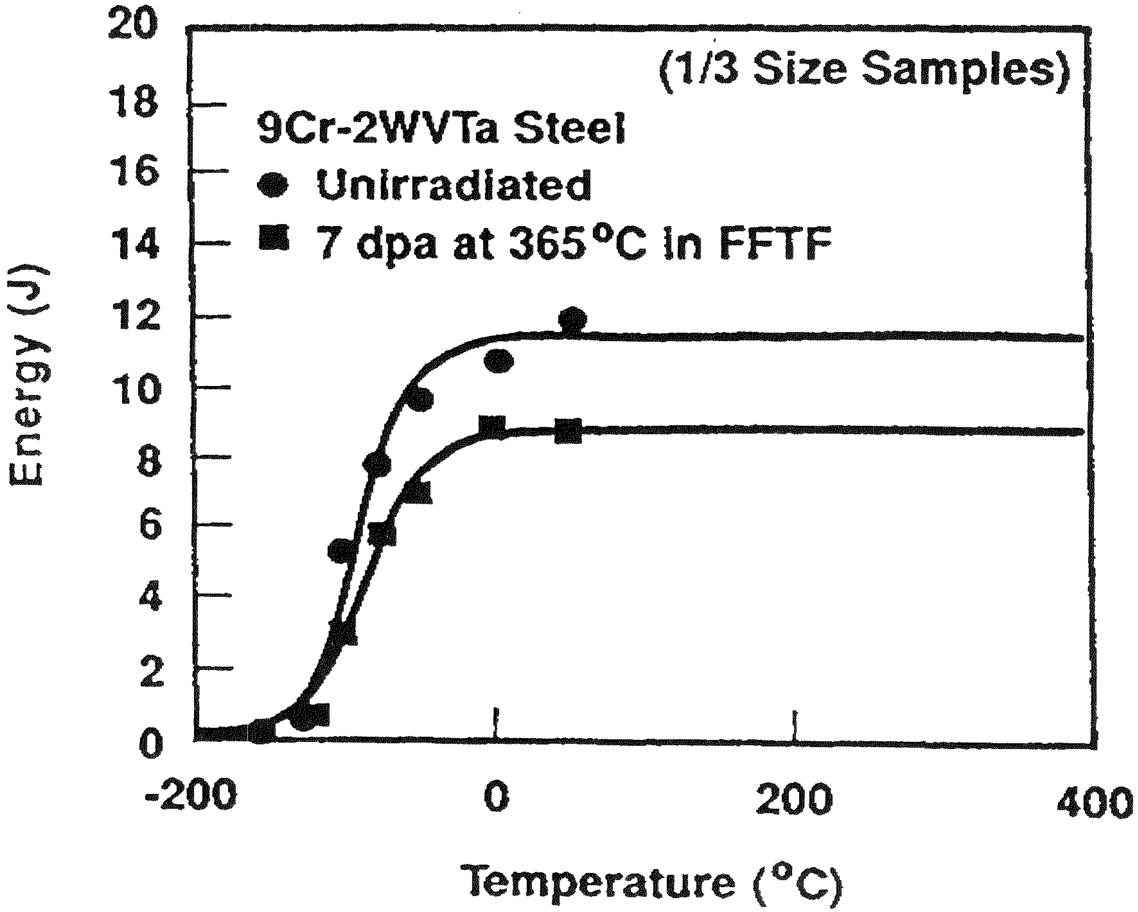
The Effect Of Irradiation On The DBTT And Fracture Toughness Has Been Identified As The Most Critical Issue To Be Addressed In The Development Of Ferritic/Martensitic Steels



Irradiation shifts DBTT and lowers the USE. The reduction of properties after irradiation in HFIR is larger than in FFTF, an effect related to higher He generation in HFIR.

ORNL-DWG 92Z-9399

At Irradiation Damage Levels Investigated To Date, The Reduced Activation 9Cr-2WVTa Martensitic Steel Has Exhibited A Smaller Shift In DBTT Than Any Other Martensitic Steel



Development of Vanadium Alloys Has Been an Important Element of the Program

Vanadium alloys offer several advantages

- Excellent compatibility with Pure Li and Pb-Li
- V and common alloying elements are reduced activation
- Temperature capability to about 700 °C
- Excellent thermal stress figure of merit

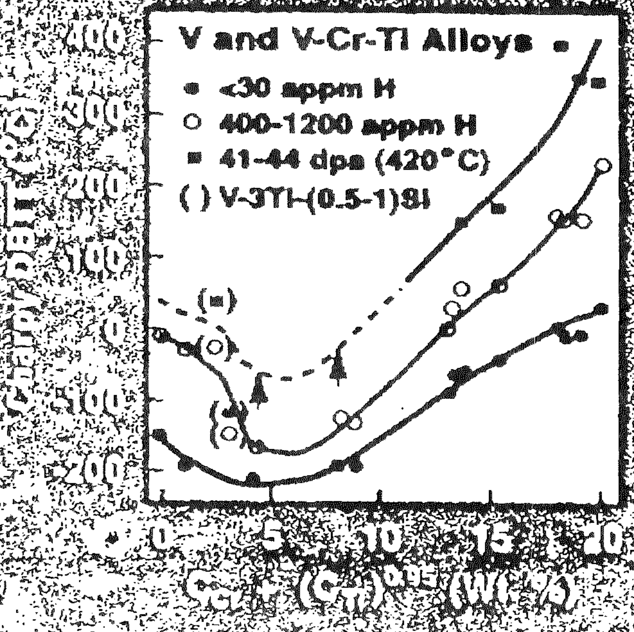
Our research has been focused on the most critical issues relating to the use of V alloys

- Corrosion and compatibility
- Radiation damage resistance
  - Swelling
  - Tensile properties
  - Fracture properties
- Effects of composition on mechanical properties
- Hydrogen effects

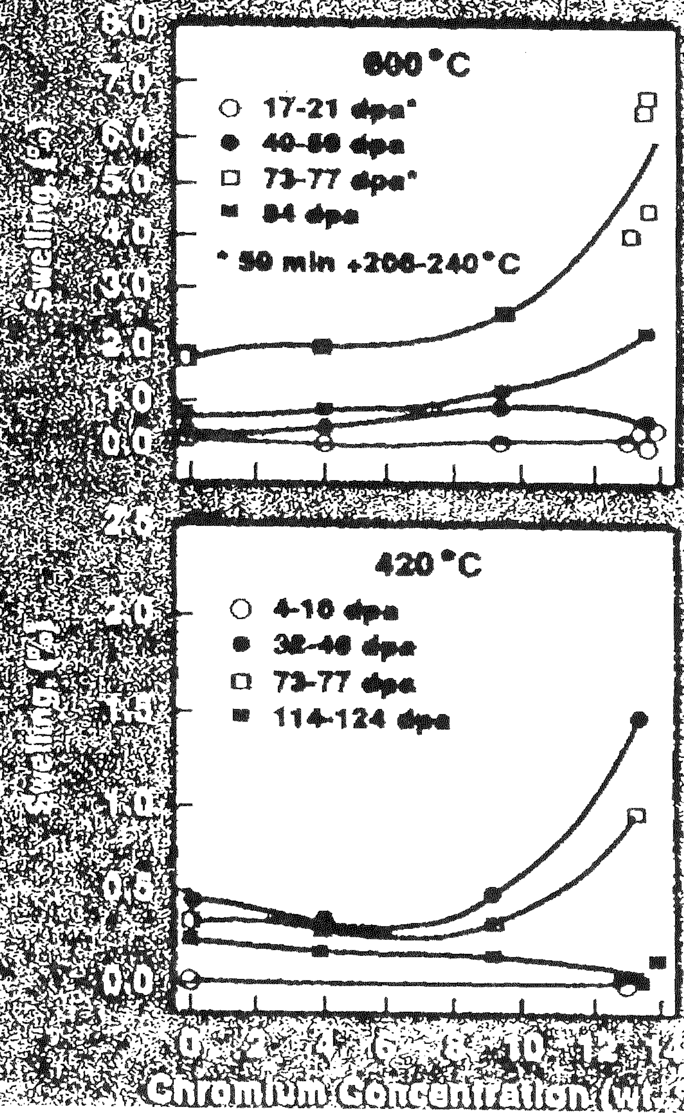
V-5Ti-5Cr Has Been Selected As A Base Composition For Further Development

This selection was based on results of a systematic investigation of the effects of Cr and Ti concentration on tensile, DBTT, irradiation hardening, and swelling

Effect of Hydrogen and Irradiation on DBTT



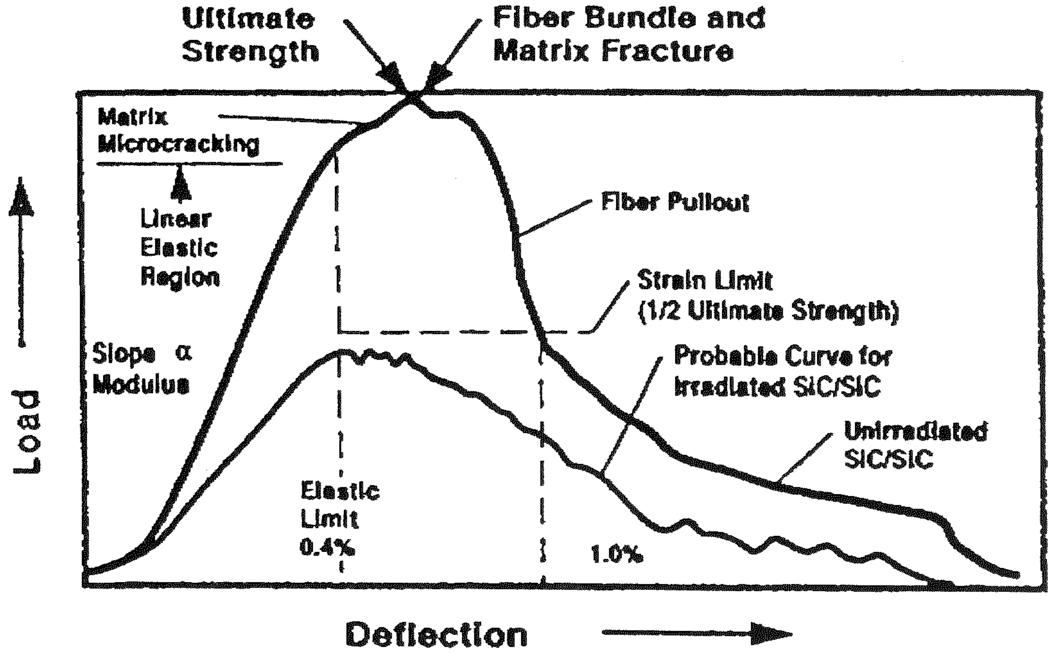
Swelling of V-Cr-5Ti Alloys



ESECOM and ARIES Studies Have Shown the Safety and Environmental Attractiveness of SiC/SiC Composites

- Two workshops to identify feasibility issues have been conducted
  - Radiation effects on properties
  - Hermetic structure
  - Fabrication and joining
  - Chemical compatibility
- Research has been initiated on these issues
- The first results of the research effort are now becoming available
  - Currently available materials exhibit degradation of mechanical properties as a result of low fluence irradiation
  - Tailoring of these materials for fusion will require improved fibers and interfaces

Initial Experiments Indicate Irradiation Induced Degradation Of Mechanical Properties In SiC/SiC Composites Using Nicalon Fiber



Summary Of Observations

- Fiber shrinkage: Interface separation, decreased modulus, and reduced fracture streng
- Matrix microcracking: Decreased modulus and fracture strength
- Fiber crystallization: Decreased fracture strength
- Failure strain may be relatively unaffected by radiation up to ~1 $\frac{MW\,y}{m^2}$ damage levels a 800 to 1000°C
- Need tailored fibers and interfaces

ORNL-DWG 92Z-9413

Why Pursue the Development of Three Different Alloy/Ceramic Systems for Structural Applications?

- **No single material has the basic physical, mechanical, and chemical properties for all concepts**

Coolant	*Breeder*	*Structural Material Options*
H_2O	Ceramic	Ferritic Steels Austenitic Steels
Li Li-Pb	Li Li-Pb	Vanadium Alloys
He	Ceramic	Si Carbide Austenitic Steels

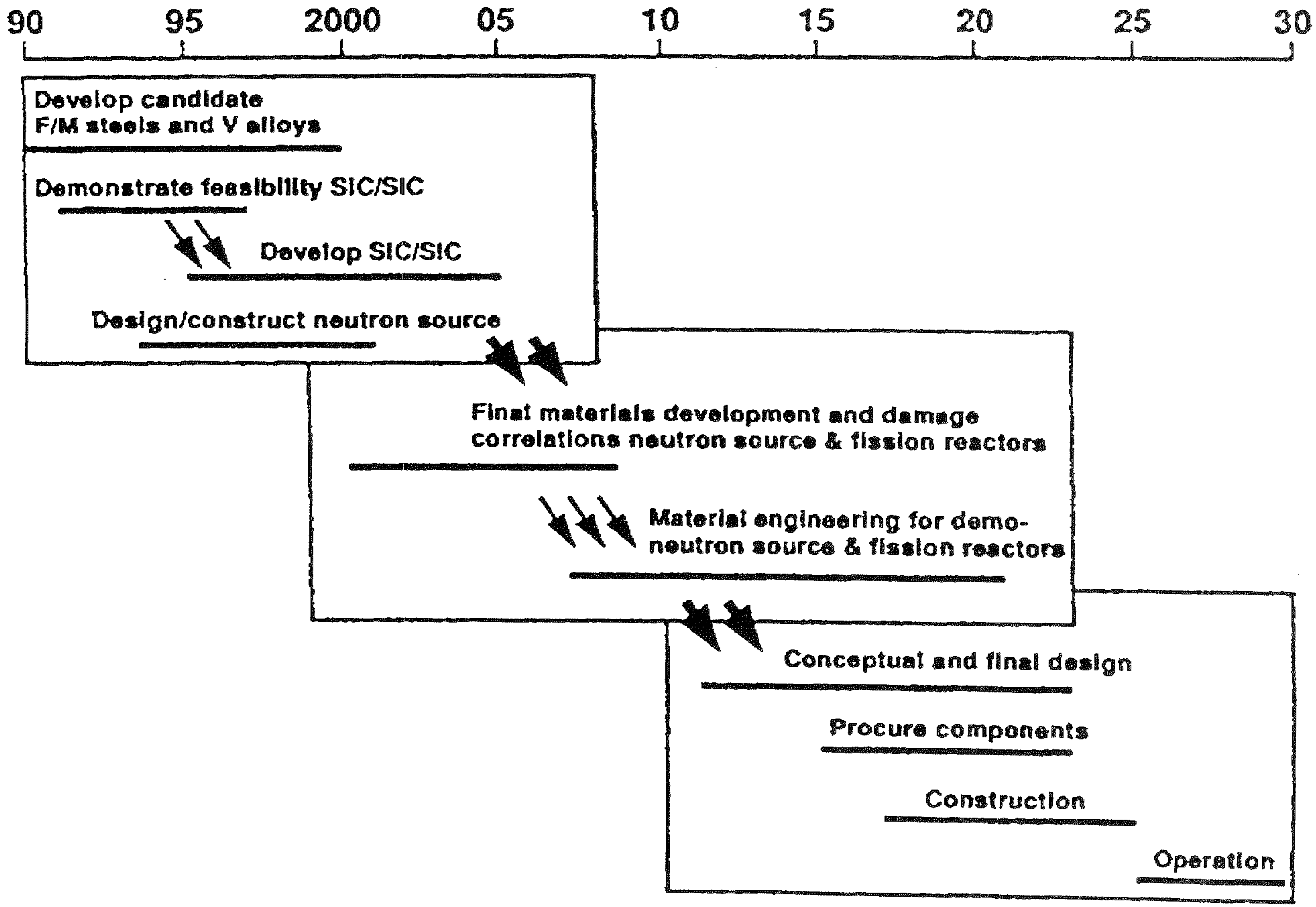
Why Pursue the Development of Three Different Alloy/Ceramic Systems for Structural Applications (cont'd)

- We do not know which system can be developed to have adequate properties. Each has attractive characteristics as well as feasibility issues.

Structural Materials	*Attractive Characteristics*	*Major Feasibility Issues*	*Design Issues/Limitations*
Ferritic Steels	Swelling and helium embrittlement resistance Established technology	Irradiation effects on fracture properties	Upper temperature limit
Austenitic Steels	Established technology Compatibility and mechanical properties	Irradiation induced swelling	Activation Thermal stress
Vanadium Alloys	Temperature capability Swelling and helium embrittlement resistance Thermal stress factor	Irradiation effects on fracture properties	Chemical compatibility
SiC/SiC Composites	Low activation Temperature capability	Radiation effects on physical and mechanical properties Fabrication/joining	Design methods Cost

ORNL-DWG 92Z-9396

Reduced Activation Materials Can Be Developed For A 2025 Demo Operation. An Expanded, Aggressive Program Will Be Required



ORNL WSZ-19627

A Fusion Neutron Source Is Required for Development of Structural Materials for Demo

- Support for ITER and the initial stages of developing materials for power reactors can be accomplished with fission reactors and innovative experiments such as spectral and isotopic tailoring, DHCE, injector foils, etc.

  - Proposed ITER structural materials contain Ni, therefore we can achieve correct He/dpa using spectral and isotopic tailoring

  - ITER damage levels are low, therefore, they can be achieved with irradiation experiments of acceptable duration consistent with the ITER schedule

  - For advanced materials we are now generally limited to exploration of basic damage mechanisms

A Fusion Neutron Source Is Required for Development of Structural Materials for Demo (cont'd)

- A fusion neutron source is required to carry the development of advanced materials to completion and demonstrate the acceptability for fusion power applications
  - The effects of irradiation on mechanical and physical properties is a central issue
  - It is not possible to adequately approximate damage (e.g, He, H, dpa) nor achieve end-of-life damage levels in advanced reduced activation structural materials, ceramics, and PFC materials with available techniques
  - The required materials development programs cannot be accomplished in the planned successive and incrementally more powerful plasma physics devices
- A fusion neutron source must be operational by about the year 2000 to support the goal of a fusion demonstration reactor by 2025
- Expanded use of fission reactors will also be required

New Fusion Research and Development Stage with an Experimental Reactor

T. Kondo

JAERI

New Fusion Research and Development Stage with an Experimental Reactor

1. Basic Understandings

(1) Appropriate stages will be fixed to undertake the R&D on fusion energy. Now is the time for Japan to embark on the R&D in a new stage. In Japan it is called "the third stage R&D", in which a tokamak-type experimental reactor is regarded as a core machine(hereinafter referred to as "the new stage").

(2) The three main objectives are established for the new stage:

- to attain the self-ignition condition
- to realize long burn
- to form the basis of fusion technology for the development of a reactor in the next stage

(3) Emphasis will be placed on the international collaboration in the R&D in the next stage. In order to reduce the risks incurred and the resources (finance and manpower) required, R&D on fusion energy can be efficiently conducted through international collaboration.

(4) During the new stage, check and review will be made taking into account of such aspects as the degree of R&D progress, the environment surrounding the fusion R&D in Japan and abroad.

2. R&D issues

2.1 Research on plasma physics with the tokamak-type devices

- self-ignition condition : aiming at an energy multiplication factor of about 20

  - improvement in confinement of high performance plasma
  - increase in heating power by means of high-energy alpha particles

- long burn : aiming at long-pulse operation (more than about 1,000 sec)

  - current drive with high efficiency
  - helium ash exhaust
  - disruption control

- tokamak-type devices besides the experimental reactor

  - complementary R&D difficult to be performed only with the experimental reactor
  - advanced R&D intended to introduce new technology

2.2 Research on plasma physics with non-tokamak-type devices

R&D with helical-type,mirror-type, reversed-field-type, and compact-torus-type devices will be continued to explore future possibilities for remarkable progress of R&D, and to make use of the result for the R&D with tokamak-type devices. Especially, as to helical-type devices, the construction and operation of the Large Helical Device will be promoted to improve the reliability of confinement scaling law.

2.3 Fusion Technology

(1) R&D for scaling-up and improvement in performance of major components required for the development of an experimental reactor

(2) R&D to form the basis of fusion technology required for a prototype reactor in the next stage

(3) R&D on fusion technology which requires a long lead-time before it is realized, but are essential to the practical use of fusion energy

2.4 Safety Research

R&D on safety will be undertaken in the following areas:

- Behavior of tritium and activated materials both inside and outside a fusion reactor
- Engineering safety research on components and equipment of a fusion reactor
- Methods of safety assessment of a fusion reactor

2.5 Others

Design studies as an integrated system of a fusion reactor will be conducted to improve the reactor concept.

3. Organizations for implementation

- R&D relating to the experimental reactor will be undertaken by JAERI.

- Other R&D activities will be conducted through close collaboration among universities, national laboratories and JAERI.

- Involvement of industries in the R&D will be encouraged to actively promote the R&D activities and to foster effective transfer of advanced technologies to other industrial fields.

- The Fusion Council of the Atomic Energy Commission of Japan will coordinate the entire plan of R&D and perform check and review.

NECESSARY MATERIAL DEVELOPMENT.

— Supplementary Comments —

FUSION MATERIAL R&D LONG-TERM VIEW
- BACKGROUND STATUS AND ISSUES -

1) Materials for Experimental Reactors (ITER, etc.)

- Bases of Engineering Data and Performance Prediction are Incomplete.
- Demands will Increase for Reliable Neutron Irradiation Data Taken under Component-Specific Conditions.
- Technology for Functional Materials are Premature.

2) Materials for Demo

- Special Exploration and Innovation are Needed in Providing Potential Candidates for Various Components.
- Performances under High-Flux-Fluence Test Environments Must be Examined on Engineering Basis
- R&D Plans Must Be Consistent with Available Test Means Including High Energy Neutrons.

STAGES II & III - PRELIMINARY VIEW

Objectives

1. Confirmative Testings and/or Demonstration on Performances of Materials for ITER.(Stage II)

2. Exploration and Innovation of Potential Candidate Materials for DEMO. (Stage III)

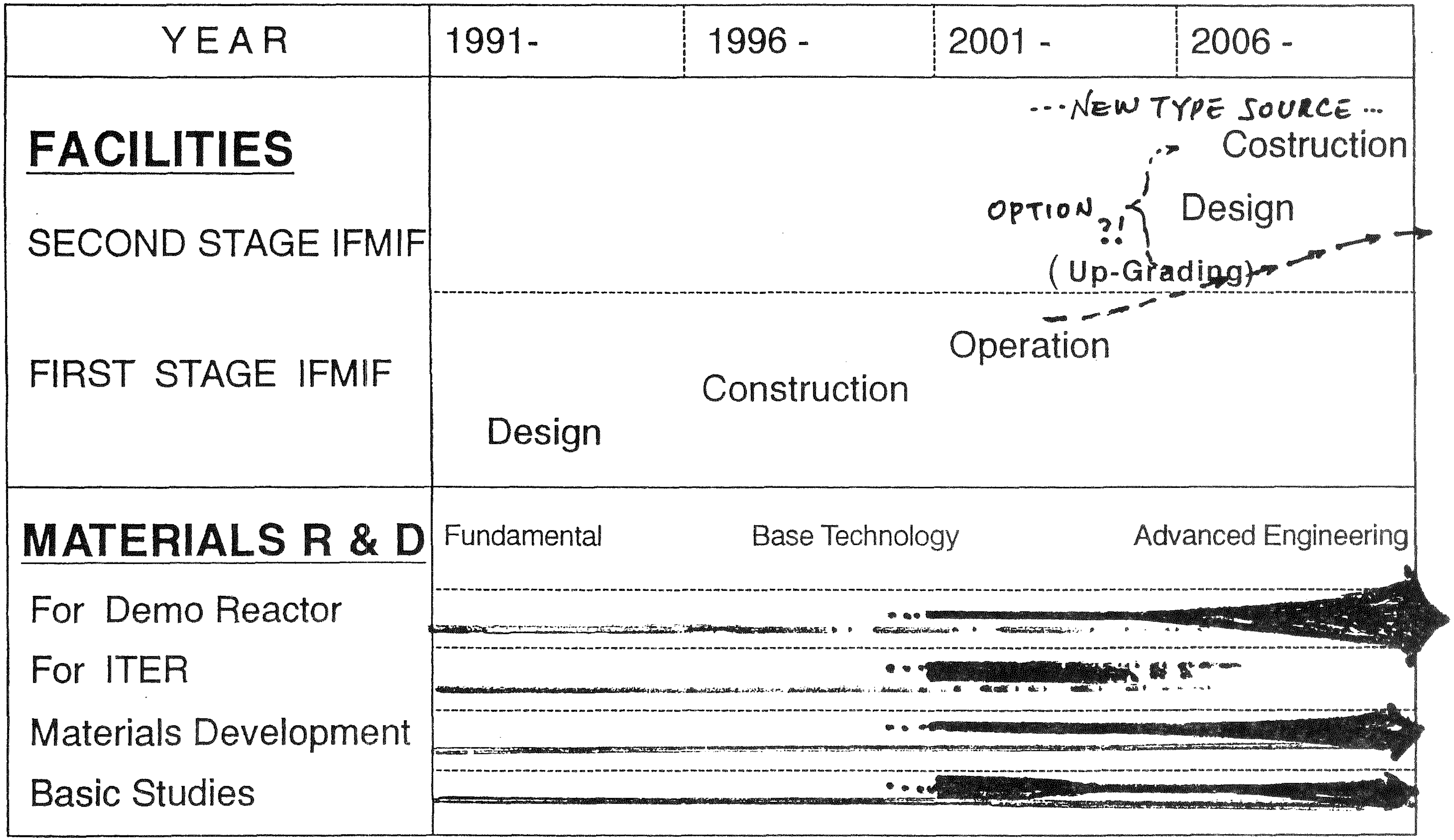
Time Frame:

- Stage II (1995 - 1999) ----- Possible Start of ITER Construction (Late 1990's)

- Stage III(2000 - 2004) ----- Possible Start of INS Operation (Early 2000)

  ----- Up-Grading (2005 - 2010)

SUGGESTED TIME SCHEDULE



Stages II & III, Scope and Approaches

Phase of Activities	Tasks to Be Covered
I Scientific	- Theoretical Analyses and Modeling of N-N Correleation - Experimental Analyses of Predicted Behavior - Physical and Chemical Data
II Base Technological	- Design & Prosessing of New Materials - Test Methodology Development - Characterization and Behavior Analyses - Qualification Testing and Data Acquisition
III Applied & Industrial	- Design & Prosessing of New Materials - Test Methodology Development - Characterization and Behavior Analyses - Qualification Testing and Data Acquisition
IV Materials Engineering	- Applications to Reactor Design

Summary

- Intensive Projection Must Be Made in Next Few Years on Implementing Plans (Ref. ITER & INS Schedules)

- Balance of Near - and Long-Term Projections is Required.

- Issue of Securing Neutron Irradiation Beds is Very Critical.

- Internationally Integrated Approaches Under Joint Planning are Essential.

Material Development for Fusion Reactors

K. Ehrlich

KfK

Workshop on Intense Neutron Sources

September 21 - 23, 1992

Karlsruhe

Karl Ehrlich, KfK

1. Operational conditions for NET / ITER
   DEMO and CRF in different programmes

2. Strategies for reactor development
   in Fusion and Fast Reactor programmes

3. Requirements for DEMO-Reactor
   material development

4. Capacity of different neutron sources
   for accumulation of radiation damage

5. SiC a Low Activation Material

Operational Conditions for the First Wall[1]

Project	NET/ITER	DEMO	CFR
Neutron Wall Loading			
[MW/m^2]	1	2 - 3	3 - 6
[dpa s^{-1}]	$3 \cdot 10^{-7}$	$(6 - 9) \cdot 10^{-7}$	$(9 - 18) \cdot 10^{-7}$
Integrated Wall Loading			
[MW y/m^2]	0,25 - 1	10-20	15 - 30
[dpa][(2)]	2.5 - 10	100 - 200	150 - 300
Mode of Operation	pulsed	quasi-cont.	quasi-cont.
Number of Cycles	$2 \cdot 10^4$	$10^3 - 10^5$	$10^3 - 10^5$
Burn Time/Cycle [s]	200 - 1500	$> 10^4$	$> 10^4$

---

(1) INTOR - Study Recommendations, July 81

(2) 1 MW y/m^2 $\hat{=}$ 10 dpa

Figure 4

EVOLUTION OF DEVICE PARAMETERS

	Before JET (1973)	*JET*	*NET (foreseen)*	*ITER (foreseen)*	*DEMO (foreseen)*	*Reactor (estimate)*
Major radius (m)		3	6.3	6.0	6.3	6.5
Minor radius (m)		1.3	2.05	2.15	1.8	1.8
Plasma volume (m^3)	~1	~140	~1,000	~1,000	~700	~800
Plasma current (MA)	0.4	4-7	25	22	20	22
On-axis toroidal field (T)		3.45	6.0	4.85	6.0	7.0
Pulse length (s)	<1	~25	>700	400-ss	s.s.	s.s.
Integral burn time (hrs)		~1	1,500	8,000	80,000	150,000
Wall loading (MW/m^2)		<0.2	~1	~1	2.2	3
Breeding ratio			tests	~0.7	>1	>1
Fusion product ($10^{20} m^{-3} keVs$)	0.03	8	50	50	50	50
Fusion power ($MW_{thermal}$)		(<30)	1,000	1,000	2,000	3,500

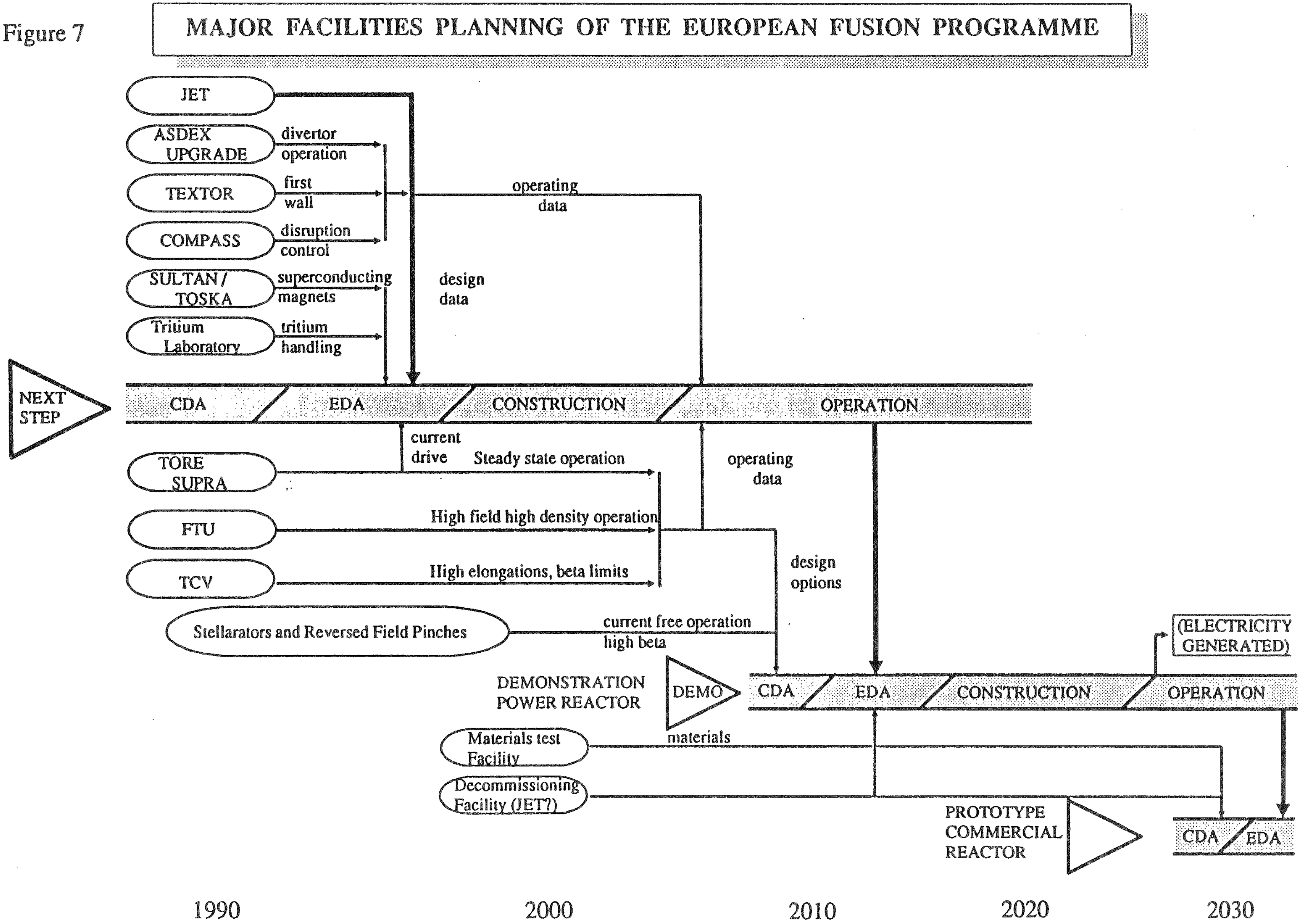
~1MWy ~2.2 MWy ~60MWy

s.s. = approximately steady-state

Falls 2000 h ≈ 1 Jahr entspricht.
Quelle EUR 13104 EN

COLOMBO - Report: 1990

Figure 7


MAJOR FACILITIES PLANNING OF THE EUROPEAN FUSION PROGRAMME
JET
ASDEX UPGRADE
divertor operation
TEXTOR
first wall
operating data
COMPASS
disruption control
SULTAN / TOSKA
superconducting magnets
design data
Tritium Laboratory
tritium handling
NEXT STEP
CDA
EDA
CONSTRUCTION
OPERATION
current drive
Steady state operation
TORE SUPRA
operating data
FTU
High field high density operation
design options
TCV
High elongations, beta limits
Stellarators and Reversed Field Pinches
current free operation
high beta
(ELECTRICITY GENERATED)
DEMONSTRATION POWER REACTOR
DEMO
CDA
EDA
CONSTRUCTION
OPERATION
Materials test Facility
materials
Decommissioning Facility (JET?)
PROTOTYPE COMMERCIAL REACTOR
CDA
EDA
1990
2000
2010
2020
2030

Strategy for Reactor Development (1, 2)

(2) Pilot Plant →	DEMO Plant →	Prototype Plant →	Commercial Plant
NET/ITER	STARLITE	ARIES I, II, IV PULSAR	

Essential Requirements for DEMO:

- DEMO and CFR are based on the same Technology
- DEMO has to demonstrate public Acceptability and Cost Viability
- DEMO should establish Licencing, Decommissioning and Decontamination
- DEMO should have the same Structural and Breeding Materials and the same Plasma Regime of Operation as the Prototype Plant

(1) R. W. Conn et al. UCLA PPG - 1394, 1992 Starlite Study

(2) See parallel Development in Fission Reactor Development (FBR)

Reactor Strategy and Material Development for Fast Breeder Reactors in Europe

	Pilot Plant	DEMO-Reactors	Prototype-Reactors	Commercial Reactors
	Rapsodie KNK DFR	Phenix (SNR 300) PFR	Superphenix	EFR
Core structural materials				
	316 s.a	316 cw / 316 Ti c.w	15/15 Ti	AIM 1
Clad	1.4988/1.4870 PE 16	1.4970 s.a + c.w PE 16		PE 16
	316	316 / EM 10	316 / EM 10	EM 10
Wrapper	1.4981	1.4981 / 1.4914		Martalloy
	321	321 / FV 448		
Accumulation of damage				
	30-50 dpa	65 - 90 dpa	130 dpa	180 dpa

Conclusion: It took 25 years with available reactors to generate a reliable data base for core structural materials up to the present level of $\leq$ 130 dpa

Requiremens for DEMO - Structural Materials

Key assumptions

1. Loading conditions under normal Operation

   Neutron Wall Loading ~ 2MW/m^2 FW, S

   Integrated Loading ~ 10 MWy/m^2 FW, S

   Thermal Loading ~ 10 MW/m^2 Div.

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

3. Quasi-steady state operation has to be achieved

4. Selected materials are the reference for Commercial Fusion Reactors

Main requirements

1. Establish complete data base for unirradiated material properties (Code-relevant-properties)

2. Generate reliable data base on irradiation behaviour and thermomechanical response for materials (2/3 of Integrated wall loading at given T-range)

3. Determine material-specific activation and analyse its influence on maintenance, safety and decommissioning.

Required, fusion-specific R + D Work

1.) Determination of nuclear data for calculating transmutation reactions, material activation, after heat and radioactive decay

2.) Study of plasma-wall interactions, steady-state-sputtering and disruptions

3.) Study of combined thermal wall loadings under irradiation

4.) Radiation phenomena under specific fusion neutron irradiation

   - Swelling and creep (Dimensional stability)
   - Radiation hardening and embrittlement
   - Isothermal and thermal fatigue
   - Fracture toughness

5.) Corrosion and compatibility

   - Irradiation-induced stress corrosion cracking IISCC
   - Radiation-induced segregation R/S

6.) Tritium-permeability and diffusivity under irradiation

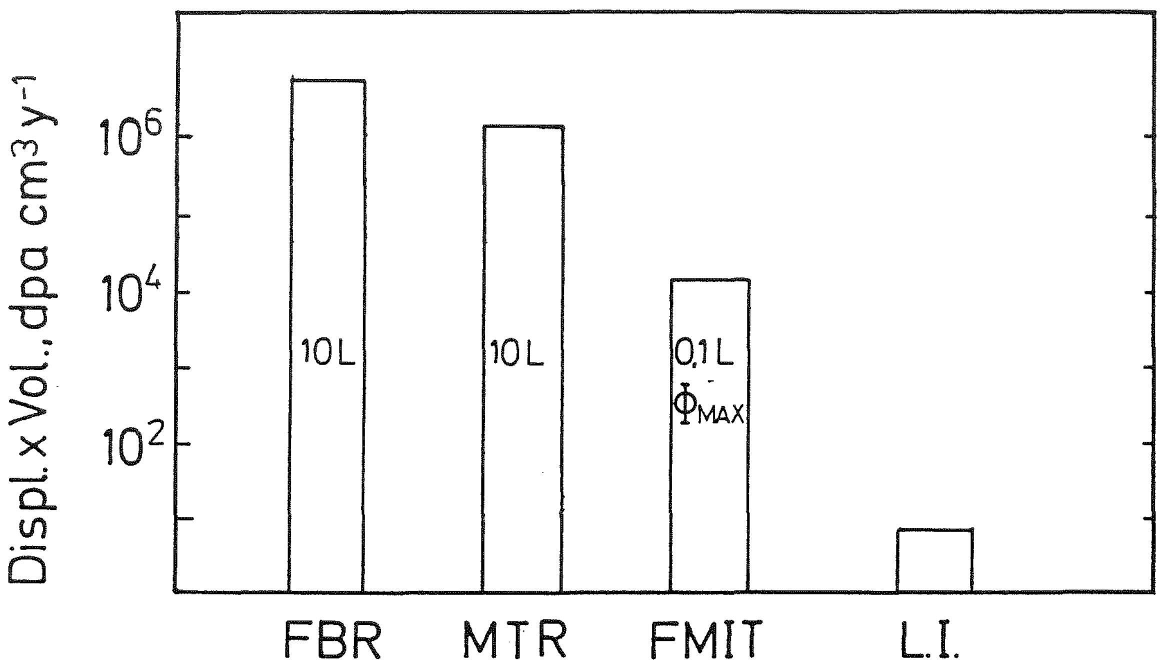


Fig. Figure of merit for different irradiation facilities

FBR = Fast Breeder Reactor
MTR = Material Test Reactor
FMIT = d-Li Int. Neutr. Source
LI = Light Ion Irrad. Fac.

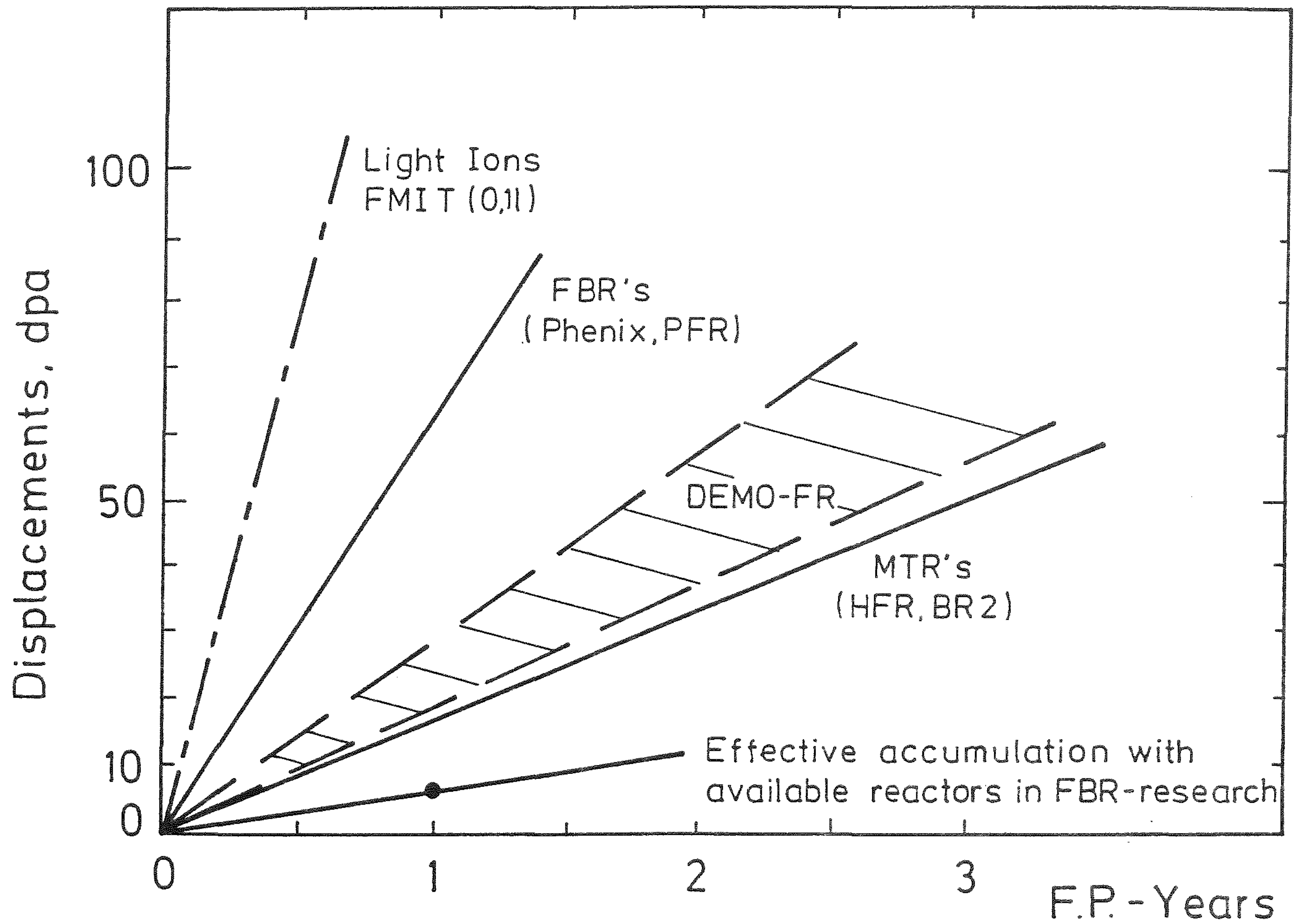


Fig. Accumulation of displacement damage in different irradiation facilities

The Role of Intense Neutron Sources and other Irradiation Facillities in MaterialsDevelopment

P. Schiller

JRC

The Role of Intense Neutron Sources and other Irradiation Facilities in the Materials Development

IEA Neutron Source Meeting

KfK Karlsruhe September 21 - 23 1992

Aim of the Materials Development:

- to select, optimise, test, and characterise materials for fusion devices and reactors

Fusion Reactors Scheduled:

- NET / ITER
- DEMO
- Commercial Reactor

The Need for Irradiation Facilities:

In all scheduled devices the first wall will be exposed to the influence of an intense high energy neutron flux of increasing intensity and duration.

For a safe operation of the devices the knowledge of the behaviour of the materials under these conditions is necessary, therefore irradiation tests are vital.

Radiation Facilities:

- Accelerators (Ions, Electrons)
- Thermal Fission Reactors
- Fast Reactors

? - 14 MeV Neutron Sources ?

All facilities can only simulate the damage by the fusion neutron spectrum.

How do the present facilities fit to the schedule:

ITER:

- There is little space left for a materials development.
- The total neutron wall loading is small.
- The necessary radiation data will come from fission reactors.
- A 14 MeV source could furnish data on the behaviour at the end of the lifetime.

DEMO:

- There is time for a materials development.
- There are actually no materials existing which could stand the extreme conditions of a DEMO first wall
- The materials development and optimisation can be done partly in fission reactors and needs relatively small volumes in a 14 MeV source
- The establishing of an engineering data base needs large volumes in a 14 MeV source

Will there still be fission reactors for testing?

Materials Test Matrix for the next Devices:

ITER:

- Existing materials,
- Irradiation testing in fission reactors
- Desirable to run tests for the determination of the end of life conditions during constructon or operation of ITER in a 14 MeV source. Space necessary will be limited

DEMO:

- New materials have to be developed.
- Irradiation tests for optimisation can be done in fission reactors, however a damage calibration will be necessary. This needs a small 14 MeV neutron source the spectrum of which is modified
- Engineering data base for the selected materials has to be established. This needs a large source

The Role of Neutron Irradiation Facilities

T. Ishino

University of Tokyo

1. Generic Issues for Neuton / Neutron Irradiation Correlation

2. Evaluation of d-Li Source as IFMIF

3. In-situ testing of some of the critical materials for near term machines

4. Modeling and experimental verification of various component processes under high energy neutron irradiation.

5. Engineering fundamentals for the best use of IFMIF and other irradiation facilities

6. Engineering properties

7. Some of the component testing.

Stages II & III, Scope and Approaches

Phase of Activities	Tasks to Be Covered
I Scientific	- Theoretical Analyses and Modeling of N-N Correleation - Experimental Analyses of Predicted Behavior - Physical and Chemical Data
II Base Technological	- Design & Prosessing of New Materials - Test Methodology Development - Characterization and Behavior Analyses - Qualification Testing and Data Acquisition
III Applied & Industrial	- Design & Prosessing of New Materials - Test Methodology Development - Characterization and Behavior Analyses - Qualification Testing and Data Acquisition
IV Materials Engineering	- Applications to Reactor Design

Irradiation Facilities

(Pure 14 MeV)
- Oktavian
- FNS
- RTNS-II (gone)

(Fission Reactors)
- JMTR
- HFIR
- JOYO
- EBR-II
- FFTF

(Accelerator-based source)
- KEK
- LAMPF/LASREF
- PIREX

(Accelarators)

- HIA/LIA/TEM
- HIT Facility
- INS FM Cyclotron
- etc.

(FUSION DEVICE)

ITER	Material Performance and modeling (Design Dependent)

FEASIBILITY ISSUES

DEPENDS ON TIME SCHEDULE

" DO WE HAVE AN AGREEABLE TIME SCHEDULE?"

DELAY OF SCHEDULE

" CAN PUBLIC SUPPORT FUSION ? "

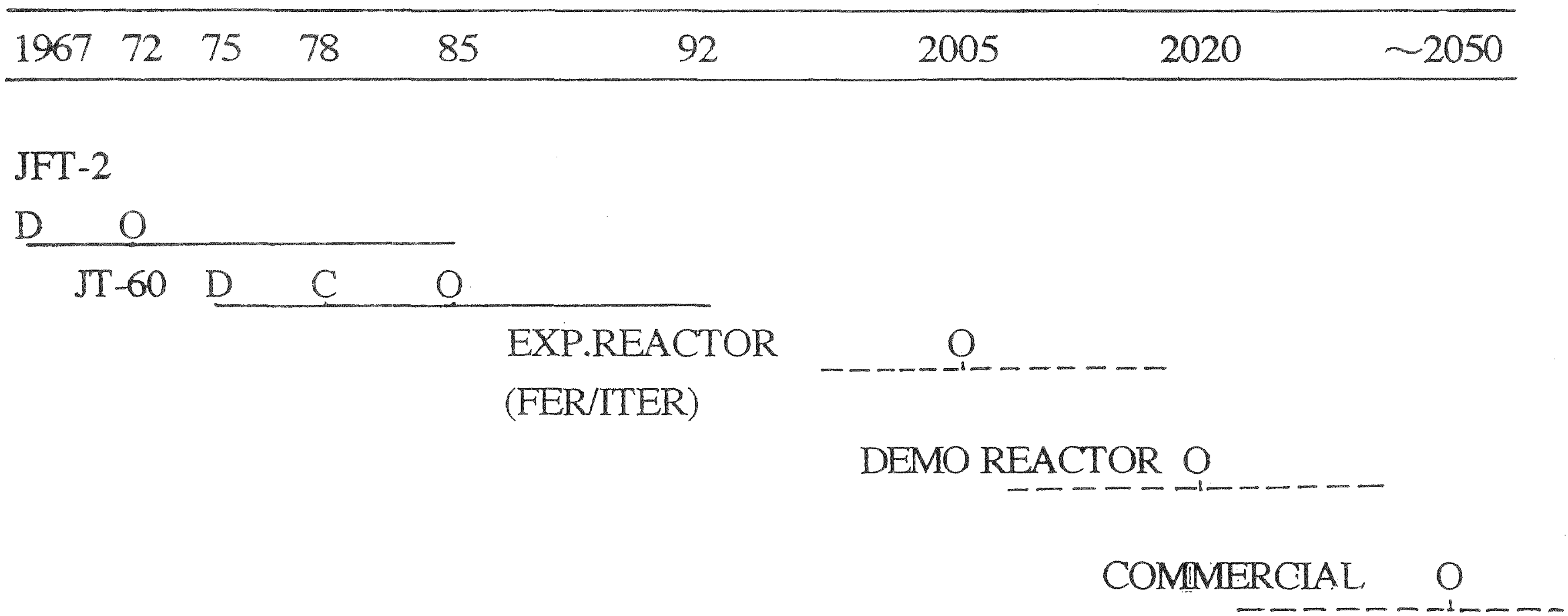
DEMO GOALS

- ○ DEMONSTRATE ENERGY PRODUCTION
- ○ DEMONSTRATE ECOMIC FEASIBILITY POTENTIAL
  → ESTIMATE OF ENERGY COST POSSIBLE
- ○ DEMONSTRATE SOLUTION OF ALL TECHNOLOGICAL PROBLEMS IN A MANNER SUITABLE FOR EXTRAPOLATION TO A COMMERCIAL POWER PLANT

SUITABILITY CRITERIA

a) NEUTRON FLUX	DEMO: $2MW/m^2$ $\sim 6 \times 10^{-7}$ dpa/s
b) NEUTRON SPECTRUM	AS CLOSE AS FIRST WALL SPECTRUM SPECTRAL TAILORING(TO GIVE APPROPRIATE dpa/s, PKA SPECTRUM, TRANSMUTATION RATE).
c) FLUENCE	100dpa/SEVERAL YEARS, AVAILABILITY >70%
d) VOLUME	10l(>$2MW/m^2$; $0.9 \times 10^{18} n/m^2 s$(uncollided)).
e) FLUX GRADIENT	< 10%/cm.
f) ACCESSIBILITY	EASY ACCESS. VOLUME COMPLETELY AVAILABLE TO EXPERIMENTERS. EASY CHANGE-IN AND -OUT.
g) TIME STRUCTURE	QUASI-CONTINUOUS IS MANDATORY.

SCHEDULE



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The Role of Intense Neutron Sources and other Irradiation Facillities in MaterialsDevelopment for Fusion

F.W. Wiffen

U.S. DOE

THE ROLE OF INTENSE NEUTRON SOURCES AND OTHER IRRADIATION FACILITIES IN MATERIALS DEVELOPMENT FOR FUSION

Presentation to the

IEA Workshop on Intense Neutron Sources

F. W. Wiffen
Office of Fusion Energy
U.S. Department of Energy

KfK - Karlsruhe

September 21-23, 1992

FUSION MATERIALS PROGRAM

The Goal:

- o Provide qualified materials for magnetic fusion devices--materials that contribute to the realization of fusion as an economically competitive, safe, and environmentally acceptable energy source.

