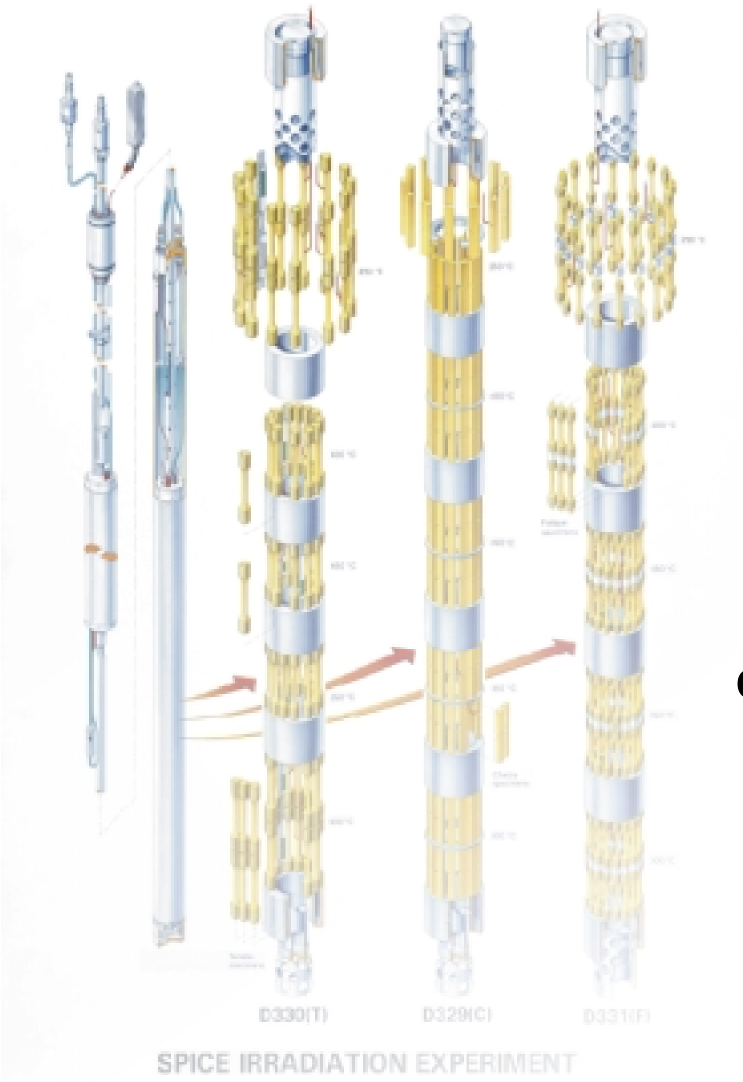


Materials Assessment Meeting

Karlsruhe, 5-8 June 2001

Irradiation Devices and Testing

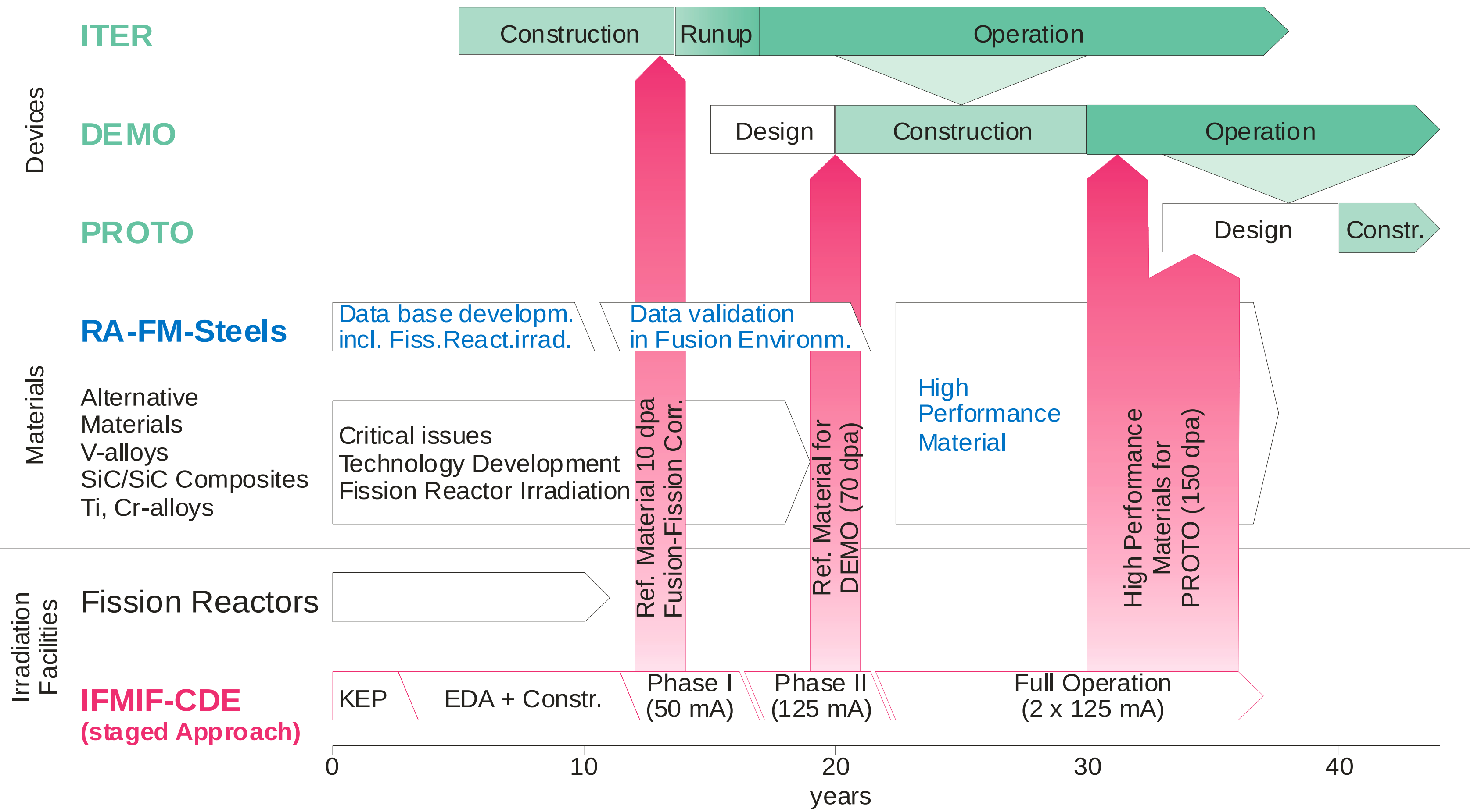
A. Möslang
Forschungszentrum Karlsruhe FZK, Germany

