Materials Assessment Meeting
Karlsruhe, 5-8 June 2001

Irradiation Devices and Testing
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Content:
- Major European Irradiation Facilities
- Long Term Strategy
- IFMIF Project
- Comparison of irradiation properties
- Small Specimen Test Technology

This file contains a cutout of the total presentation.
International Fusion Strategy

ITER

Design
Construction
Operation

DEMO

Design
Construction
Operation

PROTO

Data base development
incl. Fiss. React. irradi.

Ref. Material 10 dpa

Ref. Material for DEMO (70 dpa)

High Performance Material

RA-FM-Steels

Materials

Alternative Materials
V-alloys
SiC/SiC Composites
Ti, Cr-alloys

Critical issues
Technology Development
Fission Reactor Irradiation

Data validation in Fusion Environment

High Performance Materials for PROTO (150 dpa)

Fission Reactors

IFMIF-CDE
(staged Approach)

EDA + Constr.

Phase I
(50 mA)

Phase II
(125 mA)

Full Operation
(2 x 125 mA)

KEP

0 10 20 30 40
years

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Why do we need a dedicated International Fusion Materials Irradiation Facility?

- Existing irradiation facilities only partly fulfill the needs for materials development for DEMO reactors (≈150 dpa):
  - Fission reactors: large irradiation volumes, appropriate n-flux, but n-spectrum not adequate
  - Accelerators (e.g. p, He): appropriate dpa & gas production rates, favorable conditions for in-situ tests, but small volumes

- ITER testing is limited because fluence accumulation is restricted to ≤10 dpa and the mode of operation is very different from DEMO (e.g. low temperature, strongly pulsed operation)

  However, it is a valuable test bed for integral testing of components like TBM’s in the low fluence regime.

- There is presently no irradiation source that combines
  - fusion similar spectrum
  - high fluence for accelerated materials testing
  - sufficiently large test volume
International Fusion Materials Irradiation Facility
IFMIF

Mission:

(i) Qualification of candidate materials up to about full lifetime of anticipated use in a fusion DEMO reactor

(ii) Calibration and validation of data generated from fission reactors and particle accelerators

(iii) Identify possible new phenomena which might occur due to the high energy neutron exposure
D-Li Stripping Neutron Source

Typical Reactions:
- $^7\text{Li}(d,2n)^7\text{Be}$
- $^6\text{Li}(d,n)^7\text{Be}$
- $^6\text{Li}(n,T)^4\text{He}$

Deuterons:
- 32, 36, 40 MeV
- 2x 125 mA
- Beam footprint 5x20 cm$^2$

Liquid Li Jet

High flux (>20 dpa, 0.5 L)
Medium flux (20-1 dpa, 6 L)
Low flux (<1 dpa, >8 L)

Ion Source → RFQ → Drift Tube Linac → Deuteron Accelerator Region → Test Cell
Requirements for an Intense Neutron Source
(IEA-Workshop in San Diego 1989)

1. **Neutron flux/volume relation:** Equivalent to 2MW/m² in 10 L volume
   
   \[1 \text{ MW/m}^2 \equiv 4.5 \times 10^{17} \text{ n/m}^2\text{s; } E = 14 \text{ MeV, } 3 \times 10^{-7} \text{ dpa/s for Fe}\]

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

3. **Neutron fluence accumulation:**
   
   Demo-relevant fluence 150 dpa_NRT in few years

4. **Neutron flux gradient:** \(\leq 10\%/\text{cm}\)

5. **Machine availability:** 70%

6. **Time structure:** Quasi continuous operation

7. **Good accessibility** of irradiation volume for experiments & instrumentation

\(1 \text{ MWy/m}^2 \equiv 10 \text{ dpa}_{\text{NRT}} \text{ for Fe}\)
Charakterization of PKA spectra

IFMIF High Flux Test Module

DEMO-relevant PKA spectra can be perfectly adjusted with neutron moderators & reflectors
Sensitivity of damage to PKA spectra

Comparison of different neutron sources

IFMIF (hatched area) meets perfectly the conditions of DEMO-reactor blankets.
Helium and DPA Production

*preliminary calculation
(Filges, Haft)
## Damage and Transmutation Calculations

3D MCNP-code calculations based on collided neutrons in Fe and detailed geometrical models