The Technical Approach:

- o Focus on long range--the power-producing reactor.

- o Meet the needs of nearer term devices as intermediate steps of the program.

The Schedule:

- o An Operating Demonstration Power Plant by about 2025.

- o An Operating Commercial Power Plant by about 2040.

FUSION MATERIALS PROGRAM
NEUTRON SOURCES

- Neutron Sources are essential to the fusion program to simulate the service environment in developing materials.
  - Large numbers of specimens must be held at constant, controlled conditions for times of weeks to years.
  - A few of the physical and mechanical property measurements will be made in situ.
  - Most property determinations will be made in hot cell facilities after discharge from the neutron source.

FUSION MATERIALS PROGRAM

FUTURE NEUTRON SOURCE NEEDS FOR THE FUSION PROGRAM

The fusion program needs simultaneous, long-term use of:

- o A mixed spectrum fission reactor
  - HFIR or better
    - -- Lower nuclear heating rates
    - -- More complete instrumentation and temperature control
    - -- Larger experimental volumes
- o A fast spectrum fission reactor
  - FFTF/MOTA or equivalent
    - -- Simplified access
- o A higher energy, high flux neutron source
  - The preferred option is a 35 MeV d-Li stripping source
  - Other candidates are:
    - -- d-t source
    - -- cw spallation source, tailored to fusion needs

FUSION MATERIALS PROGRAM

MULTIPLE IRRADIATION FACILITIES WILL BE REQUIRED TO SUPPORT THE DEVELOPMENT OF FUSION ENERGY

- Fission reactors provide a wide range of test capability
  - Many are available
  - Use is at low cost; methods and equipment available
  - Temperatures 4 to 1500 K, fluences to 150 dpa
- Particle accelerator bombardments examine specific material behavior
- Medium size fusion neutron sources will be important program elements. The proposed ESNIT in Japan fits this category
  - Fundamental studies
  - Fusion - fission correlations
  - Materials development, addressing critical issues.
- An International Fusion Materials Irradiation Facility (IFMIF) with large volume and high flux is required
  - Complete fusion - fission correlations
  - Materials development
  - Design data base generation

FUSION MATERIALS PROGRAM
THE STRUCTURAL MATERIALS PROGRAM RELIES ON USE OF FISSION REACTORS

- HFIR
  - Multiple, small volume experiments, newly instrumented
  - 60-800°C, monthly access
  - 20-25 dpa per year
  - Collaborations with Japan

- FFTF/MOTA (Materials Open Test Assembly)
  - Large volume, heavily instrumented
  - 380-1200°C; annual access
  - 25-30 dpa per year
  - Collaborations with Japan, IEA, USSR, EC

- EBR-II may be used to replace or supplement the use of FFTF

- LASREF (spallation neutron source on LAMPF at LANL) may be used for specialized experiments.

FUSION MATERIALS PROGRAM
SUITABILITY CRITERIA FOR AN IFMIF

An International Fusion Materials Irradiation Facility (IFMIF) should meet these criteria:

Neutron Flux	-	Equivalent to 2 MW/m^2 ($\sim 1 \times 10^{15}$ $n/cm^2.s$, E>0.1MeV)
Neutron Spectrum	-	Similar to fusion reactor first wall (Neutron production peaked near 14 MeV)
Fluence	-	100 dpa in a few years (availability > 70%)
Irradiation Volume	-	10 liters at 2 MW/m^2
Flux Gradients	-	< 10%/cm
Accessibility	-	Irradiation volume completely available Easy experiment change-out
Flux Time Structure	-	Quasi-continuous operation

FUSION MATERIALS PROGRAM

A FUSION NEUTRON SOURCE IS REQUIRED FOR DEVELOPMENT OF STRUCTURAL MATERIALS FOR DEMO

- Support for ITER and the initial stages of developing materials for power reactors can be accomplished with fission reactors and innovative experiments such as spectral and isotopic tailoring, DHCE, injector foils , etc.

  - Proposed ITER structural materials contain Ni, therefore we can achieve correct He/dpa using spectral and isotopic tailoring.

  - ITER damage levels are low, therefore, they can be achieved with irradiation experiments of acceptable duration consistent with the ITER schedule.

  - For advanced materials we are now generally limited to exploration of basic damage mechanisms.

FUSION MATERIALS PROGRAM

A FUSION NEUTRON SOURCE IS REQUIRED FOR DEVELOPMENT OF STRUCTURAL MATERIALS FOR DEMO (Cont.)

- A fusion neutron source is required to carry the development of advanced materials to completion and demonstrate the acceptability for fusion power applications.
  - The effects of irradiation on mechanical and physical properties is a central issue.
  - It is not possible to adequately approximate damage (e.g., He, H, dpa) nor achieve end-of-life damage levels in advanced reduced activation structural materials, ceramics, and PFC materials with available techniques.
  - The required materials development programs cannot be accomplished in the planned successive and incrementally more powerful plasma physics devices.
- A fusion neturon source must be operational by about the year 2000 to support the goal of a fusion demonstration reactor by 2025.
- Expanded use of fission reactors will also be required.

FUSION MATERIALS PROGRAM

THE FMIT PROGRAM PROVIDED THE BASIS FOR ANY FUTURE FUSION NEUTRON SOURCE PROGRAM

The Fusion Materials Irradiation Test (FMIT) Program of 1978 to 1985 established the technology needed for a D-Li neutron source.

- o Radio Frequency Quadrupole accelerator prototype was completed and operated.
- o Liquid lithium target test system was fully developed and flow tested.
- o RF power supplies were purchased--they are now being used elsewhere in the fusion program.
- o Much of the accelerator, target, and test chamber design information will be valuable to any future project.

At project termination in 1985 the U.S. had spend $90M. Approximately half of this is useful to future neutron source projects and other parts of the fusion program.

Fusion Energy and Intense Neutron Sources in China

J.Qian

SWIP

FUSION ENERGY AND INTENSE NUETRON SOURCES IN CHINA**

J.P.Qian*, X.W.Deng*, K.Q.Chen# and T.L.Su@
* Southwestern Institute of Physics, China
# Institute of Modern Physics, China
@ University of Lanzhou, China

Abstract

The position of fusion energy in the energy strategy in China is very important. The energy requirement of China in next century would not be satisfied if the fusion energy was not developed in China. Intense Nuetron Sources, like IFMIF, is necessary for developing fusion energy in China. To build up IFMIF through international cooperation is a good idea. China is willing to make its own contribution to IFMIF if China will be accepted to join the cooperation.

1. The Position of Fusion Energy in Energy Strategy[1]

It is well known that the China is a country with the most population in the world. China does have a plenty of natural resources and energy, but, unfortunately, too much population make the per capita energy is very low. The lake of energy has been the major trouble to disturb the economic increment for a long time. The increasing population maybe saturates in tens years. The natural increasing rate of population in China in the nearest years is about 1.08-1.15%, and so the Chinese population in the middle of next century is estimated to be ~1.5 billion.

China is expected to become a middle developed country at that time and the value of total output per capita should be $4000-8000/year. The corresponding requirement of energy in this case will be 4 billion ton normal coal per year and the generating capacity will be more than 1500 GW. It is difficult to be changed in near term that the mineral fuel plays a major role in the energy composition in China. But limited resources and environmental pollution force us to develop nuclear energy and the fraction of nuclear power in 2050s is expected to be 25-30%, i.e. 400-500 GW.

All of the nuclear power is now given by fission reactors in the world, but this nuclear power composition can not meet the energy requirement in next century in China even though the fast fission breeders are developed and taken into account. The capacity of four possible nuclear fission power composition are shown in fig. 1, where PWR--pressured water reactor, APWR--advanced PWR, HTGR--high temperature gas-cooled reactor and FBR--fast breeder reactor while U, Pu, M and L in parentheses are uranium, plutonium, modular type and liquid metal cooled, respectively. It is obvious that the composition which consists of only thermal

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** Supported by China National Funding for Natural Science

and fast fission reactors can not meet the energy requirement before the middle of next century because of the limited uranium resources in China.

The situation would become different if fission-fusion hybrid breeders (FHB) are developed in time. The calculation results of fission and fusion nuclear power composition using FCAC code under similar conditions are give in fig. 2. The figure shows that the continuous capacity increment can be carried out easily and nuclear power of more than 400-500 GW can also be reached in 2050.

Fusion energy development is the key problem in energy development strategy of China. It is impossible to develop China national economy to high level without fusion energy in next century.

2.Intense Nuetron Sources for Fusion Reactor Materials Development

It is straightforward that the fusion reactor materials development is necessary for fusion energy. There is a R&D program for fusion reactor materials in China. The purpose of the program is to found a basis of science and technology for fusion reactor materials development in China. It is unimaginable that a big country with 1.5 billion population has to buy every thing abroad for its fusion reactors in next century. Of cause, the international cooperation in development of fusion reactor materials is necessary.

The structural materials of the first experimental fusion reactor in China, which would be built up in the beginning of next century, is estimated to be maturer steels at present, e.g. austenitic stainless steels, like 316 SS and its modified ones, because of no time of developing the new materials for it. But it is necessary to develop new materials with high quality for reactors in the middle of next century. Ferritic stainless steels (including ODS ferritic steels), vanatium-based alloys, austenitic and ferritic steels with low activity and various composites for structural application have now been developing in China, besides austenitic stainless steels. Some of them is not only been developing for fusion but also for other applications, e.g. fast fission reactors.

Which kind of structural materials will be developed in China is also determined by which kind of fusion reactor concept would be choosen. There are two main reactor concepts in China: solid tritium breeder--He cooled and liquid metal breeder--self cooled. Some feasibility problems have now to be resolved for every concept. It is not determined right now that which concept would be choosen. If the liquid metal self cooled blanket is adopted, the ferritic steels would be developing since its good compatibility with liquid metal breeder and irradiation resistance. Otherwise, the austenitic one may be hopeful but ferritic steels are still attractive because of the good irradiation resistance. So various austenitic and ferritic steels, e.g. with high strength at higher temperature and low activity, may be the major concern in near term and the V-based alloys and structural composites, e.g. SiC/SiC, would be the interest for the futhure.

Nuetron irradiation effect study is a important thing in fusion reactor materials development. Two kinds of experimental methods have been used in China: nuetron irradiation and charged particle irradiation simulation. The experimental investigation is carried out by means of fission reactors (e.g. experimental reactors and high flux isotope reactor), T-D nuetron sources, heavy ion cyclotrons and high voltage electron microscope. They are effective for basic reseach but intense nuetron sources, like International Fusion Materials Irradiation Facility (IFMIF), are necessary for fusion reactor development. There is not any plan of building intense nuetron sources, like IFMIF, in China since it is too expensive. We are waiting for international cooperation in this field and would like to make our contribution to this cooperation.

It has been noticed that the pre-construction of FMIT started in United States, though it was stopped later, and some good designs of intense nuetron sources were put up in past decade. IEA--Executive Committee has done its best to promote the international cooperation on IFMIF under IEA--Inplementing Agreement on R&D in Fusion Materials[2,3].

The D--Li nuetron source concept, which was adopted by FMIT[4] in US and developed by ESNIT[5,6] in Japan, is a more mature design for IFMIF. The criteria derived from anticipated operating conditions of DEMO reactor can be satisfied and no feasibility question remained with this concept. By the way, accelerator-based nuetron sources are preferable in China since there are many experienced engineers and specialists on accelerators in some research institutes and universities. Research of liquid metal (e.g. Na and Li) loop for fast fission reactors and fusion reactors has also been conducted in China for ages. Of cause, a lot of good idea have been offered in many alternative concepts for IFMIF. For example, target is water rather than liquid lithium in T--H2O nuetron source concept[7,8] and further it is substituted by mirror plasma in beam plasma concept[9,10]. They are more attractive and worth to be developed.

3. The Possible Contribution of China to IFMIF

The nuetron sources have been developing in Chona for ages. Many fission reactors and accelerator-based nuetron sources have been built up. They have been used for development of fission and fusion reactor materials. Fusion nuetrons from some accelerator-based nuetron sources have also been used in fusion materials development in China. One of them, a D-T nuetron source with rotating target, is shown in fig. 3. The nuetron yield was $2*10^{12}$ n/s.

There are also a lot of cyclotrons and accelerators in China, which are operating for physical, chemical and materials study. A heavy ion research facility in Lanzhou

(HIRFL) and its main cyclotron, a new separated sector cyclotron (SSC) shows in fig. 4 and 5, respectively. This is a huge system with high exactness[11]. The SSC and beam parameters are given in table 1. The 50 MeV/A C beam was extracted from SSC on Dec. 12, 1988. It means that the HIRFL was completed since then and started to operate for scientific research.

The other scientific apparatus named "Beijing Electron Positron Collider (BEPC)" is also completed on Oct., 1988. It consist meanly of a 2*2.2/2.8 GeV electron position collider, a large particle detector called Beijing Spectrometer installed at the interaction point and synchrotron radiation experimental facilities. The period of construction was only four years and the main specifications have reached the highest level in the world at that time. Some accelerators were also constructed in 1980s. One of them is shown in fig.6. The H^{+} energy of this linear accelerator is 35 MeV, pulsed current--60 mA, duration of the pulse--80-100 μs and the frequency is 12.5/s. This accelerator is now operating for reseach work and as a nuetron source.

All of these accelerators and huge apparatus were designed and manufactured by Chinese scientists, engineers and works in China. That means they can design the high energy cyclotrons and other huge, exact apparatus for scientific and engineering purpose. Their knowledge and capability would make a big contribution to IFMIF, if necessary and possible.

As mentioned above, the liquid natrium technology has been developed for fast fission reactors for more than 20 years and some liquid-Na loops are now running in China. Liquid Lithium technic has also been developing for fusion reactors in China recently. They may offer some experiences to IFMIF, if it is D-Li based concept.

The manufacture is also an important problem if the IFMIF is really built. The establishment of HIRFL and BEPC also shows the level of manufacture technology in China. Besides, atomic power stations, high flux isotope reactors and rockets for satellites have also been manufactured in China and got a great success in these fields. The manufacture and industry in China can also make its contribution to IFMIF. By the way, the price in China may be lower than that in other countries.

4. Conclusion

The position of fusion energy in energy strategy of China is very important. The highly developed national economy would be unimaginable in China if the fusion energy was not developed and adopted. Development of fusion energy is a new challenge faced by Chinese in China.

The intense nuetron sources for fusion technology is necessary for China. We would like to resolve this problem through international cooperation.

China would be able to make his contribution to IFMIF, if China is accepted to join this international cooperation.

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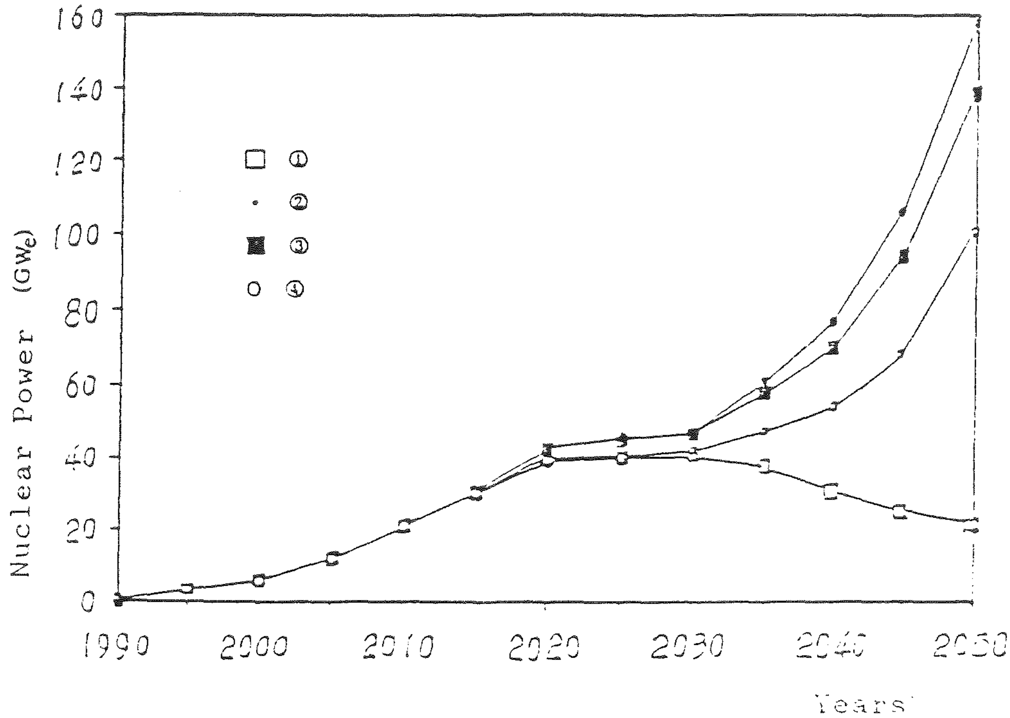
Table 1. Main Parameters of HIRFL

Ions	C--Ta
Maximum Energy	120--7.5 MeV/A
Beam Intensity	10^{10}--10^{12} PPS
Energy Resolution	$5*10^{-3}$
Gap Between Poles of SSC	10 cm
Maximum Field in The Gap	1.6 T

Fig. 1. Possible Nuclear Power Increment in Next Century in China. where 1) PWR(U)+PWR(Pu), 2) PWR(U)+FBR(M)+FBR(L), 3) PWR(U)+APWR+FBR(M)+FBR(L), 4) PWR(U)+HTGR+FBR(M)+FBR(L).
Fig. 2. Possible Nuclear Power Increment in Next Century in China. where 5) 1)+FHB, 6) 2)+FHB, 7) 3)+FHB and 8) 4)+FHB.
Fig. 3. Nuetron Souce with Rotating Target.
Fig. 4. The General Layout of HIRFL.
Fig. 5. The Structure of SSC.
Fig. 6. Layout of a 35 MeV Linear Accelerator of Proton.



160
140
120
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20
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Nuclear Power (GWe)
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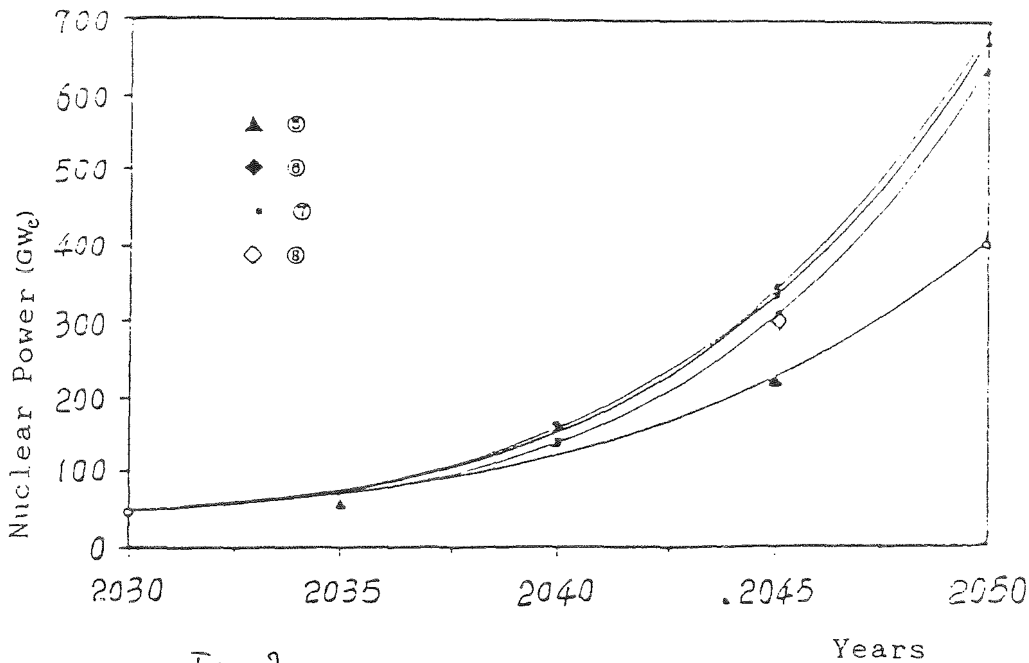
Fig. 1.



700
600
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Nuclear Power (GWe)
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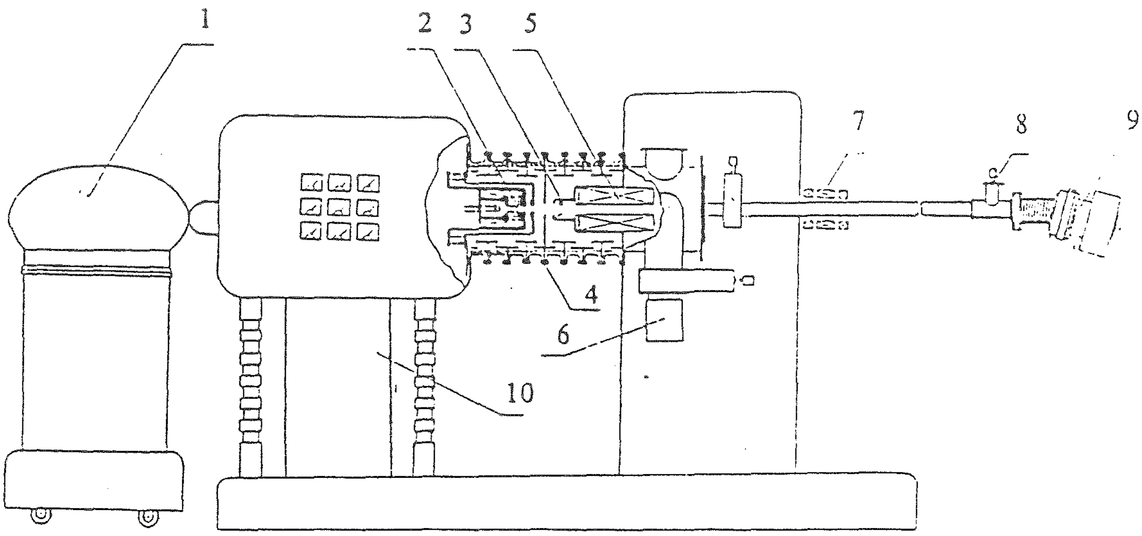
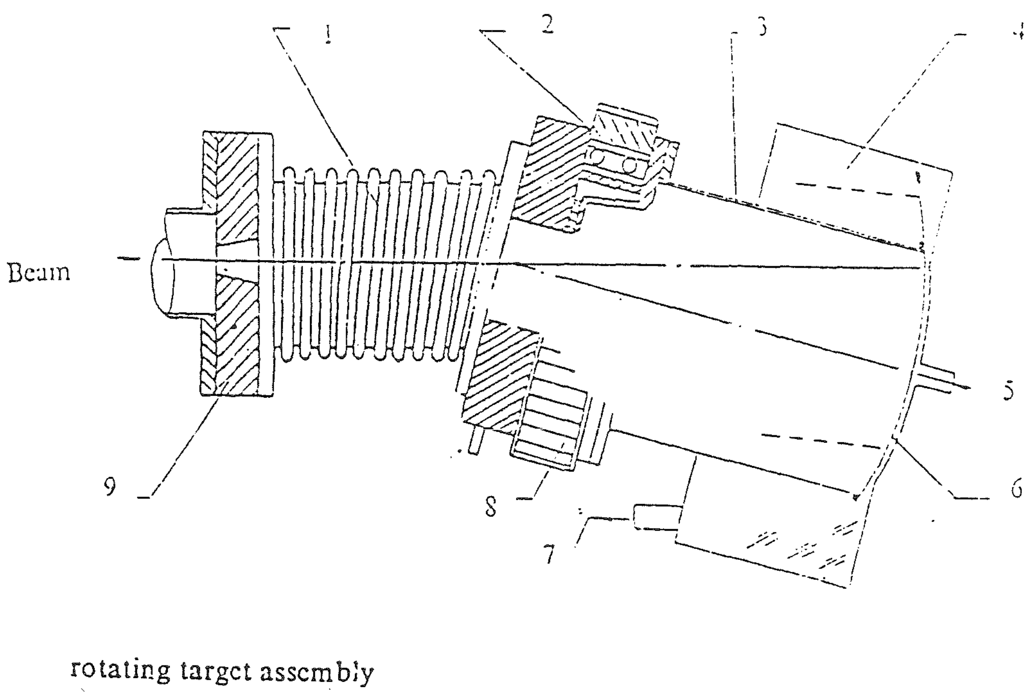
Fig. 2.



General view of the neutron generater

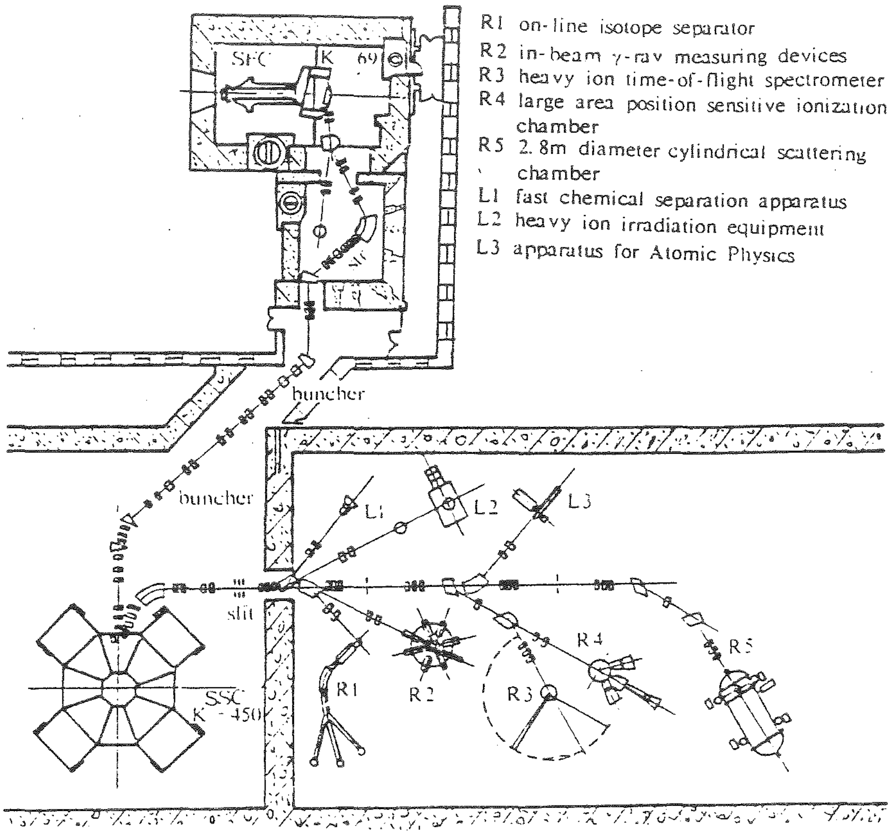
(1) H.V. supply, (2) Duoplasmatron, (3) Electron trap, (4) Acceleration tube,(5) Space charge lens, (6) Turbo moleccular pump, (7) Quadrupole triplet,(8) Plug—in type Farady cup, (9) Rotating target, (10) Insulation transformer



rotating target assembly

(1) Bellows, (2) Rotating seal, (3) Target carrier, (4) Water catch cage, (5) Cooling water supply, (6) T—Ti target, (7) Drain to recirculator, (8) Gear belt drive pulley, (9)Collimator

Fig. 3.


R1 on-line isotope separator
R2 in-beam γ-ray measuring devices
R3 heavy ion time-of-flight spectrometer
R4 large area position sensitive ionization chamber
R5 2.8m diameter cylindrical scattering chamber
L1 fast chemical separation apparatus
L2 heavy ion irradiation equipment
L3 apparatus for Atomic Physics
SFC
K 69
buncher
buncher
slit
SSC
K 450
L1
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R1
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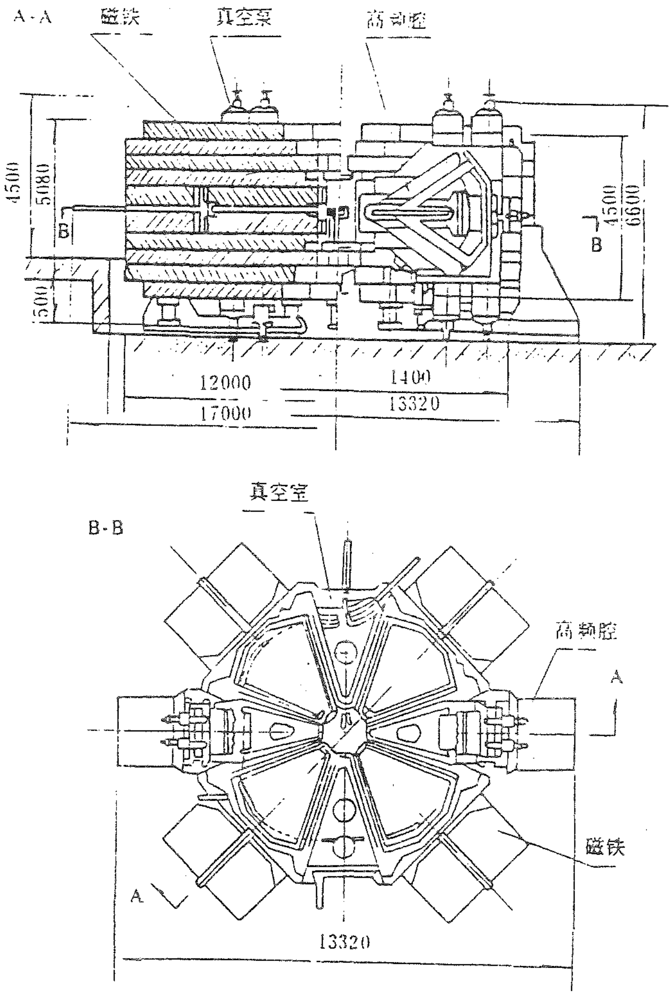
Fig.4.


A-A
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真空室
高频腔
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Fig. 5.

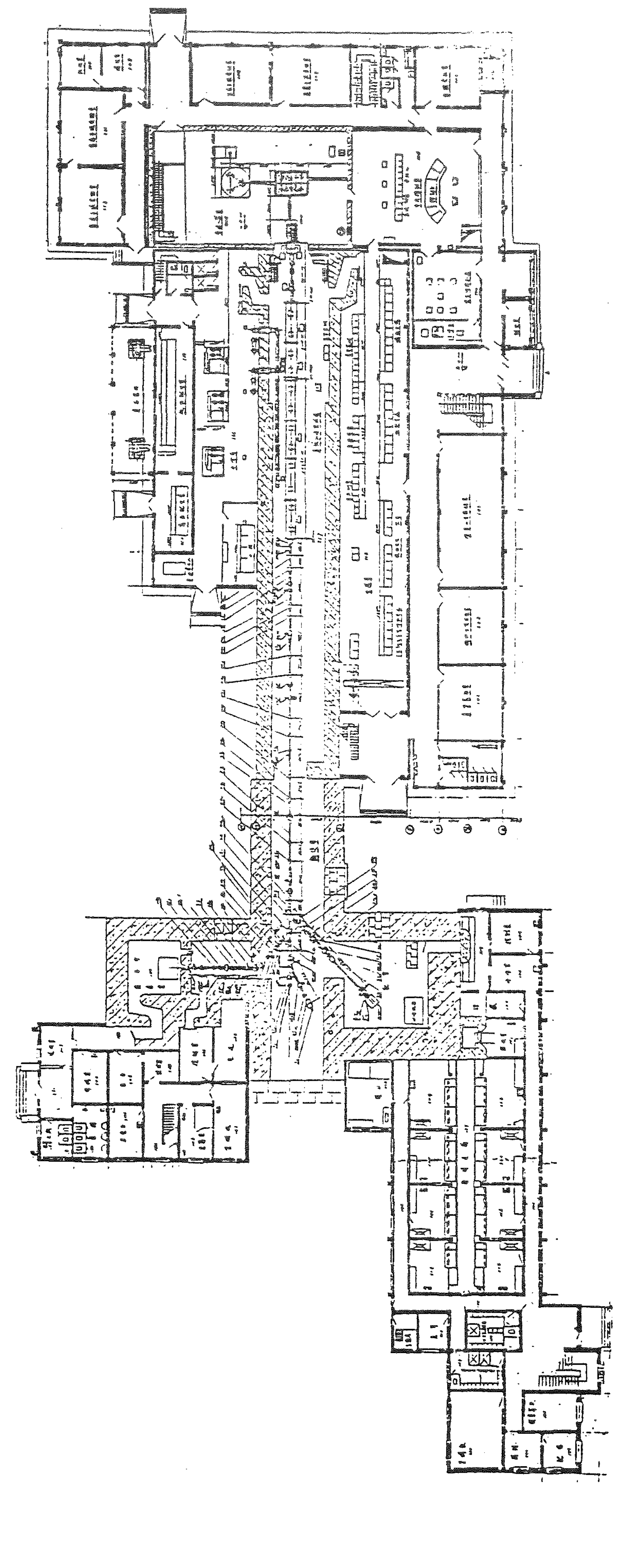


Fig. 6.

Session 2

Summary of ESNIT

K. Noda

JAERI

Status of ESNIT (The D-Li Neutron Source, a First Stage Approach)

K. Noda, H. Ohno, M. Sugimoto and Y. Kato, T. Kondo
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken, 319-11, Japan

1. INTRODUCTION

The conceptual scheme of a medium size high-energy neutron irradiation test facility with d-Li stripping neutron source was discussed at JAERI in the course of constructing the long term strategy of nuclear materials research in 1987. Regarding the needs of base research works for innovating new materials for future needs as well as the state of art in the understanding of the materials behavior under fusion neutron environment, the scheme put its emphases on the selectivity of neutron energy spectrum to have converged to the concept of ESNIT. The reality of being able to bring into construction within several years was also considered, which gave rise to the conservative selection of the optimized beam current specification. The ESNIT Program set forth since F.Y.1988 and the technical survey activity with the support of a technical advisory system was initiated in early 1989. The activities covered mostly the technical feasibility studies on the facility design with some analyses on design feasibility and optimization. To the present the program conducted several task items on the conceptual system development and evaluation on the technologies of the accelerator, the target and the remote in-situ/post-irradiation experimental techniques. It covered also the analytical evaluation of the neutron field, construction of the scheme of test matrices and surveys on facility utilization and management.

The concept of ESNIT, the current status of the technical activities and materials researches to be performed using ESNIT are summarized below.

2. CONCEPT OF ESNIT

The current ESNIT specification consists of an accelerator system (ion sources, a radio frequency quadrupole linear accelerator (RFQ), a drift-tube linear accelerator (DTL), RF source, high energy beam transport (HEBT), target interfaces, etc.), a target system (flowing Li targets, a Li circulation system) and an experimental system (irradiation cells, a post-irradiation examination (PIE) facility), as shown in fig. 1. The expected conceptual characteristics of ESNIT are as the following.

(1) Neutron spectra have relatively sharp peaking character and are variable with the energy of deuterons accelerated in the range 10 to 40 MeV, as shown in fig. 2. The peak energies of the spectra selected are at least three steps (e.g., 5, 10, 14 MeV).

(2) Maximum deuteron current of 50 mA was determined by compromis-

ing requirements from materials testing, feasibility aspects of accelerator-target technology, cost and radioactive waste managements. It is, however, desirable to considere upgrading ESNIT up to the maximum beam current of 100 mA, in order to meet world-wide demand for the materials irradiation tests using a high energy neutron source such as ESNIT.

(3) At the maximum deuteron current of 50 mA, the neutron flux higher than 1.5×10^{14} $n/cm^2.s$, which corresponds to annual damage rate of 10 dpa/y for stainless steel, can be attained for the test volume of about 5x5x5 cm^3. Fig. 3 shows the neutron flux contour map calculated at the deuteron current of 50 mA for the deuteron beam spot size of 4 cm in diameter with flat deuteron current distribution. The test volume for the flux higher than 1.5×10^{14} $n/cm^2.s$ increases with the deuteron energy, and the volume of about 5x5x5 cm^3 is attainable for the deuteron energy of 40 MeV. Such volume is estimated to be adequate for various types of in-situ experiments and irradiations for significant number of miniaturized specimens. Furthermore, the neutron flux higher than 4.5×10^{14} $n/cm^2.s$ (corresponding to annual damage rate of 30 dpa/y for stainless steel) can be attained by limiting the test volume to about 15 cm^3, as shown in fig. 4.

(4) The neutron flux and the peak energy of neutron spectra can be independently changed, although the maximum neutron flux lessens with decrease of deuteron energy accelerated. This allows irradiation tests as a function of neutron flux (i.e., damage rate) under equal conditions of neutron spectra, fluence, irradiation temperature and the other experimental conditions.

(5) Time structure of beam is quasicontinuous. In such a case the duration of beam interruption should be shorter than 10^{-6} s to avoid influence of pulse irradiation which arises from effects of concentration change of point defects on damage microstructures. This criterion can be met, since the frequency of RF power for acceleration is planed to be 120 MHz in continuous wave (CW) mode operation. Consequently, the influences of pulse irradiation on the damage microstructure can be ignored.

(6) At least two irradiation cells are provided for high availability of the facility. Good accessibility to the irradiation cells relative to the conventional research reactors allows to perform various kinds of in-situ experiments and irradiations in precisely controlled experimental conditions such as irradiation temperatures.

(7) A post-irradiation examination (PIE) facility is coupled close to the irradiation cells. A modular-type PIE facility is developed to cover various test requirements, and it is designed especially for miniaturized specimen tests.

3. PRESENT STATUS OF ESNIT PROGRAM

Technological survey and evaluation are being conducted for the neutron irradiation field, the accelerator system, the target system and the experimental system, assuming a favorable result of the official reviewing planned in F.Y. 1992 and the construction start in F.Y. 1995.

(1) Evaluation of Neutron-irradiation-field Characteristics of ESNIT and Damage Parameters

The d-Li neutron spectra including their angular dependence were experimentally measured in the deuteron energy 8 to 32 MeV using a tandem accelerator at JAERI to get precise information of d-Li neutron spectra.

Uncollided neutron spectra and flux distribution in the irradiation field of ESNIT were calculated for various deuteron energies, various beam sizes and various beam profiles using a proper source model. In addition, preliminary calculations of collided neutron spectra for Fe and Al_2O_3 test specimens were carried out. These collided calculations for various materials and various conditions of irradiation cells will be done.

The high energy region of d-Li neutron spectra extends to about 40 MeV, so that the nuclear data for neutrons in the energy range up to 40 MeV are necessary for precise calculations of collided neutron spectra and flux distribution in the irradiation field, shielding design and calculations of damage parameters for test specimens. However, at present only nuclear data for neutrons up to 20 MeV are available. The nuclear data for neutrons in the range 20 to 50 MeV are being evaluated for common elements of metallic and ceramic materials expected to be used for fusion reactors and ESNIT itself. The elements evaluated are Fe, Cr, Al, Cu, Ni, Si.

Calculation of damage parameters is important to make irradiation research plans and test matrix, and to verify the suitability of the neutron irradiation field characteristics of ESNIT for fusion reactor materials R&D. Computer codes to calculate damage parameters, i.e., PKA spectra and amount of nuclear transmutation products, are being developed.

The critical issues of nuclear data and damage parameter calculation codes for d-Li neutron source were discussed in the internal workshop on the technical review of ESNIT. Conclusions summarized in the workshop are as follows:

1)The evaluated nuclear data file should be verified by measured data.

2)The calculated source neutron spectrum should be compared with the experiments, especially in the high energy tail region.

3)Benchmark tests using the neutron fields are requested for shielding and transmutation calculations.

4)Experiments of PKA at 14 MeV are necessary for selected materials for verification of PKA calculation codes.

5)Theoretical benchmark calculations and their intercomparison are needed.

(2) Accelerator system

The accelerator system of ESNIT consists of ion sources, a radio frequency quadrupole linear accelerator (RFQ), a drift-tube linear accelerator (DTL), RF source, high energy beam transport (HEBT), target interfaces, etc. In principle, a conservative design concept was adopted at the first step, in order to secure the high availability of ESNIT in reliable beam operation. The specifications of accelerator system are shown in Table 1.

At least two ion sources are installed for simultaneous acceleration of positive and negative ions ($d^+/d^-/H_2{}^+$). Typically a dc high current d^+ beam and a pulsed low current d^- beam with low-duty cycle are injected simultaneously.

The RFQ with the exit energy of 2 MeV is used for simultaneous acceleration of positive and negative ions, and is driven by 120 MHz RF power. This frequency was chosen to avoid the heat removal problem. When such simultaneous acceleration using a RFQ is technologically difficult, use of two RFQ has to be considered.

The DTL consists of separated seven tanks to accelerate the ions at the energies of 10, 15, 20, 25, 30, 35 and 40 MeV. The tanks are individually fed by megawatt class RF sources, and they are controlled by switching on/off the RF power as the desired exit energy is obtained.

The HEBT includes a beam separation system (separator magnet) for simultaneous acceleration of positive and negative ions, achromatic beam transport lines and beam dumps.

The target interface section consists of multipole magnetic system for changing the beam size and current density distribution, and beam energy dispersion system. The former system is used to change neutron-irradiation field characteristics for various flux/test volume requirements. The latter is useful for relax the heat generation profile in the flowing Li target.

The diagnostic devices are indispensable to obtain information for minimizing the damage and activation of the accelerator components.

The most important technological issues for the accelerator system are beam acceleration and handling technologies to produce the well-controlled, stable and intense neutron field, and to realize simultaneous acceleration of positive and negative ions. Consideration of upgrading ESNIT in future is desirable for world-wide demand of materials tests using a high energy intense neutron source. Merging of the positive and negative beams which are simultaneously accelerated at the same level current is one of possible methods for upgrading ESNIT.

In the international workshop of the technical review of ESNIT, major critical issues described below were defined for the accelerator design of ESNIT:

1)The design calculations for getting the optimal machine parameters for each accelerator component, i.e., RFQ, DTL, HEBT, target interface to realize stable acceleration at high current for long periods with high reliability.

2)The choice of the future upgrading options (high current option) which influences the initial design requirements and machine parameters.

3)The design of matching section to RFQ linac when two beams are merged together into the single RFQ for simultaneous acceleration of positive and negative ions.

The following R&D items were recommended to solve the critical issues of ESNIT accelerator technology:
1)The development of both cold and hot models for the cw RFQ and the cw DTL structures.
2)The development of the ion sources with long lifetime.
3)The development of the microwave components for the high average power generation and supply.
4)The method of nondestructive beam diagnostics for on-line monitor of the beam.
5)The extensive calculations of the beam dynamics through the accelerator and the transport, and the optimization of these parameters.
6)Establishment of the remote handling methods.
7)The new simulation codes for designing the high current deuteron accelerator and the transport system with the extremely low beam spill.
8)the method for reducing the radiation damage at the accelerator section.

Technological survey and evaluation of the accelerator system and the components are in progress. some design calculations are being carried out based on the strategy that the basic specification is 50 mA, 40 MeV linac, however, the upgrading option is also considered to increase the beam current up to 100 mA. To survey the optimal system based on such a design philosophy, the extensive calculations are necessary for the extremely wide range of the parameters. The beam dynamics calculations for the RFQ and DTL linacs are being conducted for 120 MHz and 175 MHz in frequency. Especially for the RFQ, the calculations for the injection current of 50-100 mA, and the injection energy of 75-120 keV are being performed and the optimal design parameters are sought at each combination. The primary design calculations for the beam transport are done by using the beam matrix codes. The beam redistribution system using multiple magnets for the target interface is designed to provide the required beam shape (3X1 cm, 4X4 cm) and the intensity distribution (uniform, hollow)on the lithium target.

Many kinds of accelerator technology for ESNIT can be learned from FMIT program and further technological evaluation which will be followed by some additional R&D is under way. The required accelerator technology for ESNIT is in mature stage for the construction.

(3) Target System

The target system consists of flowing Li target and a Li circulation system including cooling and purification systems. Technological survey and evaluation studies are being carried out for the preliminary concept of target system similar to that of FMIT. Specifications of the target system are summarized in Table 2.

Many kinds of evaluation and R&D for major technological issues for the flowing Li target system were successfully carried out in the FMIT program, except beam-on-target experiments. Some additional technological issues left for Li target technology of ESNIT are as follows.

1)Thermal-hydraulic technology to avoid boiling of Li jet in the flowing Li target for which the incident deuteron energy and the beam current distribution are changed.
2)The beam-on-target experiment.
3)Technological evaluation and R&D to decide detailed design of flowing Li target and the Li circulation system.

At present, technological evaluation of thermo-hydraulic behavior of Li jet to define boiling conditions and design studies on Li circulation systems etc. are carried out for the target system of ESNIT.

The heat generation profile in the target depends on the beam energy. In thermo-hydraulic analysis of the target of ESNIT using a two-dimensional finite element method, the most severe situation for boiling of Li was found at the free surface of Li target in case of the lower deuteron energy, although such situation was for maximum heat generation points in case of the analysis of FMIT target. Further precise analysis of thermal-hydraulic calculation for the flowing Li target of ESNIT is necessary.

In the design study of Li circulation system, the main consideration is for a Li purification system sufficient to maintain an impurity level of 10 ppm. In this system, a concept of cold traps with mesh and hot traps containing Y and Ti sponge getters was made to trap general impurities (e.g., O, N), and d-Li nuclear reaction products (e.g., ^{7}Be, T).

(4) Experimental System

Conceptual design studies for modular-type post-irradiation examination facility (MODULAB) have been conducted since 1989. The objective is to secure maximum flexibility and high availability of the hot cells for incorporating various kinds of post-irradiation tests, especially those using small size specimen test (SST) techniques. Various types of SST techniques which are applicable to the modular-type post-irradiation examination facility are being developed.

4. MATERIALS RESEARCH TO BE PERFORMED USING ESNIT

Materials researches which should be carried out using ESNIT were defined for fusion reactor materials R&D and fundamental and base materials research in the international workshop on technical review of ESNIT. The researches are as follows.

(1) Fusion reactor materials R&D

1) Validity check of ESNIT for irradiation tests of fusion reactor materials

The neutron spectra of ESNIT have so-called high energy tail. Validity of ESNIT for fusion materials testing should be checked in the early stage of ESNIT operation by experimental verification of the calculated nuclear data and investigation of the influence of the high energy tail on the damage microstructures and the materials properties change using the neutron energy selectivity of ESNIT. If the influence of the high energy tail is found to be not so small, it can be decreased to acceptable levels in ESNIT by decreasing the peak energy of neutron spectra.

2) Materials development based on basic studies

Materials irradiation basic studies such as neutron/neutron irradiation correlation studies are very important to understand the mechanism of neutron irradiation effects. Once the correlation is established, the development of advanced radiation resistant materials can be done under the sound physics basis.

The materials which fulfill the severe demands at the lifetime for high flux region of DEMO fusion reactors do not exist in the present stage. Thus, the development of advanced materials for DEMO fusion reactors should be conducted on the basis of materials irradiation basic studies.

3) Materials properties tests under fusion-reactor operation condition

The neutron flux can be adjusted to the neutron wall load levels of ITER (International Thermonuclear Experimental Reactor) and DEMO fusion reactors. In-situ experiments of creep, fatigue, corrosion including IASCC (Irradiation Assisted Stress Corrosion Cracking) for the structural materials, of tritium release for ceramic breeders, of electrical conductivity and dielectric loss for insulator ceramics and of optical properties for diagnostic materials should be carried out using ESNIT to evaluate the materials properties during operation of ITER and DEMO fusion reactors.

4) Materials lifetime tests

Verification tests of performance of ITER materials at the lifetime under simulated ITER conditions can be performed by proper accelerated dose rate tests using ESNIT. It would be helpful for ITER design and operation. Lifetime tests of structural materials for DEMO fusion reactors at the fluence of 100 dpa are possible by limiting test volume to about 15 cm^3 and extending the test period to a few year. The medium and low flux regions of ESNIT can be used for lifetime tests of ceramic breeders, insulator ceramics and diagnostic materials. Typical examples of test items for the lifetime issues are as follows; mechanical properties and dimensional stability for structural materials, ceramic breeders and insulator ceramics, thermal properties for ceramic breeders and insulator ceramics, optical properties for diagnostic materials. However, for the materials irradiation tests of structural materials of DEMO fusion reactors in the high flux region of ESNIT, the main object will be the development of materials tolerable for the severe irradiation environment rather than the lifetime tests.

(2) Fundamental and base materials research

1) Radiation damage and materials properties change due to high energy neutrons

ESNIT will be the first high energy neutron irradiation facility of which the neutron flux allows various kinds of materials irradiation researches. Thus, radiation damage and materials properties change due to high energy neutron irradiation should be studied using ESNIT to obtain their fundamental knowledge.

2) Neutron/neutron irradiation correlation

Radiation damage and materials properties change are affected by damage parameters, i.e., PKA spectra, nuclear transmutation products, damage rate, ionization rate and their synergistic effects. These damage parameters depend on neutron-irradiation conditions such as neutron spectra and flux. The mechanism of radiation damage and materials properties change due to neutron irradiation can be better understood by investigating correlation of radiation damage and materials properties change in various neutron-irradiation conditions (i.e., neutron/neutron irradiation correlation). Such investigations should be done using ESNIT which allows irradiation tests in various neutron-irradiation conditions.

3) Materials behavior under neutron irradiation

Many kinds of interesting materials behavior under neutron irradiation are remained to be studied, because of difficulty in conducting advanced in-situ experiments using the conventional research reactors. The good accessibility to the irradiation field and the proper neutron flux gradient of ESNIT are suitable to carry out the advanced in-situ experiments. Such advanced in-situ experiments should be carried out using ESNIT.

5. CONCLUSION

In this paper, concept of ESNIT, present status of ESNIT program and materials research to be performed using ESNIT were described. It has been evaluated from these that ESNIT can be a useful and indispensable neutron irradiation test facility for fusion materials R&D not only for the fundamental phase of works but also for a significant part of engineering tasks.

There is no radiation resistant materials which can fulfill the demands for the lifetime service in the high flux region of a DEMO level fusion reactor. It is a consensus that a long period, e.g., a few decades, is required to develop such materials. For fusion reactor materials development, constructing a high energy neutron facility of the size of ESNIT to start its operation by the very beginning of the 21th. century is considered to be the most essential step among many issues to be cleared.

Table 1 Specifications of Accelerator System

Ion Sources	
$d^+/d^-/H_2^+$	60 mA max.
Output Energy	75 keV
Emittance (90%)	1 pi mm mrad
Lifetime	Longer Than 300 h
Operation mode	Continuous
	Pulse: Lower Than 1 % Duty
RFQ	
Structure	Four Vain, Charge/Mass=1/2
Frequency	120 MHz (CW)
Exit Energy	2 MeV
Beam Current	50 mA Max.
Transmission	Higher Than 90 %
Max. Surface Field	Lower Than 1.5 kilpatrick
DTL	
Structure	Charge/Mass=1/2
Frequency	120 MHz
Exit Energy	10,15,20,25,30,35,40 MeV
Field Gradient	1 to 1.5 MV/m
Beam Spill	Lower Than 0.01 mA/m
RF Source	
Frequency	120 MHz
Power	1 MW/Unit x 9 Sets
	(RFQ: 1 Set, DTL: 8 Sets)
Required Power	4.35 MW
	RFQ Total: 0.45 MW
	DTL Total: 3.9 MW
HEBT	
Beam Separation System for Simultaneously Accelerated Positive and Negative ions	1 Set
Achromatic Beam Transport	Material: 2 Sets
	Basic: 2 Sets
Beam Dumps	
Target Interface	
High Current T. I. with Function of Beam Size/ Current Distribution Change and Beam Energy Dispersion	2 Sets
Beam Monitor	
Beam Monitor (Nondestructive/Destructive)	
Beam Loss Monitor	

Table 2 Specifications of Target System

Target	
d^+ Energy	10 to 40 MeV
d^+ Current	50 mA Max.
Beam Power	2 MW Max.
Li Inlet Temp.	220 C
Li Velocity	15 to 20 m/s
Li Jet Thickness	7 to 20 mm
Li Free Surface Pressure	10^{-4} Pa
Li Circulation System	
Structural Material	316 SS
Li Flow Rate (Main Loop)	40 l/s
Operation Temp.	
Cold Leg	220 C
Hot Leg	250 to 300 C
Li Purification System	
Li Flow Rate	0.5 l/s
Outlet Temp.	
Cold Trap	200 C
Hot Trap (Y Getter)	250 C
Hot Trap (Ti Getter)	600 C

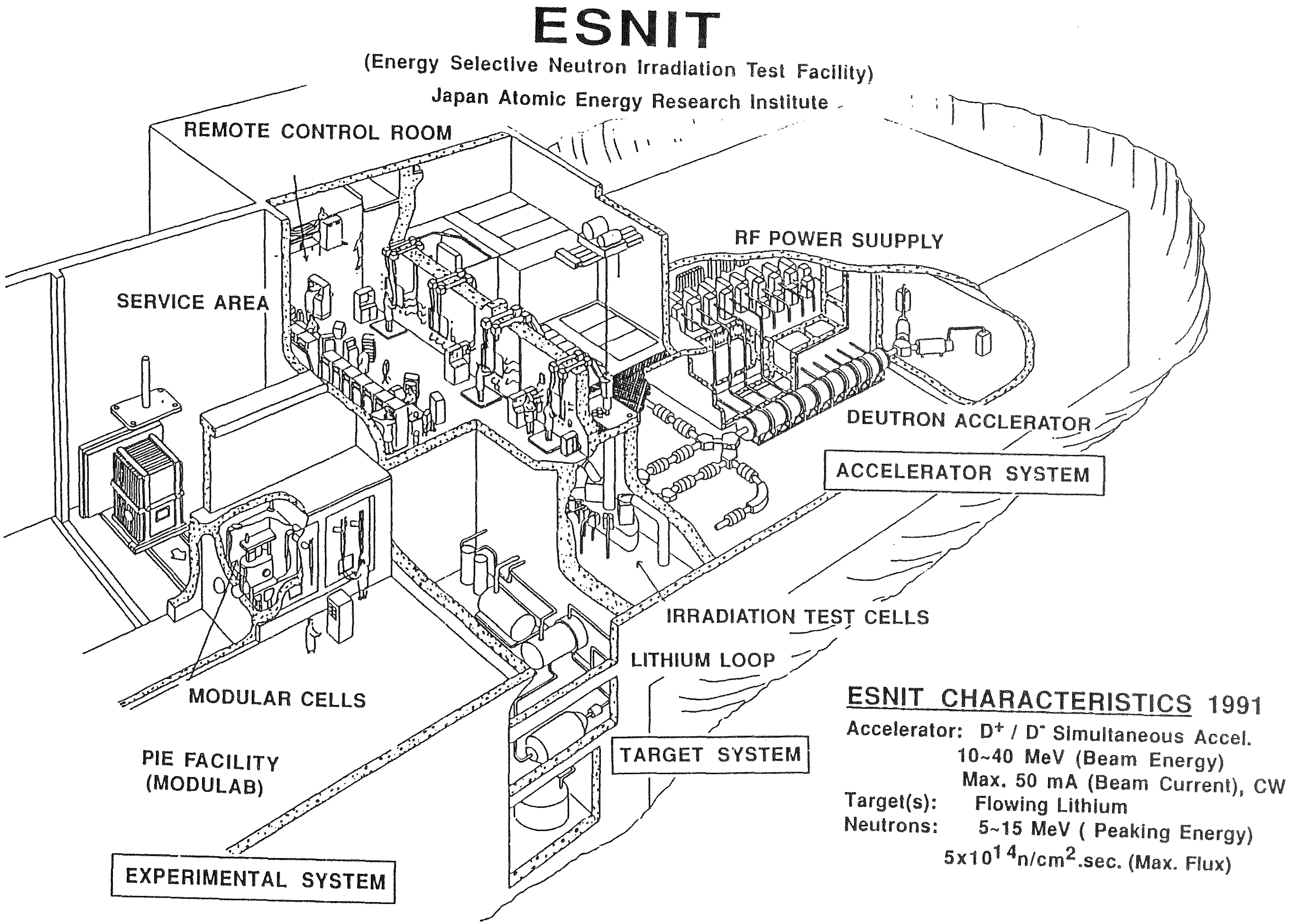


Fig. 1 Bird's-eye view of ESNIT.

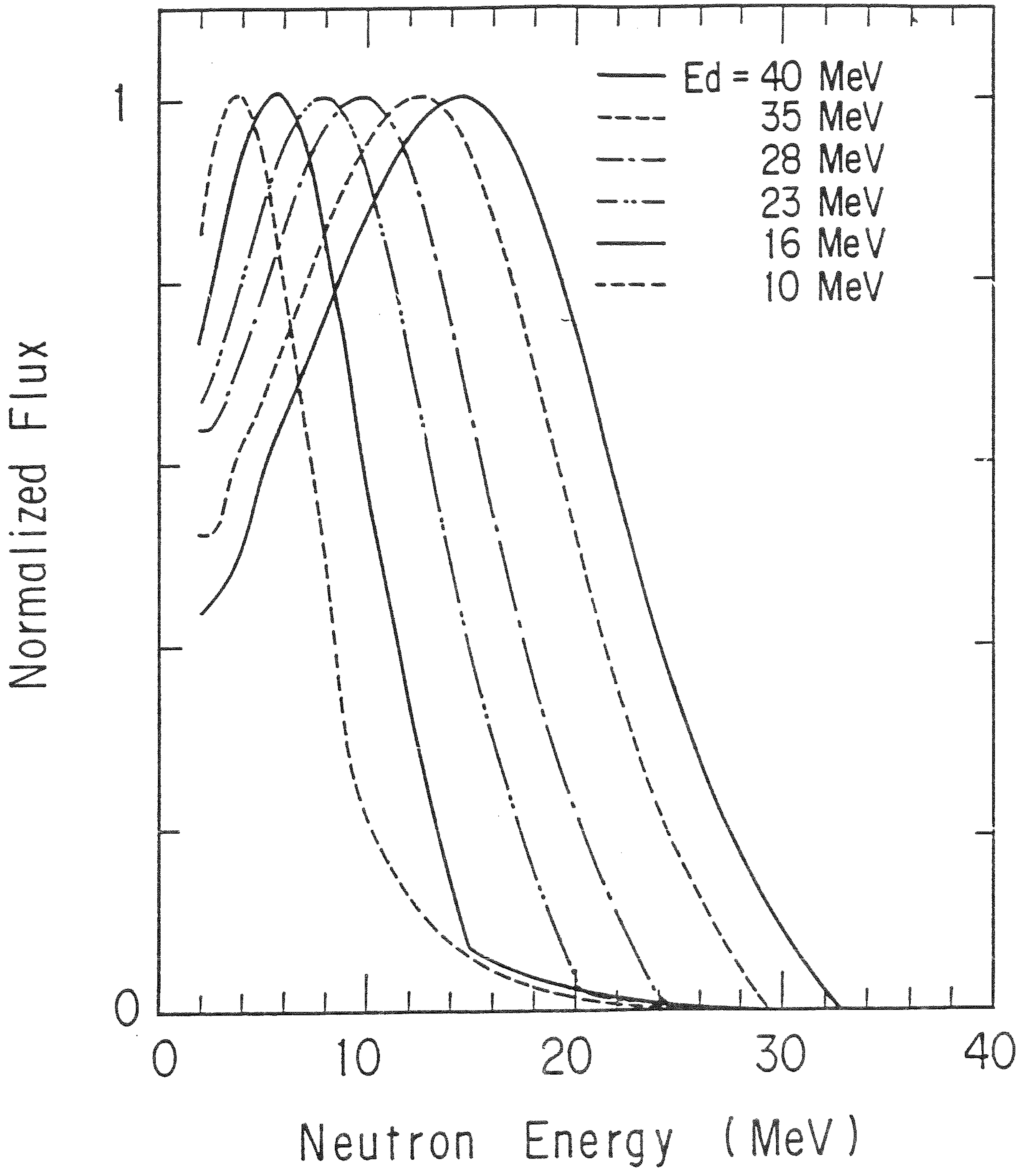


Fig. 2 Neutron spectra of ESNIT at various deuteron energies.

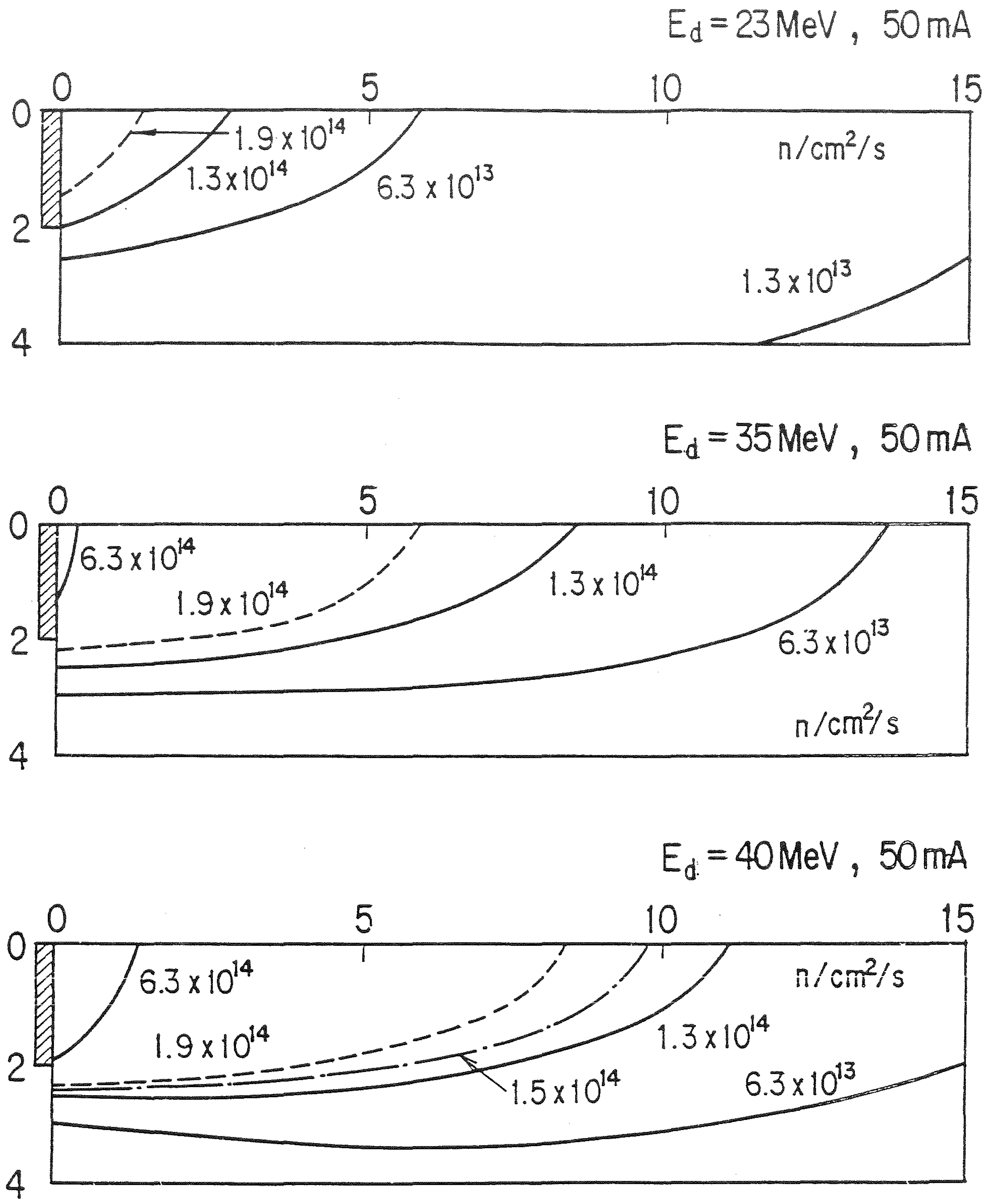


Fig. 3 Neutron flux distribution contour map at various deuteron energies for deuteron beam current of 50 mA.

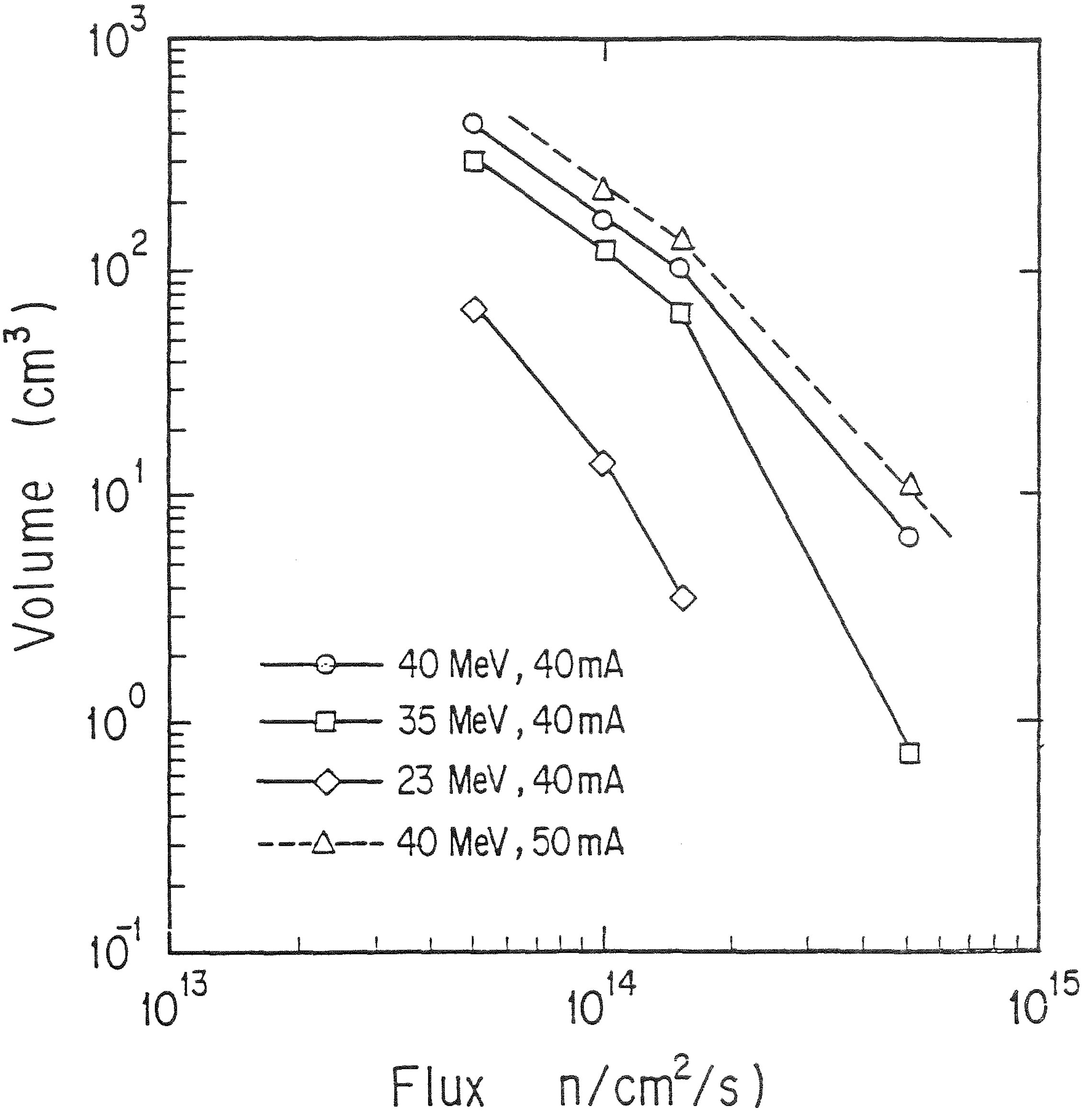
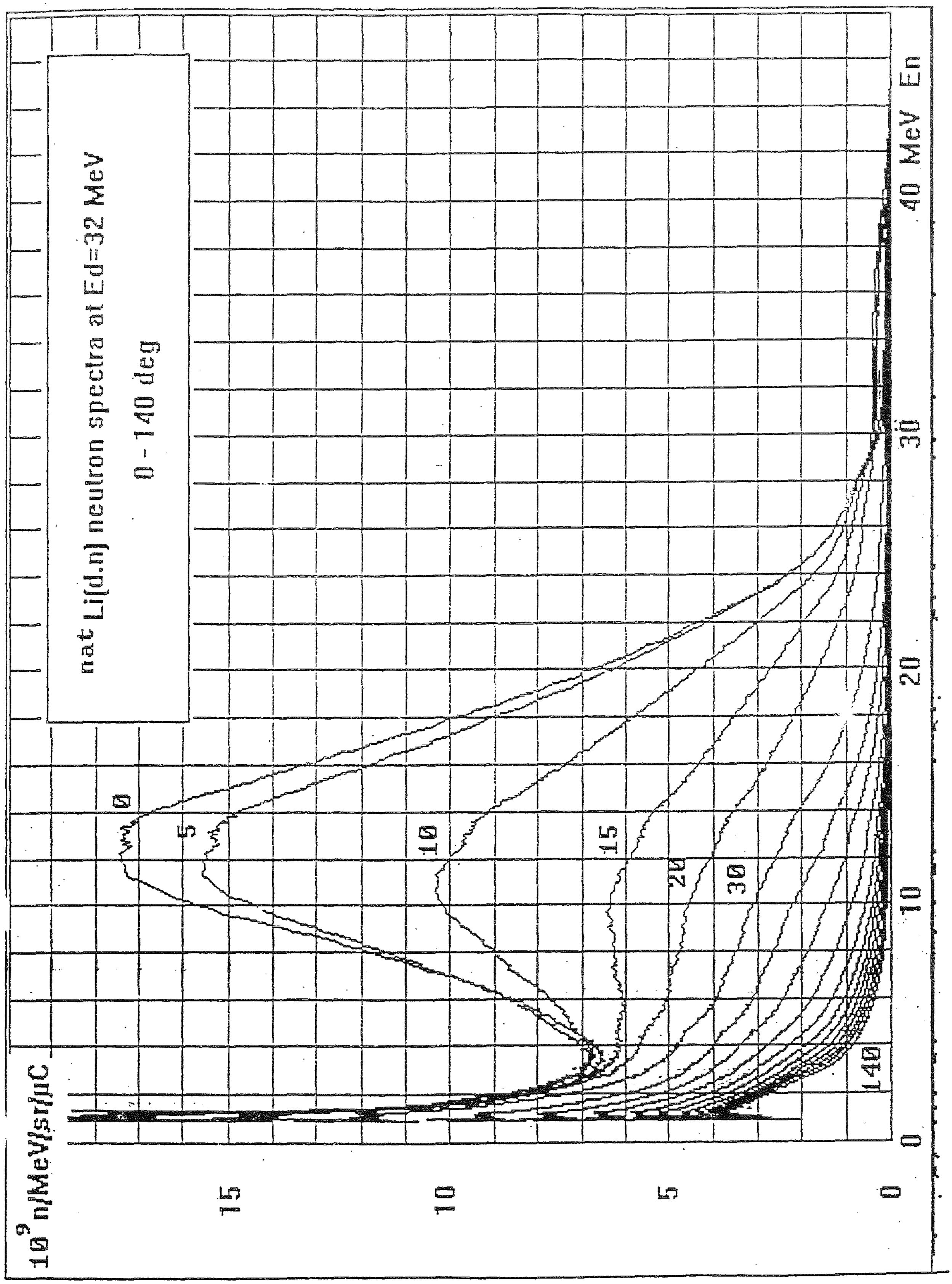
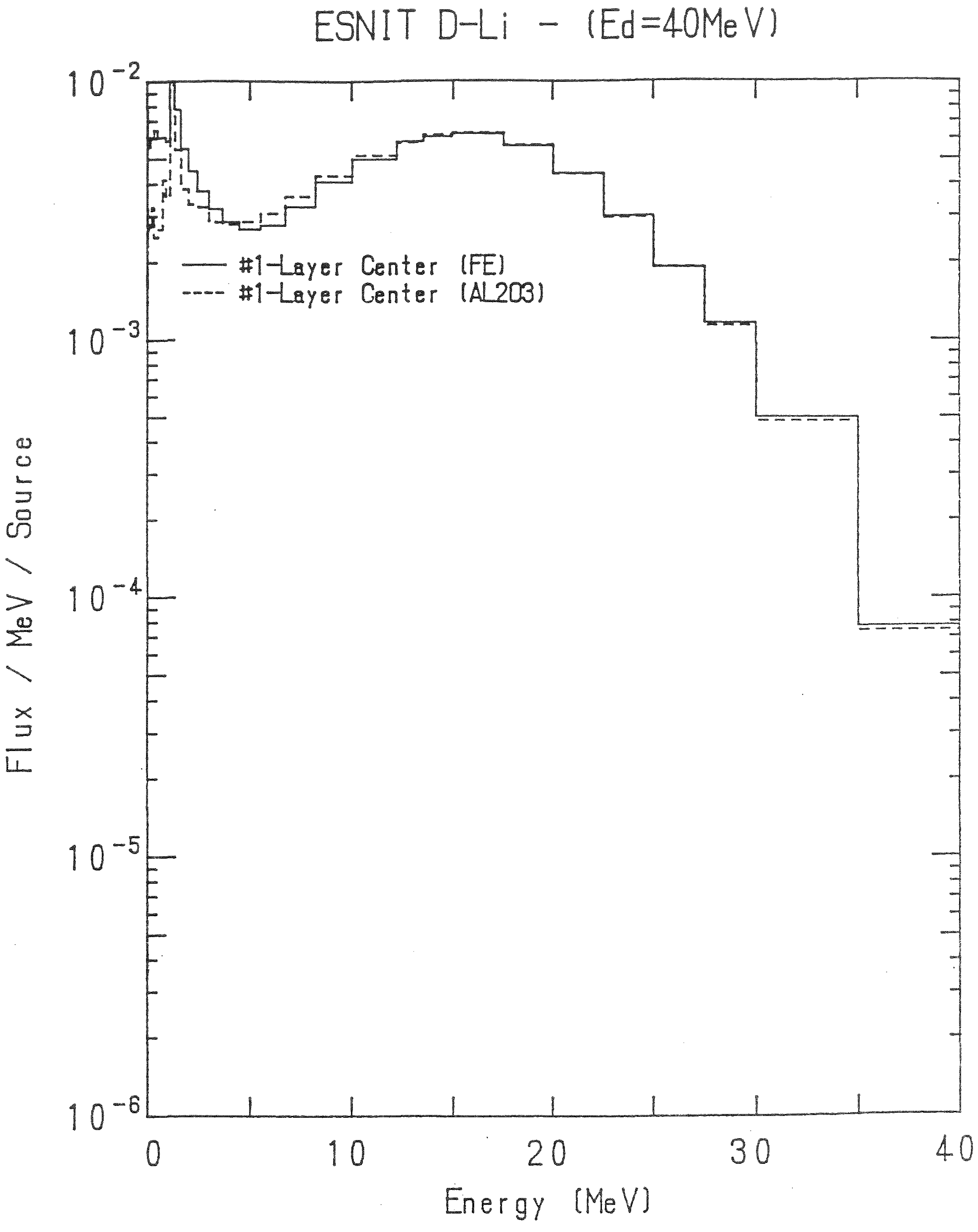


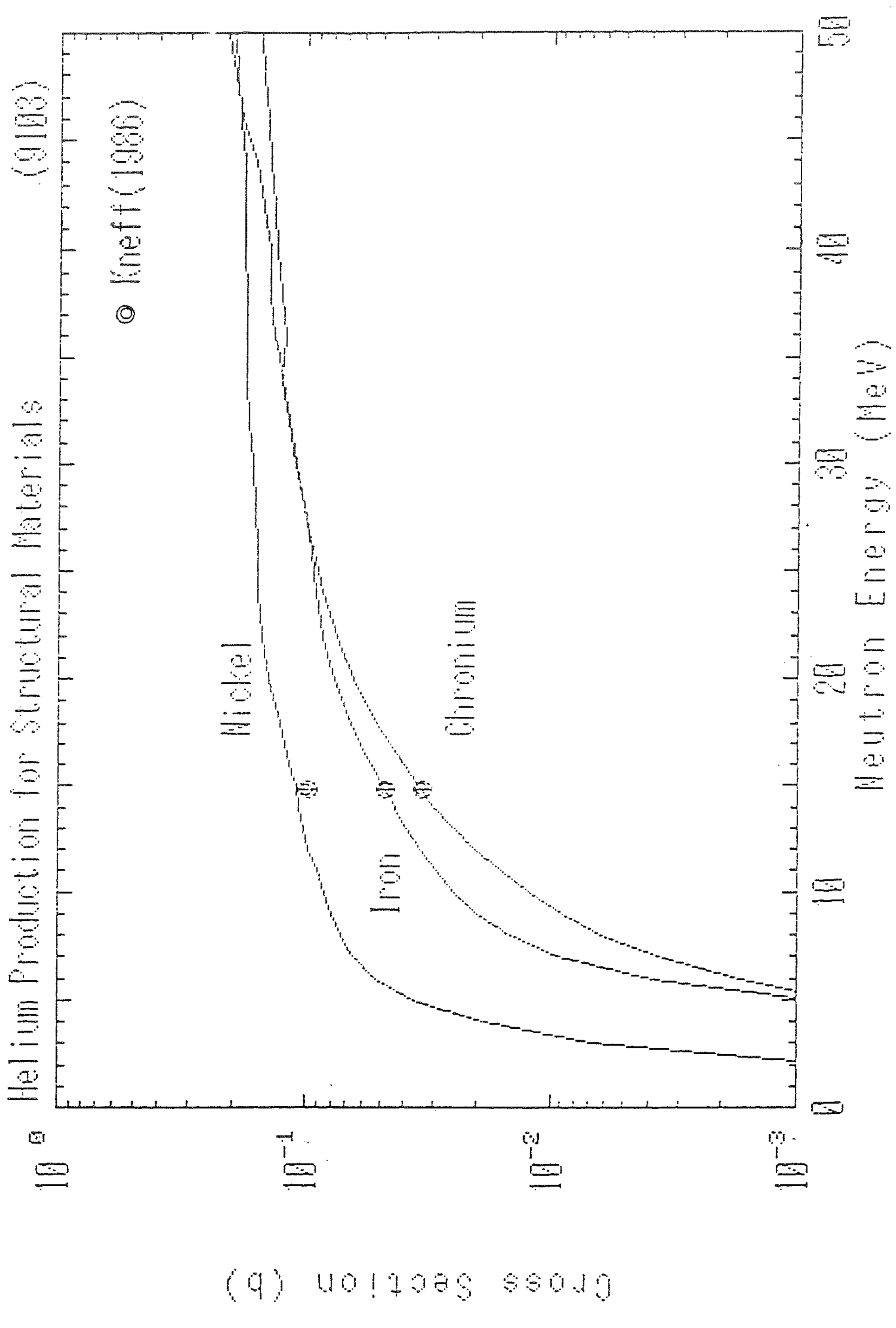
Fig. 4 Relationship between neutron flux and test volume at various deuteron energies for deuteron current of 40 mA.

Appendix to the presentation of Mr. Noda

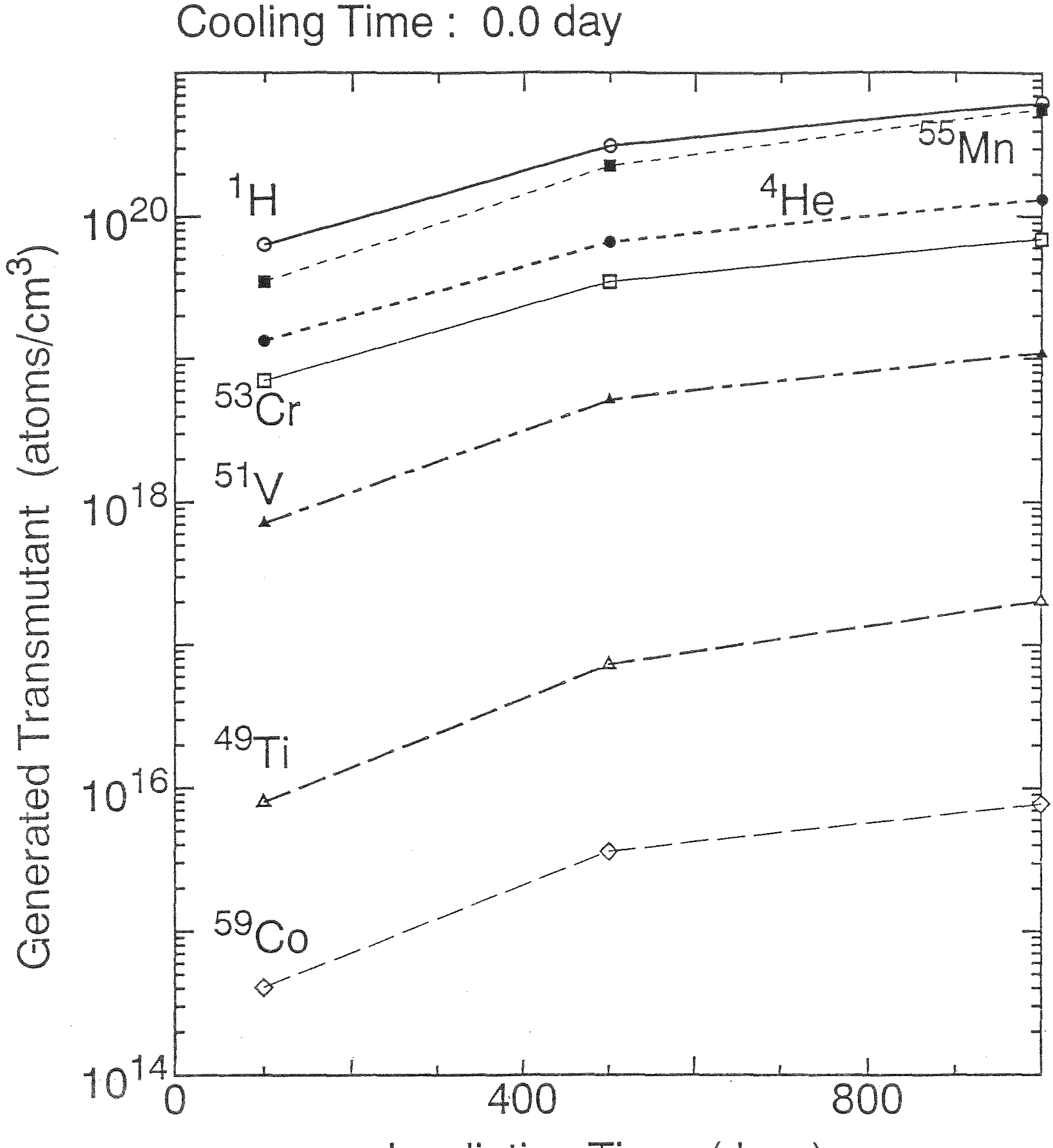

nat Li(d,n) neutron spectra at Ed=32 MeV
0 - 140 deg
10⁹ n/MeV/sr/μC
0
5
10
15
0
10
20
30
40 MeV En
0
5
10
15
20
30
140



ESNIT D-Li - (Ed=40MeV)
Flux / MeV / Source
Energy (MeV)
#1-Layer Center (FE)
#1-Layer Center (AL2O3)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
10
20
30
40



Helium Production for Structural Materials
(9103)
⊚ Kneff(1986)
Nickel
Iron
Chromium
Neutron Energy (MeV)
Cross Section (b)
0
10
20
30
40
50
10^0
10^-1
10^-2
10^-3



Amount of Transmutants Generated in Iron by ESNIT Irradiation (40MeV,Collided)

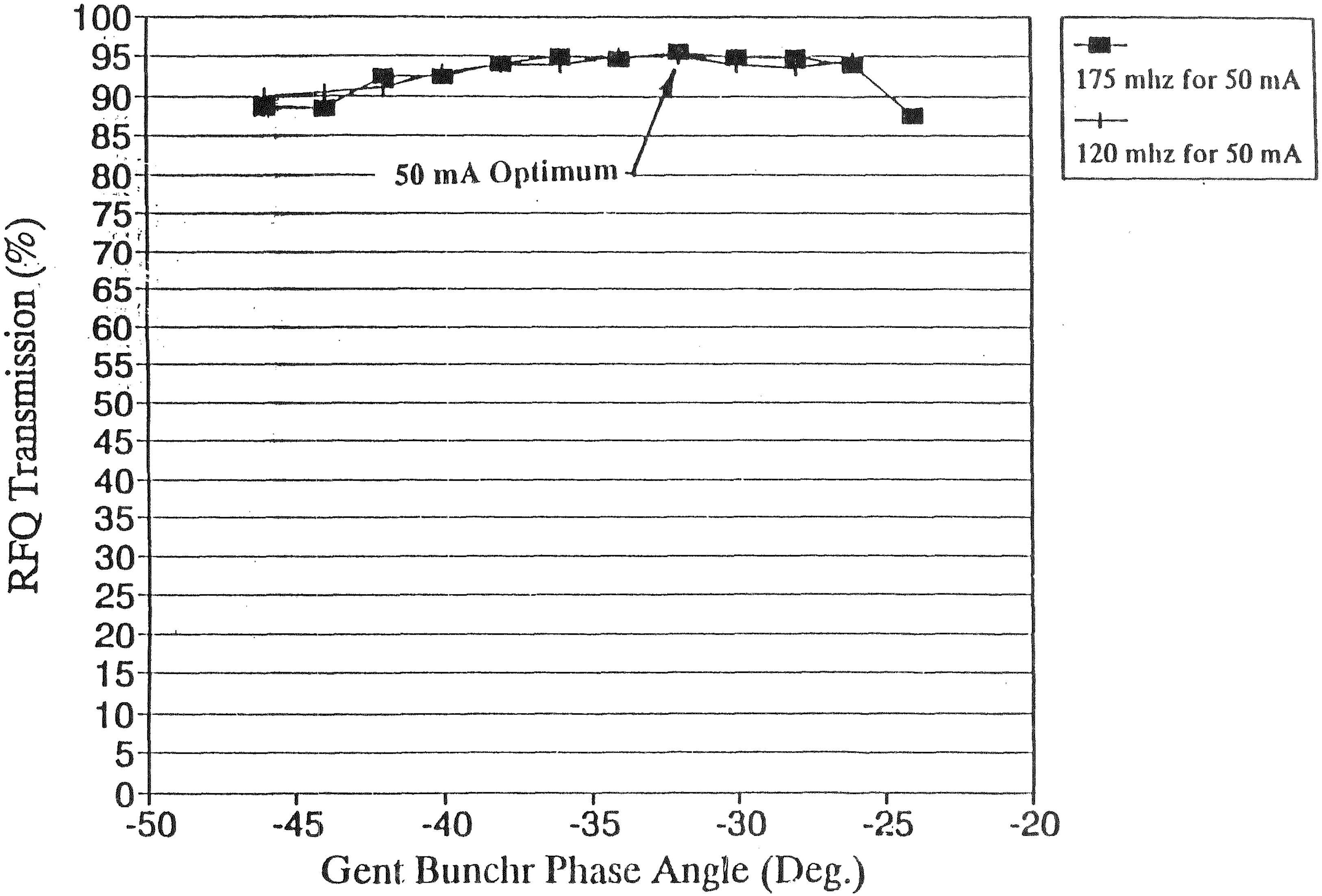


Fig. 6 Comparison of transmission for 50 mA design current optimized RFQs at 120 MHz and 175 MHz, vs. phase angle at the end of the gentle buncher.

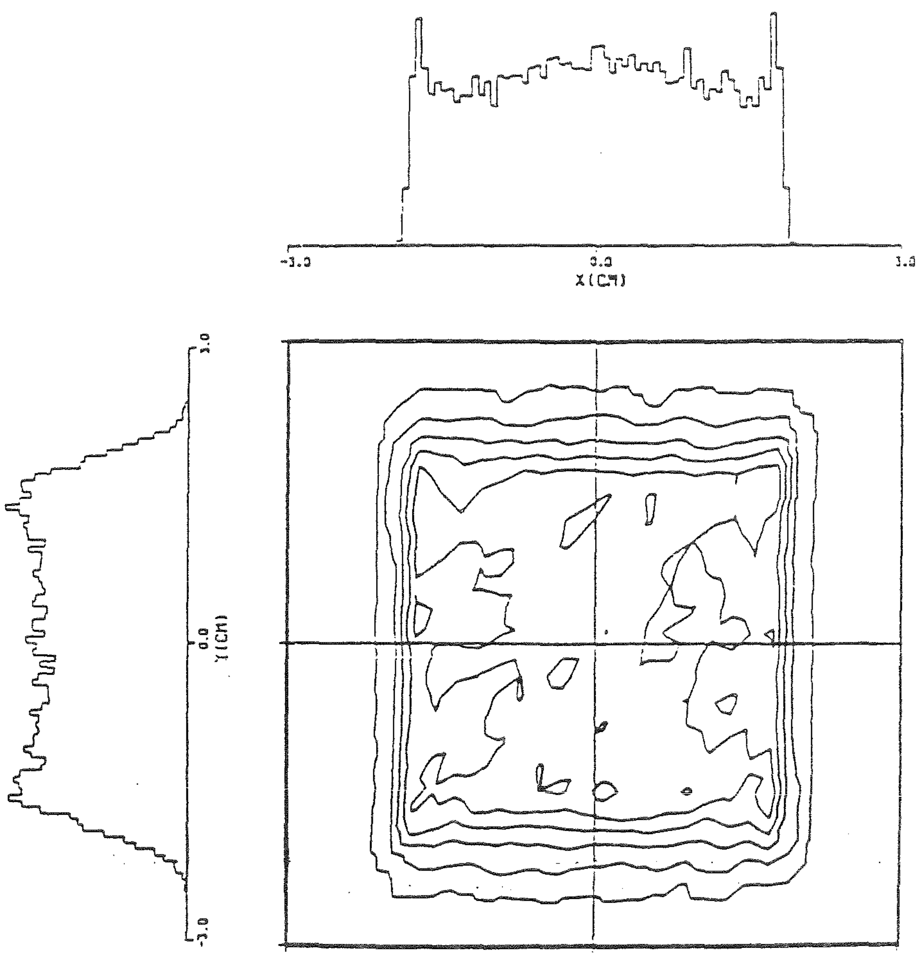


Figure 3

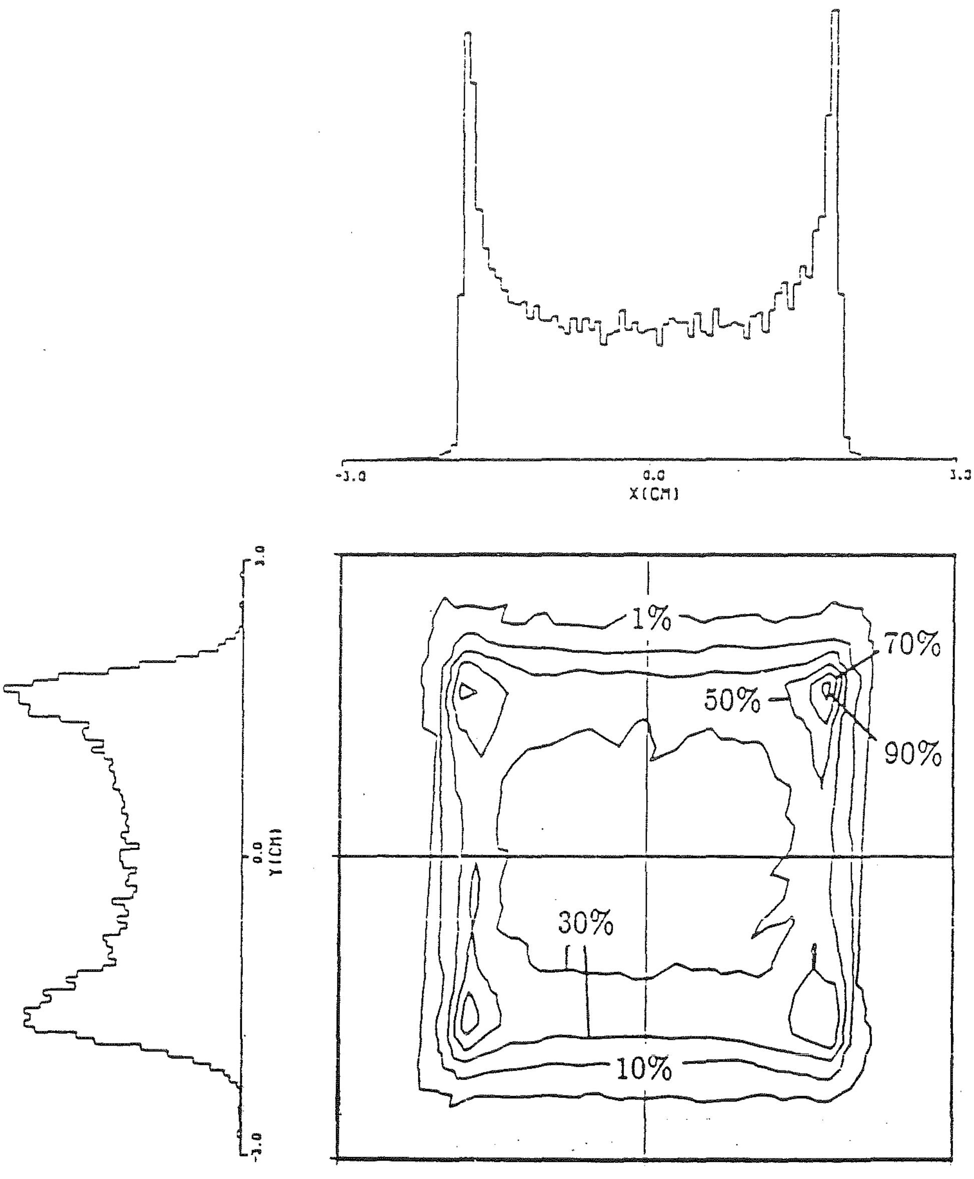
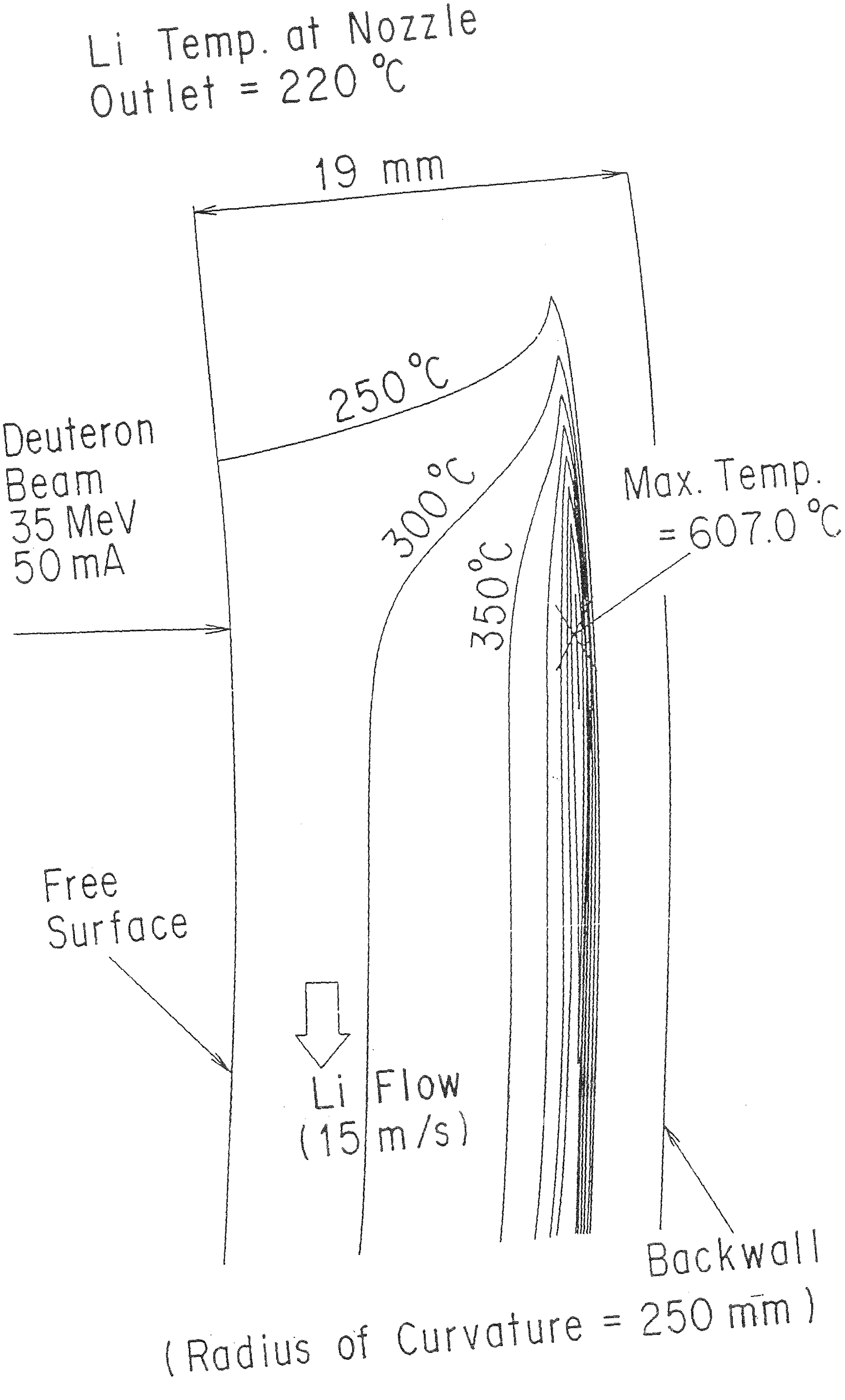
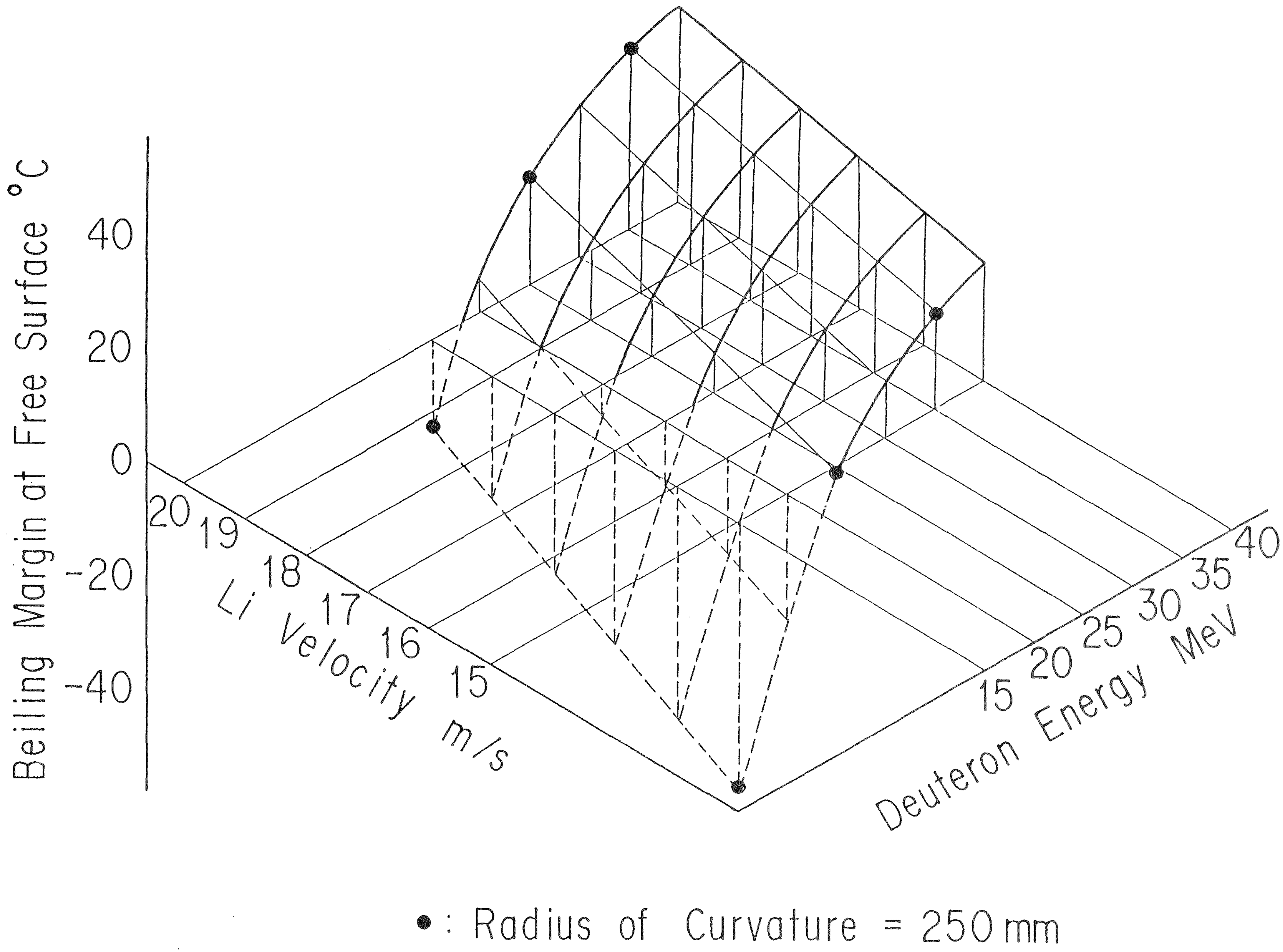


Figure 7


Li Temp. at Nozzle
Outlet = 220 ℃
19 mm
250℃
300℃
350℃
Deuteron
Beam
35 MeV
50 mA
Max. Temp.
= 607.0 ℃
Free
Surface
Li Flow
(15 m/s)
Backwall
(Radius of Curvature = 250 mm)


Beiling Margin at Free Surface °C
40
20
0
-20
-40
20
19
18
17
16
15
Li Velocity m/s
15
20
25
30
35
40
Deuteron Energy MeV
●: Radius of Curvature = 250 mm

The High Intensity D-Li Source

M.J. Saltmarsh

ORNL

THE HIGH INTENSITY D-LI SOURCE*

M. J. Saltmarsh
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

presented at

IEA Workshop on Intense Neutron Sources
Karlsruhe, Germany

September 21, 1992

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*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

The US neutron source effort has concentrated on the D-Li concept as used for FMIT

This concept provides the best combination of

- near-term physics and technology base
- spectral characteristics
- experimental volume, flux, and fluence capability
- experimental access

In the years since FMIT was designed advances in accelerator technology have provided the option of improved performance, as discussed in previous workshops

This talk will review some of the work in the US related to IFMIF design options.

The US studies on the D-Li concept for IFMIF are co-ordinated as a single project.

Overall design responsibilities are partitioned between ANL, LANL and ORNL.

A work breakdown structure has been defined

A requirements document has been issued to provide a framework for future work

The primary goal has been to prepare for participation in a future IFMIF design activity.