<table>
<thead>
<tr>
<th>Irradiation parameter</th>
<th>ITER*</th>
<th>DEMO*</th>
<th>IFMIF HFTM**</th>
<th>IFMIF MFTM***</th>
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<tbody>
<tr>
<td>Total neutron flux</td>
<td>$4 \times 10^{14}$</td>
<td>$7.1 \times 10^{14}$</td>
<td>$4 \times 10^{14} - 10^{15}$</td>
<td>$3.8 \times 10^{14}$</td>
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<td>Hydrogen production</td>
<td>445</td>
<td>780</td>
<td>1000 - 2500</td>
<td>300</td>
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<td>Helium production</td>
<td>114</td>
<td>198</td>
<td>250 - 600</td>
<td>78</td>
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<tr>
<td>Damage production</td>
<td>10</td>
<td>19</td>
<td>20 - 55</td>
<td>9</td>
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<td>H/dpa ratio</td>
<td>44.5</td>
<td>41</td>
<td>35 - 50</td>
<td>33</td>
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<tr>
<td>He/dpa ratio</td>
<td>11.4</td>
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<td>9.5 - 12.5</td>
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<tr>
<td>Nuclear heating</td>
<td>10</td>
<td>22</td>
<td>30 - 55</td>
<td>9</td>
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<td>Wall load</td>
<td>1.0</td>
<td>2.2</td>
<td>3 - 8</td>
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* Outboard blankets  ** Dependent on the exact position inside the HFTM  ***Presently improved
3D MCNP-code calculations based on collided neutrons in Fe and detailed geometrical models

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- Correct scaling of H, He and dpa production in all facilities
- IFMIF: Accelerated irradiation in limited volume
Comparison of different neutron spectra

[Diagram showing neutron flux versus neutron energy for different sources: DEMO fusion reactor, HFR Petten, IFMIF HFTM, IFMIF MFTM.]
Neutron spectra in high flux region

Neutron flux density \([10^{10} \text{ s}^{-1} \text{ cm}^{-2} \text{ MeV}^{-1}]\)

Neutron energy [MeV]

CDA-Design (1996)
KEP-Design (2001)
DEMO fusion reactor

IFMIF High Flux Test Module
Neutron spectra improvement: Substantial progress has been achieved very recently.

High and medium flux volumes can be irradiated practically under DEMO reactor conditions.
PKA spectra

$^{56}\text{Fe}$

$d\sigma/dT$ [barn/eV]

PKA energy

- IFMIF High Flux Test Module
- Fusion Demo Reactor (HCPB)
- Fast Reactor (Phenix)
- High Flux Fission Reactor (Petten)
Baseline design concept:
- Gas coolant systems for all test modules
- Modular and highly flexible
- Easy user access
- Capacity for upgrades
IFMIF

Model of Li-Target and Test Assemblies

[Diagram showing a model of Li-Target and Test Assemblies with labeled parts: Shield, Test Assembly, Vertical Test Assembly, Lithium Flow, and Deuterium Beam.]
IFMIF  High Flux Test Module

- 27 rigs, He-gas cooled
- Individual rig temperatures (ohmic heating)
- $T_{irr}$: 300 - 1000 °C
- S Ginny:
  - 7 specimen types
  - 400-700 specimen
  - significant volume reduction (20-125 times)
DPA Distribution of High Flux Test Module

- >40 dpa/fpy
- >30 dpa/fpy
- >20 dpa/fpy
Small Specimen Test Technology (SSTT)

### Proposed specimen geometry

| TEM | ✔️ development not necessary |
| Tensile | ✔️ development completed; YS, UTS and $A_g$ independent on size; generation of material intrinsic properties. |
| Fatigue | ✔️ development almost completed at FZK; generation of material intrinsic properties; |
| Creep tube | ✗ experience under irradiation is required; potential for material intrinsic properties |
| Tension fracture toughness | ✗ Properties strongly size & geometry dependent |
| Tension crack growth | World wide efforts ongoing in US, JA, EU |
| Charpy / dynamic fracture toughness | Modelling includes presently: |
| | - Master curve shift approach |
| | - FEM modelling |
| | - Micro-toughness modelling |
| | ✔️ Charpy tests: KLST specimen has become quasi standard in IEA countries |
| | Frac. toughness tests: R&D efforts ongoing |

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Conclusions  IFIMIF

1. The availability of a dedicated neutron source is indispensable for the qualification of materials for design and safe operation of DEMO-type fusion reactors.

2. Why the accelerator based D-Li neutron source IFMIF?
   - Suitability: IFMIF meets all relevant user requirements (in contrast to earlier concepts like FMIF or ESNIT)
   - Feasibility: IFMIF is based on almost established technology and has practically no technological risk
   - The developed reference design includes detailed RAM and safety analyses and is conceived for long-term operation with an annual availability of at least 70%

3. The IFMIF conceptual design is at a level of maturity that would readily justify, on a technical basis, a positive decision towards an engineering phase.

4. SSTT is of outstanding importance for IFMIF