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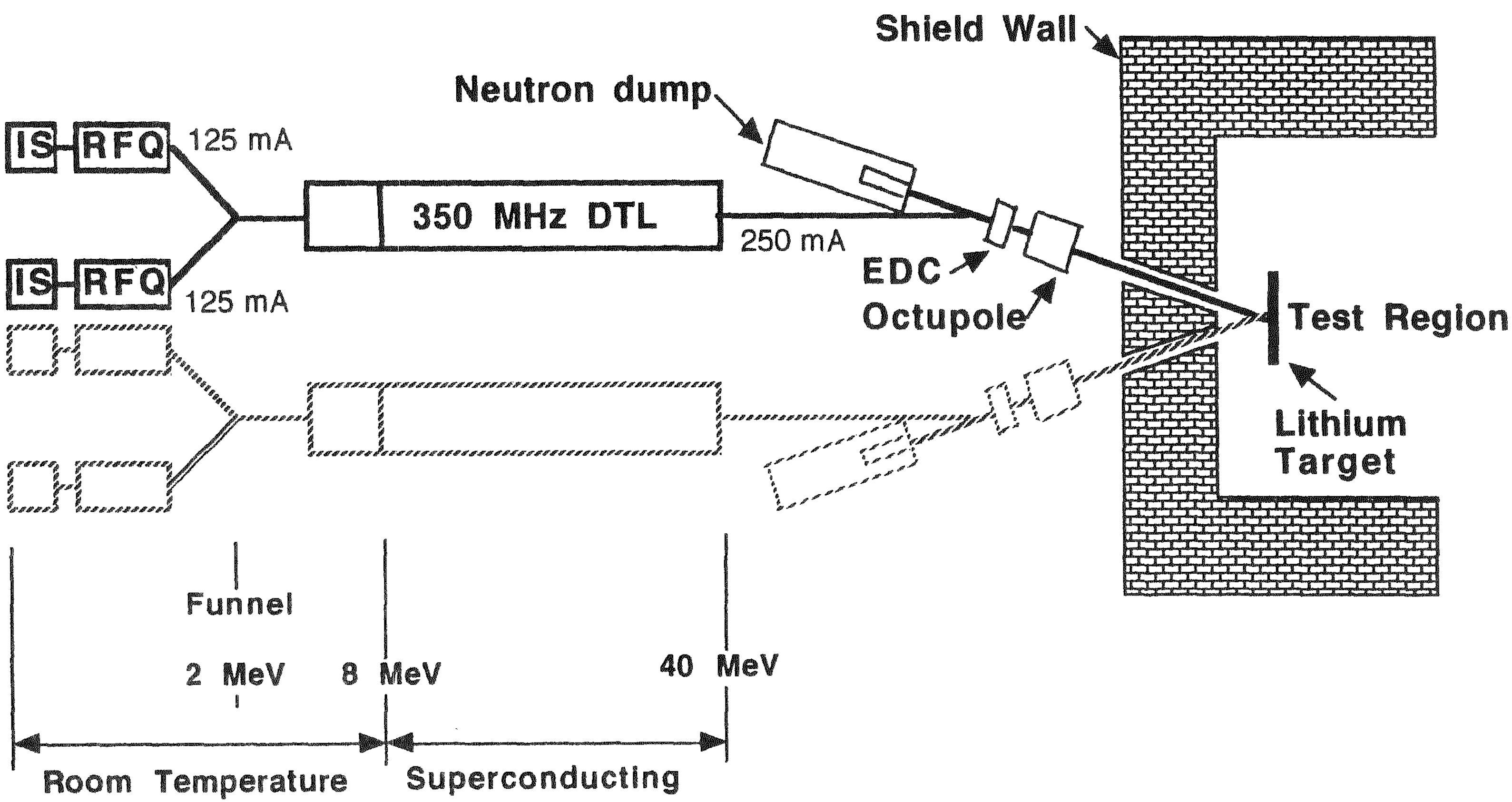
Reference D-Lithium Neutron Source Concept

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

Lightly drawn module suggests upgrade path to 500-mA system



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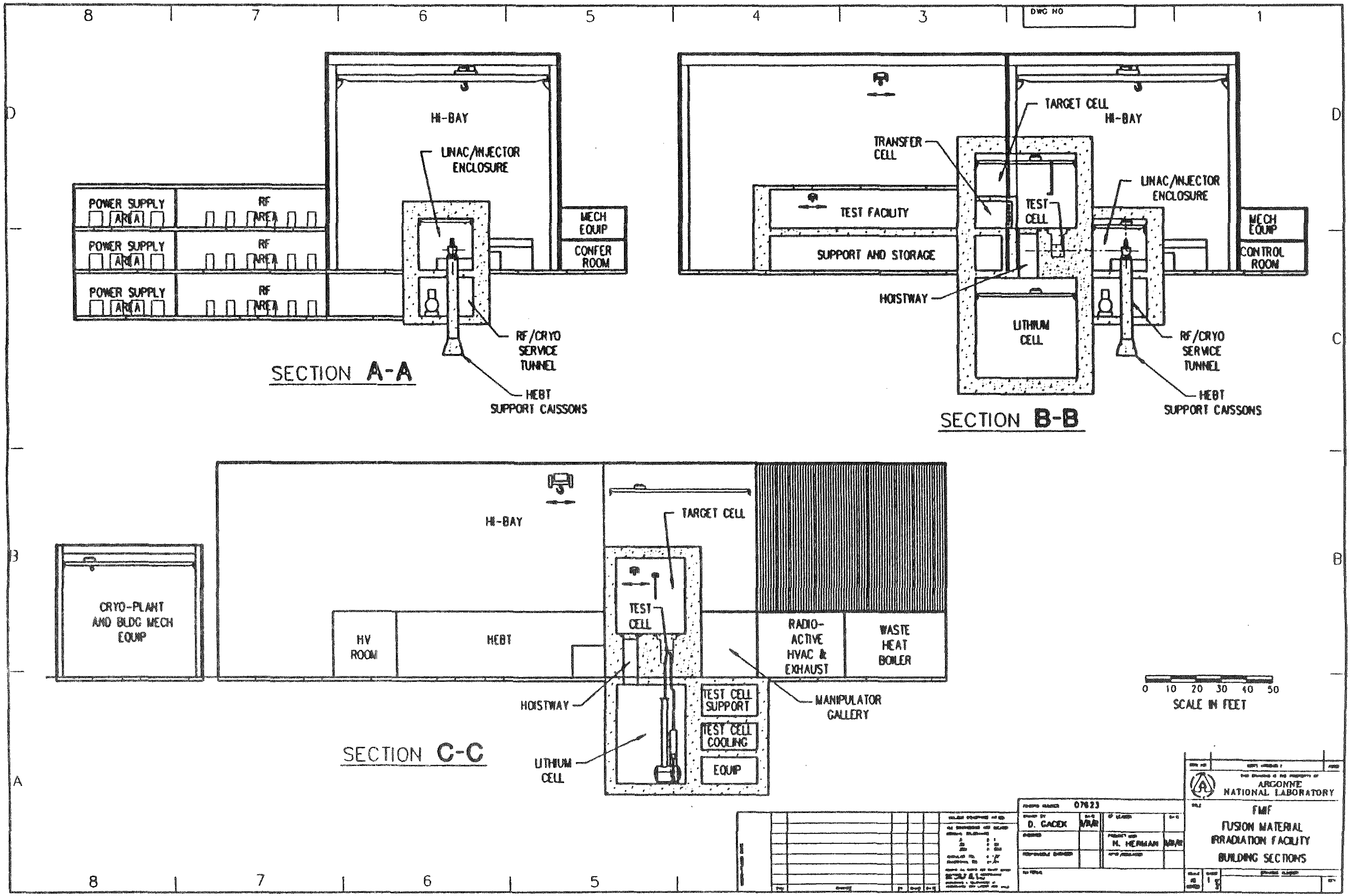
Facility Layout
Based on Appropriate Remote Handling Technology

Modular Component Design for Ease of Assembly, Transport and Maintenance.

Crane Mounted Telescoping Boom with Servo Manipulators for More Flexibility in the Layout of the Target and Test Cells

Hot Cell Maintenance and Material Test Laboratory Concepts Based on State-of-the Art Equipment and Facilities



SECTION A-A
HI-BAY
LINAC/INJECTOR ENCLOSURE
POWER SUPPLY AREA
POWER SUPPLY AREA
POWER SUPPLY AREA
RF AREA
RF AREA
RF AREA
MECH EQUIP
CONFER ROOM
RF/CRYO SERVICE TUNNEL
HEBT SUPPORT CAISSONS
SECTION B-B
TARGET CELL
HI-BAY
TRANSFER CELL
TEST FACILITY
SUPPORT AND STORAGE
TEST CELL
LINAC/INJECTOR ENCLOSURE
MECH EQUIP
CONTROL ROOM
HOISTWAY
LITHIUM CELL
RF/CRYO SERVICE TUNNEL
HEBT SUPPORT CAISSONS
SECTION C-C
HI-BAY
TARGET CELL
CRYO-PLANT AND BLDG MECH EQUIP
HV ROOM
HEBT
TEST CELL
RADIO-ACTIVE HVAC & EXHAUST
WASTE HEAT BOILER
HOISTWAY
TEST CELL SUPPORT
TEST CELL COOLING
EQUIP
MANIPULATOR GALLERY
LITHIUM CELL
0 10 20 30 40 50
SCALE IN FEET
DWG NO
D. GACEK
N. HERMAN
07823
ARGONNE NATIONAL LABORATORY
FMIF
FUSION MATERIAL IRRADIATION FACILITY
BUILDING SECTIONS

Several design issues have been examined

Target backplate

- Backplate lifetime ~ 1 yr required
- ANL design for free jet (no backplate) may be an option

Target configuration

- number of targets in test cell
- beam geometry

S/C or room-temperature accelerator technology

Reliability and Maintainability will be major design driver

The optimum beam/target geometry for a high intensity source

Large beam spot (50 - 100 cm^2)

- Lower damage to target backwall
- Avoid excessive experimental fluxes
- Ease velocity requirement on Li jet by reducing instantaneous heating
- More accessible experimental configuration

Uniform beam spot

- Lower peak damage rates
- Reduce undesirable flux gradients

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Criteria for beam geometry

If the nominal DEMO first wall flux is ϕ_0 some experimental volume with flux at $\phi \sim (2\text{-}3) \times \phi_0$ will be needed for accelerated testing. Higher fluxes would not be useful because of rate-dependent effects, and would limit the backplate lifetime.

The relationship between flux (ϕ), beam current (I) and experimental volume (V) for a given value of target thickness (d), and beam energy (E) is

$$V(\phi) = C\,(I/\phi)^{3/2}$$

where C is only weakly dependent on beam geometry for $\phi < 2 \times \phi_b$

The peak backplate flux (ϕ_b) limits the target lifetime and depends on the target beam density

$$\phi_b \sim C_1\,(I/A)$$

A suitable criterion would be to choose the beam spot area such that

$$\phi_b \sim (4\text{-}6) \times \phi_0$$

For $\phi_0 \sim 20$ dpa/yr this implies $\phi_b \sim 100$ dpa/yr

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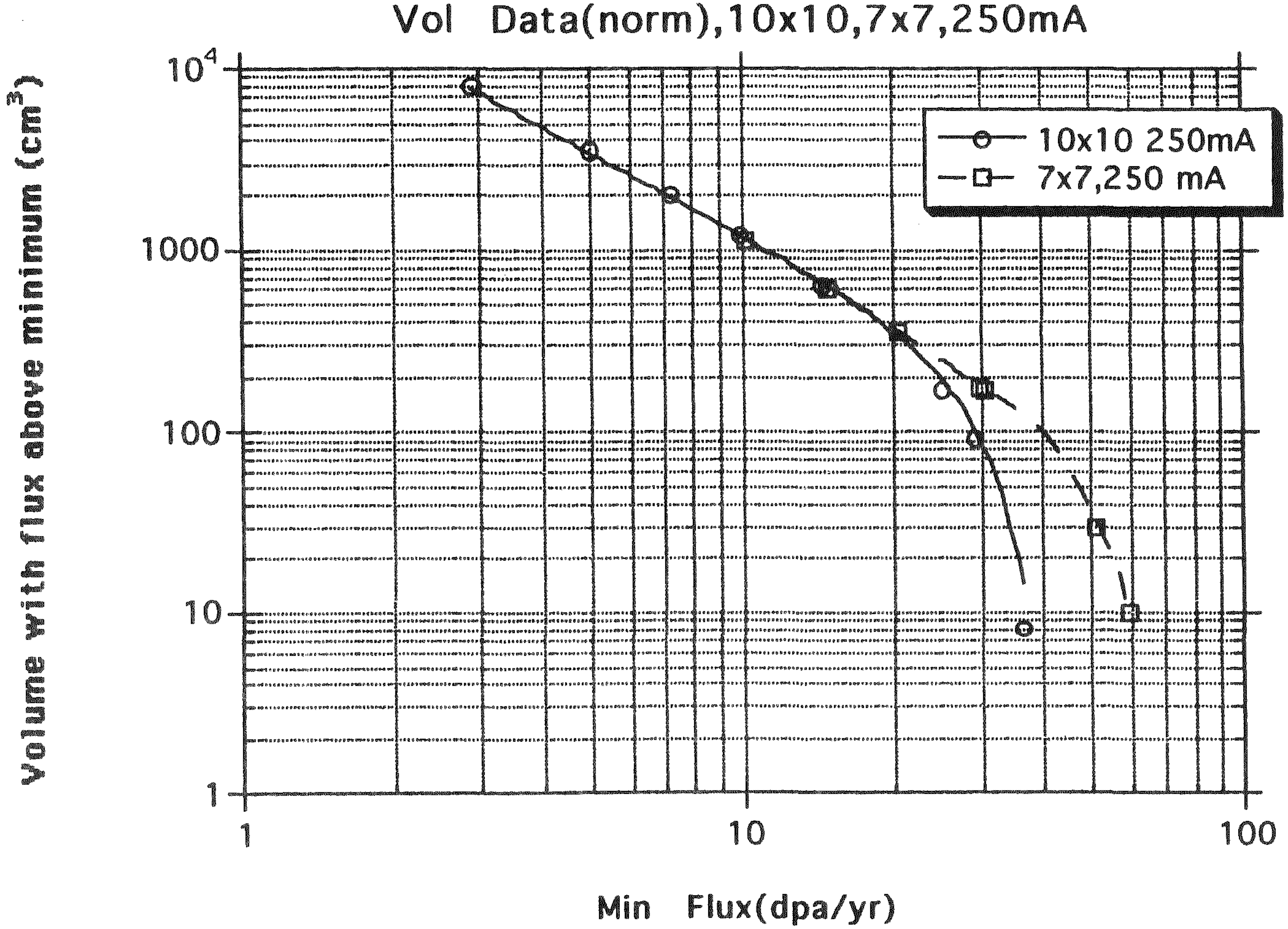
Volume is proportional to $\phi^{-3/2}$ for $\phi > 2 \times \phi b$



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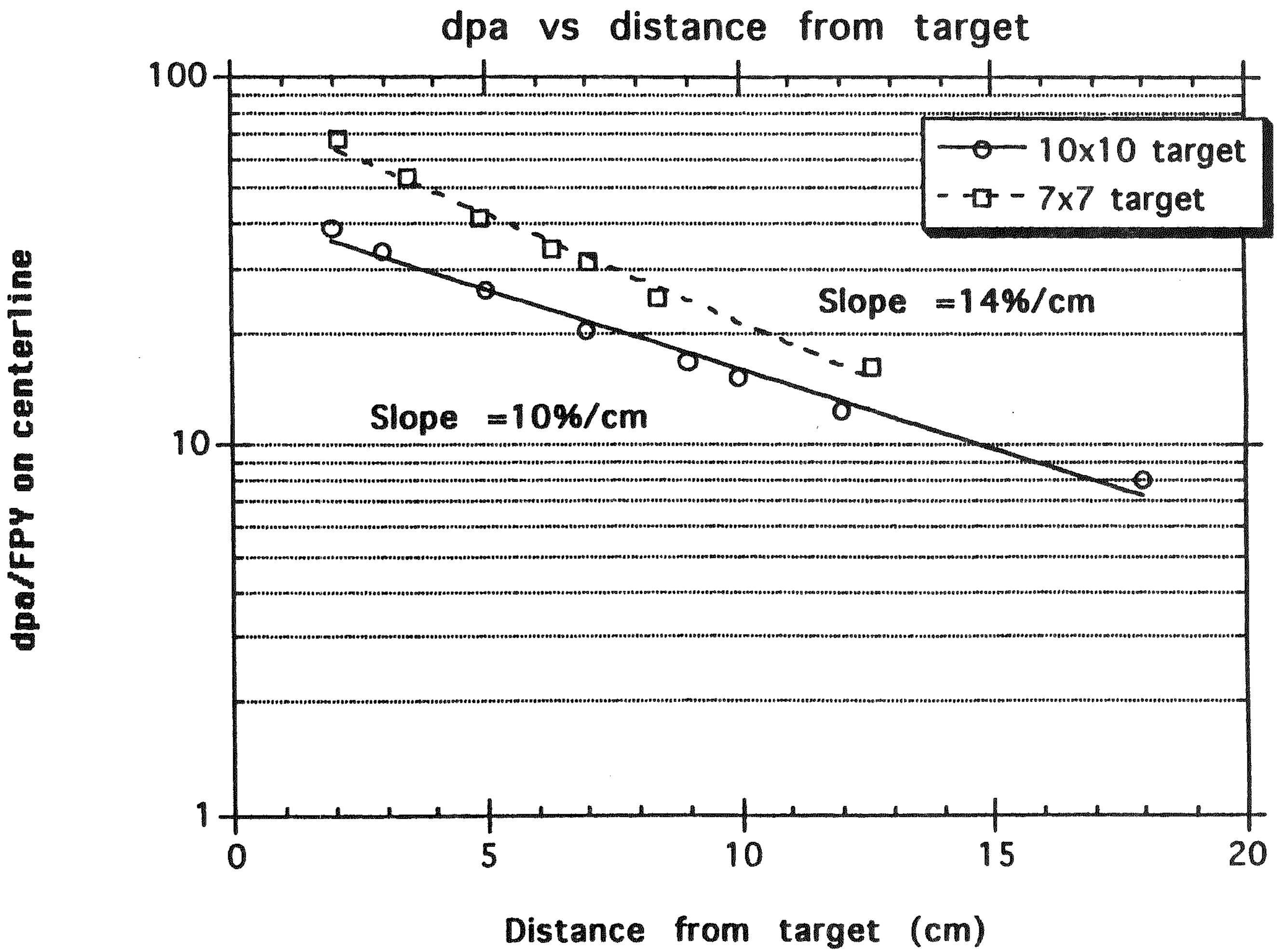
Flux gradients ~ 10%/cm can be obtained with large area uniform beam spots



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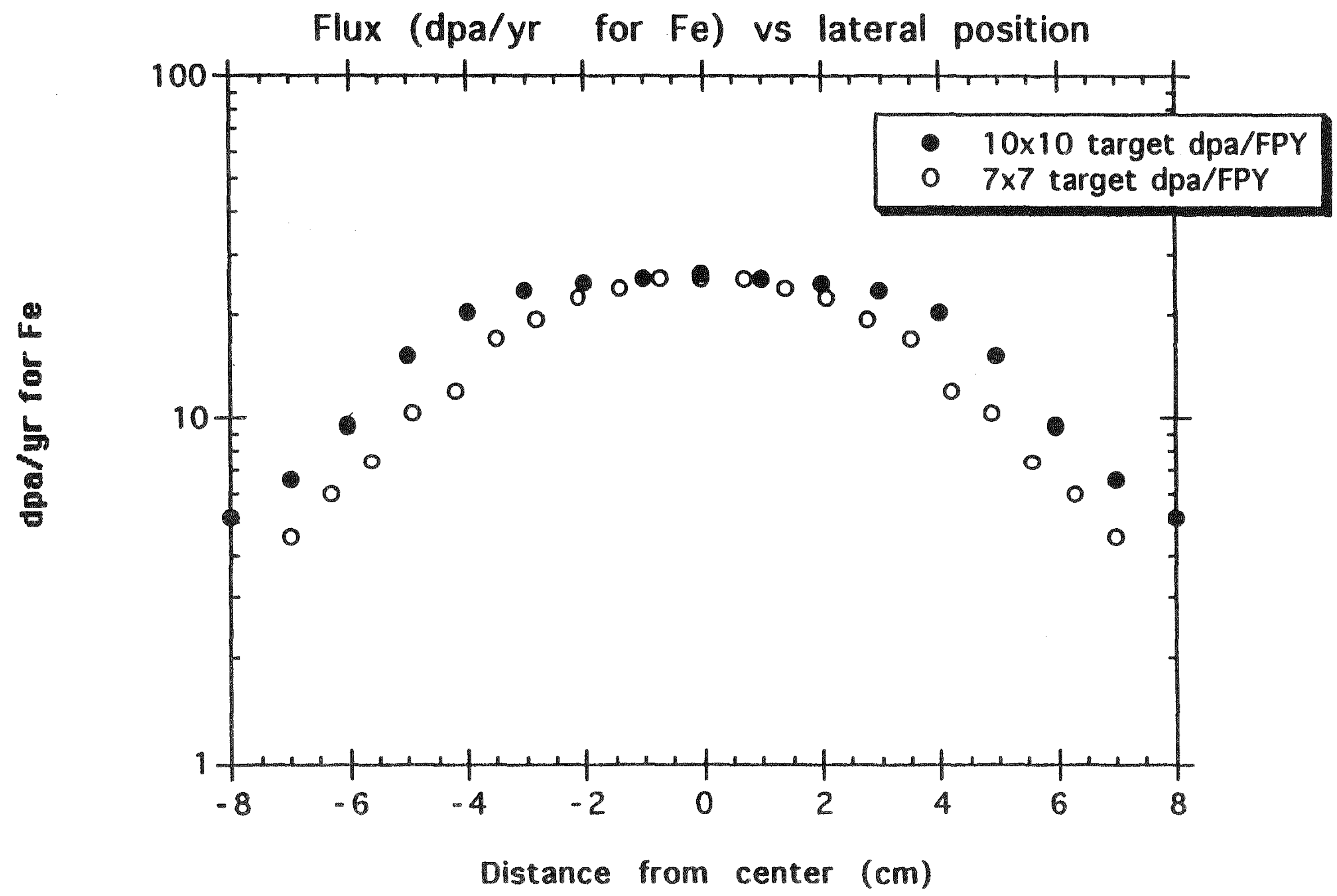
Flux (dpa/yr for Fe) vs lateral position
100
10
1
-8
-6
-4
-2
0
2
4
6
8
Distance from center (cm)
dpa/yr for Fe
10x10 target dpa/FPY
7x7 target dpa/FPY

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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

Target backplate damage rates

Beam current = 250 mA. Deuteron energy 35MeV. Uniform beam spot
Target thickness = 1.90 cm. Back-plate thickness = 0.16 cm.

	3 x 1[1]		7 x 7[2]		10 x 10[2]		20 x 20[2]	
	Material	No Material	Material	No Material	Material	No Material	Material	No Material
dpa/yr	510	500	93	90	55	48	17	15
He appm/yr[3]	7000	7300	1130	1100	650	600	180	170
He-MCNP[4] appm/yr	7300		1230		700		195	

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

3 Helium production using cross-section data from Greenwood

4 Helium production calculations using the standard MCNP cross sections

10/5/92

ANL data

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

Staging options

Add second accelerator to increase beam current to 500 mA

Provide capability to steer beam to same target or to a separate target

Same target :

- Double area of beam spot
- Volume will increase by factor of three
- No increase in backplate fluxes

Separate target:

- Experimental volume increased by a factor of two
- Extra redundancy
- Experimental flexibility is increased.

9/16/92

ornl

Future Plans

Preliminary design and cost estimate.

Develop systems code for trade-off studies

Preliminary Reliability Availability Maintainability (RAM) Analysis

R&D Needs Assessment

The schedule proposed to the DOE would support an international design activity beginning early in 1994

9/17/92

ornl

The Intense T-H_2O Neutron Source

S. Cierjacks

KfK

The Intense t-H_2O Neutron Source[x]

S. Cierjacks, IMF 1
G. Class, IRS
E. Daum, IMF 1
K. Ehrlich, IMF 1
Y. Hino, Guest IMF 1
S. Kelzenberg, IMF 1
S. Malang, IATF
Kernforschungszentrum Karlsruhe

M. Drosg, IEP
University of Vienna

G. Ernst et al., ITT
University of Karlsruhe

[x]For previous work see S. Cierjacks, J. Fus. Eng. 8 193 (1989)
S. Cierjacks et al., Nucl. Sci. Eng. 106 183 (1990)
S. Cierjacks et al., Act. Phy. Hungar. 69 285 (1991)

General Features of the t-H_2O Source

The general design of a t-H_2O neutron source is very similar to that of a d-Li source.

Similarities

1. Accelerator concept and components

2. Concept for a staged design

3. Concept for flux enhancement in test cell by multi-source irradiation of the same test cell

Crucial Differences

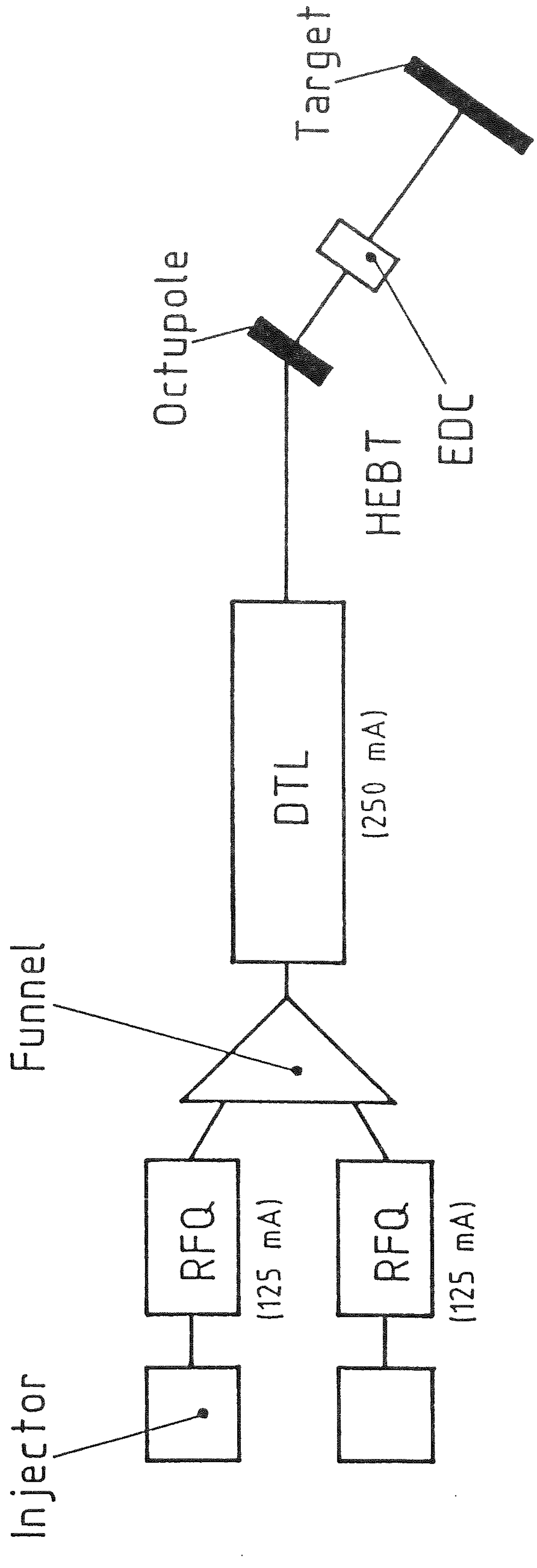
1. Use of another neutron producing reaction namely that based on the $^{1}H(t,n)^{3}He$ reaction

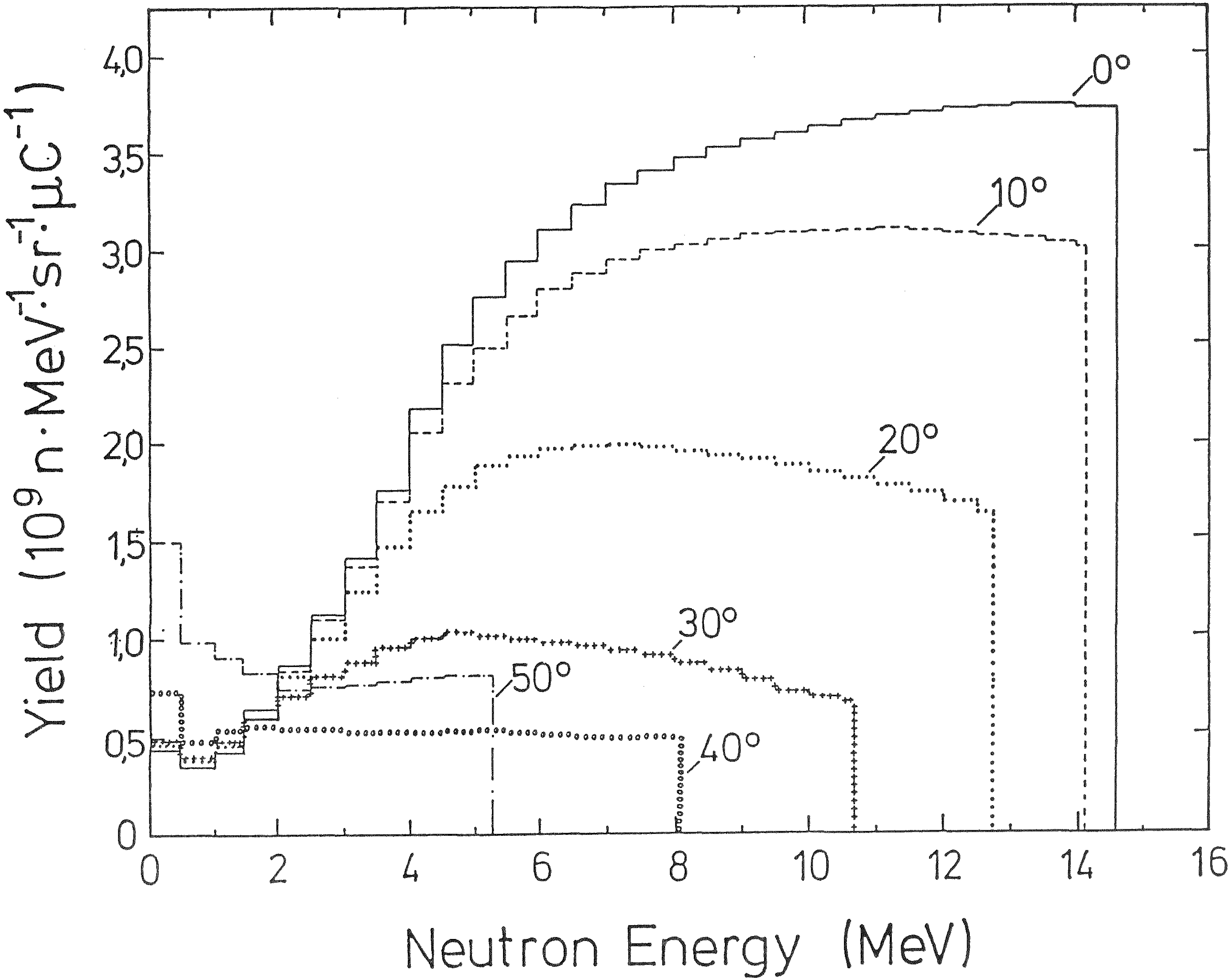
2. 21 MeV tritons on ^{1}H give an intense continuous neutron spectrum with

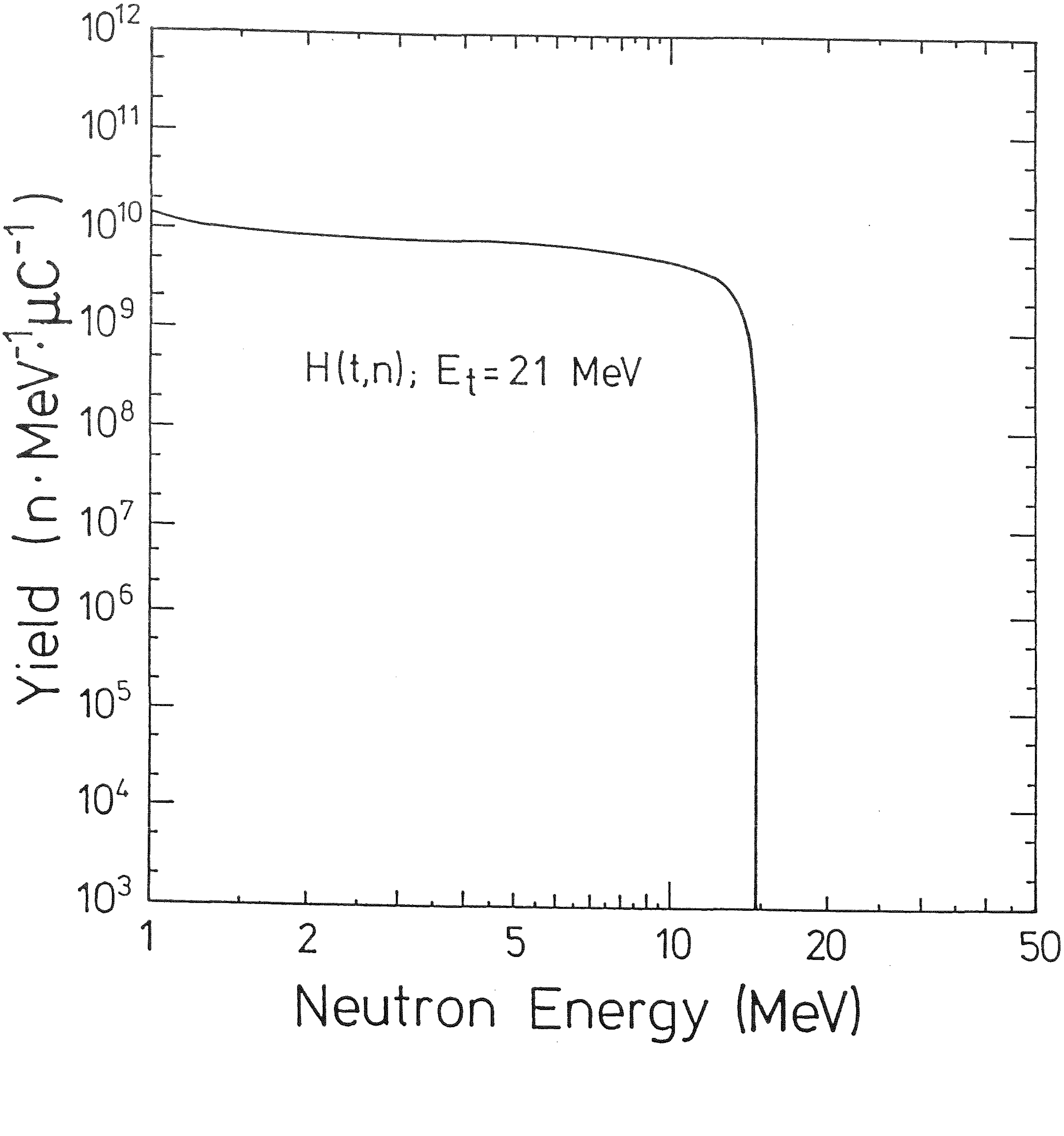
   a. A sharp cut off energy at 14.6 MeV

   b. High spectral intensity over the whole range from 0-14.6 MeV

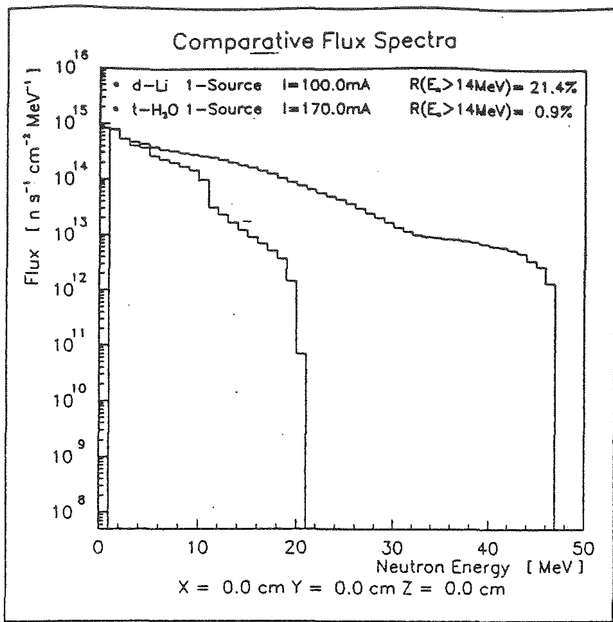
3. Usage of a different neutron target (a liquid water jet)

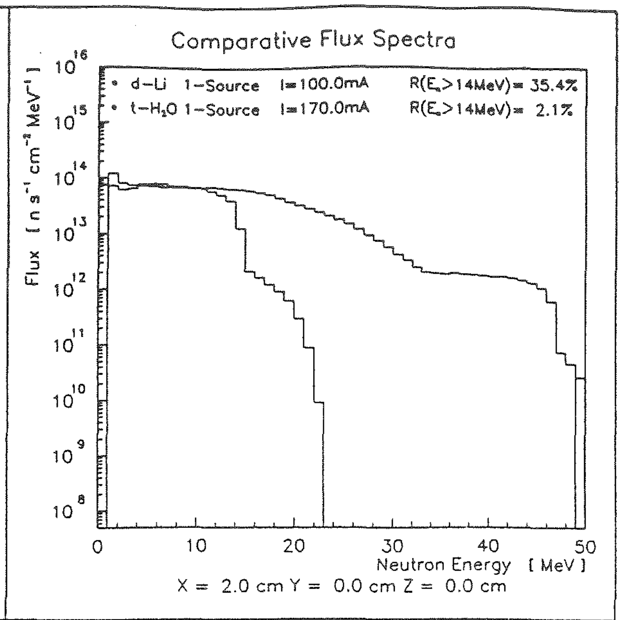

Injector
RFQ
(125 mA)
RFQ
(125 mA)
Funnel
DTL
(250 mA)
HEBT
Octupole
EDC
Target

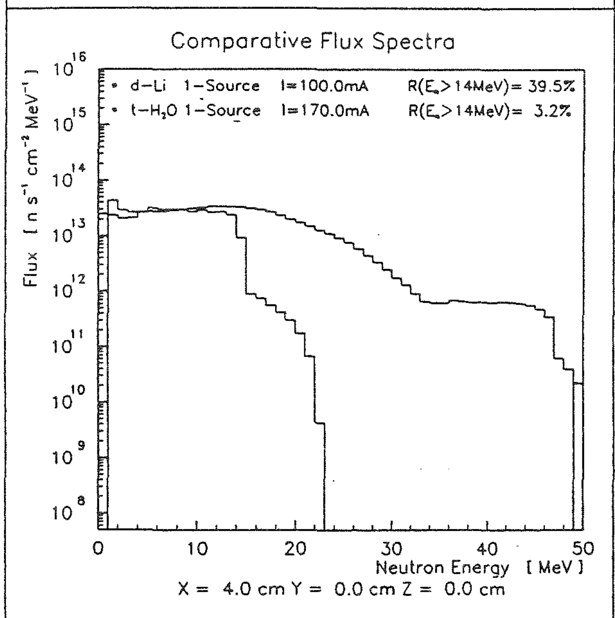

Yield (10^9 n · MeV^-1 · sr^-1 · μC^-1)
Neutron Energy (MeV)
0°
10°
20°
30°
40°
50°
0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
0
2
4
6
8
10
12
14
16

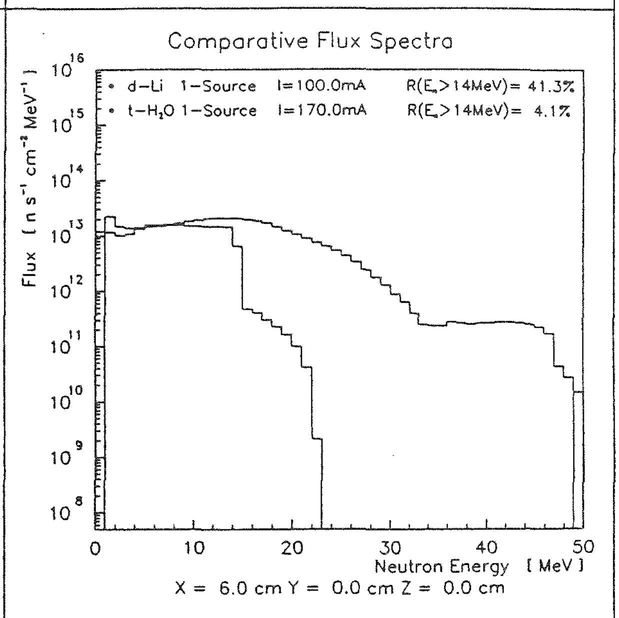


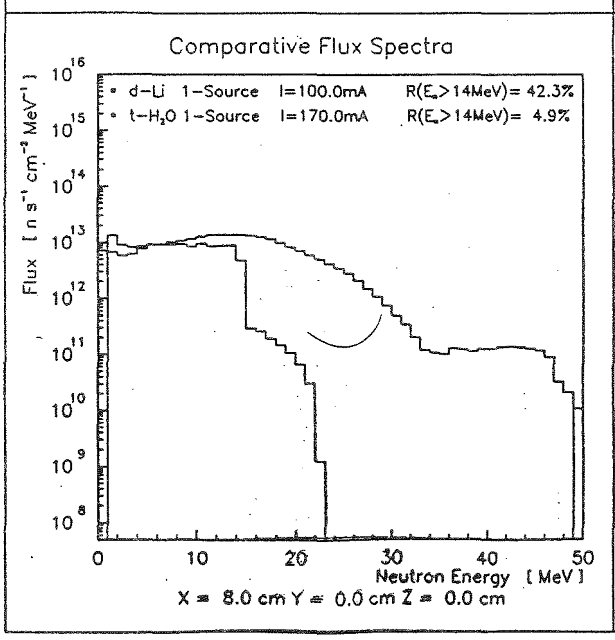
H(t,n); E$_t$ = 21 MeV
Yield (n · MeV^{-1} · μC^{-1})
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
1
2
5
10
20
50
Neutron Energy (MeV)

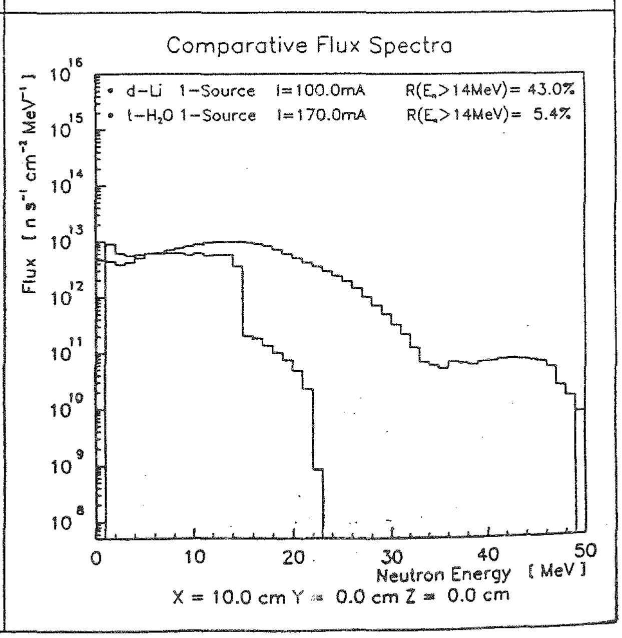

Comparative Flux Spectra
d–Li 1–Source I=100.0mA R(E>14MeV)= 21.4%
t–H2O 1–Source I=170.0mA R(E>14MeV)= 0.9%
Flux [n s⁻¹ cm⁻² MeV⁻¹]
Neutron Energy [MeV]
X = 0.0 cm Y = 0.0 cm Z = 0.0 cm

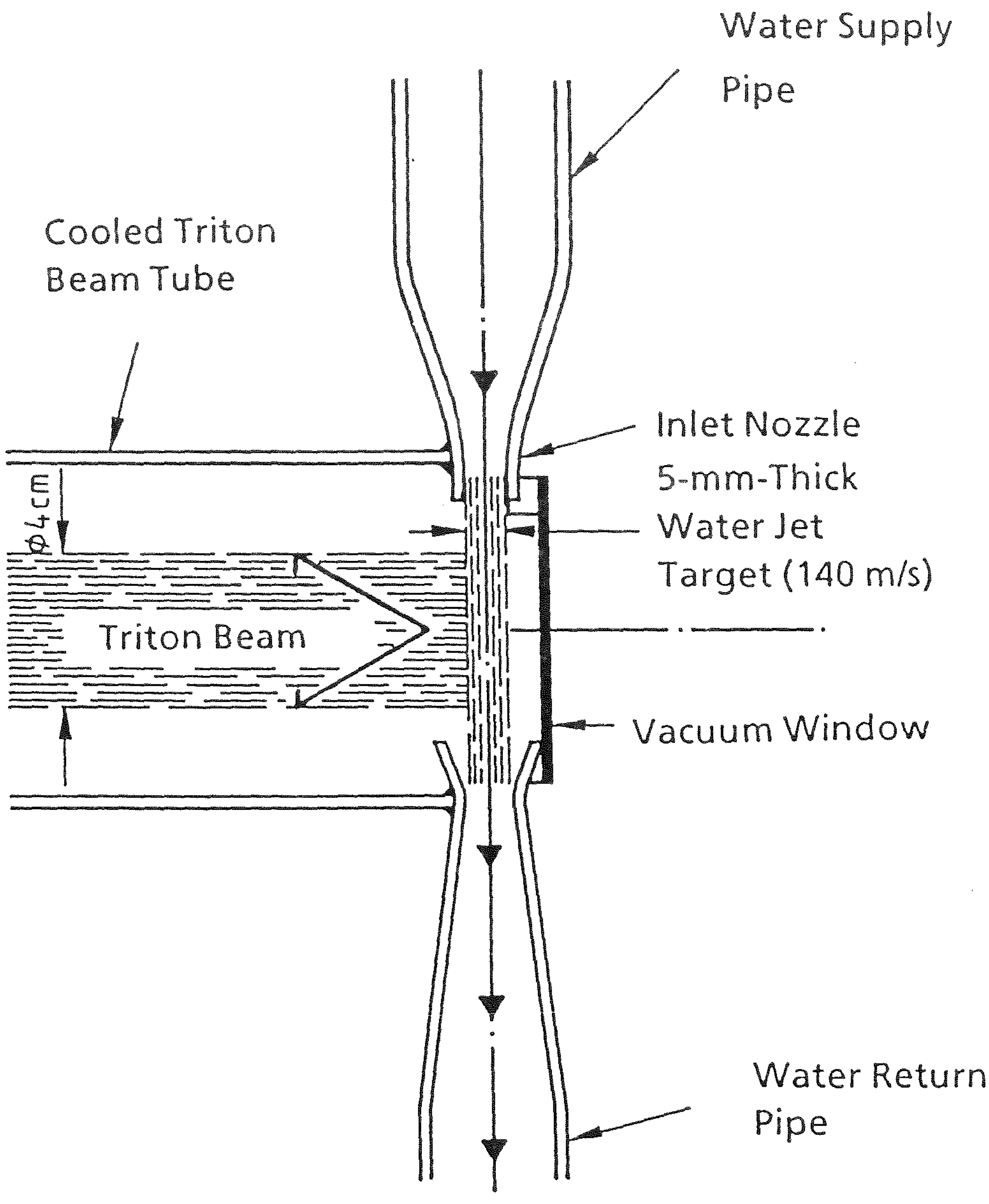

Comparative Flux Spectra
d–Li 1–Source I=100.0mA R(E>14MeV)= 35.4%
t–H2O 1–Source I=170.0mA R(E>14MeV)= 2.1%
Flux [n s⁻¹ cm⁻² MeV⁻¹]
Neutron Energy [MeV]
X = 2.0 cm Y = 0.0 cm Z = 0.0 cm


Comparative Flux Spectra
d–Li 1–Source I=100.0mA R(E>14MeV)= 39.5%
t–H2O 1–Source I=170.0mA R(E>14MeV)= 3.2%
Flux [n s⁻¹ cm⁻² MeV⁻¹]
Neutron Energy [MeV]
X = 4.0 cm Y = 0.0 cm Z = 0.0 cm


Comparative Flux Spectra
d–Li 1–Source I=100.0mA R(E>14MeV)= 41.3%
t–H2O 1–Source I=170.0mA R(E>14MeV)= 4.1%
Flux [n s⁻¹ cm⁻² MeV⁻¹]
Neutron Energy [MeV]
X = 6.0 cm Y = 0.0 cm Z = 0.0 cm


Comparative Flux Spectra
d–Li 1–Source I=100.0mA R(E>14MeV)= 42.3%
t–H2O 1–Source I=170.0mA R(E>14MeV)= 4.9%
Flux [n s⁻¹ cm⁻² MeV⁻¹]
Neutron Energy [MeV]
X = 8.0 cm Y = 0.0 cm Z = 0.0 cm


Comparative Flux Spectra
d–Li 1–Source I=100.0mA R(E>14MeV)= 43.0%
t–H2O 1–Source I=170.0mA R(E>14MeV)= 5.4%
Flux [n s⁻¹ cm⁻² MeV⁻¹]
Neutron Energy [MeV]
X = 10.0 cm Y = 0.0 cm Z = 0.0 cm


Water Supply
Pipe
Cooled Triton
Beam Tube
Inlet Nozzle
5-mm-Thick
Water Jet
Target (140 m/s)
ϕ4cm
Triton Beam
Vacuum Window
Water Return
Pipe

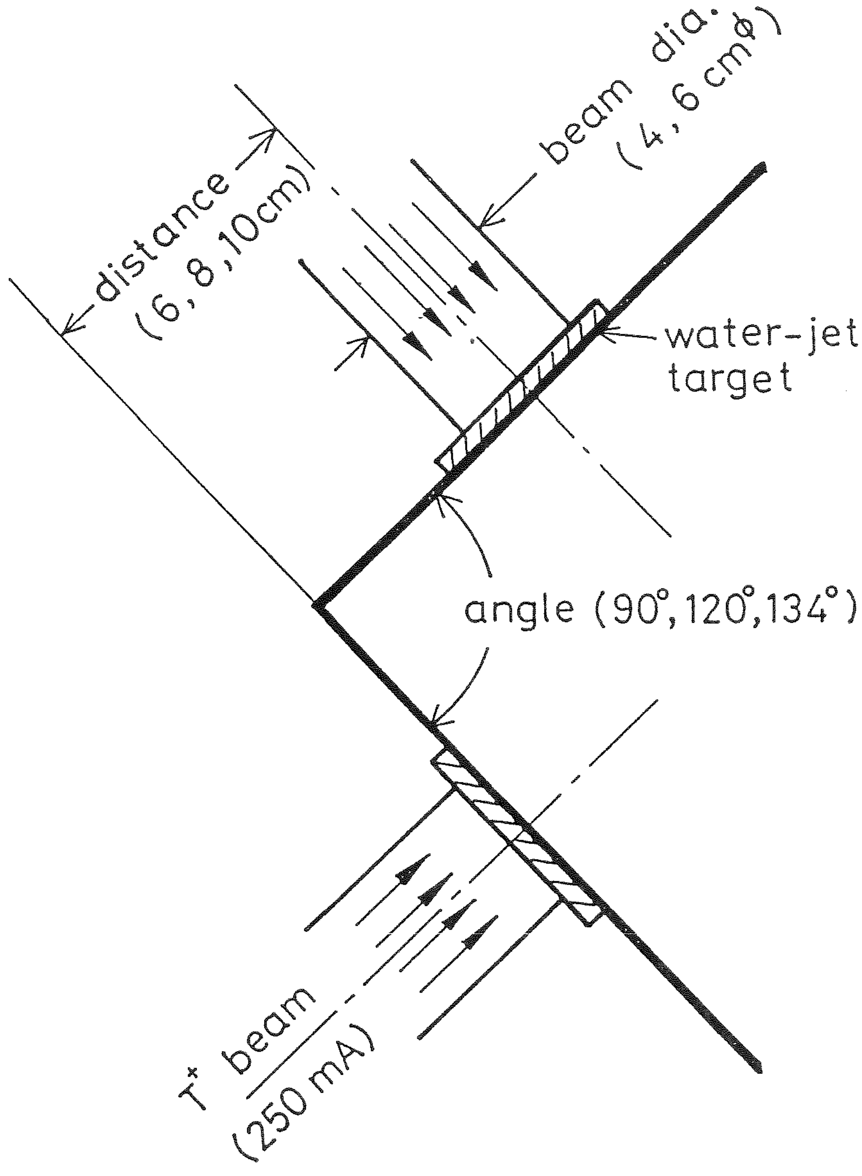

beam dia.
(4, 6 cmφ)
distance
(6, 8, 10cm)
water-jet
target
angle (90°, 120°, 134°)
T+ beam
(250 mA)

Table 1. **Summary and Comparison of the First Stage Version of t-H_2O and Medium Size d-Li Sources.**

	t-H_2O 21 MeV, 85mA	d-Li	
		(ESNIT) 35 MeV, 50 mA	(FMIT) 35 MeV, 100mA
Flux-Test Volume $> 1x10^{17} n/m^2s$ $> 1x10^{18} n/m^2s$ $> 1x10^{19} n/m^2s$	 2305 cm^3 80 cm^3 0 cm^3	 4250 cm^3 138 cm^3 0 cm^3	 11500 cm^3 450 cm^3 8 cm^3
Advantages	- Negligible Neutrons $>$ 14 MeV - Upper Limit 20-22 MeV	- Technical Feasibility - Optimized for Cost and Reliability	- Technical Feasibility - Capability of Accelerated Tests
Issues	- Acceleration, Handling and Recovery of Tritium - In-Vacuum and Beam-On Target Demonstration	- $>$ 14 MeV Tail - Beam-On Target Demonstration	- $>$ 14 MeV Tail - Beam-On Target Demonstration

Tritium Handling

Tritium Deposition

- Tritium deposition in the water target for 2x417mA triton beams is 2.25 gr/d. The tritium occurs mainly in form of tritated water.

- Tritium loss in the low energy end of the accelerator is ~15-20 %. The equivalent amount of 0.34-0.45 gr/d occurs in the vacuum system mainly in form of t-gas.

Tritium Removal and Recovery

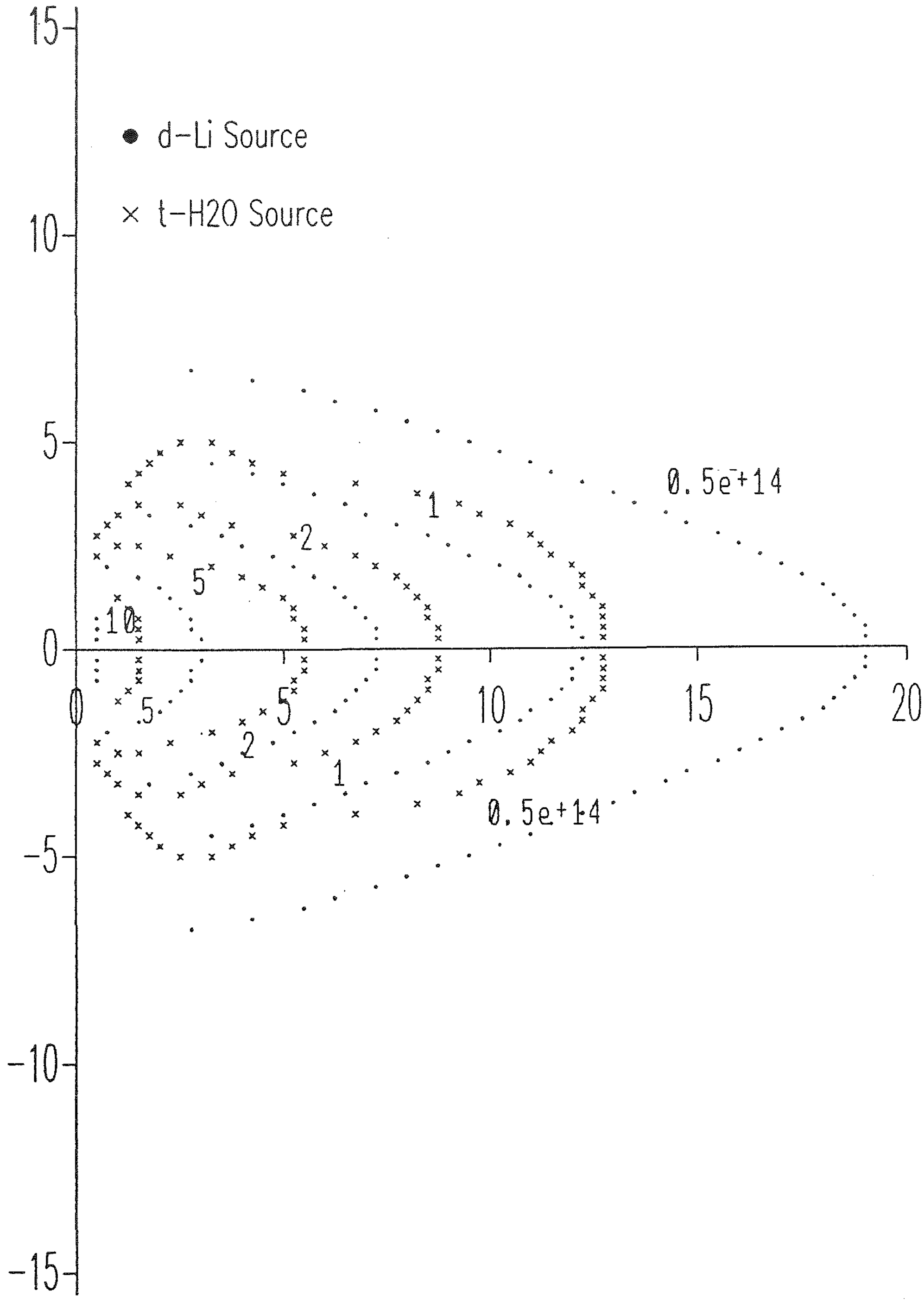
- Can be performed in a small isotope separation facility extracting the tritium down to a concentration of 0.1 to 1.0 Ci/dm^3.

- Commercial facilities for this task are available and well explored over many years (4 CANDU reactors, Chalk River and ILL reactors).

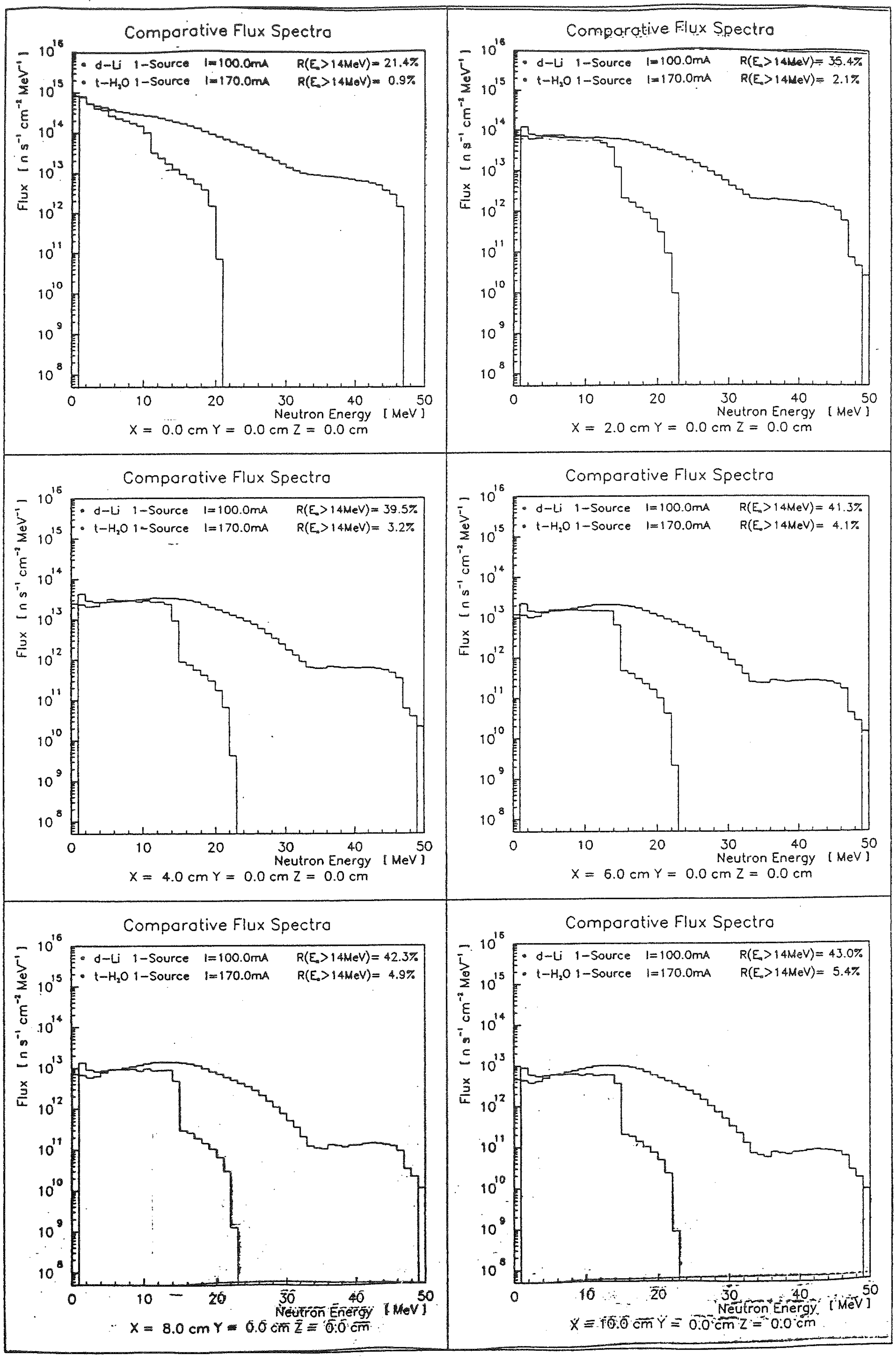
- Investment costs for the required facility ~10 MUS$.

Note: Tritium separationmay not be an extra task for the t-H_2O source only. Nuclear interactions produce also in a d-Li source large inventories of the order of 10-15 gr/~~d~~ yr by $^{x}L(d,t)$, $^{x}L(n,t)$ and $^{x}L(p,t)$ reaction.

Contours, Minimum Flux, z = 1 cm Plane



Single Source, 3.0 cm * 1.0 cm Beam


Comparative Flux Spectra
d-Li 1-Source I=100.0mA R(E>14MeV)= 21.4%
t-H2O 1-Source I=170.0mA R(E>14MeV)= 0.9%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 0.0 cm Y = 0.0 cm Z = 0.0 cm
Comparative Flux Spectra
d-Li 1-Source I=100.0mA R(E>14MeV)= 35.4%
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Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
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Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
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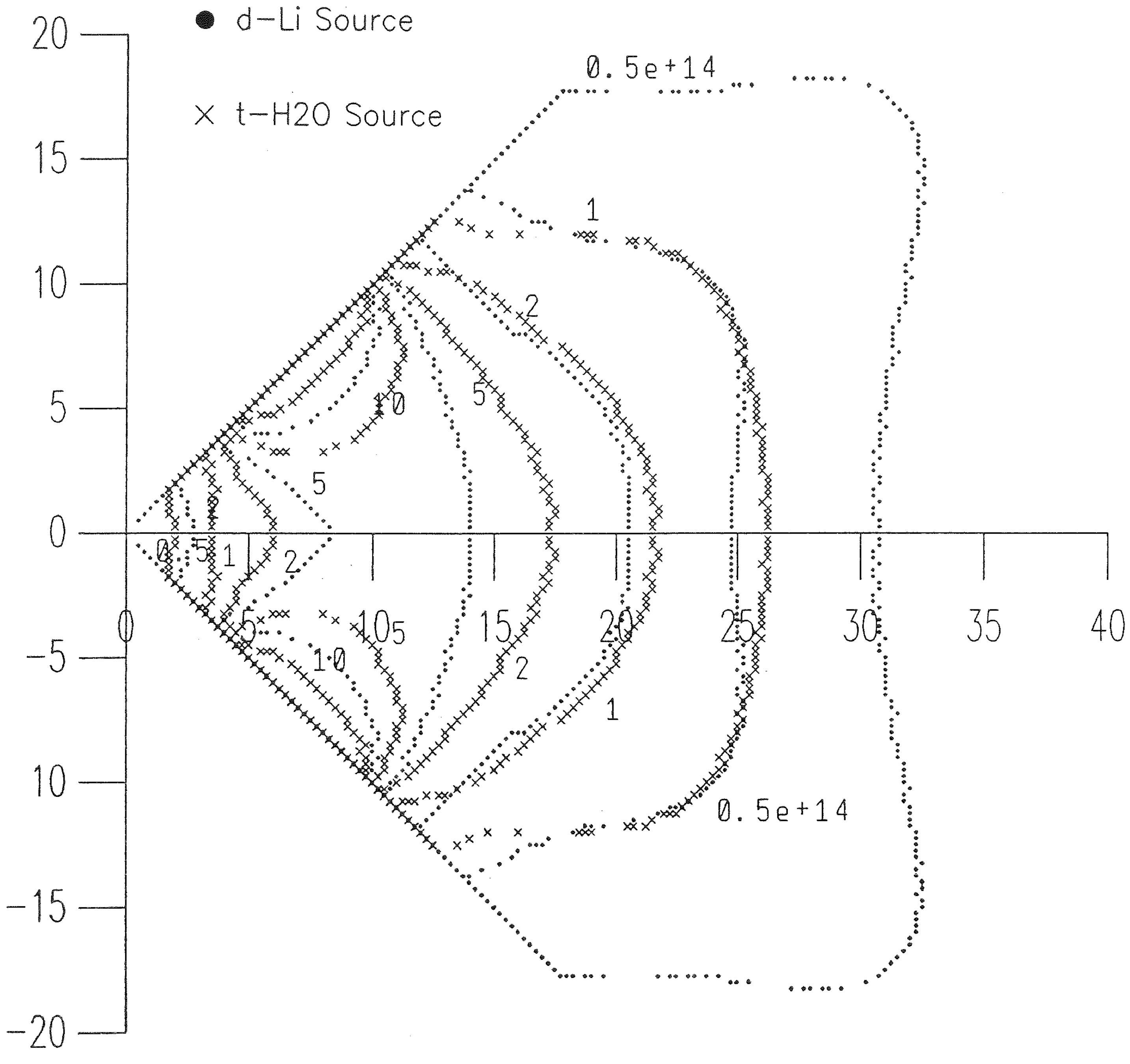
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 8.0 cm Y = 0.0 cm Z = 0.0 cm
Comparative Flux Spectra
d-Li 1-Source I=100.0mA R(E>14MeV)= 43.0%
t-H2O 1-Source I=170.0mA R(E>14MeV)= 5.4%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 10.0 cm Y = 0.0 cm Z = 0.0 cm

Table 2. **Test cell volume vs included minimum flux level. First stage (medium size)[1] t-H_2O and d-Li neutron source.**

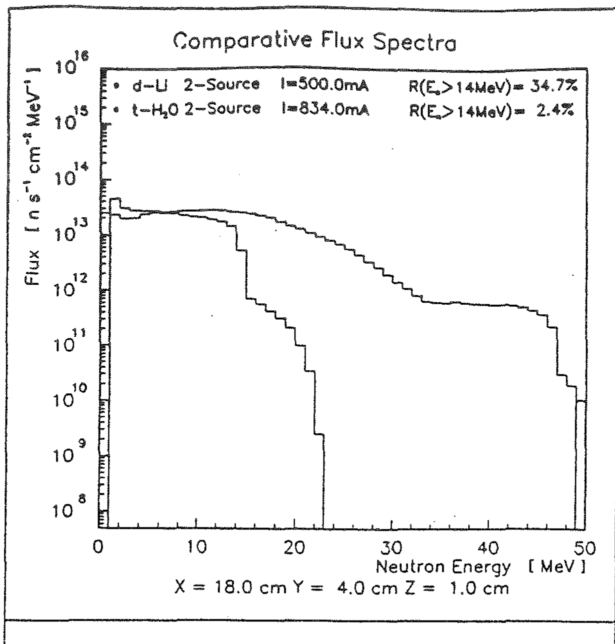
	t-H_2O (KfK Proposal)	d-Li (ESNIT)
Flux-Test Volume		
> $5x10^{17} n/m^2s$	582 cm^3	1204 cm^3
> $1x10^{18} n/m^2s$	209 cm^3	405 cm^3
> $2x10^{18} n/m^2s$	76 cm^3	134 cm^3
> $5x10^{18} n/m^2s$	19 cm^3	28 cm^3
> $1x10^{19} n/m^2s$	6.4 cm^3	7 cm^3
> $2x10^{19} n/m^2s$	1.6 cm^3	0.8 cm^3

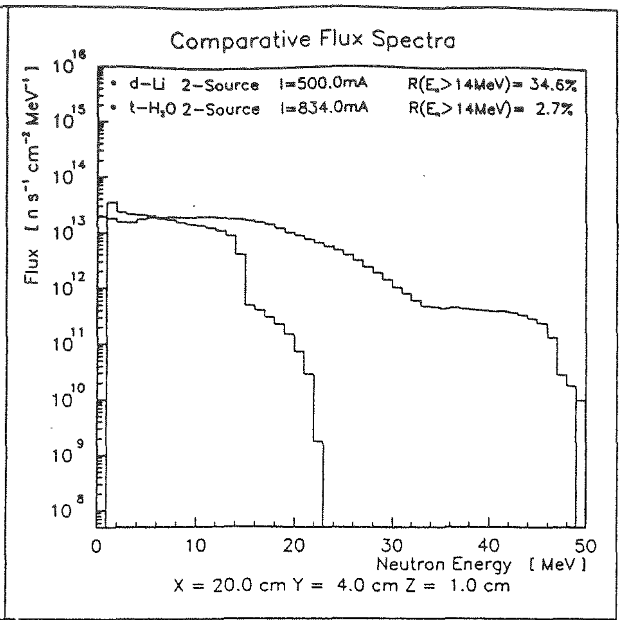
1 One-beam, one-target case, 3.5 MW beam power, beam dimensions: 3x1 cm^2, uniform intensity

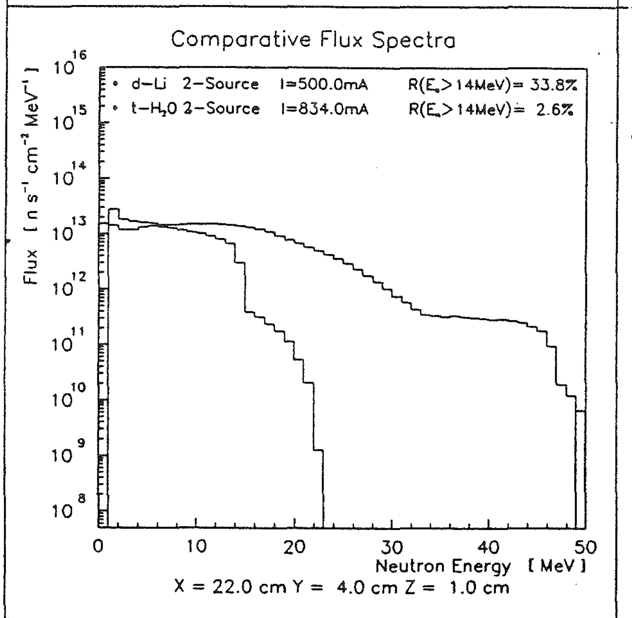
Contours, Minimum Flux, z = 1 cm Plane

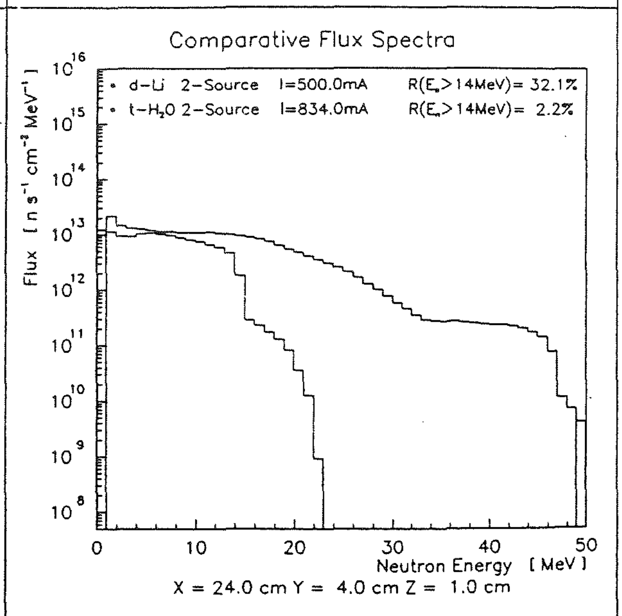


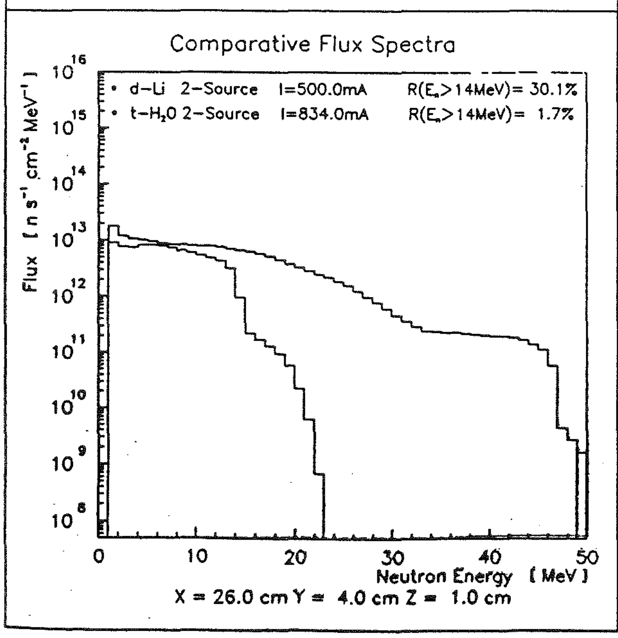
2 Sources
7.5 cm * 2.5 cm Beam
90 Degree, 10 cm Shift


Comparative Flux Spectra
• d-Li 2-Source I=500.0mA R(E>14MeV)= 34.7%
• t-H2O 2-Source I=834.0mA R(E>14MeV)= 2.4%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 18.0 cm Y = 4.0 cm Z = 1.0 cm


Comparative Flux Spectra
• d-Li 2-Source I=500.0mA R(E>14MeV)= 34.6%
• t-H2O 2-Source I=834.0mA R(E>14MeV)= 2.7%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 20.0 cm Y = 4.0 cm Z = 1.0 cm


Comparative Flux Spectra
• d-Li 2-Source I=500.0mA R(E>14MeV)= 33.8%
• t-H2O 2-Source I=834.0mA R(E>14MeV)= 2.6%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 22.0 cm Y = 4.0 cm Z = 1.0 cm


Comparative Flux Spectra
• d-Li 2-Source I=500.0mA R(E>14MeV)= 32.1%
• t-H2O 2-Source I=834.0mA R(E>14MeV)= 2.2%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 24.0 cm Y = 4.0 cm Z = 1.0 cm


Comparative Flux Spectra
• d-Li 2-Source I=500.0mA R(E>14MeV)= 30.1%
• t-H2O 2-Source I=834.0mA R(E>14MeV)= 1.7%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 26.0 cm Y = 4.0 cm Z = 1.0 cm

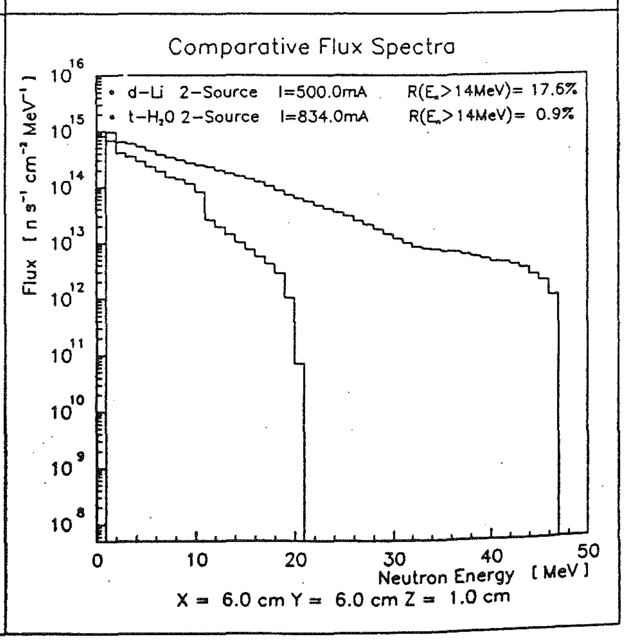

Comparative Flux Spectra
• d-Li 2-Source I=500.0mA R(E>14MeV)= 17.6%
• t-H2O 2-Source I=834.0mA R(E>14MeV)= 0.9%
Flux [n s-1 cm-2 MeV-1]
Neutron Energy [MeV]
X = 6.0 cm Y = 6.0 cm Z = 1.0 cm

Table 3. Test cell volume vs included minimum flux level. IFMIF stage (large size)[2] t-H_2O and d-Li sources

	t-H_2O (KfK Proposal)	d-Li (IFMIF)
Flux-Test Volume		
> $5x10^{17} n/m^2s$	6088 cm^3	12711 cm^3
> $1x10^{18} n/m^2s$	2540 cm^3	5075 cm^3
> $2x10^{18} n/m^2s$	1024 cm^3	1998 cm^3
> $5x10^{18} n/m^2s$	184 cm^3	454 cm^3
> $1x10^{19} n/m^2s$	49 cm^3	80 cm^3
> $2x10^{19} n/m^2s$	4.4 cm^3	3.4 cm^3

2 Two-beam, two-target case, 17.5 MW beam power, beam dimensions: 2.5x7.5 cm^2, uniform intensity

Target Design Analysis for an Intense T-H_2O Neutron Source

S. Malang

KfK

Target Design Analyses for an Intense $t\text{-}H_2O$ Neutron Source

G. Class[1] and S. Malang[2]
Kernforschungszentrum Karlsruhe

[1]Institut für Reaktorsicherheit

[2]Institut für Angewandte Thermo- und Fluiddynamik

Critical items raised in IEA IFMIF Working Group discussions, and studied at KfK

1. Heating and Stability of the Water Jet

2. Pumping Power and Nozzle Erosion

3. Evaporation Rate into Accelerator Vacuum and Icing

4. Neutron Production in a Possible "Vapour Cloud"

1. Heating and Stability of the Water Jet

General Assumptions

- The water should dissipate as little water as possible into the vacuum

- Water target must have a laminar flow pattern

- Water jet should flow as fast as possible to minimize heat at focal spot

- Important for the stability of the jet inside the beam are:

    - Avoidance of steam generation

    - Low rate of evaporation into the vacuum

Main Result

- The temperature limit of spontaneous, homogeneous generation of boiling nuclei is, at zero pressure, around 89% of the critical temperature (647 K for water)

Conclusions

- It can be assumed that no steam will be generated in the high-power water jet below the temperature limit of 303 °C.

- Neither heating nor water jet stability are critical, i.e. limiting effects in the design of the suggested water jet. ehp2.

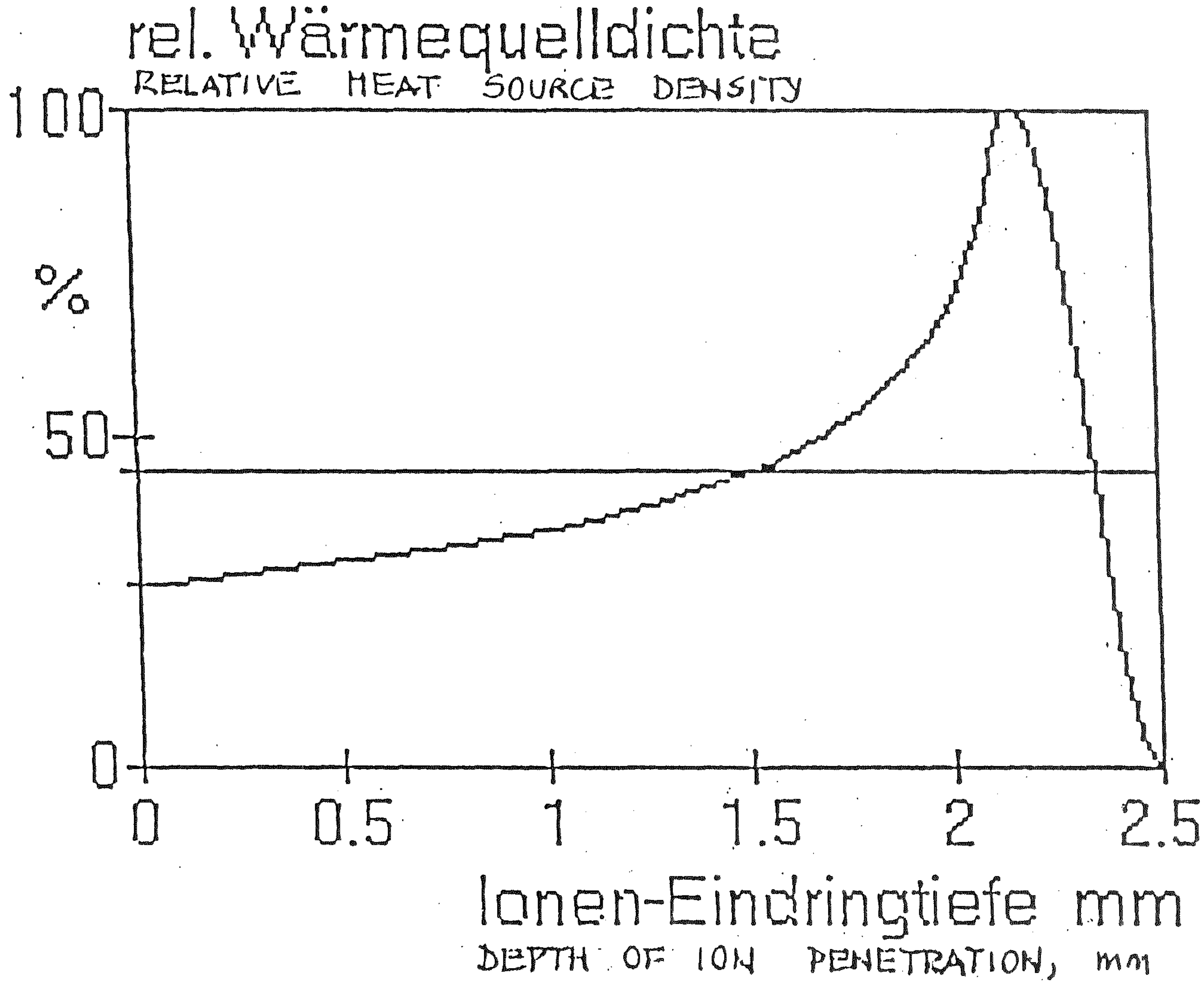


Fig. 1 Distribution of heat source density over the depth of penetration of the ion beam into the water (the minimum value is approx. 62%, the maximum value, approx. 220%, of the average indicated).

w m/s	b = 0,05 m			b = 0,1 m		
	$\Delta\vartheta$	$\Delta\vartheta_{max}$	$\Delta\vartheta_{min}$	$\Delta\vartheta$	$\Delta\vartheta_{max}$	$\Delta\vartheta_{min}$
140	71,8	158,0	44,5	35,9	79,0	22,3
120	83,3	184,3	51,9	41,9	92,2	26,0
100	100,5	221,1	62,3	50,3	110,6	31,2
80	125,7	276,5	77,9	62,8	138,2	39,0
60	167,6	368,6	103,9	83,8	184,3	51,9
40	251,4	553,0	155,8	125,7	276,5	77,9

Table 1: Enthalpy rises, $\Delta\delta$ K, of the water target (within the t-depth of penetration) as a function of the water velocity, w, and the jet width, b.

2. Pumping Power and Nozzle Erosion

Pumping Power

The pumping powers N, required to provide the velocities w, of the water of 40 to 140 m/s are given in Tab. 2.

- The power requirements of the pumps are always seen to be low compared to the thermal power of the t-beam to be dissipated.

- Calculated temperature increase of the water, caused by the power loss, is neglegibly small.
  ⇒ No need for water cooling downstream the pump.

Nozzle Erosion

- Wear does not play any role in the input nozzle (see water turbines, high-velocity water cleaners etc.)

- Cavitation in the collection nozzle poses the problem, because the water jet must be brought out of the vacuum.

Solutions:

- At lower velocities conventional baffles
- Collection nozzle with a diffusor
- Recovery of kinetic jet energy with a Pelton wheel

Pumping Powers, N Required for Jet Velocities

Jet width, b = 100 mm

w [m/s]	Δp [bar]	N [kW]	L_v [kW]	$\Delta\vartheta_w$ [K]
140	109.7	940.8	310.5	1.06
120	80.6	592.4	195.5	0.78
100	56.0	342.8	113.1	0.54
80	35.8	175.5	57.9	0.35
60	20.1	74.1	24.4	0.20
40	8.9	21.9	7.2	0.09

Jet width, b = 50 mm

w [m/s]	Δp [bar]	N [kW]	L_v [kW]	$\Delta\vartheta_w$ [K]
140	109.7	470.4	155.2	1.06
120	80.6	296.2	97.8	0.78
100	56.0	171.4	56.6	0.54
80	35.8	87.8	29.0	0.35
60	20.1	37.0	12.2	0.20
40	8.9	11.0	3.6	0.09

Table 2: Water pressure, Δp; pump power, N; power loss, L_v; and heating, $\Delta\vartheta_w$, of the target water due to the power loss, plotted as a function of the water velocity, w.

3. Evaporation Rate into the Vacuum and Icing

Assumptions

- In addition to equilibrium considerations for the mass flux through the open surface, cooling of the surface as a result of heat removal by evaporation must be taken into account.

- The surface exponed to the high vacuum must be minimized by means of suitable beam guide systems.

Results

- At 20 °C inlet temperature the evaporation hardly exceeds 1kg/m^2 s over the exposure time of 0.8 ms.

- At a jet width of 100 mm and a water velocity of 80 m/s a maximum surface temperature of 60°C would be attained at 20°C inlet temperature. In this case the evaporation rate rises to ~2-6 gr/s for a surface of 12 cm^2.

Solutions

- Cryo surfaces with LN cooling
- Continuously regenerated cryo pump (LN cooled drum).

Conclusion

- Evaporation into the vacuum and icing appear to be a handable problems in a high-power t-H_2O target system.

4. Neutron Production in a Possible "Vapour Cloud"

Results

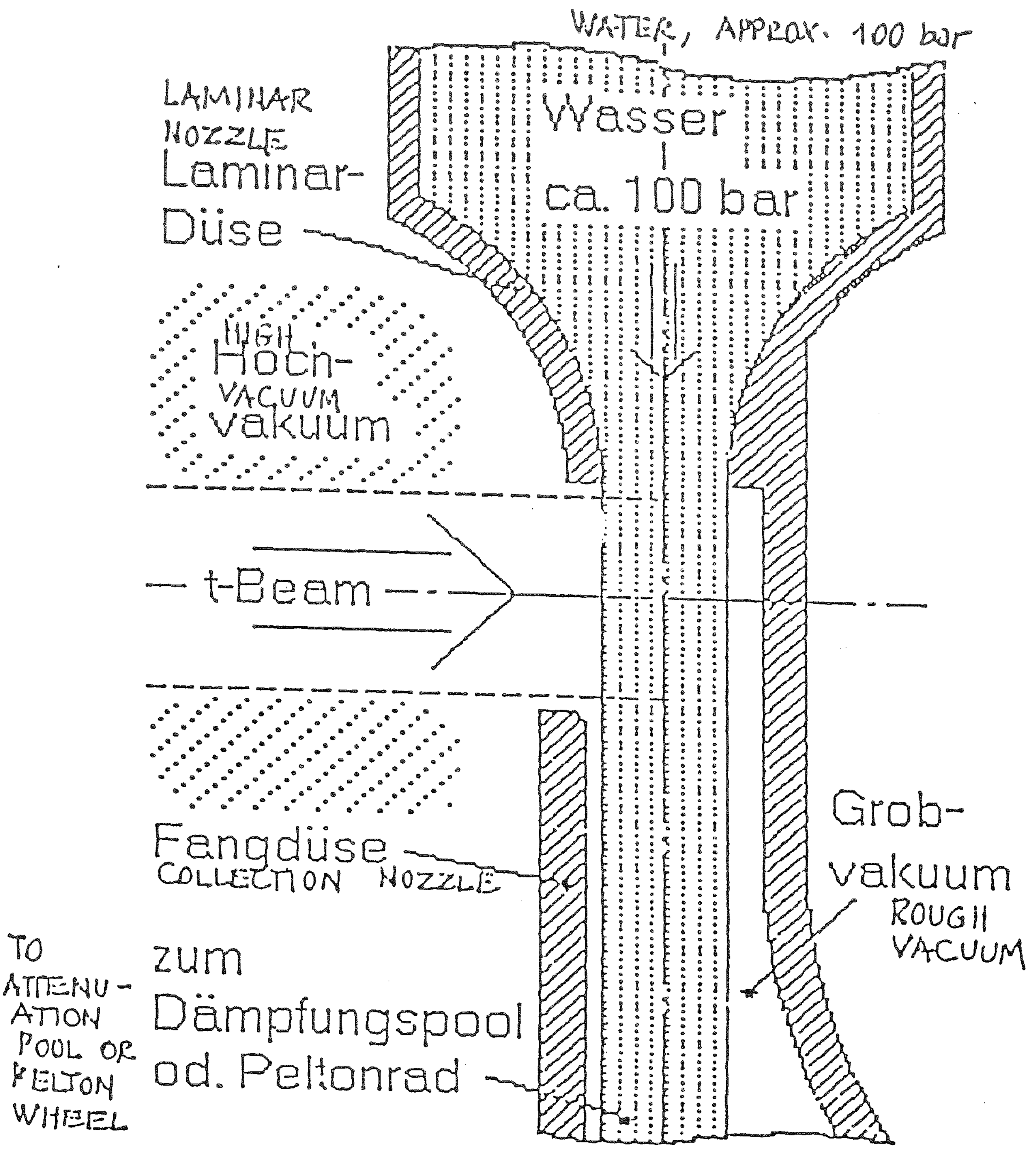
- Evaporation rates and mass flows into the vacuum follow from calculations under item 3.

- Vapour molecule concentrations in front of the target are estimated to correspond to pressure between 10-100 mbar, if molecule velocities follow a Maxwellian distribution.

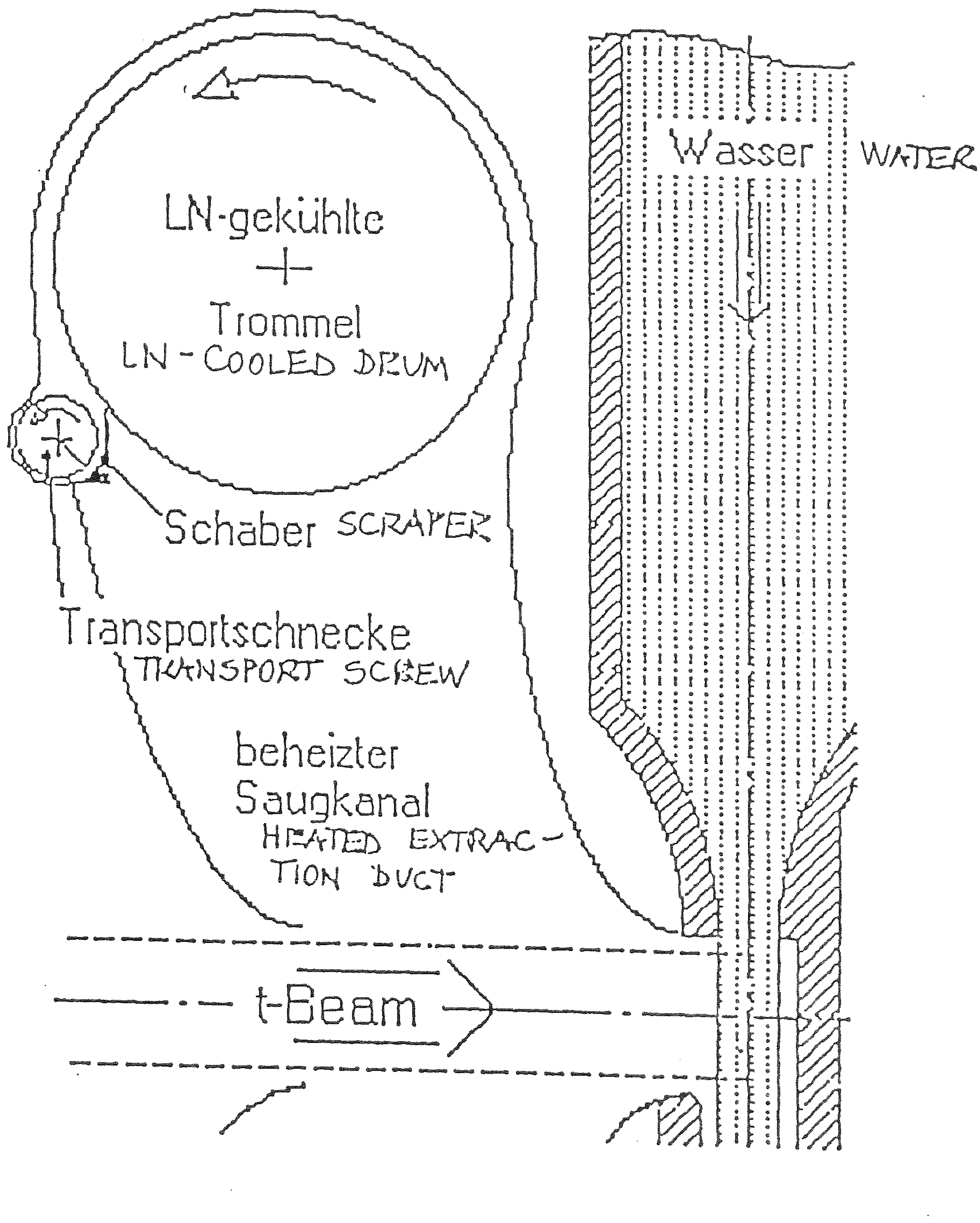
- This corresponds to $\sim 10^{-4} - 10^{-5}$ times the water density.

Conclusion

- A fraction of roughly $2x(10^{-4} - 10^{-5})$ times the total neutron production would occur in the vacuum beam tube, which is not critical at all.



WATER, APPROX. 100 bar
Wasser
ca. 100 bar
LAMINAR NOZZLE
Laminar-Düse
HIGH
Hoch-
VACUUM
vakuum
t-Beam
Grob-
vakuum
ROUGH
VACUUM
Fangdüse
COLLECTION NOZZLE
TO ATTENU-ATION POOL OR PELTON WHEEL
zum
Dämpfungspool
od. Peltonrad


Wasser
WATER
LN-gekühlte
Trommel
LN-COOLED DRUM
Schaber
SCRAPER
Transportschnecke
TRANSPORT SCREW
beheizter
Saugkanal
HEATED EXTRAC-
TION DUCT
t-Beam

Summary

Critical target design problems have been studied for the intense neutron source proposed by KfK-IMF.

Studied Problems

- Surface evaporation from a windowless water target
- Water jet stability
- Pumping power as a function of jet velocity
- Erosion of material
- Water evaporation into the vacuum
- Spurious neutron production

Results

- Proper thermodynamic design of an open t-H_2O target promises feasibility in terms of physics and engineering to operate the source uninterrupted over the order of several months.

- The required investment and operation costs of the target (~ 5 Mio. US$ without tritium recovery) appear to be in reasonable proportion to the total project costs.

Mirror Type Plasma Neutron Source

R. Ryutov

INP

IEA-Workshop on Intense Neutron Sources
Karlsruhe, September 21—23, 1992

MIRROR-TYPE PLASMA NEUTRON SOURCE

Presented by D.D. Ryutov

Budker Institute of Nuclear Physics,
Novosibirsk, Russia

LIST OF CONTRIBUTORS:

INP, Novosibirsk

A. Alexandrov
A. Anikeev
P. Bagryansky
E. Bender
A. Ivanov
I. Kotel'nikov
E. Kruglyakov
V. Mirnov
V. Mishagin
A. Podyminogin
A. Rogozin
D. Ryutov
K. Schreiner
A. Sitnikov
Yu. Tsidulko

Efremov, St.Petersburg

A. Astapkovitch
V. Katyshev
A. Komin
V. Krivosheev
L. Saksaganskii

Kurchatov, Moscow

V. Orlov
G. Shatalov

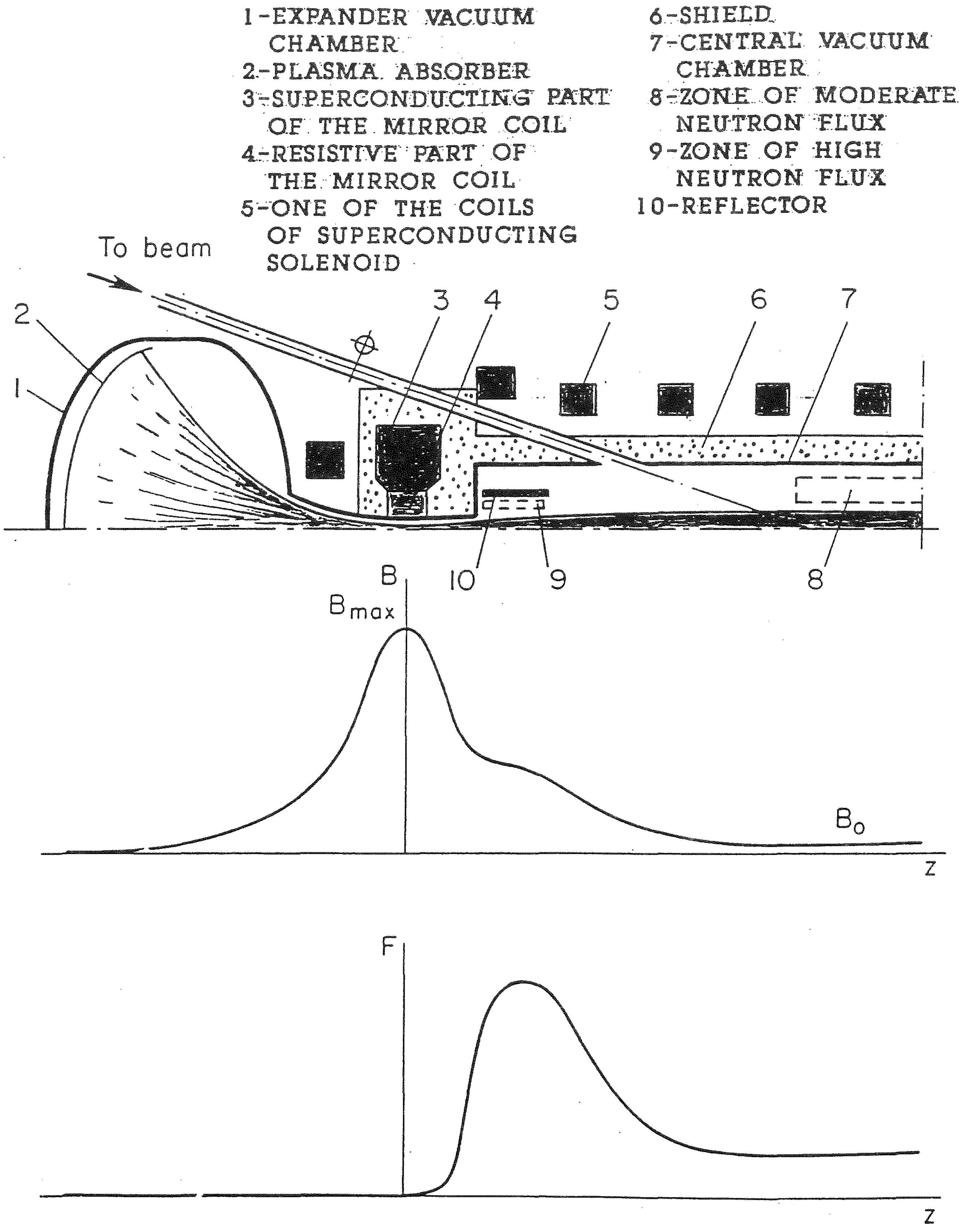
FZ Rossendorf

H. Kumpf
K. Noack

OUTLINE

* General description of the neutron source based on the GDT concept
* Developments since February 1989
* Summary of conceptual design
* Critical elements
* Further strategy
* Conclusion

GDT-Gas Dynamic Trap, axisymmetric, high mirror ratio open-ended machine.


1-EXPANDER VACUUM CHAMBER
2-PLASMA ABSORBER
3-SUPERCONDUCTING PART OF THE MIRROR COIL
4-RESISTIVE PART OF THE MIRROR COIL
5-ONE OF THE COILS OF SUPERCONDUCTING SOLENOID
6-SHIELD
7-CENTRAL VACUUM CHAMBER
8-ZONE OF MODERATE NEUTRON FLUX
9-ZONE OF HIGH NEUTRON FLUX
10-REFLECTOR
To beam
1
2
3
4
5
6
7
8
9
10
B
B_{max}
B_0
z
F
z

Developments since February, 1989

* Switching to a three-component concept
* Completion of the conceptual design (3-component)
* Considerable progress in plasma simulation experiments (GDT)
* Beginning of construction of the Hydrogen Prototype (INP)
* Positive conclusions of the evaluation panels (national and international)

PLASMA PARAMETERS

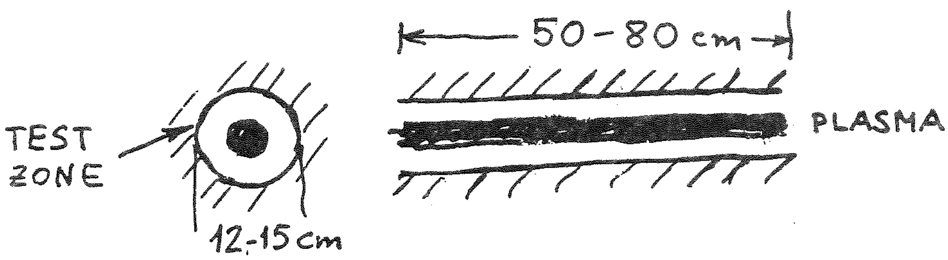
PARAMETER	2-COMPONENT*)	3-COMPONENT**)
n_e, cm^{-3}	$3 \cdot 10^{14}$	$2{,}6 \cdot 10^{14}$
n_h^*, cm^{-3}	$3 \cdot 10^{14}$	$5 \cdot 10^{14}$
T_e, keV	0,5	0,8
W_{inj}, keV	230	80
L, m	10	10
d, cm	16	16
d^*, cm	5	5

*) COLD D, FAST T (230 keV)

**) COLD D (OR H), FAST T, FAST D (80 keV)

SOURCE PARAMETERS

PARAMETER	TWO-COMPONENT (FAST T; COLD D)	THREE-COMPONENT (FAST D, T; COLD H)
W_{inj}, keV	230 (T)	80 (D, T)
P_{inj}, MW	20	15 (60)
θ_{inj}, deg	20	20
B_{max}, T	28	25
B_{min}, T	1.4	1.25
L, m	10	10
P_n, MW	1	0.8
F_n, MW/m^2	4	3

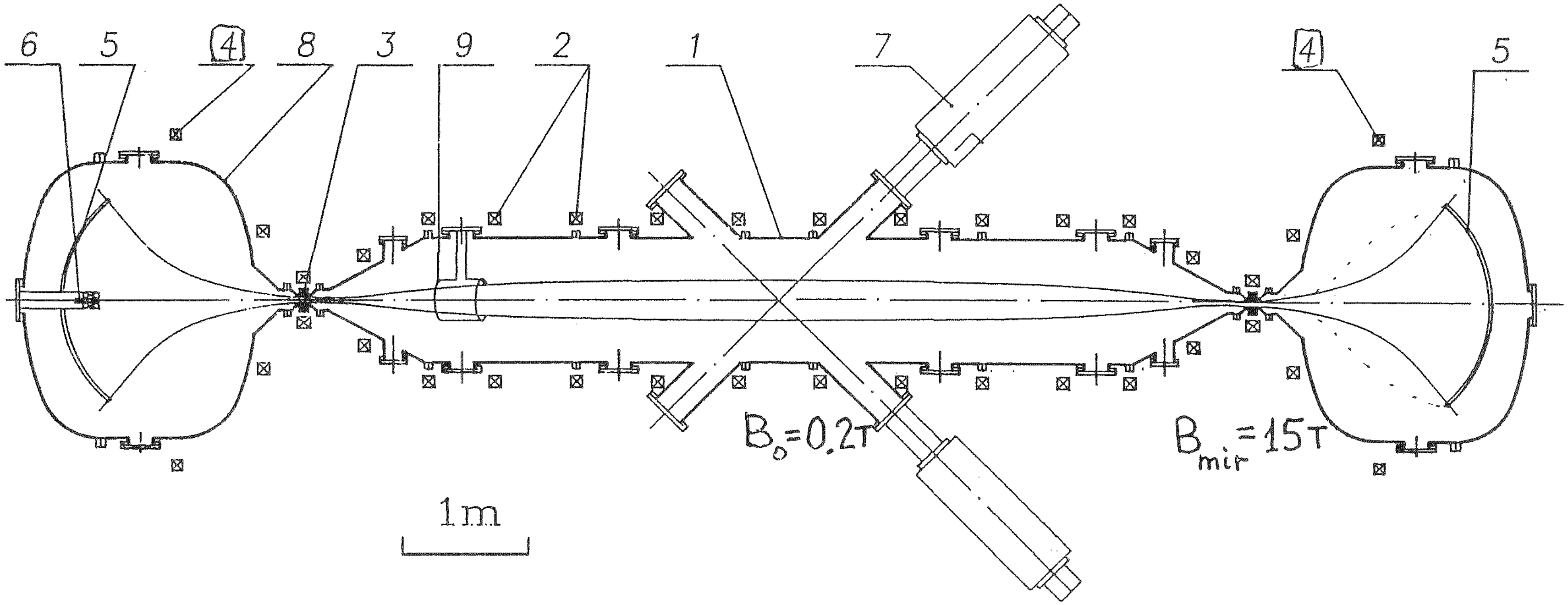


THE FEATURES OF THE NEUTRON SOURCE BASED ON GDT

- RELATIVELY SMALL POWER
- COMPACTNESS
- AXIAL SYMMETRY
- WEAK MAGNETIC FIELD IN SOLENOIDAL SECTION
- SMALL PLASMA RADIUS IN THE MIRROR
- SPATIAL SEPARATION OF HIGH NEUTRON FLUX AND MIRROR REGIONS ALLOWING TO AVOID "RADIAL" SHIELDING OF THE COIL
- LOW NEUTRON AND HEAT WALL LOADING AT THE MAJOR PART OF THE DEVICE

Stationarity!

GAS–DYNAMIC TRAP



1–VACUUM CHAMBER
2–COILS OF THE SOLENOIDAL MAGNETIC FIELD
3–MIRRORS
[4]–EXPANDER COILS
5–PLASMA ABSORBERS
6–PLASMA GUN
7–NB INJECTORS (6) $\Sigma P_{inj} = 4 MW$
8–EXPANDERS
9–RF ANTENNA

GDT diagnostic instrumentation

Plasma parameters	Diagnostic	Location central cell	Location expander
Density profile	Pseudotomography of beam attenuation array data	+	-
	Beam Emission Spectroscopy	+	-
	NB-induced charge-exchange	+	-
	Tripple probes	+	+
	Thomson scattering	+	-
Line density	Optical interferometers	+	-
	NB attenuation array data	+	
Electron temperature	Tripple probes	+	+
	Thomson scattering	+	-
	H-Ar-He neutral beam attenuation data	+	-
Ion temperature	Beam Emission Spectroscopy	+	-
	Rutherford scattering	+	-
Plasma energy	Diamagnetic loops	+	-
Plasma potential	Emitting probes	+	+
	End-loss analyzer	-	+
Impurities	End-loss ion spectrometer	-	+
	Visible lines emission	+	-
Power loss	Bolometers & calorimeters	+	+
Fluctuations	Langmuir probes	+	+
	Faraday cups	-	+
NB power	Beam voltage and current	+	-
	Calorimeters	+	-
Sloshing ion distribution	Neutral-particle analyzers	+	-

THE ESSENTIAL PARAMETERS OF GDT PLASMA

Bulk plasma

Density, cm^{-3}	$1\text{-}5 \cdot 10^{13}$
Plasma radius, cm	6.5-10
Electron temperature, eV	1-80
Ion temperature, eV	1-100

Sloshing ions

Density, cm^{-3}	$2 \cdot 10^{12}$ (10^{13})
Mean energy, keV	5-7
Angular spread, deg.	8

COMPARISON
OF PLASMA PARAMETERS
IN 2XIIB DEVICE
AND IN THE TEST ZONE
OF THE NEUTRON SOURCE

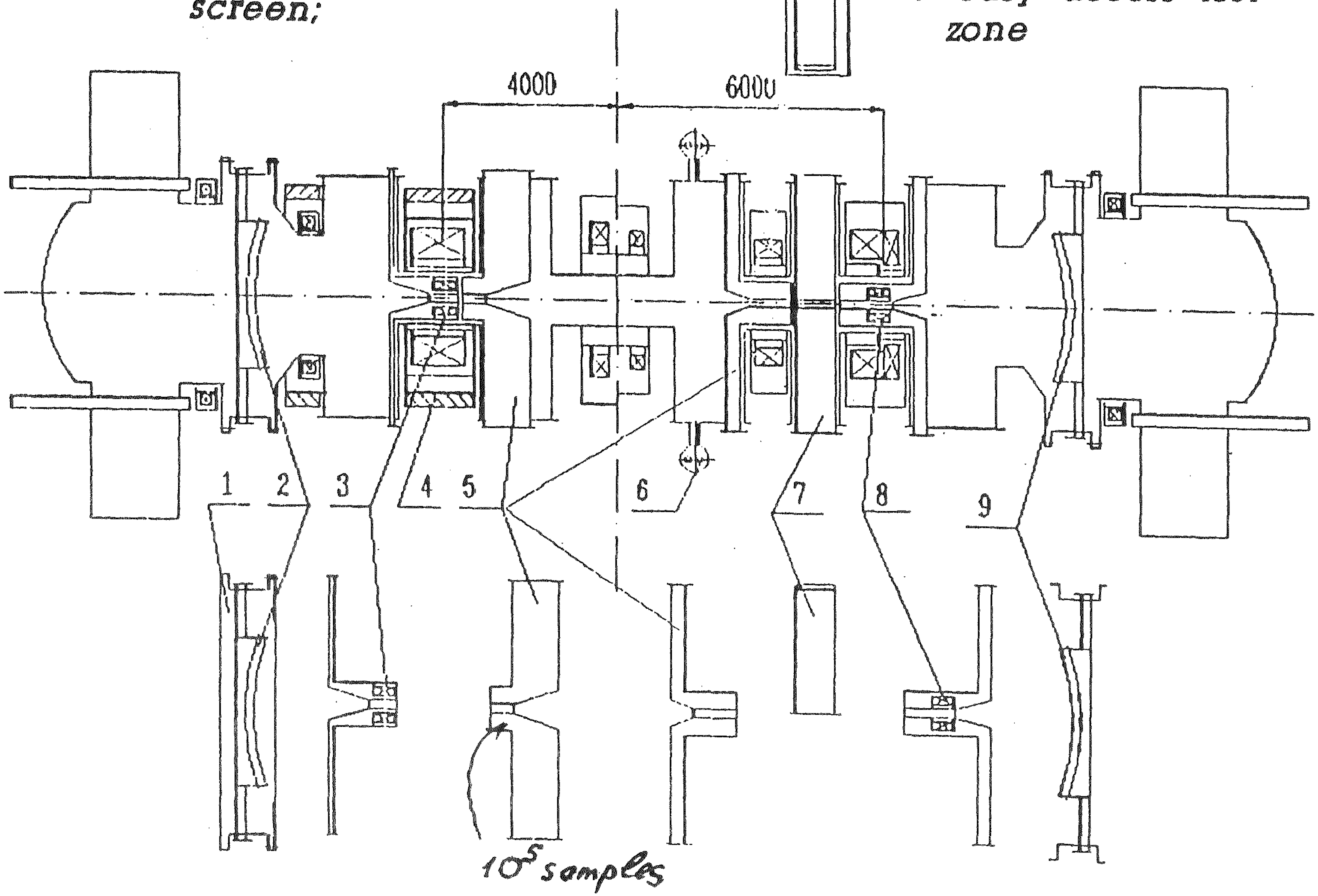
DIMENSIONLESS PARAMETER	2XIIB	NEUTRON SOURCE
W_{inj}/T_e	100	100
ω_{pi}/ω_{Bi}	120	60
a/ρ_i	2.5	4.5
n_c/n_h	10^{-2}	$4 \cdot 10^{-2}$ (0.5)
β	0.1 — 1	0.4

WE ASSUME THAT IN THE SOURCE

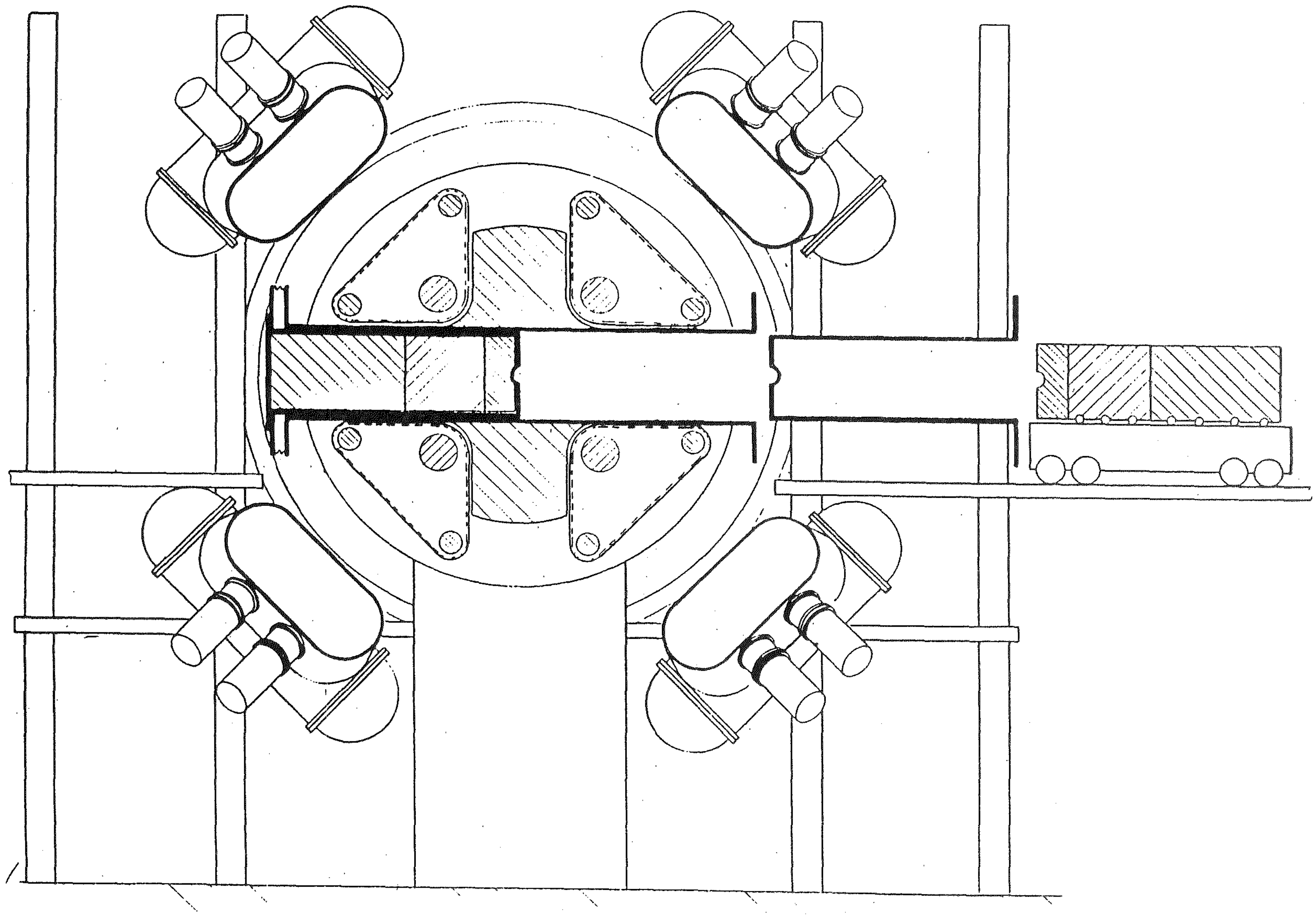
$$\alpha \equiv \frac{T_e}{W_{inj}} < 10^{-2}$$

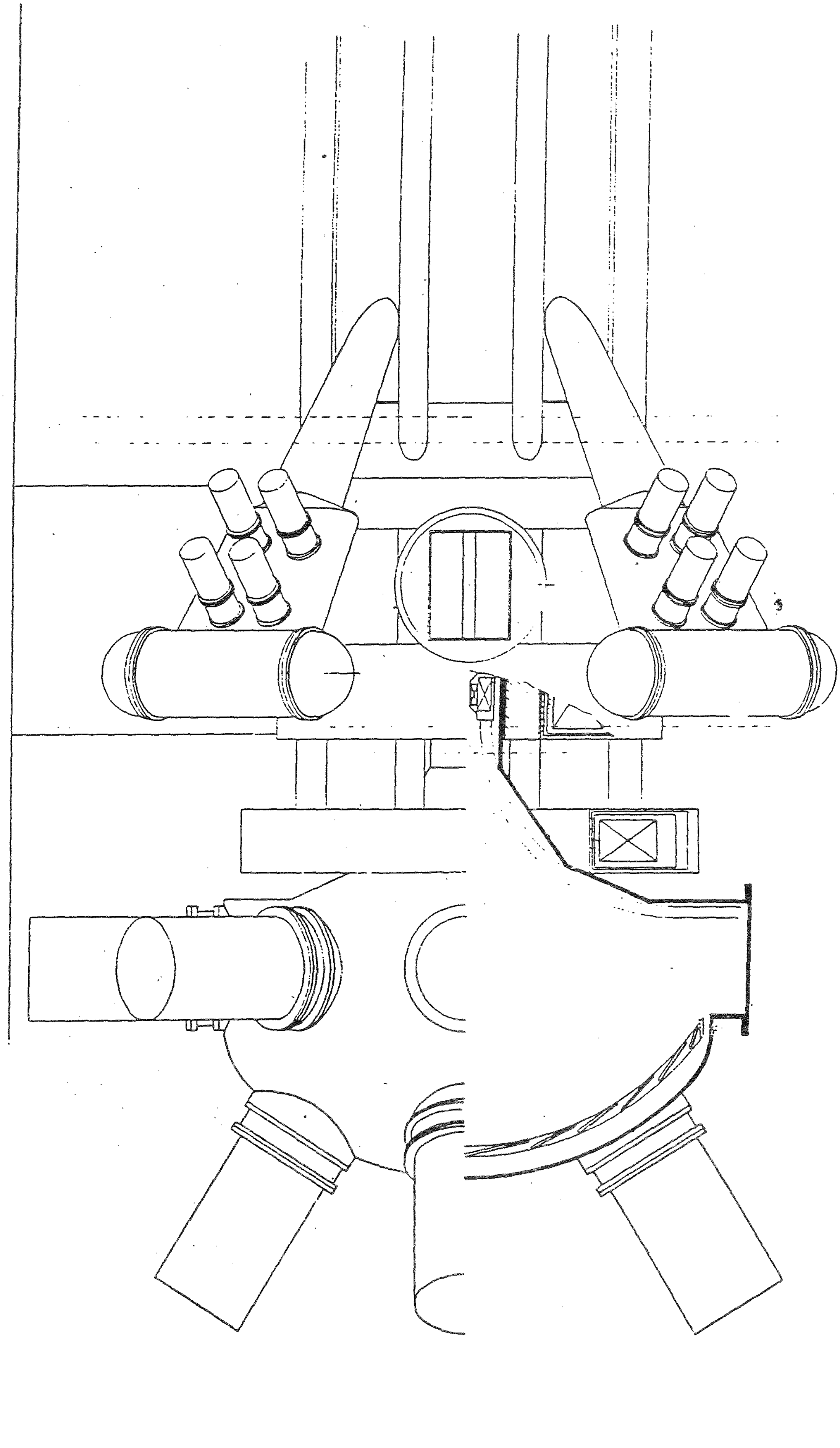
IN-1 (Efremov)

1-assemblying robot;
2,9-plasma dumps;
3,8-resistive solenoids;
4-ferromagnetic screen;
5-test-zone for permanent irradiation;
6-pellet injector;
7-easy-access test zone



ACCESS TO THE TEST ZONE





COMPARISON OF TECHNICAL SUBSYSTEMS OF GDT-BASED NEUTRON SOURCE AND ITER/INTOR

	GDT		ITER/INTOR
	2-component	3-component	
INJECTION SYSTEM			
•ENERGY, MeV	0,23(T)	0,08(D,T)	0,45-1,6(D) /0,15(D)
•POWER, MW	20	15	100/75
•EFFICIENCY, %	50	45	40-60
SUPERCONDUCTING MAGNETS			
•FIELD STRENGTH,T	1,4	1,25	5,3/5,5
•VOLUME OF SC WINDING, m^3	5	5	300
MIRROR COIL		(EXISTING - KS-250)	
•FIELD STRENGTH,T	28	25	
TRITIUM SYSTEM			
•T CIRCULATION, kg/yr	82	70	840/560
•T BURNUP, kg/yr	0,08	0,07	12/7
•T INVENTORY, kg	0,25	0,22	?/5,7
PLASMA DUMPS			
•THERMAL WALL LOAD, MW/m^2	0,2	0,2	10/2 (divertors)

"HYDROGEN PROTOTYPE"

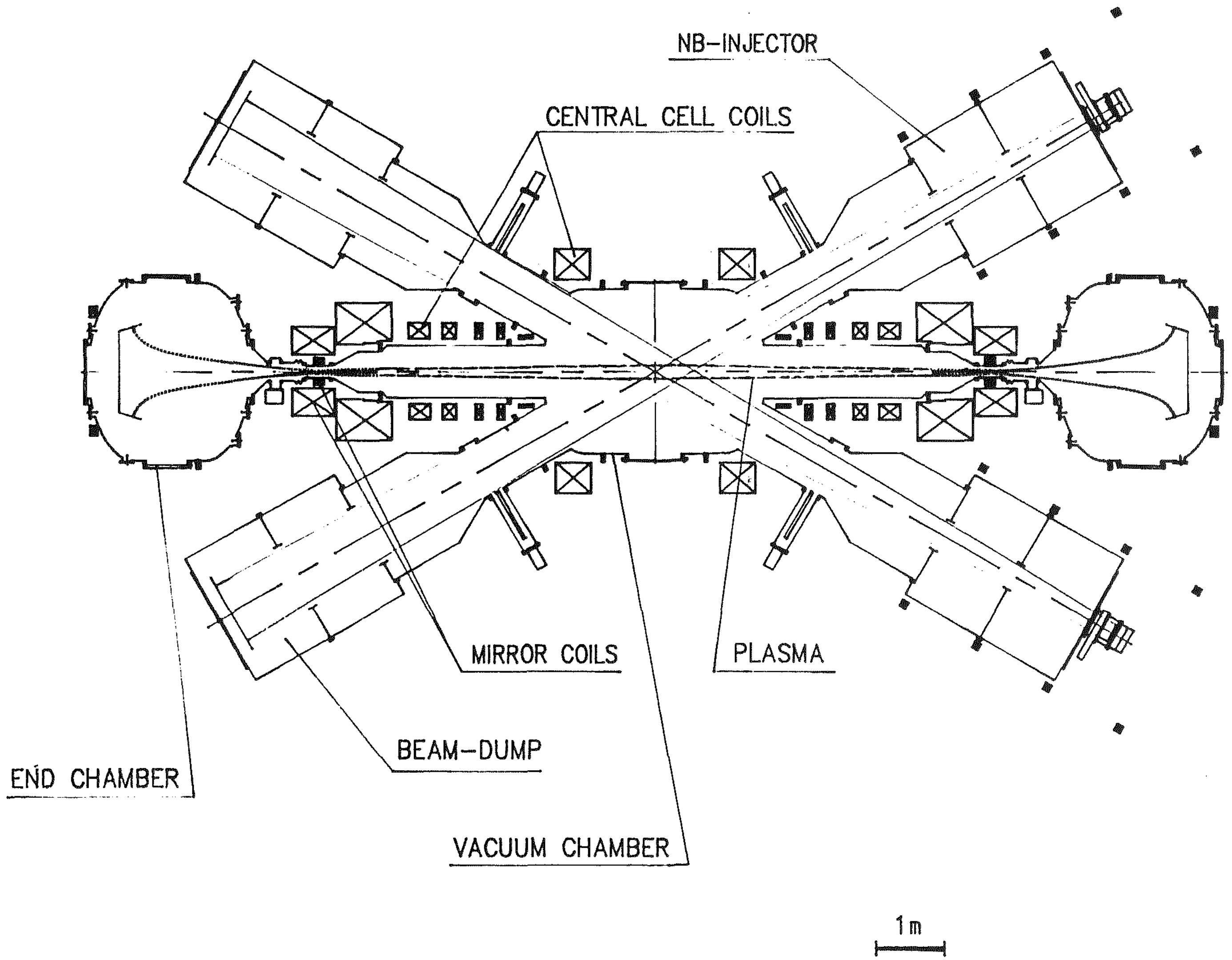
"HYDROGEN PROTOTYPE" IS A DEVICE WHOSE PARAMETERS (INCLUDING THE PLASMA PARAMETERS) ARE CLOSE TO THE ONES EXPECTED IN THE NEUTRON SOURCE

<u>BUT</u>

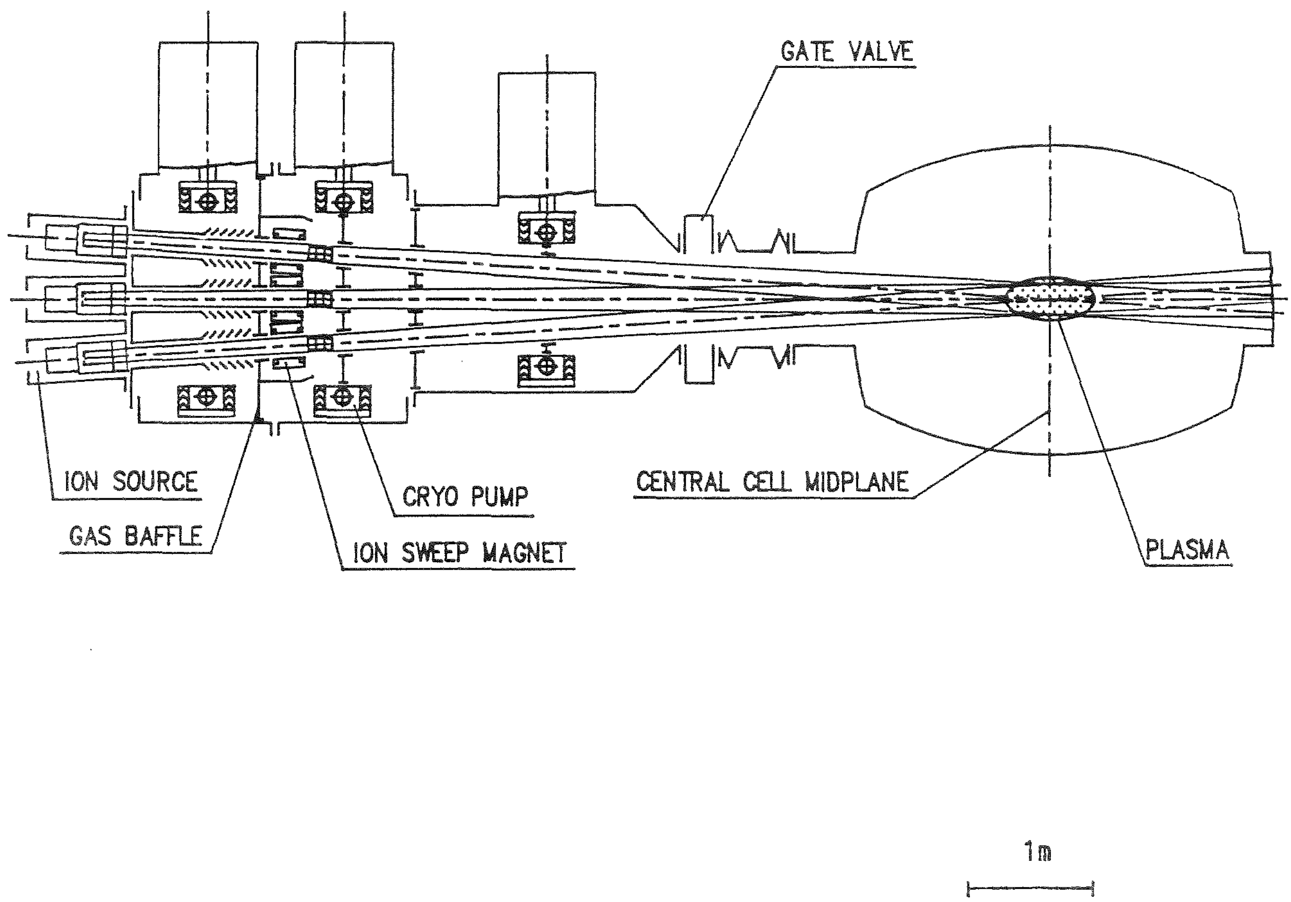
WHERE ONLY HYDROGEN AND, POSSIBLY, DEUTERIUM ARE USED, THUS ELIMINATING ALL DIFFICULTIES ASSOCIATED WITH ACTIVATION PROBLEMS IN A REAL SOURCE

"HYDROGEN PROTOTYPE" IS A RELATIVELY INEXPENSIVE DEVICE (USD M 25–30)

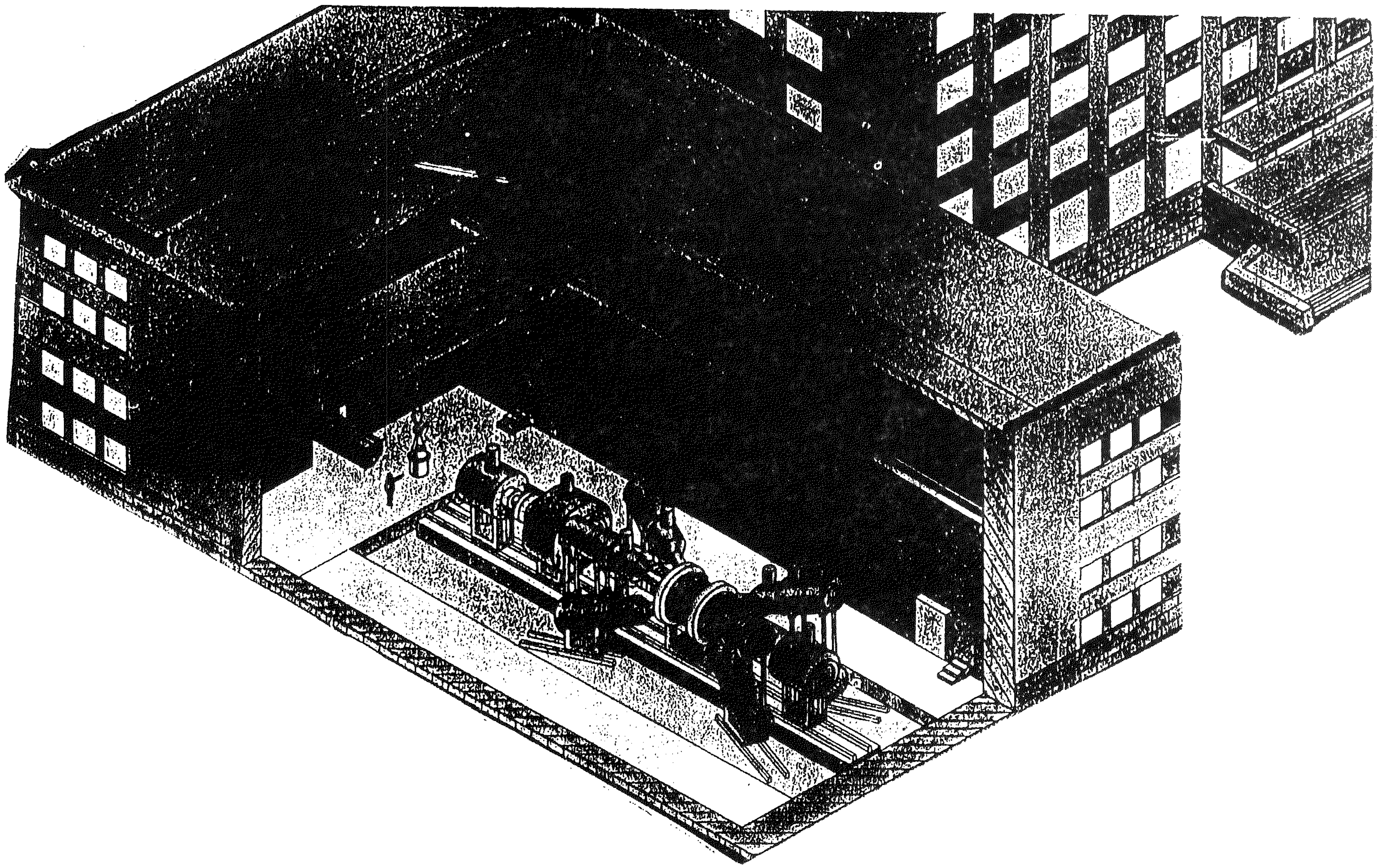
HYDROGEN PROTOTYPE OF A NEUTRON SOURCE (HPNS)



HPNS INJECTOR MODULE



HPNS (NOVOSIBIRSK)



HYDROGEN PROTOTYPE

Nominal Operating Point Parameters

H^{O}beam energy	40 keV
H^{O}beam power	20MW
B_{O}	(0.7T)1T
B_{m}	up to 20T
l_{c}	10m
T_{e}	0.2-0.4 keV
n_{h}	0.15-0.7 $10^{14}cm^{-3}$
n_{e}	0.7-1.2 $10^{14}cm^{-3}$
a	10cm

STATUS OF THE HPNS PROJECT

- DESIGN COMPLETE
- EXPERIMENTAL HALL READY
- MANUFACTURING OF THE VACUUM CHAMBER AND MAGNETS HAS BEGAN
- MANUFACTURING OF THE PROTOTYPE INJECTOR IS CLOSE TO COMPLETION
- AT PRESENT FINANCING LEVEL THE DEVICE WILL START ITS OPERATION AT THE BEGINNING OF 1997
- FINANCIAL PARTICIPATION OF THE OTHER COUNTRIES AT THE LEVEL OF USD 1-2 M PER YEAR, WOULD ALLOW TO COMPLETE THE DEVICE BY THE BEGINNING OF 1995

POSSIBLE SCHEDULE

- 1991–1995 DESIGN AND CONSTRUCTION OF THE "HYDROGEN PROTOTYPE"
- 1994–2000 DESIGN AND CONSTRUCTION OF THE FULL–SCALE SOURCE
- 2001–2010 ACCUMULATION OF THE FLUENCE OF 30 $MWyr/m^2$

- NOTE THAT ITER WILL BE ABLE TO PRODUCE ONLY THE FLUENCE OF 1 $MWyr/m^2$ BY 2020 (!)

CONCLUSION

- IF FUSION ENERGY IS TAKEN SERIOUSLY, THEN THE URGENCY OF DEVELOPMENT OF THE DEDICATED NEUTRON SOURCE IS OBVIOUS

- MIRROR-TYPE NEUTRON SOURCES HAVE A NUMBER OF POTENTIAL ADVANTAGES:

  - high neutron fluxes;
  - adequate neutron spectrum;
  - natural geometry;
  - stationary operation;
  - relative compactness

- NEUTRON SOURCE BASED ON GDT CONCEPT RELIES ON VERY MODERATE ASSUMPTIONS ON THE ACHIEVABLE PLASMA PARAMETERS AND ON ESSENTIALLY THE PRESENT-DAY TECHNOLOGY LEVEL

CONCLUSION (CONT'D)

- THE MIRROR BASED NEUTRON SOURCE WILL BE THE FIRST FUSION PRODUCING "INSTRUMENT" THAT OPERATES AS A USER SERVICE RATHER AS AN EXPERIMENT (WHOSE MAIN PURPOSE IS TO DETERMINE OPERATIONAL CHARACTERISTICS). SUCH A SERVICE WILL GIVE INVALUABLE EXPERIENCE IN THE OPERATIONAL PROCEDURES OF A FUTURE FUSION PRODUCING SYSTEMS.

Mirror Beam Plasma Neutron Source

H. Coensgen

LLNL

Mirror Beam-Plasma Neutron Source

For Fusion Reactor Materials Development and Blanket Component Testing

Arthur W. Molvik

and

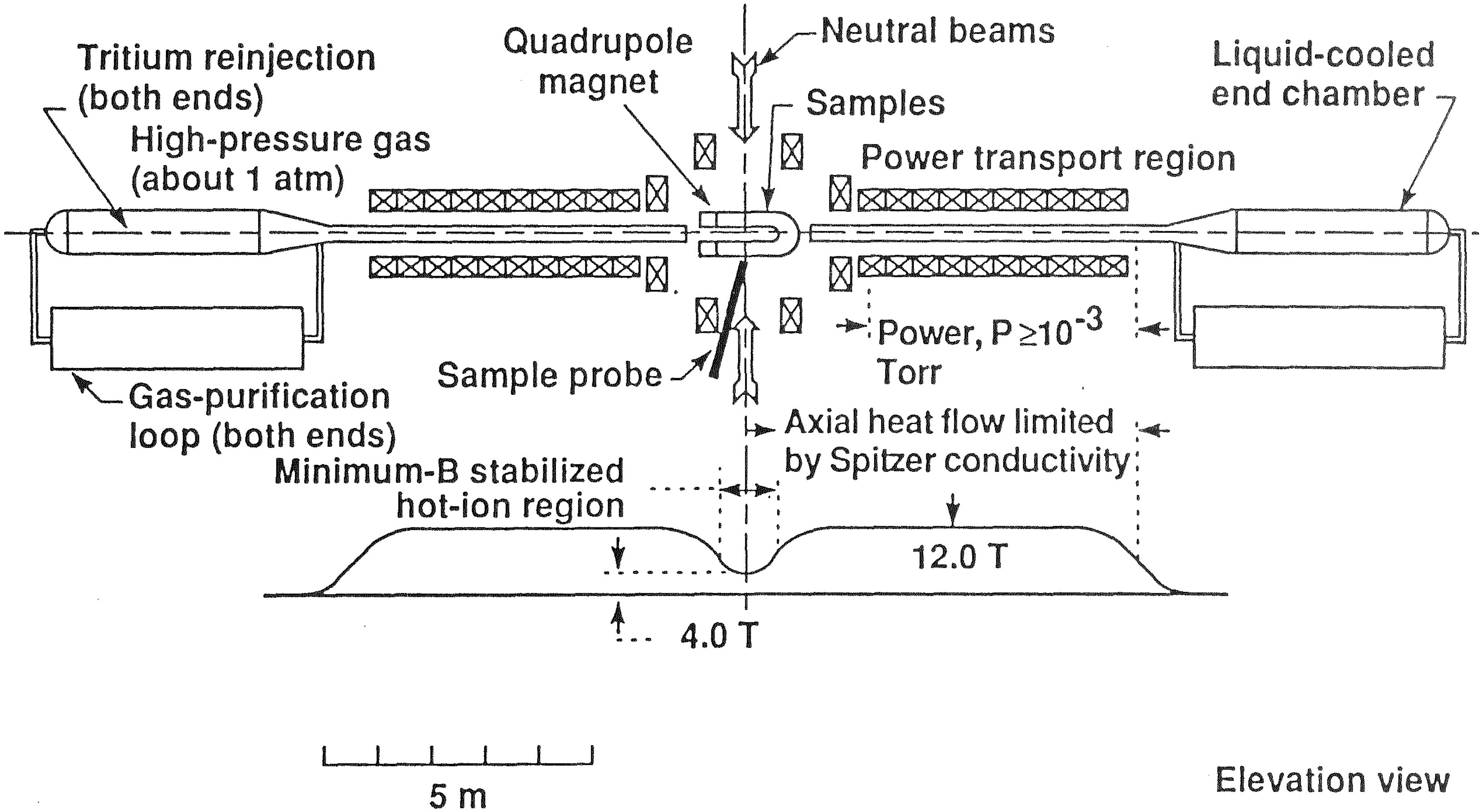
Frederic H. Coensgen

IEA-Workshop on Intense Neutron Sources
Karlsruhe
September 21-23, 1992

Characteristics of Mirror Neutron Source

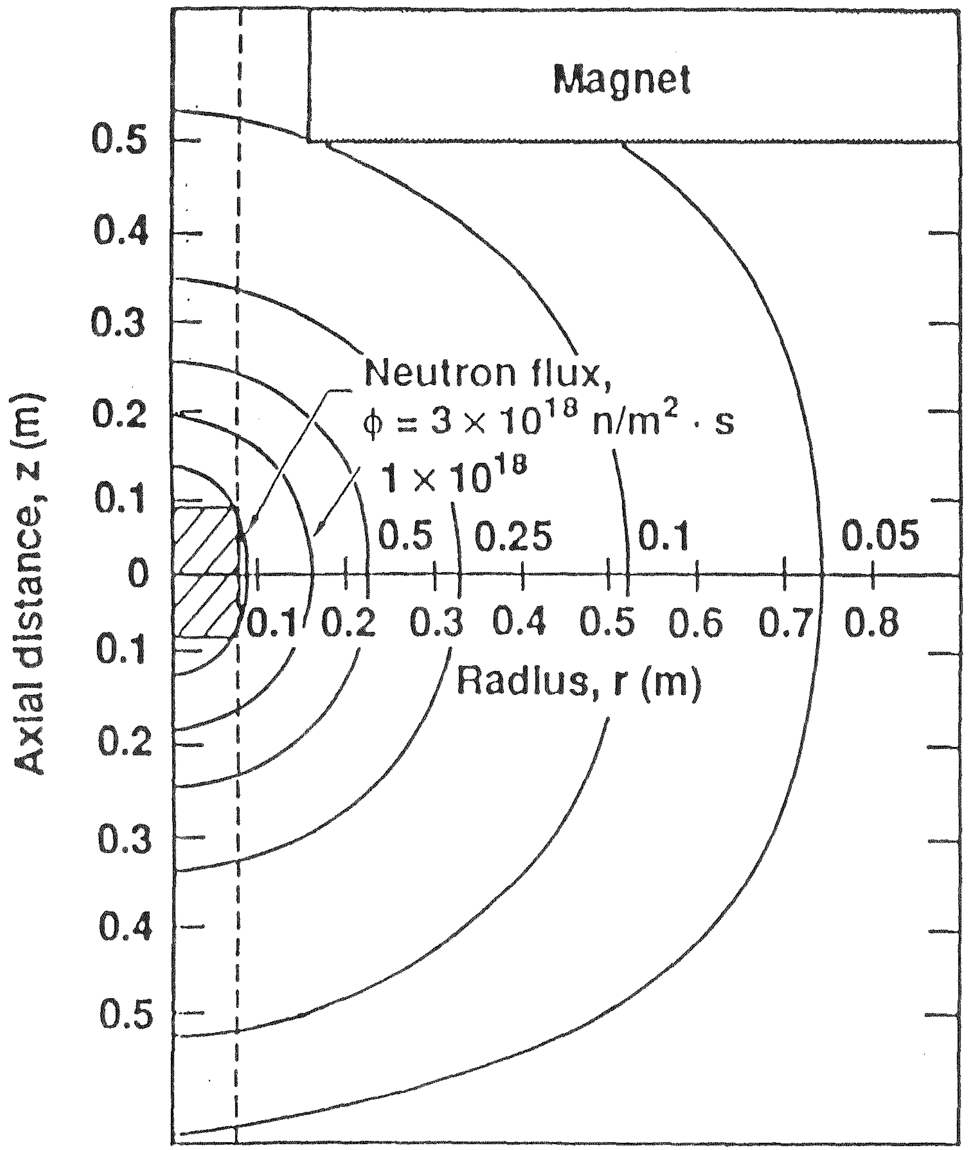
- Magnetic mirrors do three things especially well:
  - Steady-state
  - High-ß (2XIIB confined ions $2 \times 10^{20}\ m^{-3}$, 10 keV in 0.5 T)
  - Strong heat conduction along magnetic field
- Other features:
  - No structure required between plasma and samples
  - No disruptions
  - No feedback control of position needed
  - One heating system only: NBI evaluated, ICH a possibility
  - Develop safety and reliability techniques for fusion reactor

Materials testing neutron source; LLNL design utilizes a linear, two component plasma



20-A-1090-0333B
TCF-AS8-U-13136-0333B

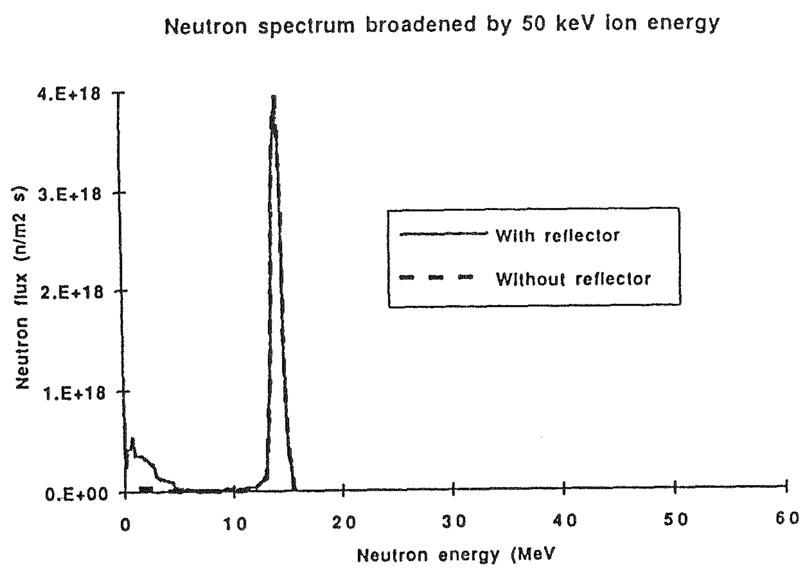
Neutron flux contours



FHC/11-3-89/9
QT-U-|-7766-6

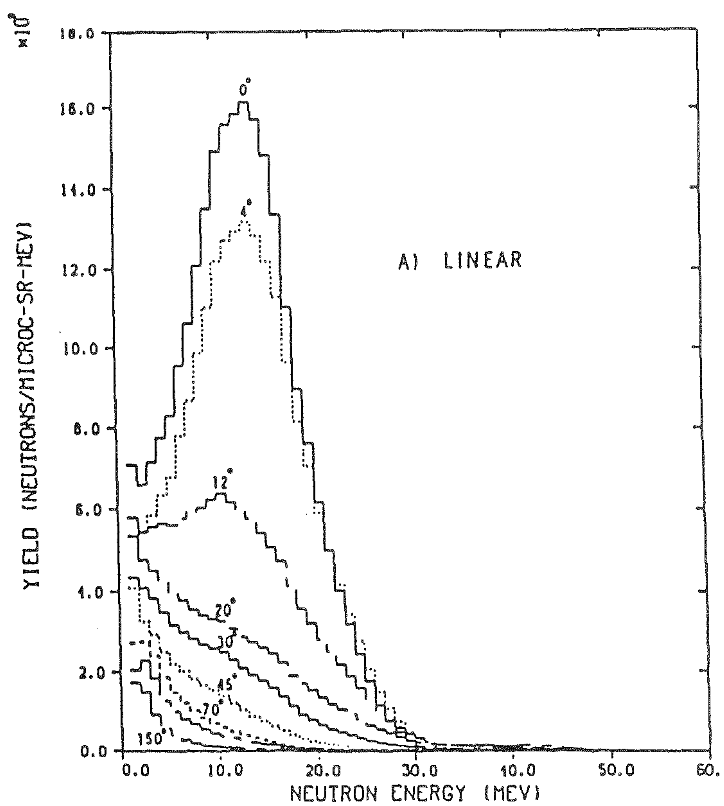
Neutron energy spectra from Beam-plasma and D-Li sources

Beam-plasma (At any angle)



F. H. Coensgen, et al., Journal of Fusion Energy **8**, 237 (1989);
D. R. Slaughter, Rev. Sci. Instrum. 60, 552 (1989).

D-Li (As function of angle)



S. Cierjacks, Workshop on Internat'l Fusion Materials Irradiation Facility, San Diego, Feb. 14-17, 1989.

The Beam Plasma Neutron Source is Feasible

- Minimal extrapolation of physics
  - Neutron source is a linear two-component plasma scaled up from 2XIIB
  - Stability, ß = 1 containment, and startup demonstrated in 2XIIB
- The technology exists in the fusion program
  - 12 T magnets tested in MFTF
  - 80 - 150 keV neutral beams operating on TFTR, JET, DIII-D, for multiple seconds
  - Any Beam-Plasma Source development of technology and reliability builds fusion technology data base. Can capitalize on ongoing developments (e.g., Negative-ion beams).

Mirror Based Fusion Neutron Sources for Fusion Material Testing

T. Kawabe

University of Tsukuba

MIRROR BASED FUSION NEUTRON SOURCES FOR FUSION MATERIAL TESTING

Takaya KAWABE

Institute of Physics, University of Tsukuba
Tsukuba, Ibaraki, 305 JAPAN

Shoichi HIRAYAMA

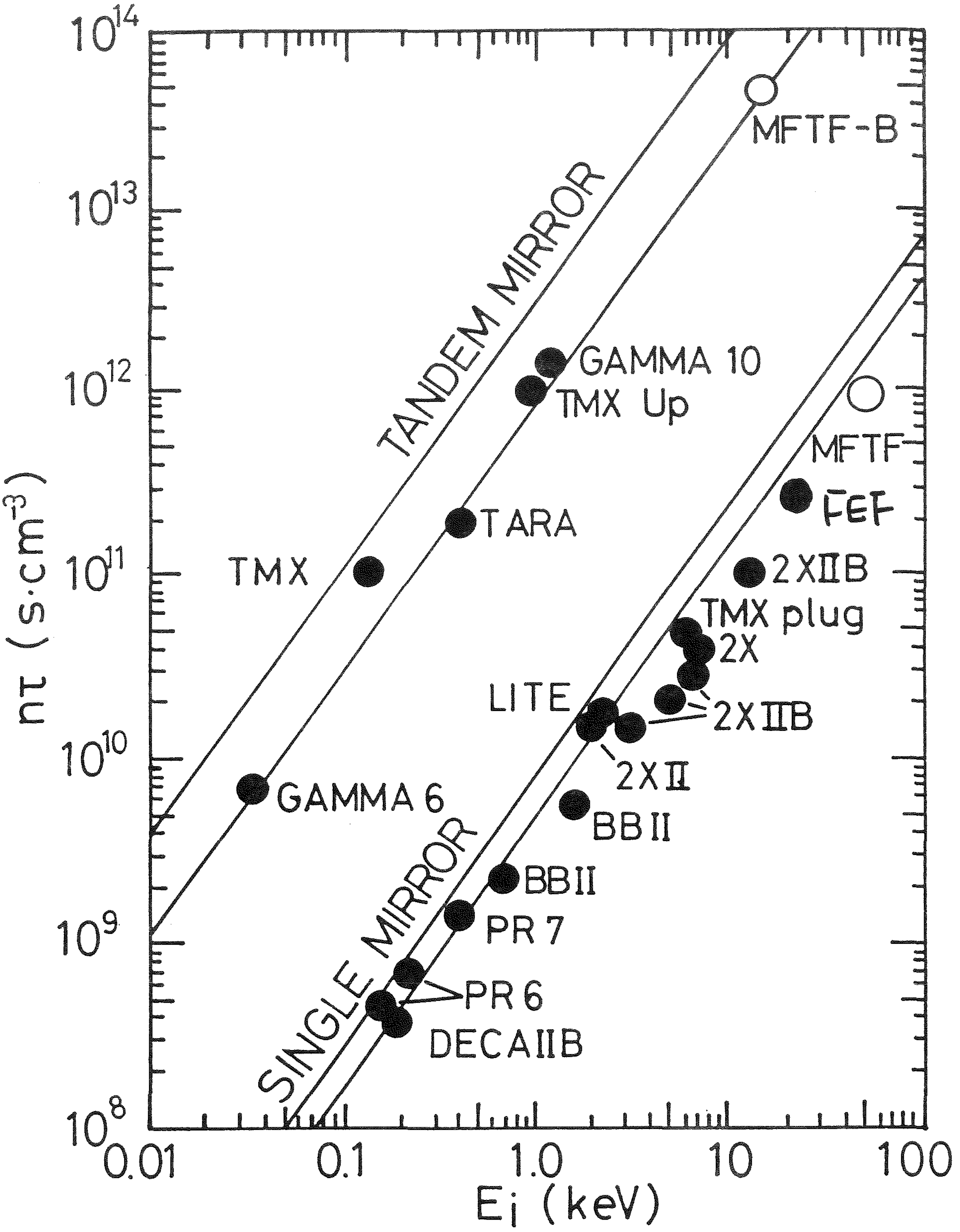
Department of Mechanical Engineering
Kanagawa Institute of Technology
Atsugi, Kanagawa, 243-02 JAPAN

Complete data set of fusion reactor materials cannot be obtained from one facility (neutron source).

In the history of development of the fission reactor, 64 test reactors have been built in the world.

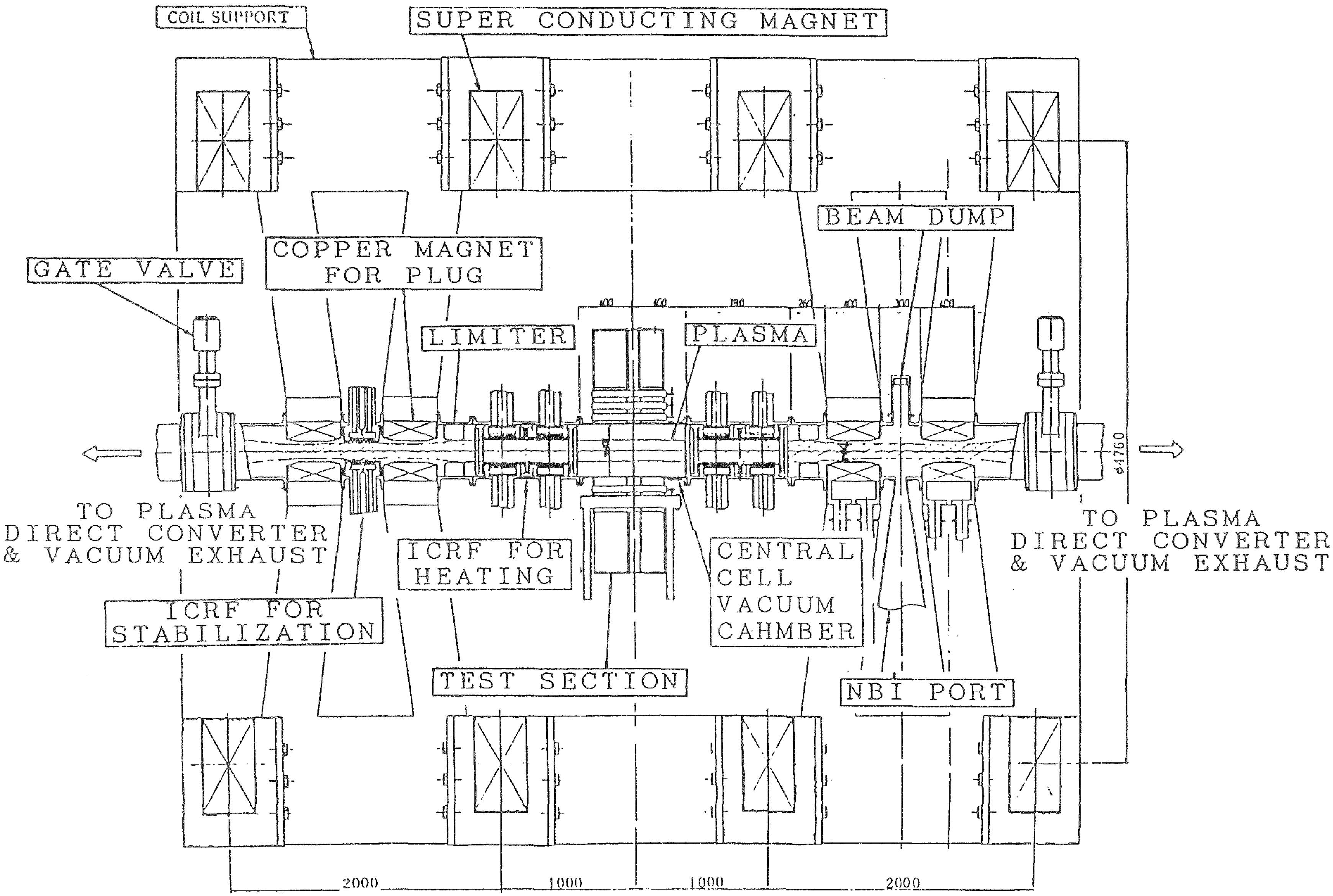
FEF

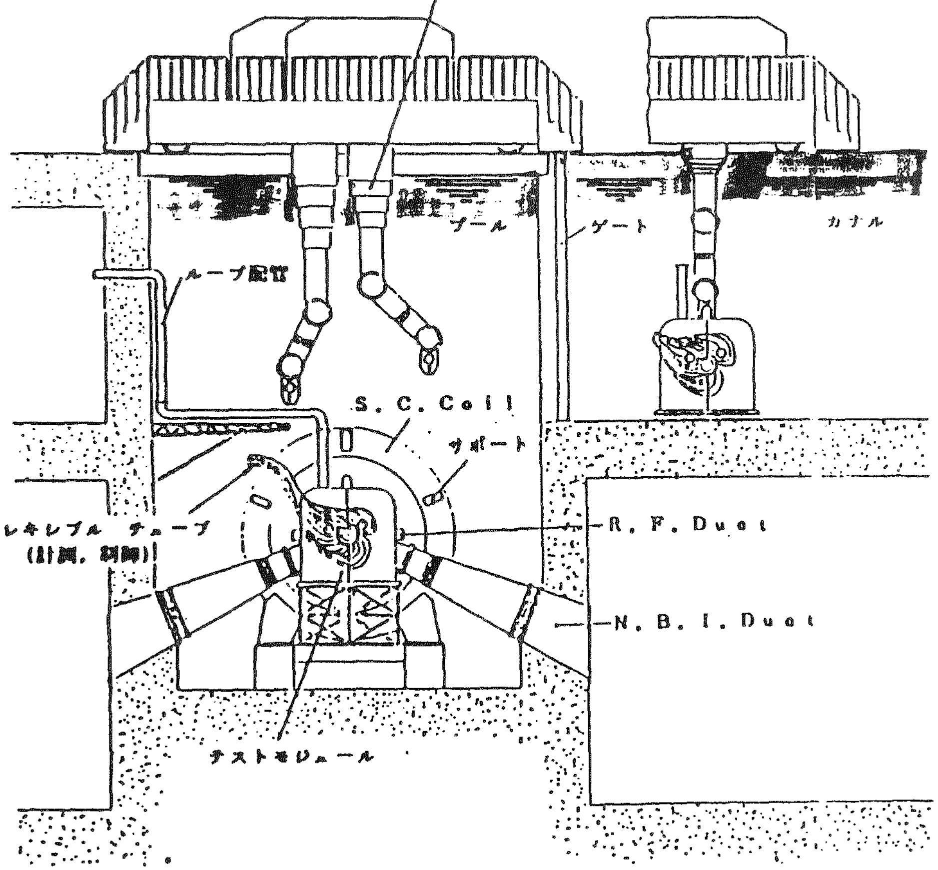
- A mirror based DT neutron Source
- 1981 started (Conceptual design)
- Joint Effort
  - Universities (Tsukuba, IPP Nagoya) Kyoto
  - JAERI (JMTR)
  - Industries (Hitachi, Toshiba, Mitschubishi)
  - Chiyoda chemical plant.
- FEF II (near term construction)
- Physics Experiment
  - HIEI (kyoto Univ.)
  - GAMMA
  - PHAEDRUS



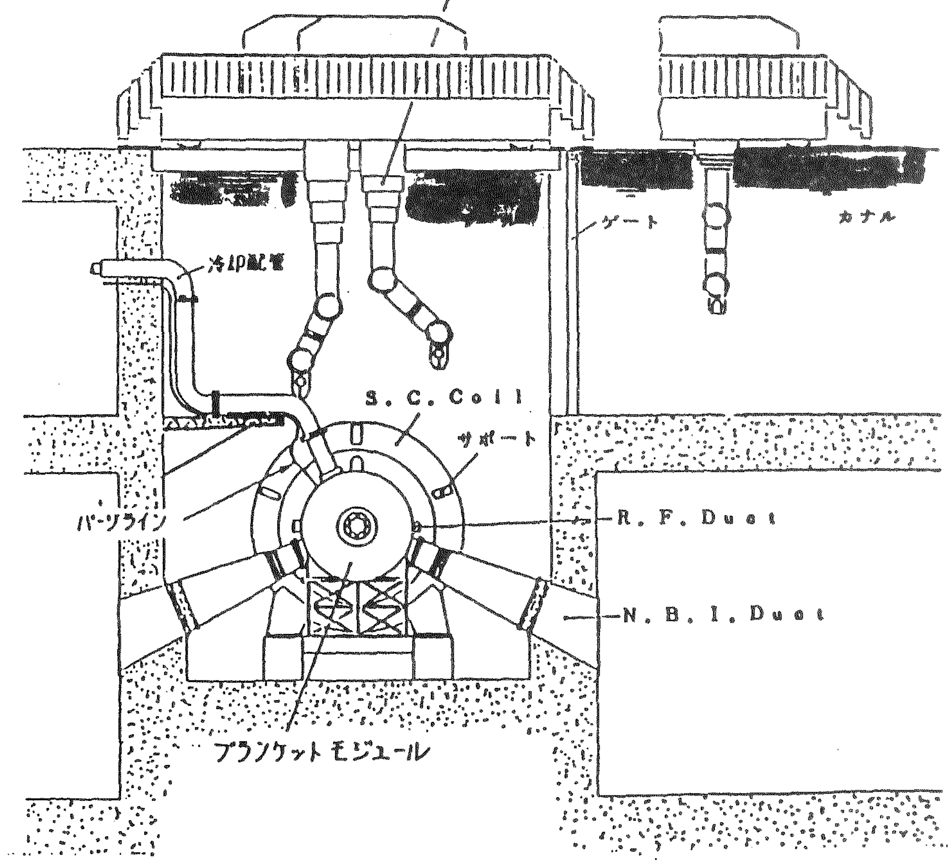
nτ (s·cm⁻³)
Ei (keV)
TANDEM MIRROR
SINGLE MIRROR
MFTF-B
GAMMA 10
TMX Up
TARA
TMX
GAMMA 6
MFTF
FEF
2XIIB
TMX plug
2X
LITE
2XIIB
2XII
BBII
BBII
PR 7
PR 6
DECAIIB

Schematics Diagram of Core Part of FEF

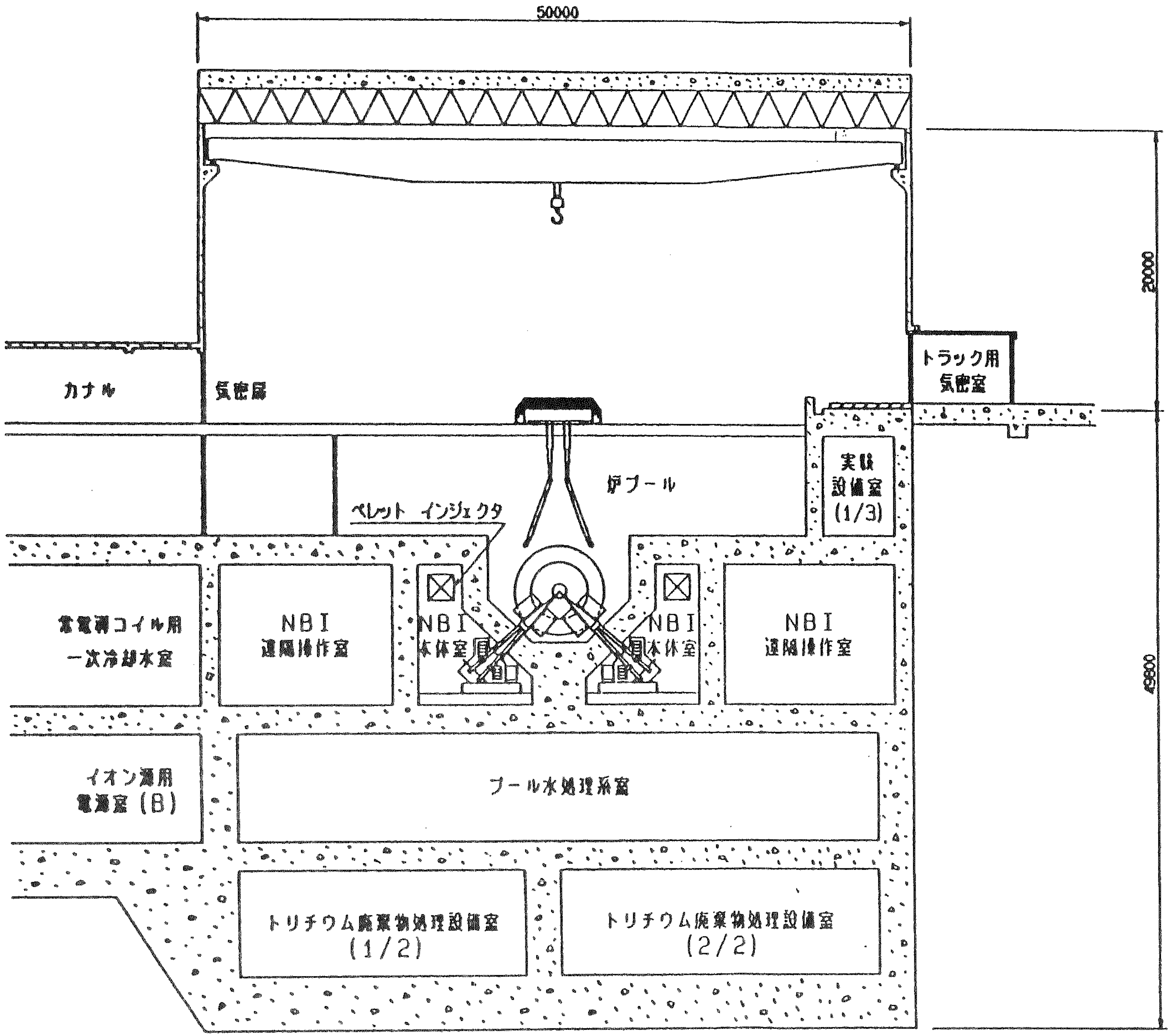




(a) テストモジュール ハンドリング概念図



(b) ブランケットモジュール据付概念図



REV | DATE | APPROVED
ISSUED FOR CONSTRUCTION
DATE
BY
DRAWN | DSGND | CHKD | APVD | APVD
FOR

CHIYODA CHEMICAL ENGINEERING & CONSTRUCTION CO., LTD
YOKOHAMA JAPAN

TITLE
FEF A-A 断面図

SCALE 1/300 | JOB NO.
PROJECT | DRAWING NO. 図 12・7 | REVISION 0

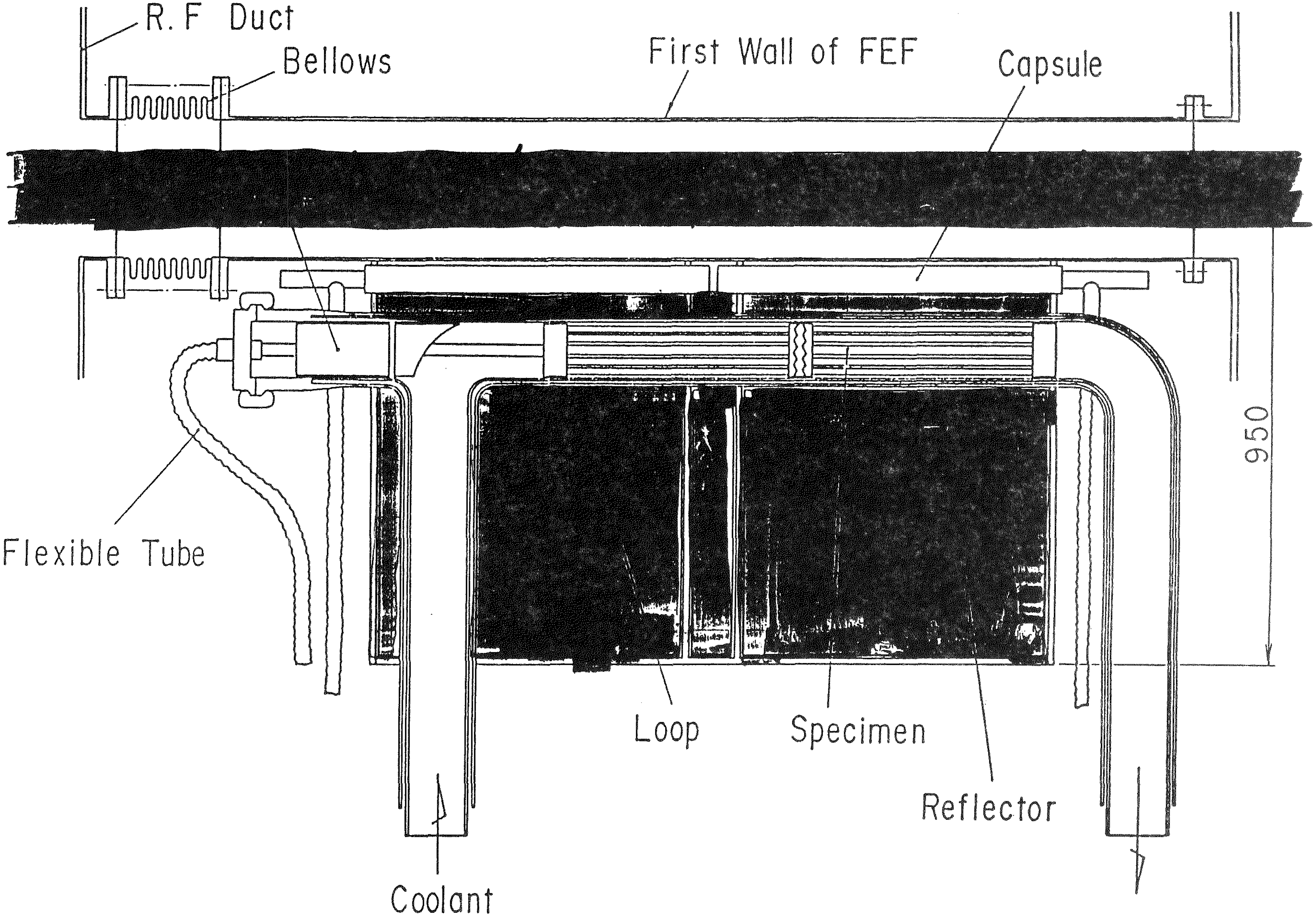


Fig. 2 Schematic Drawing of Test Section

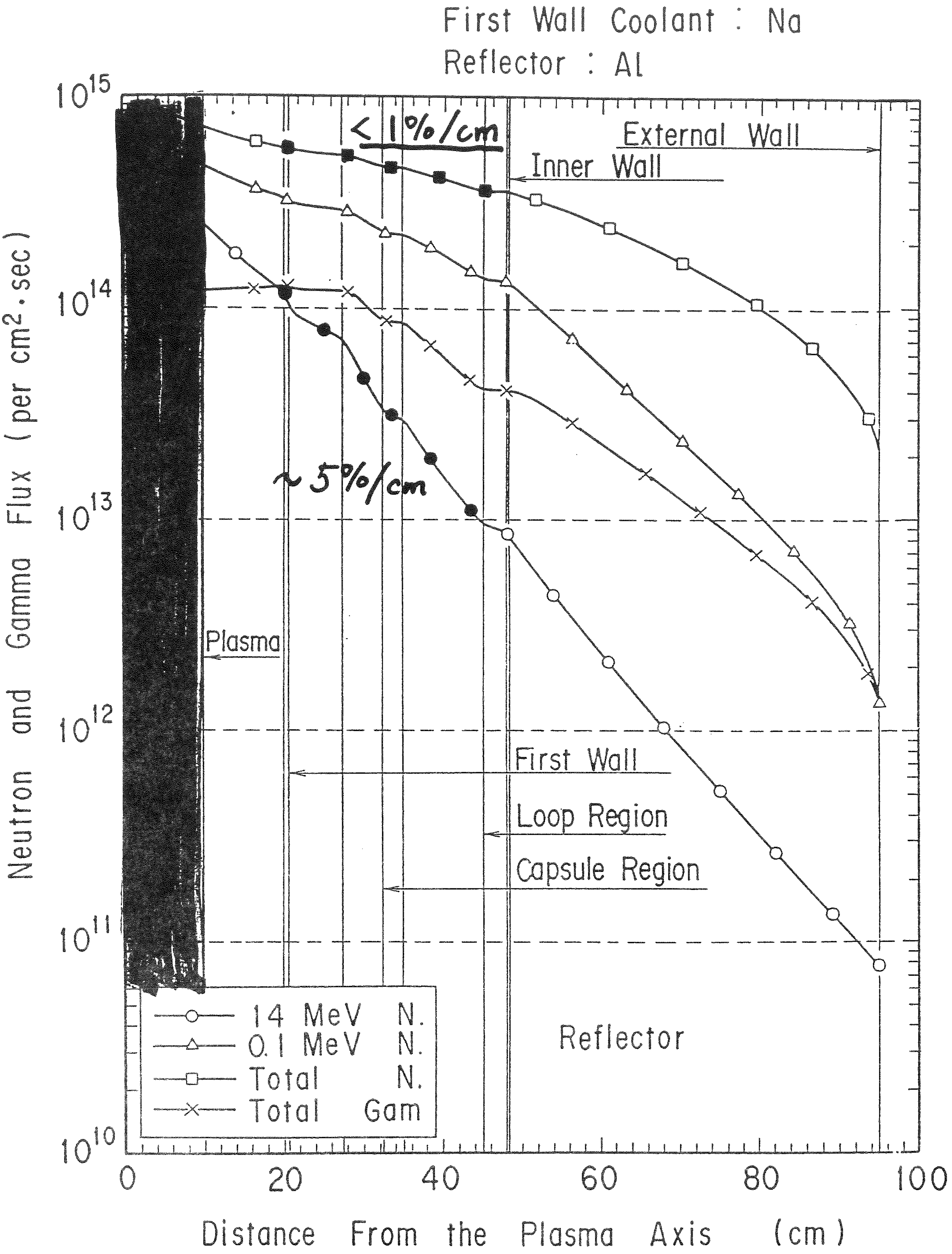
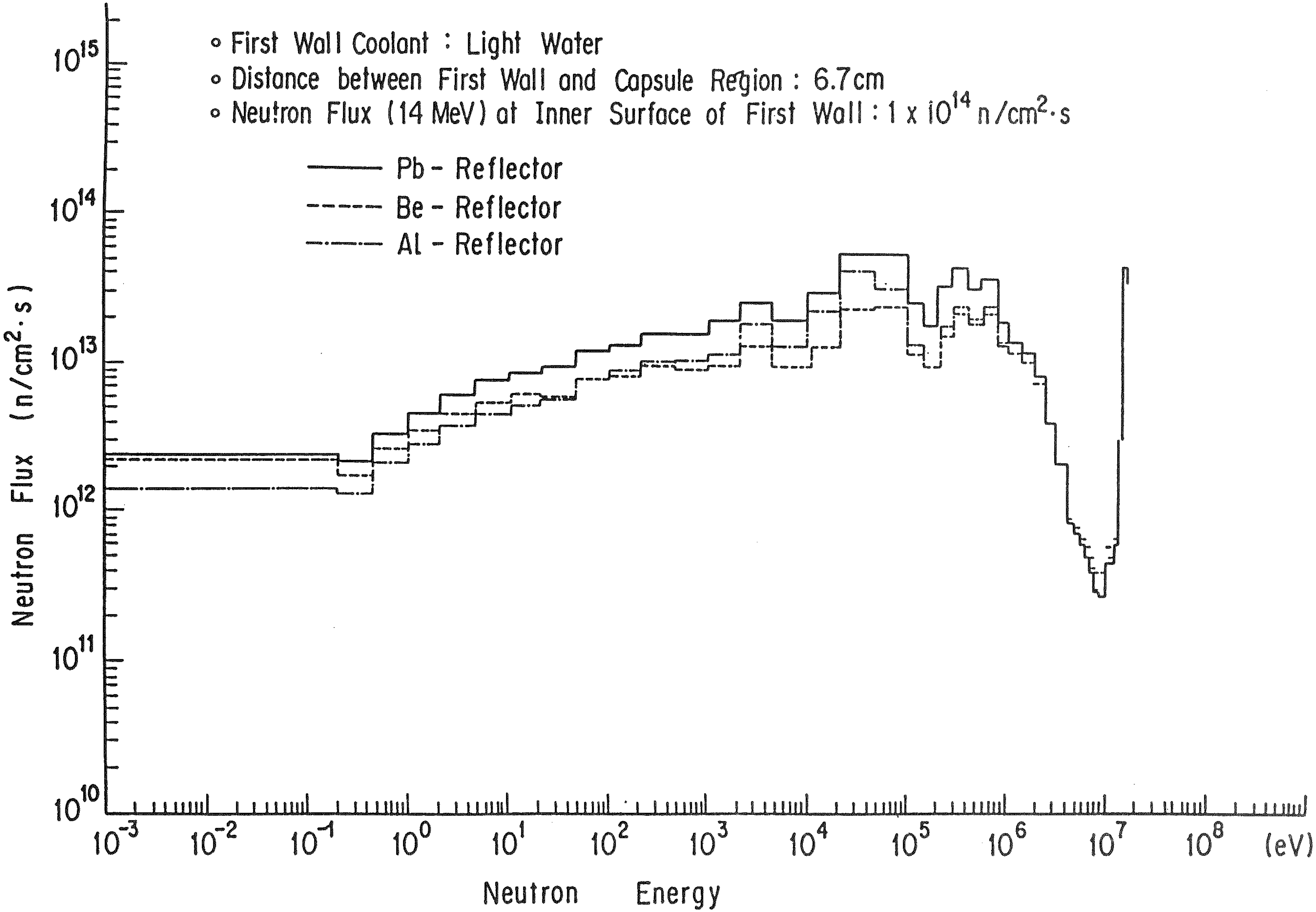
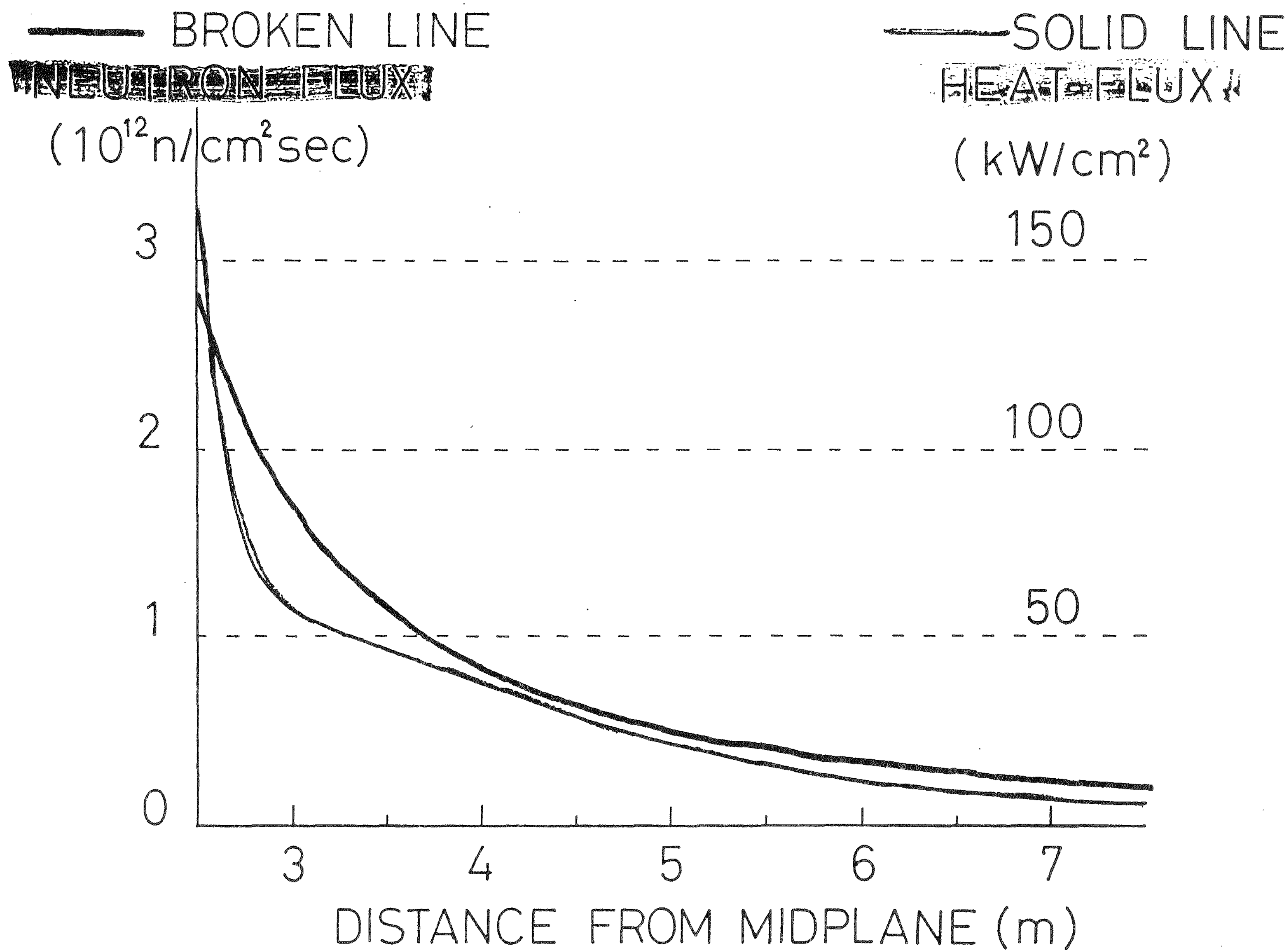


Fig. Neutron and Gamma Ray Fluxes

NEUTRON ENEGY SPECTRUM IN FEF





BROKEN LINE
NEUTRON FLUX
(10^12 n/cm^2 sec)
SOLID LINE
HEAT FLUX
(kW/cm^2)
3
2
1
0
150
100
50
3
4
5
6
7
DISTANCE FROM MIDPLANE (m)

FEF

RF (MHD, heating)
Water shielding
Direct Energy Conversion

BPNS

Quadrupole (MHD)
Two Component (NBI)

GDT

Slohsing Ion (NBI)
GDT (MHD)

FEF-I

single mirror confinement

MHD stabilization by r.f.

use of direct energy conversion system

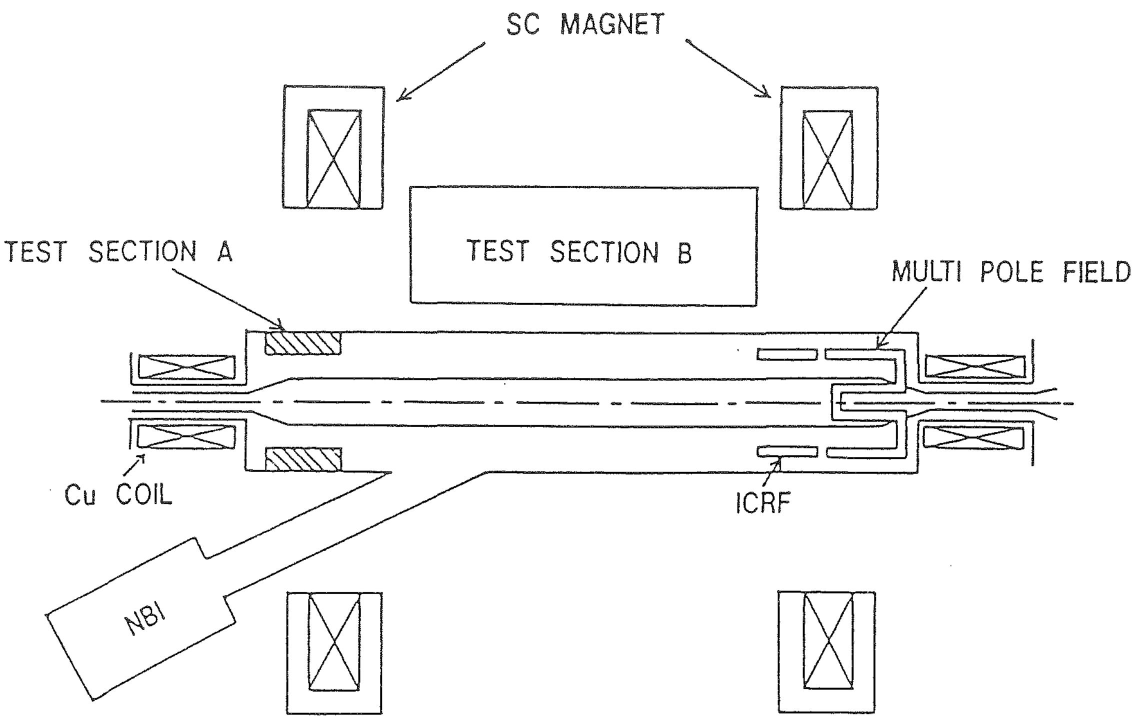
FEF-II

single mirror confinement

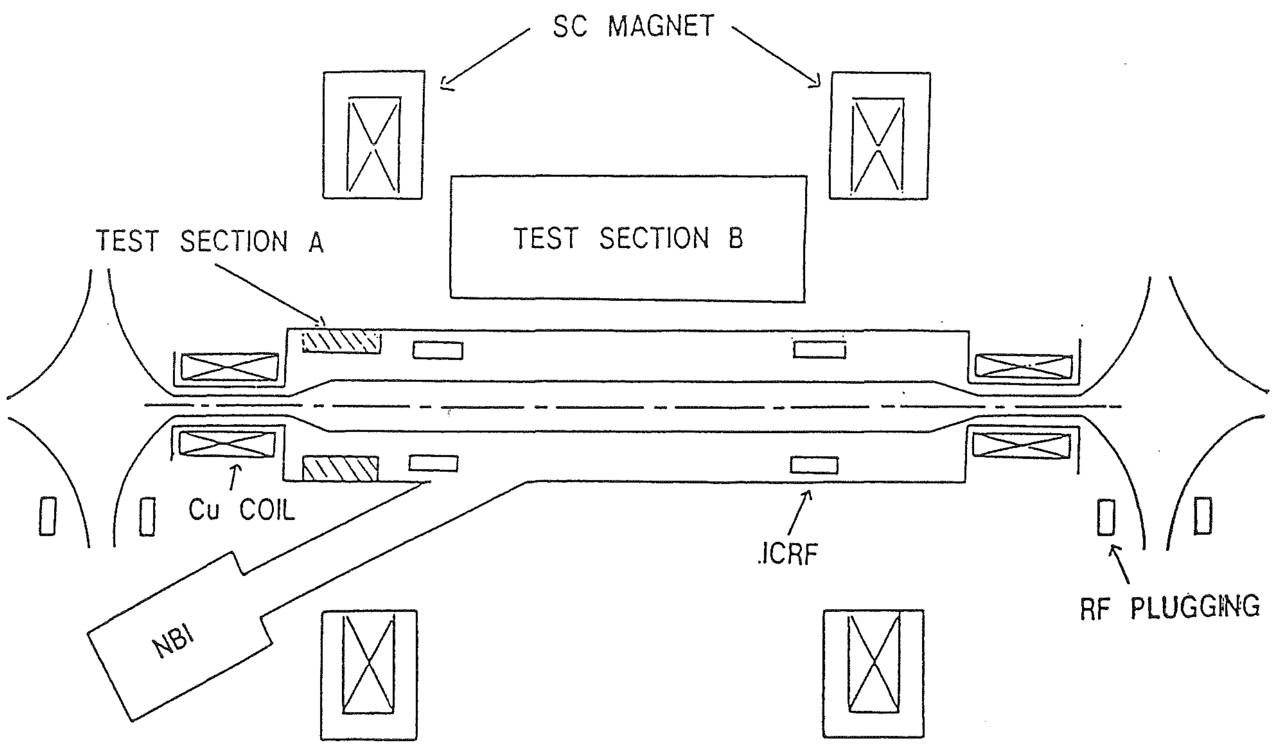
MHD stabilization by r.f., cusp or multipolefield

sloshing ion distribution for NBI

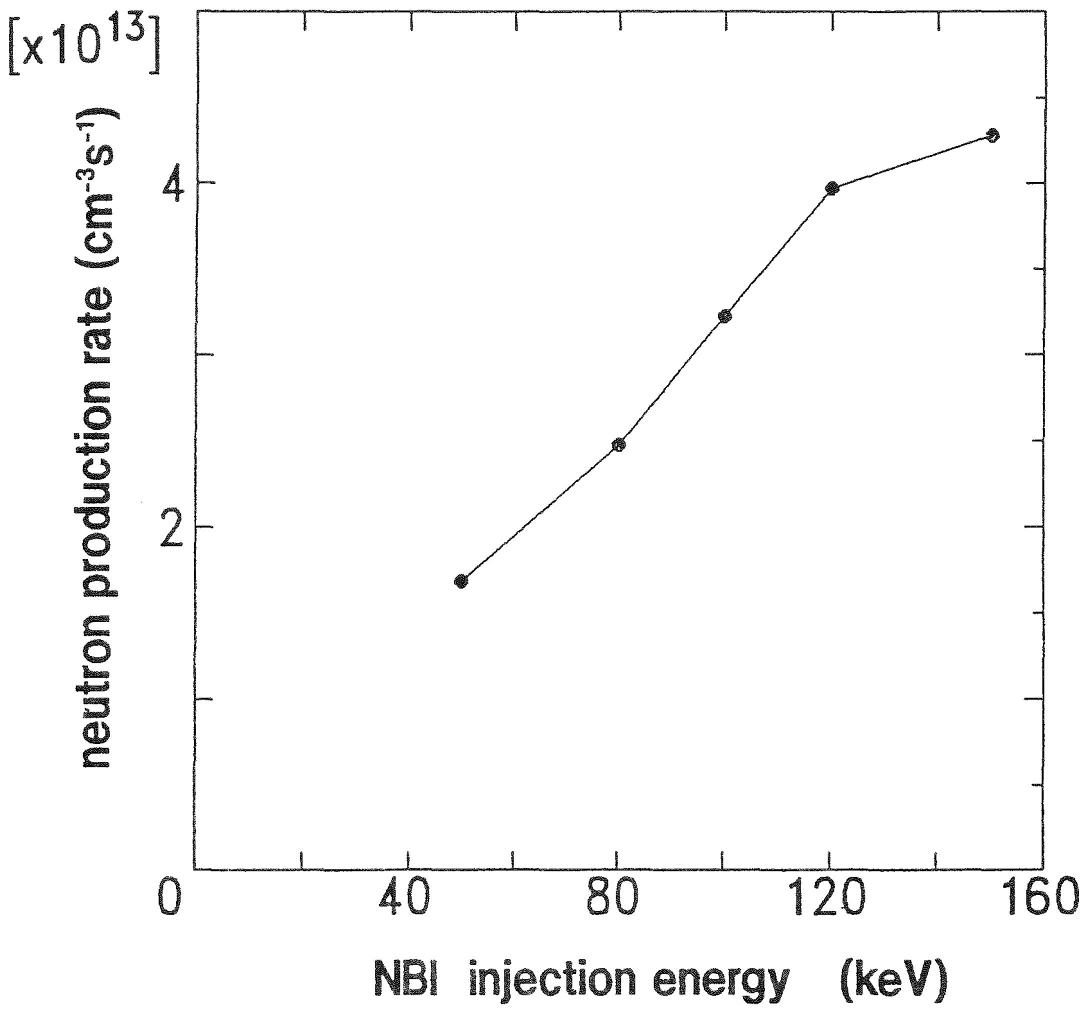
Schematics of FEF-II (Version1)



Schematics of FEF-II (Version2)



Neutron Production Rate versus NBI Injection Energy



θ_o = 45° T_e = 3keV   R = 3.4

Proposal of an Intense 14 MeV Neutron Source based on μCF

S. Monti

ENEA

PROPOSAL OF AN INTENSE 14 MeV NEUTRON SOURCE BASED ON μCF

F.Amelotti, G.Gherardi, S.Monti, M.Vecchi
ENEA - Bologna

F.De Marco, M.Pillon
ENEA - Frascati

C.Petitjean, H.K.Walter
PSI - Villigen

1. General motivation

The continuous progress toward breakeven deuterium-tritium fusion reactors requires a quick development of materials that are resistant to large fluences of fast neutrons [1]. Mainly for this purpose, but also for other needs of nuclear research (actinide transmutation, hybrid mesocatalytic reactors [2], etc.), there is a growing demand for high-intensity fast neutron sources. In this context, some scientists of ENEA Bologna had the idea of exploring the possibility of a high-intensity 14-MeV neutron source based on muon-catalyzed fusion for accelerated end-of-life testing of fusion reactor materials. Fig. 1 shows the first conceptual scheme of the facility and its performances [3]. An intense flux (up to $5 \cdot 10^{14}$ n/cm^2 s) of 14-MeV neutrons is produced in a high-density D-T mixture at 400 to 600 K and 10^3 kg/cm^2, by injecting a current of 10^{15} μ^-/s into the reactor chamber. These muons derive from decay in flight of a $2 \cdot 10^{16}$ π^-/s current. To obtain this current an intense deuteron beam is accelerated onto a low-Z (e.g. Beryllium or Lithium) target, by a power driven, high-energy (1.5 to 4 GeV), high-current (10 mA) accelerator.

To develop such a project, three activities are foreseen:

1. The design of a pilot facility, making use of a 50 μA - 600 MeV proton beam, diverted e.g. from the PSI accelerator (see the conceptual scheme and performances in fig. 2). This device should produce a neutron source of 10^{13} n/s and, therefore, check the physical problems as π^- collection, μ^- confinement and total efficiency. This "expertise" should optimize the system's design from pion production target to the D-T reaction chamber, and assess the costs for this facility.

2. Realization of this pilot project, e.g. at PSI.

3. The design of the final intense neutron source able to achieve the goal of 10^{17} n/s. At this level, if the physical problems are under control, the principal arguments are power exhaust and radiation screening.

2. Present state of μCF research and technology

Due to the continuous progress of μCF theory and experiments in recent years, it is well established that a negative muon can produce during its lifetime of 2.2 μsec more than X_c=100 dt fusions [4,5]. This number may be improved only slightly, since sticking ω_s of the muon to the reaction products (μα) seems to mark the technical limit $X_c \leq \omega_s^{-1} \sim 170$. The development of basic research in μCF is still going on at many institutes and laboratories. PSI represents in this respect one of the most active centers of the international μCF research and expertise [5].

The number X_c=100 already results in a sizeable energy output per muon (1.7 GeV), but this is not sufficient to make the energy balance of the direct d-μ-t fusion cycle positive. About one order of magnitude more energy would be needed for technical breakeven in the optimal (but still realizable) case.

Yu.V.Petrov [2] first pointed out that the overall energy balance becomes clearly positive if μCF is applied in a muon catalyzed hybrid reactor system (MCHR) designed for breeding an uranium blanket (see fig. 3).

His scheme for a MCHR works as follows:

1. Use a high current accelerator, e.g. with a deuteron beam of up to 100 mA and 2÷4 GeV energy, which is ideal for optimal pion production.

2. Produce in a high magnetic field (5÷11 T) as many π^- as possible, i.e. use a thick, low-Z, neutron rich pion production target (d, t, Li, Be, C, etc.).

3. Collect the μ^- from π^- decay in flight and direct them into a deuterium-tritium fusion chamber ("synthesizer").

4. Irradiate an uranium blanket with the 14 MeV neutrons from dt reactions.

5. Use the produced Pu as fuel in conventional nuclear power reactors.

6. Improve the energy balance of this system by using the waste beam and radiation from the π production target for additional blanket breeding ("electrical breeding").

During the last decade, Yu.V.Petrov and collaborators in Gatchina worked out many more details of this originally proposed scheme. They reacted also to various criticisms about too optimistic efficiency estimates. A detailed technical design, however, calculating and taking into account the system as a whole has not been undertaken yet. Also the problems with high power accelerators and beams inducing unprecedented thermal loads and radiation levels on targets and surroundings, were not addressed sufficiently so far.

Recently, the need for very intense 14 MeV neutron sources was emphasized for the research on wall materials of future fusion reactors [1]. Such 14 MeV sources are needed since other neutron sources hardly can simulate the exact radiation spectrum of dt fusion reactors. It also became evident that a μCF type source according to the Petrov's scheme might be more efficient by several orders of magnitude than low energy - high current accelerators, because a ratio of output energy of neutrons to accelerator input energy of 0.01 may be approached (see e.g. [6]). Althogh the design criteria differ partly from those of a MCHR (here neutron flux per cm^2 should be optimized rather than the overall energy balance), the use of μCF looks very promising. To assess the really achievable figures of merit with μCF, it is now necessary to study the overall system with detailed calculations, using technically realizable concepts.

3. Guide lines for the reference design of a 50 μA - 600 MeV pilot facility

For the overall study of a μCF 14-MeV neutron source, the following calculational tools must be made available or developed:

- A pion production routine giving the fluxes of negative pions versus production angle Θ, for various target materials, target geometries and thicknesses (by taking pion absorption, multiple pion production into account), for various incident beam parameters (particle, energy).

- A pion-muon ray tracing code in magnetic fields by tacking into account π - μ decay, π absorption and π^-, μ^- energy loss in matter.

- A 14 MeV n-luminosity routine calculating the neutron fluxes per cm^2 by tacking n-scattering and absorption into account.

Using these tools the following aspects will have to be considered for getting the reference design (of course this list is incomplete, because the study certainly will reveal new and other problems):

- Magnetic field configurations, e.g. homogeneous field and fringing field of a solenoid entrance, mirror field trapping backward π^-, field strength, length of π/μ decay region, etc.. Also magnetic bottle fields will have to be considered.

- Beam angle to pion acceptance, e.g. 0°, 90° versus beam energy (p,d).

- Target materials and length versus beam energy, technical feasibility, beam dump.

- dt cell size in length and radius, entrance window (materials, thickness), temperature-density of dt mixture.

- Heat and radiation loads on materials.

- Shielding.

- Radiation damage test stations.

- Cost evaluation and time schedule.

- Conditions and consequences for a pilot project at PSI.

4. Preliminary results

In the framework of the activity exposed in § 3, some calculations have already been performed for the setup target-convertitor-entrance window-synthesizer.

To this end the Monte Carlo code GEANT [7] has been used, which permits to simulate all the phisical events (π-μ decay, π and μ absorption and energy loss in matter, etc.).

Starting from the differential pion production cross section measured at PSI for 590 MeV protons [8,9], the π-distribution in the phase-space around a carbon target 20 cm long and 1 cm of diameter has been determined.

The adopted geometrical model is shown in fig. 4.

A primary 590 MeV proton beam, perpendicular to the converter axis(1), impinges against the target and produces the above mentioned π^- distribution. The pions are confined by a 5 T solenoidal magnetic field inside a vacuum channel 10 m long and 40 cm of diameter.An entrance titanium window 2 cm thick and a reaction chamber filled with a dt mixture of density Φ=0.5 complete the setup.

At the end of the converter 40% of muons per π^- entering the magnetic trap has been collected.

Of course, further calculations are necessary to optimize the system's design in order to get the maximum score of muons absorbed in the synthesizer. Particularly, the score and distribution in phase-space of μ^- at the end of the converter will be analyzed as a function of:

- the angle of the target with respect to the converter's axis;

- the dimensions (L,R) of the converter;

- the strength of the magnetic field.

Also the effect of a magnetic mirror behind the target, in order to collect π^- travelling backward, will be investigated, as

---

(1) This scheme is assumed to avoid large neutron damage of the converter's coils and to limit the length of the converter itself.

well as a "reinforcement" of the magnetic field at the very beginning of the converter.

Finally, with the geometry of the reaction chamber shown in fig. 5, the neutron flux on the test material has been calculated, starting from a normalized to one isotropic neutron source in the synthesizer. For this calculation the Monte Carlo MCNP 3 code was used [10]. A flux of $5.6 \cdot 10^{-3}$ n/cm^{2}s per starting n/s has been obtained.

References

[1] J.G. Cordey et al., "Progress toward a Tokamak Fusion Reactor", Phisics Today (January 1992) 22.

[2] Yu.V. Petrov, Nature 285 (1980) 466; Muon Catalyzed Fusion 1 (1987) 351, 3 (1985) 525.

[3] S. Monti, "A Proposal for a 14 MeV Neutron Source based on Muon Catalyzed Fusion", ENEA NUC-RIN Bologna, int. report (20/12/91).

[4] L.I. Ponomarev, "Muon Catalyzed Fusion" Contemporary Physics 31 (1990) 219.

[5] C. Petitjean, "Progress in Muon Catalyzed Fusion", Few Body XIII, Adelaide (1992), PSI-PR-92-05.

[6] Studies on Intense Neutron Sources, see e.g. FMIT Report (HEDL, 1982), Proceedings of the International Fusion Materials Irradiation Facility (IFMIF) Workshop (for the IEA), San Diego, CA, USA, February 14-17, 1989, 2 Volumes; M. Martone, "Feasibility Study of a 14 MeV Neutron Source", ENEA Frascati (1990).

[7] R. Brun et al., "GEANT 3" CERN, Data Handling Division, (September 1987).

[8] J.F. Crawford, et al., "Measurement of Cross Sections and Assimetry Parameters for the Production of Charged Pions from Various Nuclei by 585-MeV Protons", Physical Review C 22 (1980) 1184.

[9] J.F. Crawford, et al., "Production of Low Energy Pions by 590 MeV Protons in Nuclei", Helvetica Physica Acta 53 (1980) 497.

[10] J.F. Briesmeister et al., "MCNP - A General Monte Carlo Code for Neutron and Photon Transport, Version 3A", LANL report LA-7396-M, rev.2 (1986).

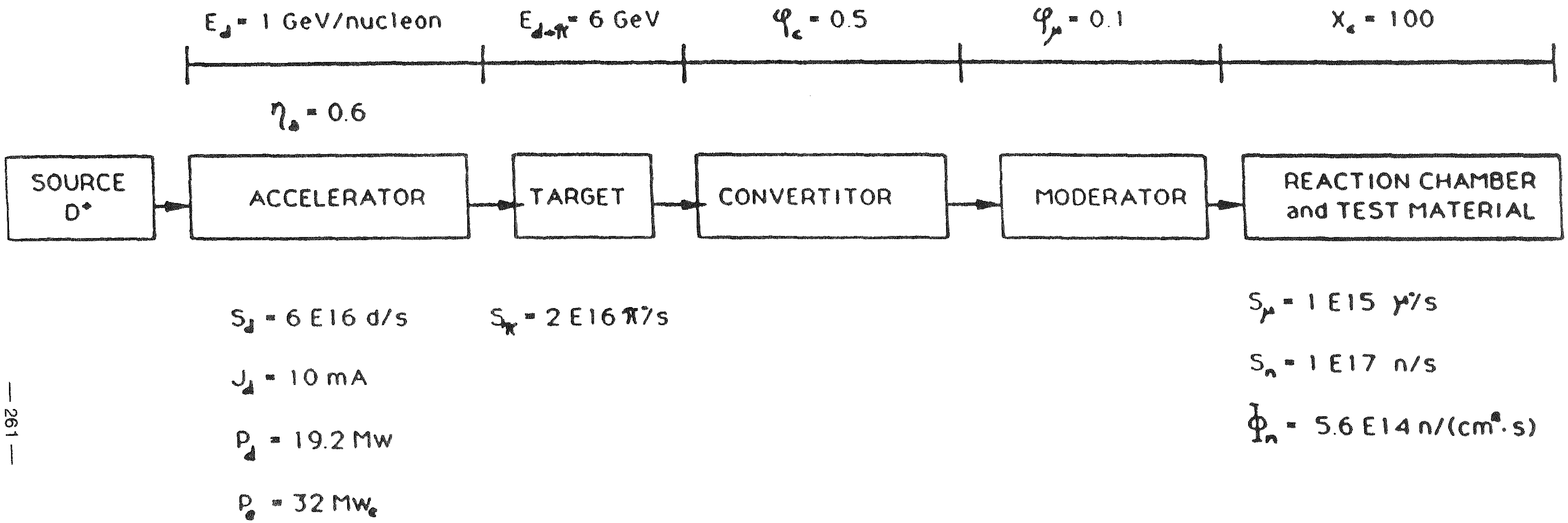


Fig.1: Conceptual scheme of the machine and high-performances

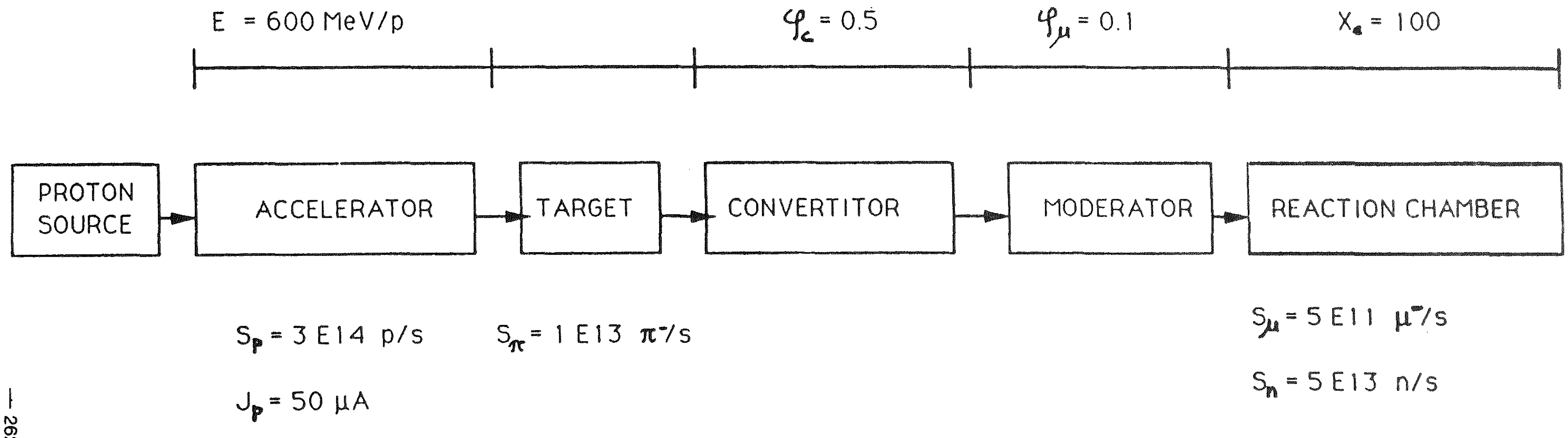
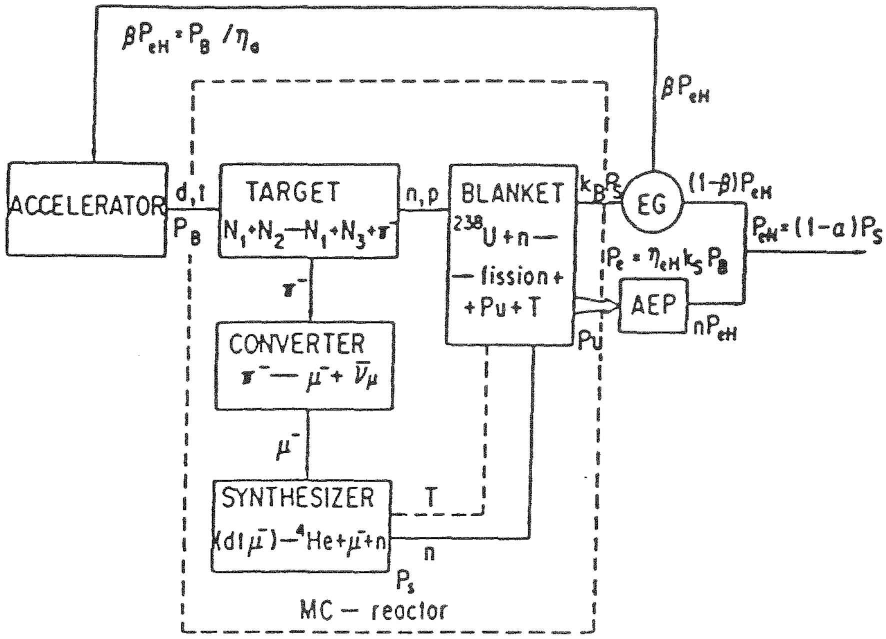


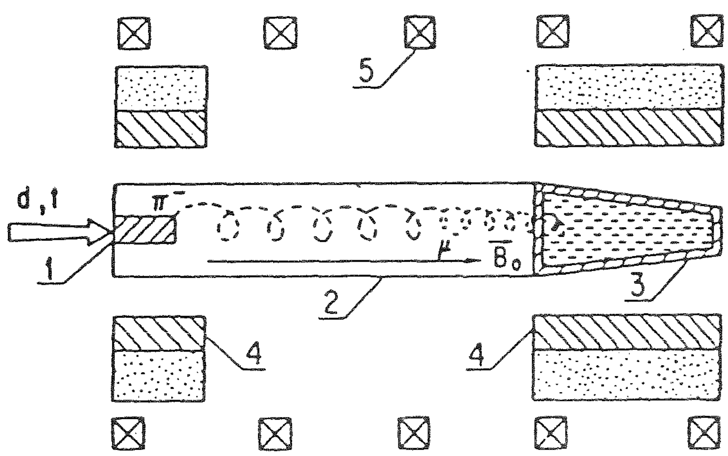
Fig.2: Pilot project: conceptual scheme of the machine and performances

Yu. V. Petrov, A muon-catalyzed reactor concept

from Muon Catalyzed Fusion Vol. 1 (1987)



Scheme of the mesocatalytic (MC) method of energy production. EG is the electric generator; AEP are the atomic energy plants, four times more powerful than the MC reactor.



Conceptual version of a hybrid mesocatalytic reactor. 1: pion-producing target, 2: converter, 3: synthesizer, 4: blanket, 5: the solenoid's magnets.

FIG. 3

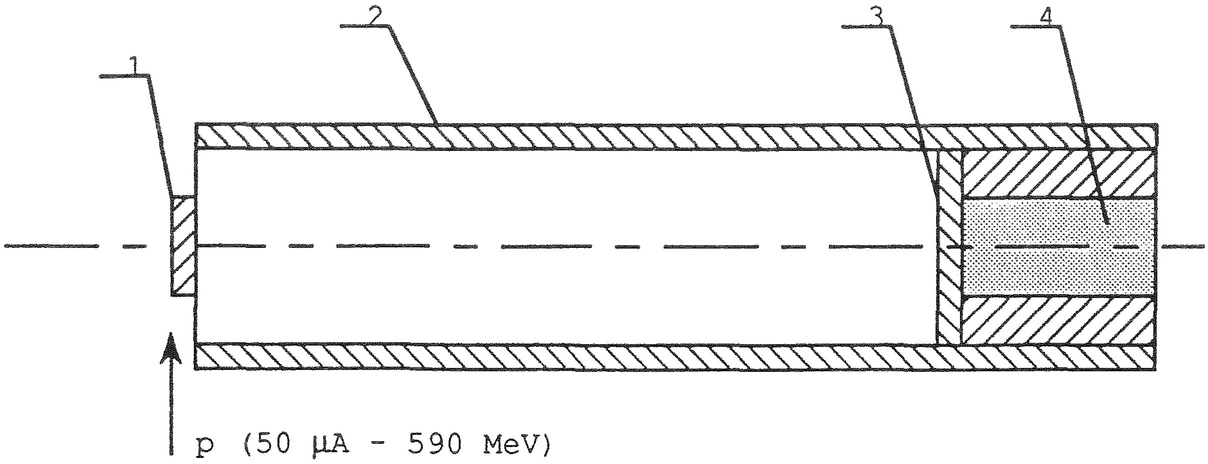


Fig.4: Geometrical model; 1:pion-producing target; 2:converter and solenoid's magnets; 3:entrance window; 4:synthesizer with dt mixture

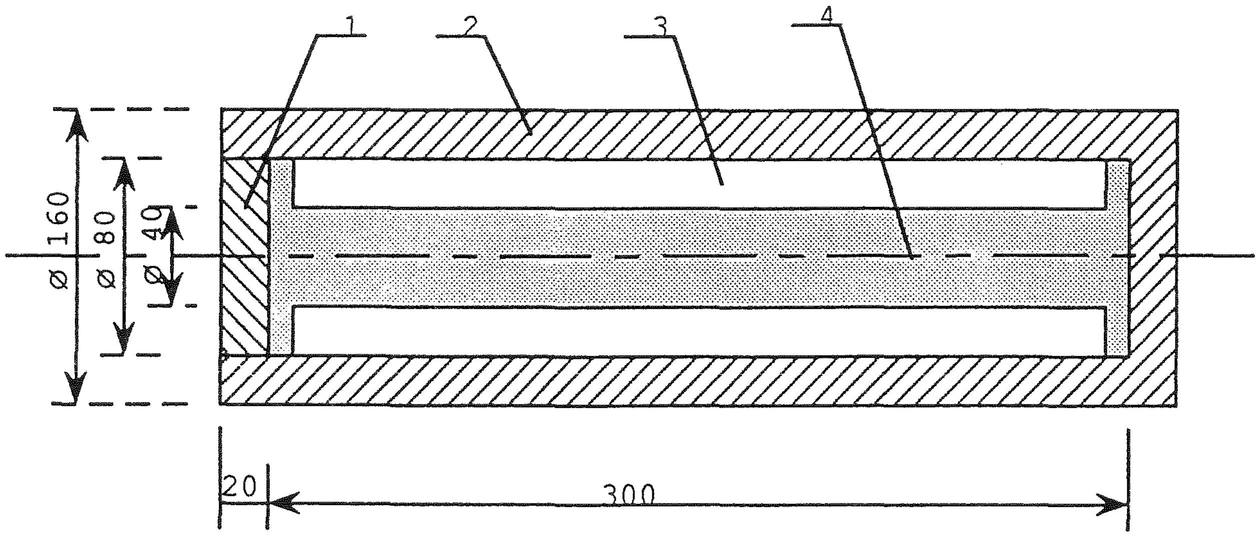


Fig.5: synthesizer's geometrical model; 1: titanium front wall; 2: synthesizer; 3: test material; 4: dt mixture. (measures in mm)

Some Information and Remarks concerning plans to build a European Spallation Source for Neutron Scattering Application

H. Ullmaier

KFA-Jülich

Workshop on Intense Neutron Sources for Fusion Materials R& D

KfK, Karlsruhe, Sept. 21 - 23, 1992

Some Information and Remarks concerning plans to build a European Spallation Source for Neutron-Scattering Applications

by

H. Ullmaier, KFA-Jülich

Spallation Source for Neutron Scattering

as alternative for HFR as a source for
cold, thermal and epithermal neutrons

- application for funding through CEC prepared by group of European laboratories (leaders. RAL / UK ("ISIS") and KFA/D ("SNQ"))
- several workshops on accelerators, targets, instrumentation, etc.
- Sept. 17: Meeting in Jülich for final formulation of application to CEC

Technical Data

Beam Power	5 MW
Pulse Repetition	50 Hz
Pulse Duration	< 3 μs

2 Accelerator Options:

- LINAC 800 MeV 6.3 mA, 3 parallel compressor rings, convent. cavities
- SYNCHROTRON (fixed field altern. grad.) 3 GeV 1.7 mA injector LINAC 460 MeV

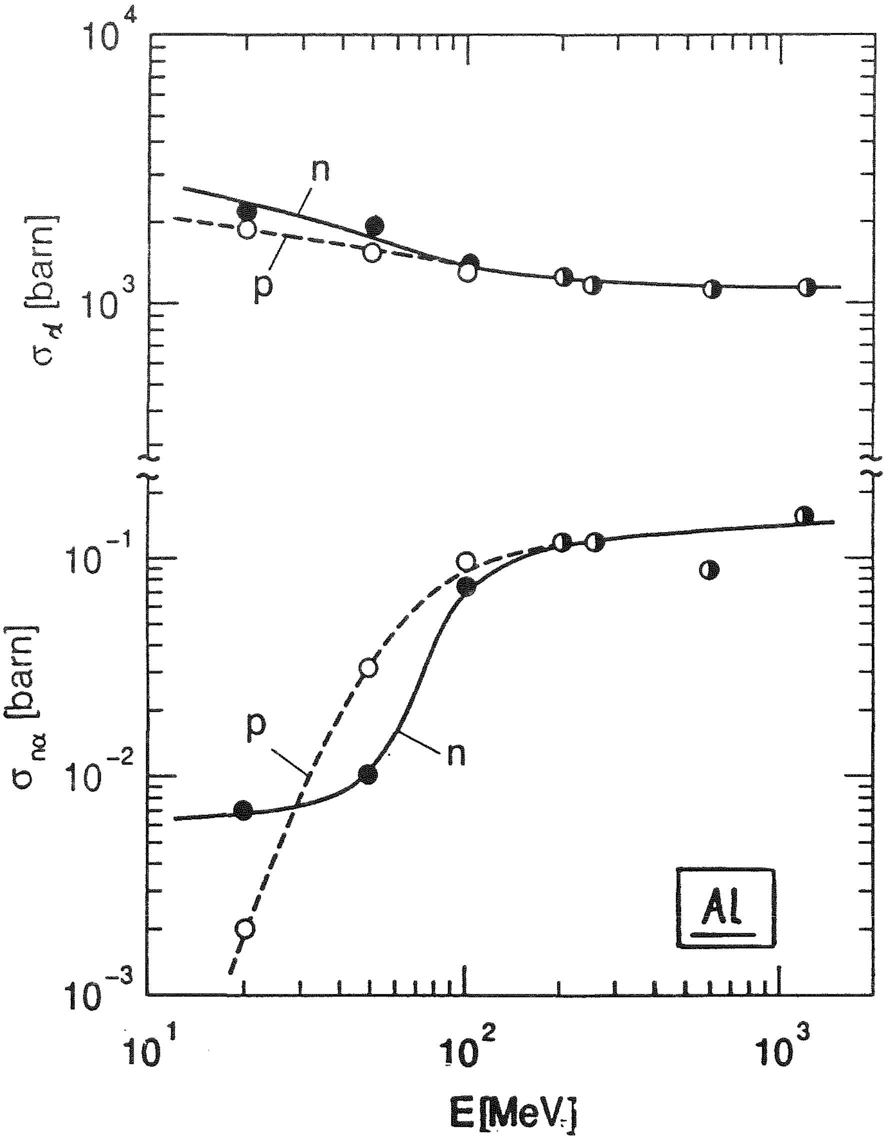
Target Options:

- Heterogen cooled SOLID TARGET, moving (or stationary)
- Homogen. cooled LIQUID TARGET, pumped or natural convection

Cross-sections :

e.g. p-beam

6.3 mA



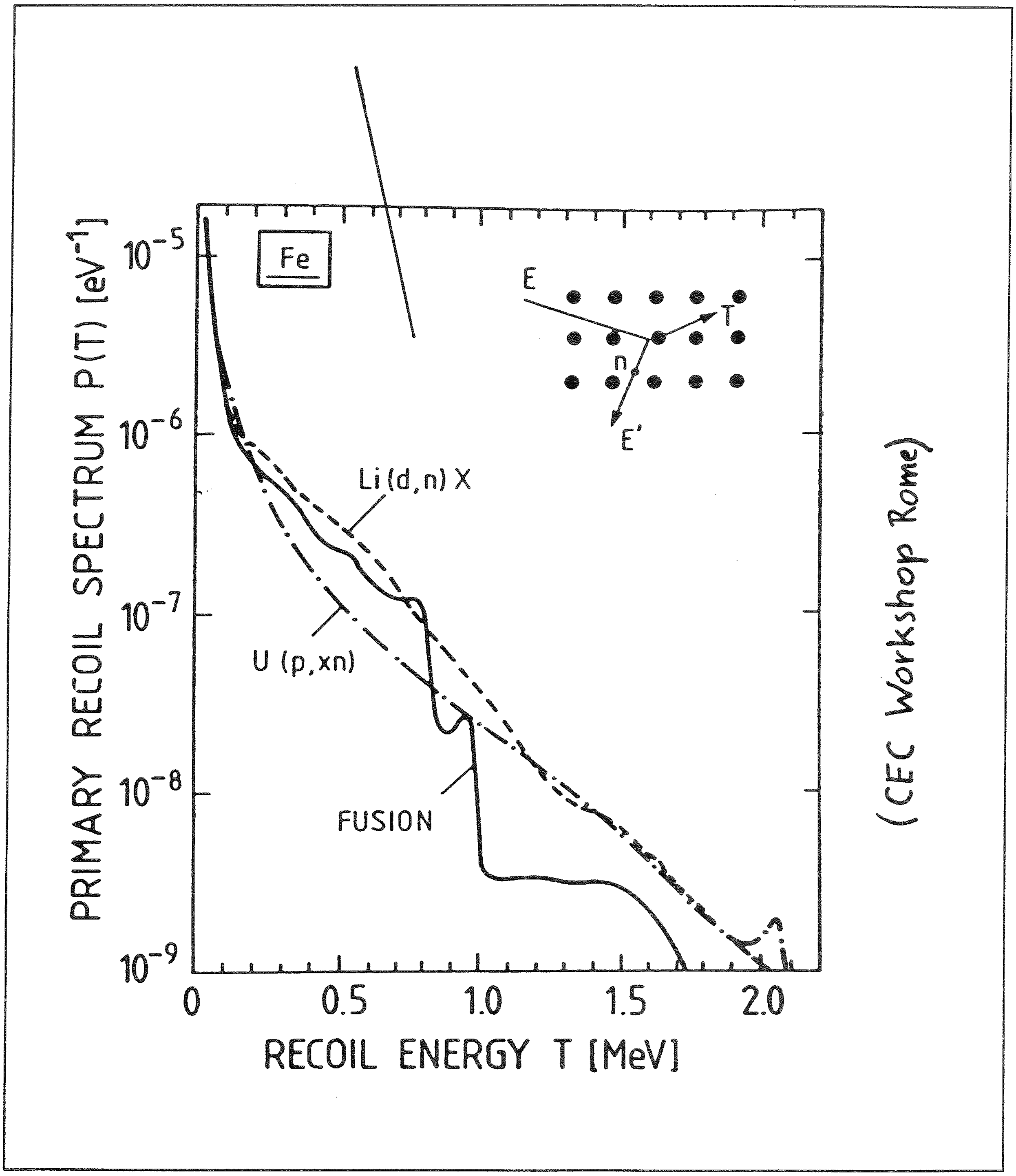
\- 60 dpa / yr

\- 6000 ppm He / yr

(Filges et al.)

Handicaps for use as irradiaton source for fusion:

- Pulsed Flux: $\Phi_m / \overline{\Phi} \cong 10^4$
- High Energy Tail



- Reluctance of low energy users to supply high energy parts (through the moderator)

Session 3

Summary of IEA Neutron Source Working Group Activities

D. Doran

Washington State University

IEA Neutron Sorce Working Group

S. Cierjacks

D. Doran, chair

F. Hegedus (M. Victoria)

E. Hodgson

S. Ishino

K. Noda

P. Schiller

SUMMARY OF IEA NEUTRON SOURCE WORKING GROUP ACTIVITIES

D. G. DORAN, CHAIRPERSON

IEA WORKSHOP ON INTENSE NEUTRON SOURCES
KARLSRUHE
September 21-23, 1992

OUTLINE

REVIEW OF EARLIER SOURCE COMPARISON STUDY AND PRIOR CONCLUSION

NEUTRONICS COMPARISON OF D-Li AND T-H2O

- METHODS
- RESULTS
- CONCLUSIONS – INTERIM

TEST MATRICES AND TEST VOLUME NEEDS

- APPROACHES
- INTERIM CONCLUSIONS

EARLIER SOURCE COMPARISON STUDY

1989 SAN DIEGO WORKSHOP RECOMMENDED NEUTRONICS COMPARISON STUDY
OF: D-Li, SPALLATION, AND BEAM-PLASMA WITH DEMO

SPECTRA OBTAINED FROM:

DEMO: KfK (EHRLICH)/CULHAM

D-Li (uncollided, 2-beams at 90 degrees, 10 cm from apex; point is 8.5 cm from apex along plane of symmetry): LANL (LAWRENCE/VARSAMIS)/HANFORD

SPALLATION (uncollided): PSI (VICTORIA)/PSI-Pepin; INF MADRID (PERLADO)/PSI

BEAM-PLASMA (w/ and w/o Al reflector): LLNL (COENSGEN)/TSUKUBA UNIV.

DPA, GAS AND SOLID TRANSMUTATION RATES (TO 50 MeV) CALCULATED AND COMPARED BY DORAN (WSUTC/PNL), MANN (WHC) AND GREENWOOD (PNL)--PORTION PUBLISHED IN JNM 174(1990)125; MORE COMPLETE REPORT IN PNL DOCUMENT PNL-SA-18514

RATIO (Q) OF HELIUM(appm) TO DPA

TARGET	DEMO 1st wall dpa	DEMO 1st wall He/dpa	B-P w/refl. dpa	B-P w/refl. Q/Qdem	D-Li 8.5 cm dpa	D-Li 8.5 cm Q/Qdem	Spall. (Pepin) dpa	Spall. (Pepin) Q/Qdem
			RELATIVE TO DEMO					
Be	36	470	41	1.2	44	1.1	55	0.5
C	50	240	23	3.1	22	2.7	67	0.03
Si	115	17	112	1.8	92	1.4	146	0.3
V	86	4	92	1.5	76	2.5	95	1.0
Fe	80	9	80	1.4	80	1.5	80	0.7
Cu	108	12	129	1.5	104	1.4	110	0.5
Mo	54	10	49	1.5	54	1.3	59	0.5
W	23	3	28	1.3	23	6	24	3

Ref.: Doran, Mann, & Greenwood, PNL-SA-18514, 7/31/90

RATIO(S) HYDROGEN (appm) TO DPA

TARGET	DEMO 1st wall		RELATIVE TO DEMO: B-P w/refl.		RELATIVE TO DEMO: D-Li 8.5 cm		RELATIVE TO DEMO: Spall. (Pepin)	
	dpa	H/dpa	dpa	S/Sdem	dpa	S/Sdem	dpa	S/Sdem
Be	36	10	41	1	44	5.2	55	2.4
C	50	0.2	23	1.5	22	350	67	70
Si	115	77	112	1.6	92	1.4	146	0.4
V	86	20	92	1.7	76	1.6	95	0.5
Fe	80	61	80	1.2	80	1.2	80	0.5
Cu	108	40	129	1.4	104	1.2	110	0.5
Mo	54	37	49	1.4	54	1.9	59	0.8
W	23	3	28	1.3	23	10.7	24	7.7

Ref.: Doran, Mann, & Greenwood, PNL-SA-18514, 7/31/90

RATIO OF SOLID TRANSMUTANTS (APPM) TO DPA

TARGET	PRODUCT	DEMO 1st wall	B-P w/refl.	D-Li 8.5 cm	SPALL. Pepin
Be	Li	31	24	55	55
C	Be	32	91	86	10
	B			68	14
Si	Mg	17	29	32	8
	Al	28	46	49	12
V	Ti	17	28	46	20
	Cr	36	(3.2)	(0.6)	(2.7)
Fe	Cr	12	13	18	6
	Mn	58	45	66	21
Cu	Co	12	19	15	6
	Ni	270	186	135	54
	Zn	24	(2.1)	(0.5)	(2.7)
Mo	Y	5.9	9	6	2
	Zr	9.6	15	17	8
	Nb	44	53	72	31
	Tc	480	(116)	(46)	(29)
	Ru	39	(3)	(0.4)	(3.4)
W	Hf	6.1	9	26	14
	Ta	252	607	374	96
	Re	6500	(1460)	(650)	(340)
	Os	870	(13)	(0.9)	(1.2)

NOTES:
1. ( ) indicates large uncertainty in (n, gamma) produ
due to poor definition of low energy end of spectra.
2. DPA levels can be found in He and H tables.

Ref.: Doran, Mann, & Greenwood, PNL-SA-18514, 7/31/90

EARLIER SOURCE COMPARISON STUDY (CONTINUED)

CONCLUSIONS:

B-P GENERALLY, BUT NOT ALWAYS, CLOSER TO DEMO THAN D-Li, AS EXPECTED.

B-P RATIOS OF TRANSMUTATION RATES TO DISPLACEMENT RATES WITHIN FACTOR OF 3 OF DEMO. COULD BE IMPROVED WITH CHANGE IN REFLECTOR/BLANKET

D-Li RATIOS WITHIN FACTOR OF 3 OF DEMO, EXCEPT FOR H FROM Be (5); H (11) AND He (6) FROM W; AND FOR H (350) AND B (INFINITE) FROM C (CORRELATED). LIGHT ELEMENT PERFORMANCE COULD BE IMPROVED BY SOFTENING SPECTRUM.

EARLIER SOURCE COMPARISON STUDY (CONTINUED)

SPECIFIC SPALLATION SPECTRUM TOO SOFT; RATIOS ONLY HALF OR LESS OF DEMO FOR He (5 of 8 elements), H (4 of 8 elements), AND SOLID TRANSMUTANTS (8 of 15 products from 6 of 8 elements studied).

SPALLATION OPTION TO BE DROPPED UNLESS STRONG ADVOCATE APPEARS.

RATIOS FOR 6 TRANSMUTATION PRODUCTS $\leq$ 0.2 OF DEMO VALUE FOR ALL 3 SOURCES--ALL FROM LOW ENERGY N,GAMMA REACTIONS SO MEANINGLESS BECAUSE ONLY DEMO SPECTRUM ADEQUATELY DEFINED AT LOW ENERGIES WHERE N, GAMMA CROSS SECTIONS ARE LARGE.

D-LI VS. T-H2O NEUTRONICS COMPARISON

CONCEPT (of Cierjacks) OUTLINED AT SAN DIEGO.
ALTERNATIVE SOURCE WITH NO NEUTRONS ABOVE 15 MeV.
ADDED LATER TO WORKING GROUP'S COMPARISON STUDIES.

SUMMARY OF METHOD OF COMPARISON:

KfK AND HANFORD AGREED TO STUDY A SINGLE 1 X 3 CM SOURCE, 100 mA D-Li AND 170 mA T-H2O, 35 & 21 MeV, respectively.

CIERJACKS AND MANN (WHC) EXCHANGED DATA BASES AND CODES.

BECAUSE OF DIFFICULTY IN INTERPRETING DATA, MANN STARTED FROM SCRATCH FOR T-H REACTION.

MANN'S RESULTS SUPPORTED CIERJACKS' CALCULATIONS, SO LATTER WERE USED AS CONSISTENT SET FOR BOTH SOURCES.

GREENWOOD (PNL) COMBINED DISPLACEMENT AND HELIUM CROSS SECTIONS WITH KFK CALCULATED SPECTRA AT SELECTED NUMBER OF POINTS FOR BOTH SOURCES. CROSS SECTIONS ABOVE 20 MEV ARE REASONABLE EXTRAPOLATIONS.

DORAN (WSUTC/PNL) ESTIMATED THE FLUX VOLUME AND THE TEST VOLUME MEETING CERTAIN CRITERIA:

DISPLACEMENT RATE > 10 DPA/FPY (2.5 FOR CARBON)
HE/DPA RATIO WITHIN FACTOR OF 2 OF FIRST WALL VALUE

<u>D-LI VS. T-H_2O NEUTRONICS COMPARISON</u> (CONTINUED)

VOLUME ESTIMATED AS FOLLOWS:

(DEUTERON BEAM IN X DIRECTION, LI FLOW IN Z DIRECTION; UNIFORM BEAM IS IS 3 CM IN Y DIRECTION, 1 CM IN Z).

XY CONTOURS OF FLUX AND DPA WERE PLOTTED AT INTEGRAL VALUES OF Z (USUALLY 0, 1, 2, AND 3 CM) AND AREAS MEASURED.

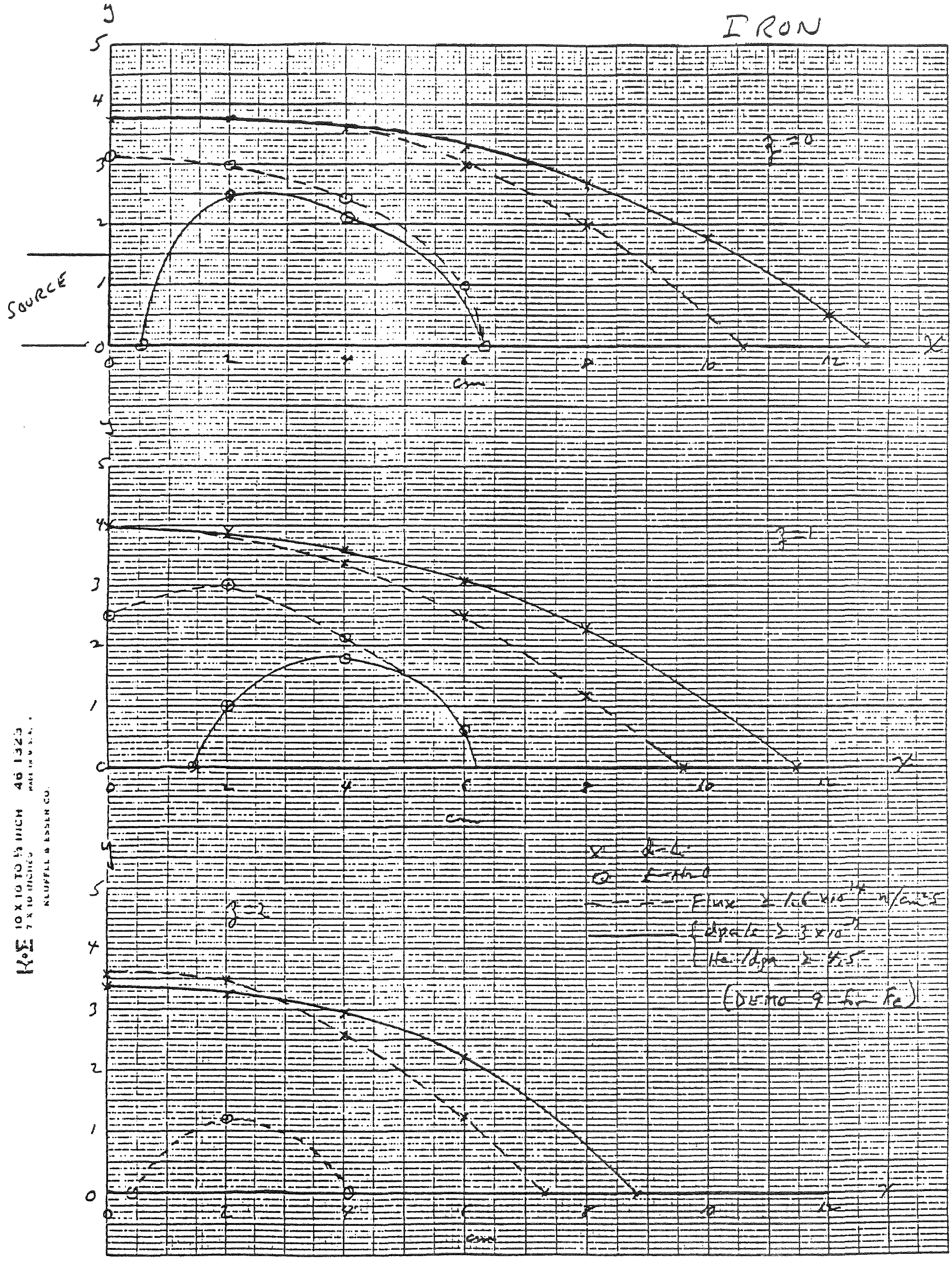
A CURVE FIT TO AREA(Z) WAS INTEGRATED NUMERICALLY TO ESTIMATE VOLUME FOR EACH PARAMETER.

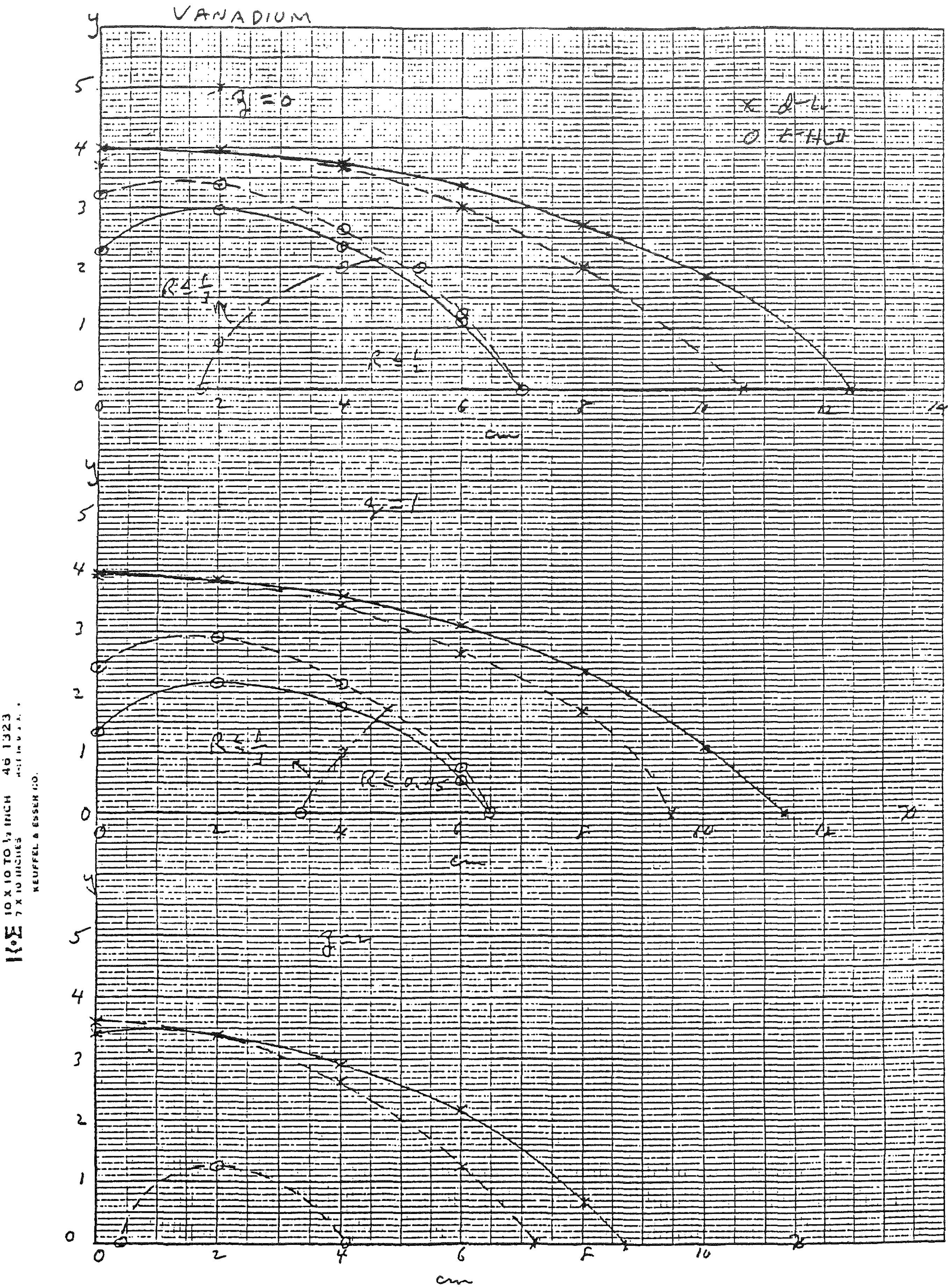
"LIMITED VOLUMES" ARE THOSE WHICH MEET THE LIMITS IMPOSED ON THE DAMAGE PARAMETERS.

DONE FOR THE FOLLOWING ELEMENTS: C, SI, FE, V

> (TUNGSTEN CALCULATIONS INDICATE T-H_2O SPECTRA ARE TOO SOFT TO MEET HE/DPA LIMIT)

RESULTS (SUMMARIZED IN TABLE): TEST VOLUME IN D-Li (100 mA) AT LEAST TWICE THAT IN T-H_2O (170 mA); LARGER FACTOR IF COMPARED AT EQUAL CURRENTS.


IRON
SOURCE
cm
Flux = 1.6 x10^14 n/cm²s
dpa/s = 3 x10^-7
He/dpa = 4.5
(DEMO 9 for Fe)


VANADIUM
y
cm
R ≤ 1/2
R ≤ 0.45

SUMMARY OF FLUX-VOLUME & DAMAGE PARAMETER-VOLUME ESTIMATES BY DORAN
FLUX-SPECTRA BY CIERJACKS; DAMAGE PARAMETERS BY GREENWOOD

ELEMENT	(1) LOWER LIMIT DPA/S	T-H2O (170 mA) (2) R RANGE	T-H2O (170 mA) VOL. CM^3	D-Li (100 mA) (2) R RANGE	D-Li (100 mA) VOL. CM^3	(3) RATIO D-Li/ T-H2O
FLUX>1.6e+14			105		269	2.6
FLUX-KfK			107		234	2.2
Fe	3.0E-07		48		310	6.5
Fe-limited	3.0E-07	0.5<R<2.0	48	0.5<R<2.0	310	6.5
C	8.0E-08	Rmax=2.2	58	Rmax=4.5	328	5.7
C-limited	8.0E-08	0.5<R<2.0	58	0.5<R<2.0	142	2.4
Si	3.7E-07		79	Rmax=2.6	303	3.8
Si-limited	3.7E-07	0.5<R<2.0	69	0.5<R<2.0	144	2.1
V	3.0E-07	Rmax=0.52	77		315	4.1
V-limited	3.0E-07	0.3<R<0.5	24	0.5<R<2.0	315	13.1
V-limited	3.0E-07	0.5<R<2.0	0	0.5<R<2.0	315	infin.

NOTES:

(1) REQUIRE DPA RATE > 9-12 DPA/FPY (2.5 FOR C), CORRESPONDING TO FLUX OF 1.6E+14 N/CM^2 IN HARDEST T-H20 SPECTRUM.

(2) R = (He/DPA)/(He/DPA)demo, i.e., NORMALIZED TO DEMO 1ST WALL.

REQUIRE R > 0.5 (BUT NOT POSSIBLE FOR VANADIUM).

(3) VOLUME RATIOS MIGHT DOUBLE IF COMPARED AT EQUAL BEAM CURRENTS.

D-LI VS. T-H2O NEUTRONICS COMPARISON (CONTINUED)

TRANSMUTATION RATES

MANN USE REAC CODE SYSTEM ON 5 ELEMENTS:

C, Si, V, Fe, AND W

FOR TWO KfK SPECTRA FOR EACH SOURCE:

(0,0,0) RELATIVELY SOFT, VERY HIGH FLUX

(4,0,0) RELATIVELY HARD, FLUX DOWN BY 10.
D-Li----50 DPA(Fe)/FPY
T-H2O---20 DPA(Fe)/FPY

TRANSMUTANTS (APPM) NORMALIZED TO DPA

CARBON

	DEMO(1)	D-Li		T-H2O	
	1st wall	0,0,0	4,0,0	0,0,0	4,0,0
DPA	50	45	12	41	6
H/DPA	0.17	59	108	0.93	1.80
He/DPA	240	522	924	97	454
Li/DPA	0.02	0.18	0.14	0.05	0.02
Be/DPA	32	76	105	39	118
B/DPA	0	55	101	0.8	1.4
C					

TRANSMUTANTS (APPM) NORMALIZED TO DPA

SILICON

	DEMO(1)	D-Li		T-H2O	
	1st wall	0,0,0	4,0,0	0,0,0	4,0,0
DPA	115	96	59	90	28
H/DPA	77	100	139	36	89
He/DPA	17	19	27	6	19
Ne/DPA	0.01	0.00	0.01	0.00	0.00
Na/DPA	0.01	0.00	0.04	0.00	0.00
Mg/DPA	17	27	39	6	19
Al/DPA	28	40	64	4	19
Si/DPA					
P/DPA	0.09	(0.01)	(0.01)	(0.01)	(0.01)

TRANSMUTANTS (APPM) NORMALIZED TO DPA

VANADIUM

	DEMO(1)	D-Li		T-H2O	
	1st wall	0,0,0	4,0,0	0,0,0	4,0,0
DPA	86	80	51	69	23
H/DPA	20	27	38	6	18
He/DPA	4.0	8.0	12	0.7	2.6
Ca/DPA		0.00	0.01	0.00	0.00
Sc/DPA		0.40	0.13	0.02	0.02
Ti/DPA	17	29	46	2	13
V					
Cr/DPA	36	(0.4)	(0.3)	(0.7)	(0.5)

TRANSMUTANTS (APPM) NORMALIZED TO DPA

IRON

	DEMO(1)	D-Li		T-H2O	
	1st wall	0,0,0	4,0,0	0,0,0	4,0,0
DPA	80	80	53	64	23
H/DPA	61	65	88	25	50
He/DPA	9	12	15	4	9
Ti/DPA	0.004	0.006	0.029	0.000	0.000
V/DPA	0.9	0.79	0.82	0.26	0.54
Cr/DPA	12	12	18	5.1	11
Mn/DPA	58	48	75	13	26
Fe					
Co/DPA	0.13	(0.00)	(0.00)	(0.00)	(0.00)

TRANSMUTANTS (APPM) NORMALIZED TO DPA

IRON	DEMO(1)	D-Li		T-H2O		5 STEPS D-Li
	1st wall	0,0,0	4,0,0	0,0,0	4,0,0	0,0,0
DPA	80	80	53	64	23	80
H/DPA	61	65	88	25	50	65
He/DPA	9	12	15	4	9	12
Ti/DPA	0.004	0.006	0.029	0.000	0.000	0.01
V/DPA	0.9	0.79	0.82	0.26	0.54	0.3
Cr/DPA	12	12	18	5.1	11	12
Mn/DPA	58	48	75	13	26	48
Fe						
Co/DPA	0.13	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

TRANSMUTANTS (APPM) NORMALIZED TO DPA

TUNGSTEN

	DEMO(1)	D-Li		T-H2O	
	1st wall	0,0,0	4,0,0	0,0,0	4,0,0
DPA	23	24	17	17	7
H/DPA	3	28	37	1	2
He/DPA	3.3	14	20	0.7	1.7
Yb/DPA	0.000	0.000	0.001	0.000	0.000
Lu/DPA	0.000	0.000	0.001	0.000	0.000
Hf/DPA	6	15	20	0.7	1.6
Ta/DPA	252	74	91	27	75
W					
Re/DPA	6522	(161)	(168)	(156)	(283)
Os/DPA	870		(0.0)	(0.2)	(0.1)

D-LI VS. T-H2O NEUTRONICS COMPARISON (CONTINUED)

RESULTS (SUMMARIZED IN TABLES)--DRAWN FROM C, Si, V, AND Fe:

D-Li: HIGH FLUX, SOFT SPECTRUM GENERALLY HIGHER (/DPA) THAN DEMO BUT PRETTY GOOD; LOWER FLUX, HARDER SPECTRUM GENERALLY EVEN HIGHER.

T-H2O: HIGHEST FLUX POSITION GENERALLY TOO SOFT; LOWER FLUX, HARDER SPECTRUM GENERALLY GOOD BUT STILL SOFT FOR HELIUM IN VANADIUM.

HIGH HYDROGEN (AND BORON) PRODUCTION IN CARBON, ESPECIALLY WITH D-Li.

TUNGSTEN SHOWS HIGH GAS PRODUCTION/DPA IN D-Li AND LOW PRODUCTION IN T-H2O SPECTRA; HOWEVER, TUNGSTEN GAS PRODUCTION CROSS SECTIONS MAY HAVE LARGE UNCERTAINTIES.

RATIO OF INITIAL HELIUM PRODUCTION RATES (APPM/S)
TO DISPLACEMENT RATES (DPA/S)----GREENWOOD 1992

	DEMO(1)	D-Li		T-H2O	
	1st wall	0,0,0	4,0,0	0,0,0	4,0,0
CARBON	290	625	1039	84	421
SILICON	27	33	43	16	36
VANADIUM	3	5	6	1	1.8
CHROMIUM	14	13	18	2.2	6.6
IRON	8.7	9.5	12.2	3.4	8.1
NICKEL	31	35	40	23	38
COPPER	5.1	7.5	9.5	2.8	6.6
NIOBIUM	2.0	1.80	2.3	0.7	1.7
TUNGSTEN	0.90	5	6.3	0.2	0.3

Neutron Source Comparisons

Conclusions to date:

1. Beam-plasma best but not "nearest-term".
2. Spallation no relative advantages; less advanced than d-Li.
3. t-H2O has advantages of no neutrons > 15 MeV
   Better simulation of damage parameters for some elements than d-Li.
4. d-Li provides significantly greater test volume than t-H2O at equal beam power.
5. 35 MeV d-Li spectra overly hard for some elements. Should investigate 30 MeV as operating option.
6. Differences in laboratory gas production cross secton files not believed to compromise comparisons, but clarification well be sought.

Test Matrices/Volumes

Must begin with assumptions. General agreement on:

1. Tasks to be done
   - Lifetime tests of ITER materials
   - Calibrate/validate fission reactor data
   - Devleopment of new mateials
   - Engineering data base for DEMO

2. DEMO data base requires largest test volume.

3. "2-stage" approach has advantaqges:
   - 1st stage provides facility concept verification
   - 1st stage provides operating experience
   - Upgradeable facility easier to sell.

4. 10 l $\gtrsim$ 2 MW/m^2 nice but not necessary
   (FFTF/MOTA ~2.5 l in core)

5. International accelerator-based sorce requires international irradiation program.

Not General Agreement on:

1. Required specimen sizes.
2. Demo integrated exposures.

Test Matrices /Volumes (cont.)

Approaches:

1. Review previous test matrices, including FMIT.
   FMIT of marginal size.
2. Qualitative description of use of intermediate (stage 1) source, followed by larger source (stage 2).
   No volume estimate but stage 1 assumed to be 50 - 100 mA d-Li facility. ($\lesssim$100 cm^3 above 10 dpa/yr).
3. Quatnitative estimate of number and volume of specimens for DEMO data base.

   Using miniaturized specimens currently used in US program, specimen volume ≈200 cm^3 per material. Implies calculated <u>test</u> volume of ≈800 cm^3.

   Could be much larger if larger sepecimens required.

   Specimen size largest uncertainty in volume estimates - - needs to be resolved.

Test Matrices/Volumes (cont.)

Conclustions:

DEMO Design requires neutron source test

volume of at least several hundred cm^3
giving ≥ 20 dpa (Fe)/yr.

More volume needed of "standard" miniaturized specimens not acceptable and large specimens cannot be irradiated in fission reactors.

Accelerator-based source meeting alloy test volume needs will meet insulator test volume needs also.

A 250 mA d-Li source provides (uncollided volume):

> 5 dpa/FPY	~ 300 cm3
> 20 dpa/FPY	~ 400 cm3
≥ 50 dpa/FPY	~ 100 cm3

The Possibilities for a Staged Approach in the Development of Intense Neutron Sources

A. Miahara

Teiko University

The Possibilities for a Staged Approach in the Development of Intense Neutron Source

A. Miyahara

Teikyo University, Tokyo 192-03, Japan

Explore the Possibility of a Staged Approach

ESNIT	→	IFMIFM-1	→	IFMIF-2
10-40Mev		35Mev		35Mev
50mA		250mA		250mA×2

ESNIT → IFMIF-1

Current Reduction through

Low Duty Cycle ?

Impact to Material Research

is Significant ?

IFMIF-1 ⟶ IFMIF-2

Higher Frequency DTL is Desirable

Higher Frequency is Adoptable

for ESNIT ?

Further Stage of IFMIF

35Mev 1A

D^- Acceleration ?

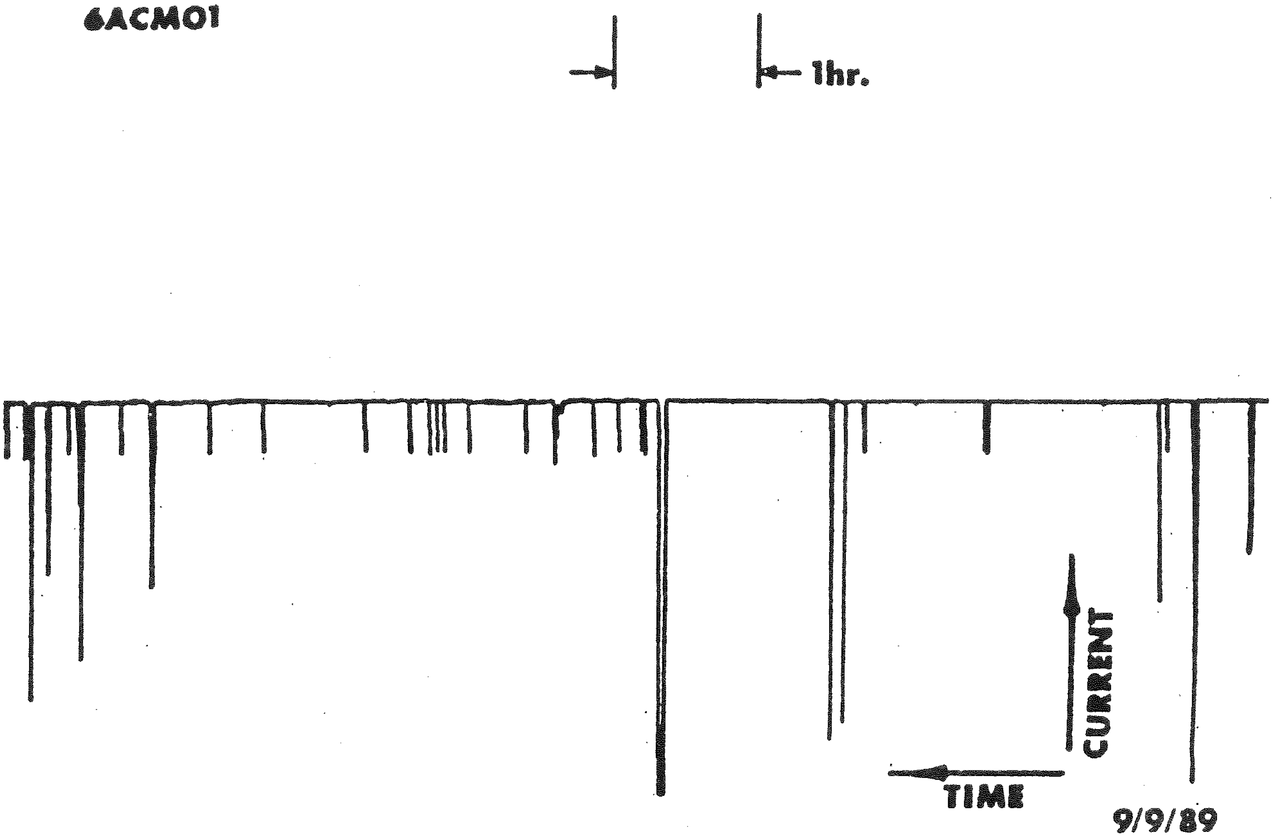


図１．プロトンビームの時間変化の例（マクロスケール）

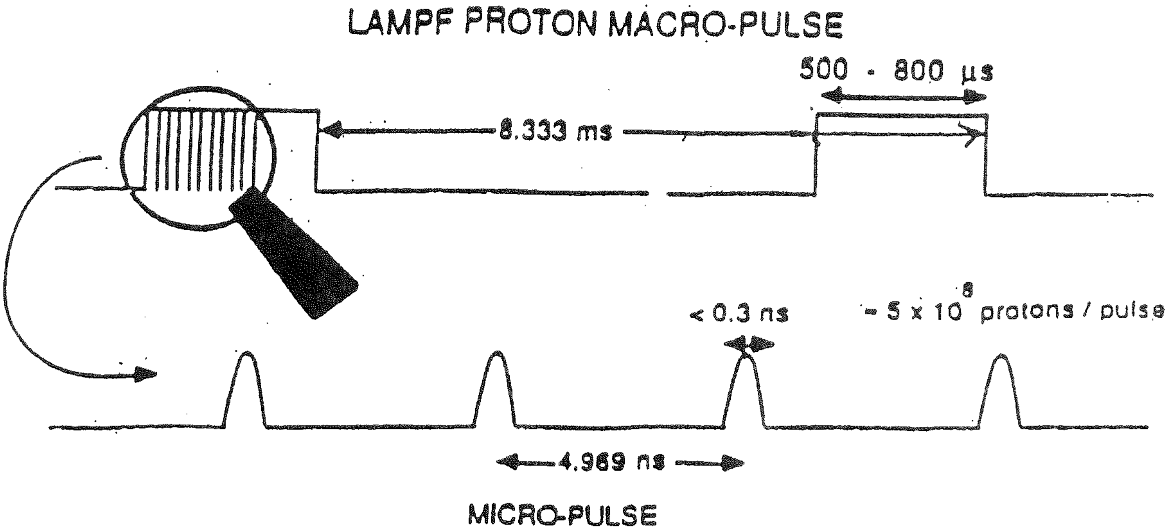


図２．プロトンビームの時間変化（ミクロスケール）

After T. Muroga

High Frequency Klystron is Longer Life

compare to Tetrode

Other Merit to Move to High Frequency

Operation

THE WAY TO THE STAGED APPROACH CAN BE CATEGORIZED IN (1) AND (2) THE CRITERIA ARE AS FOLLOWS:

(1) IF WE RECOGNIZE THE ESNIT TO BE BUILT AS A RELIABLY RUNNING ACCELERATOR WITH HIGH CURRENT, CW OPERATION IS ALREADY A CHALLENGING TASK. THE ENGINEERING DESIGN SHOULD BE TO OPTIMIZE THE ORIGINAL REQUIREMENTS OF MATERIALS RESEARCH WITH CONSIDERATIONS TO OBTAIN THE PHYSICS AND ENGINEERING DATABASE FOR IFMIF.

(2) IF WE JUDGE PHYSICS AND TECHNOLOGIES FOR THE ESNIT ARE SUFFICIENTLY RIGID, WE CAN BUILDTHE MACHINE AS A LOWER CURRENT VERSION OF IFMIF ACCELERATOR ALTHOUGH PROBLEM REMAINS AS TO HOW TO REDUCE THE CURRENT.

THE ESSENTIAL POINT IS, THE ESNIT IS NO LONGER A PAPER PLAN BUT TO CONSTRUCT A REAL RUNNING MACHINE. ALTHOUGH MANY EFFORTS HAVE BEEN DONE BY AECL-CHALK RIVER, LANL AND KEK TO ESTABLISH HARDWARE DATABASE FOR ESNIT ACCELERATOR COMPONENTS, BUT STILL WORLD WIDE COLLABORATIONS ARE NEEDED TO COMPLETE THE ENGINEERING DESIGN OF THE ESNIT ACCELERATOR.

EACH COMPONENT MUST BE EVALUATED CRUCIALLY FROM THE STANDPOINT OF RELIABLE CW OPERATION WITH LONG LIFETIME. IT WILL REQUIRE CHECKING THE DATABASE OBTAINABLE NOT ONLY FROM ACCELERATOR AND FUSION COMMUNITIES BUT FROM OTHER RELATED FIELDS.

STATUS OF DATABASE FOR THE ESNIT ACCELERATOR

	SOFTWARE PROPOSAL/ DESIGN	HARDWARE R&D	PROBLEM AREA	ACHIEVEMENT WITHIN 3 YEARS	REMARKS
ION SOURCE	○	○	FILAMENT LIFE	X	MICROWAVE SOURCE
RFQ	○	(CHALK RIVER) ○	HIGH CURRENT	○	
DTL	○	○	FOCUSING MAGNET	○	ALSO ACTIVATION
RF POWER SOURCE — TETRODE	○	X	LONG LIFE CW/HIGH P	?	
RF POWER SOURCE — KLYSTR.	X	○		○	
RF TRANSDUCER		X	OXIDATION	○	
LEBT	○	X		?	ION SOURCE
HEBT	○	X		?	
TEMPERATURE CONTROL/COOLING	ESTABLISH SPECIFICATION		COMPREHENSIVE SYSTEM DESIGN	○	UTILIZATION OF WASTE HEAT
ACTIVATION OF ACCELERATOR	X	HONEYCOMB ALUMINIUM	ACTIVATION FOR WIDE NEUTRON ENERG.SPECTRUM	?	
FUNNELING					