This file contains a cutout of the total presentation

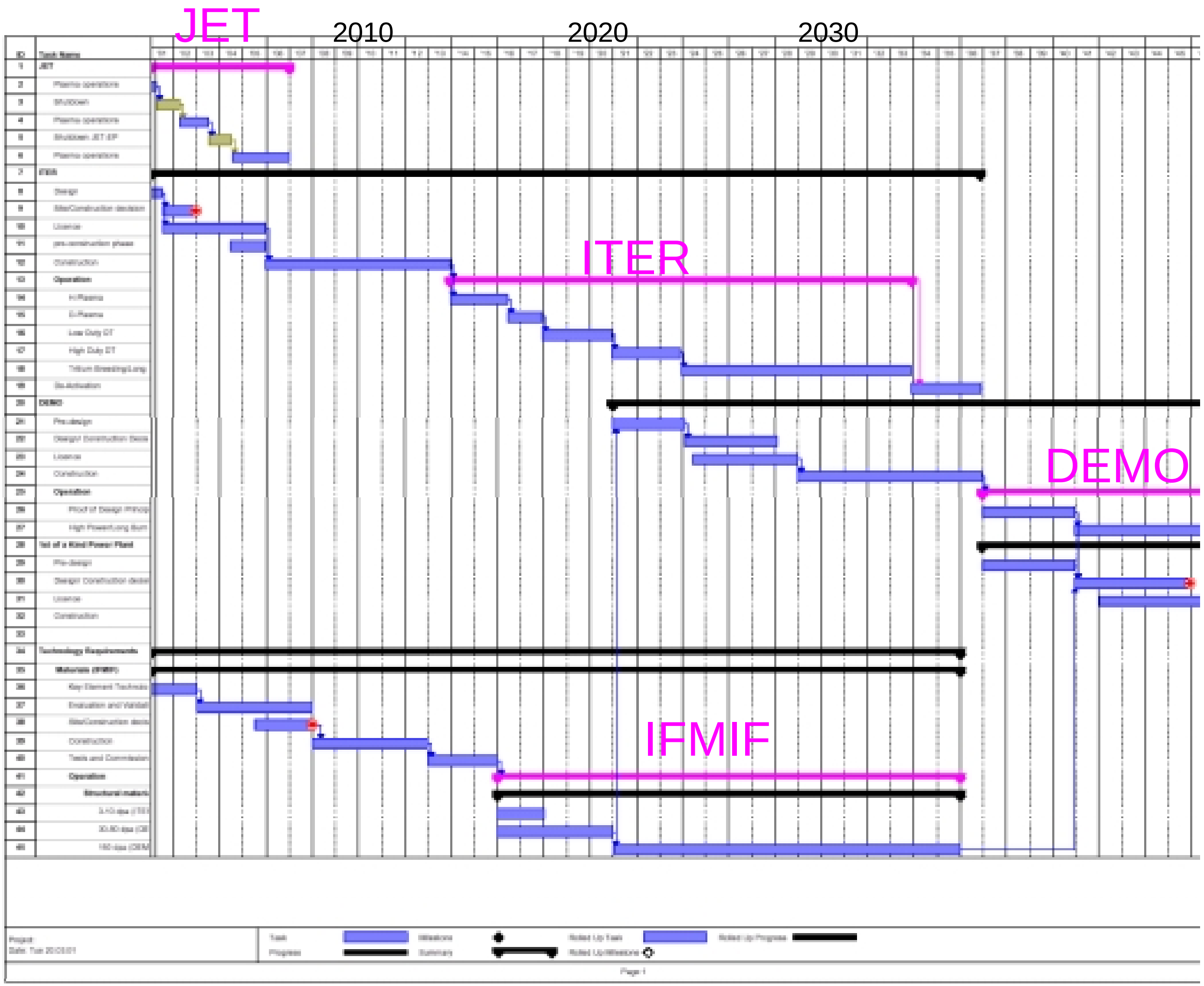
Content:

- **Major European Irradiation Facilities**
- **Long Term Strategy**
- **IFMIF Project**
- **Comparison of irradiation properties**
- **Small Specimen Test Technology**

International Fusion Strategy



International Fusion Strategy



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**

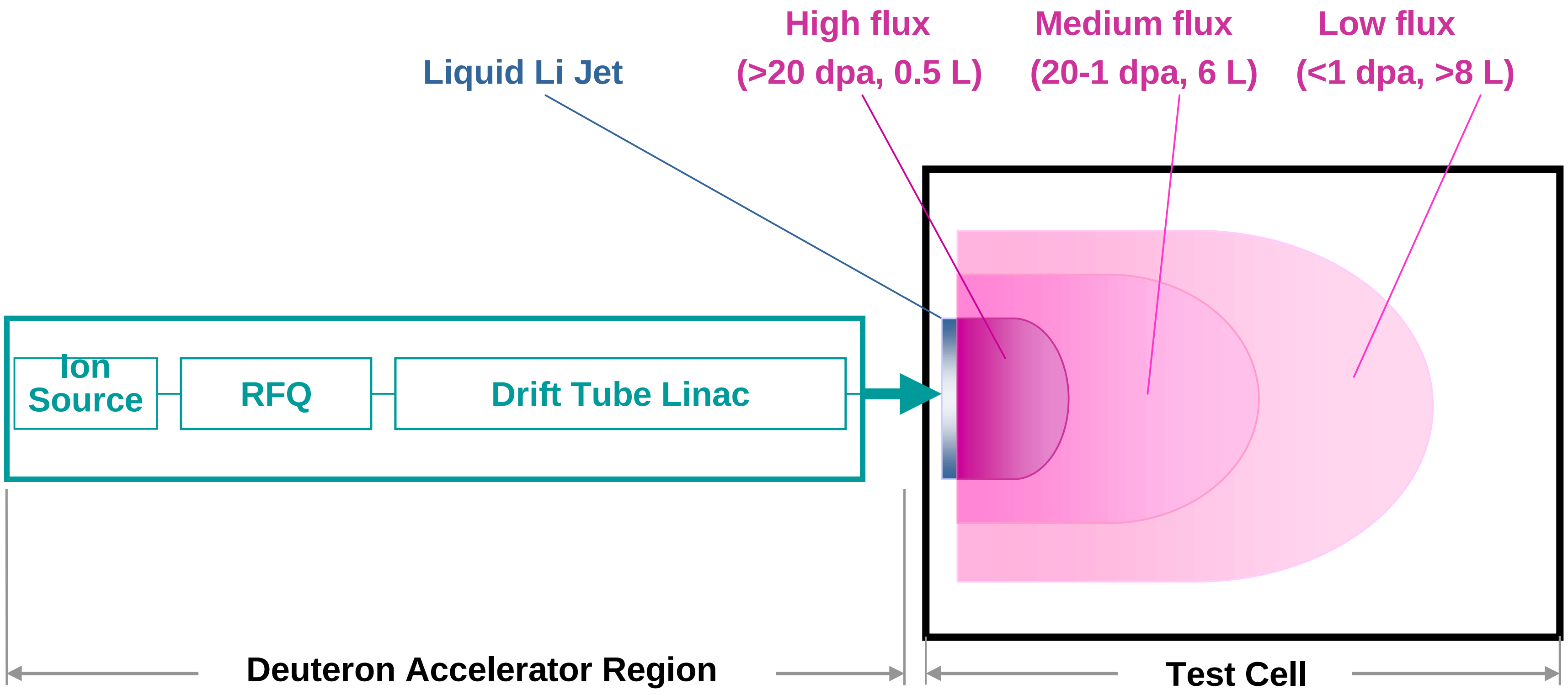
(ii) **Calibration and validation of data generated from fission reactors and particle accelerators**

(iii) **Identify possible new phenomena which might occur due to the high energy neutron exposure**

D-Li Stripping Neutron Source

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

Deuterons: 32, 36, <u>40 MeV</u> 2x 125 mA Beam footprint 5x20 cm^2



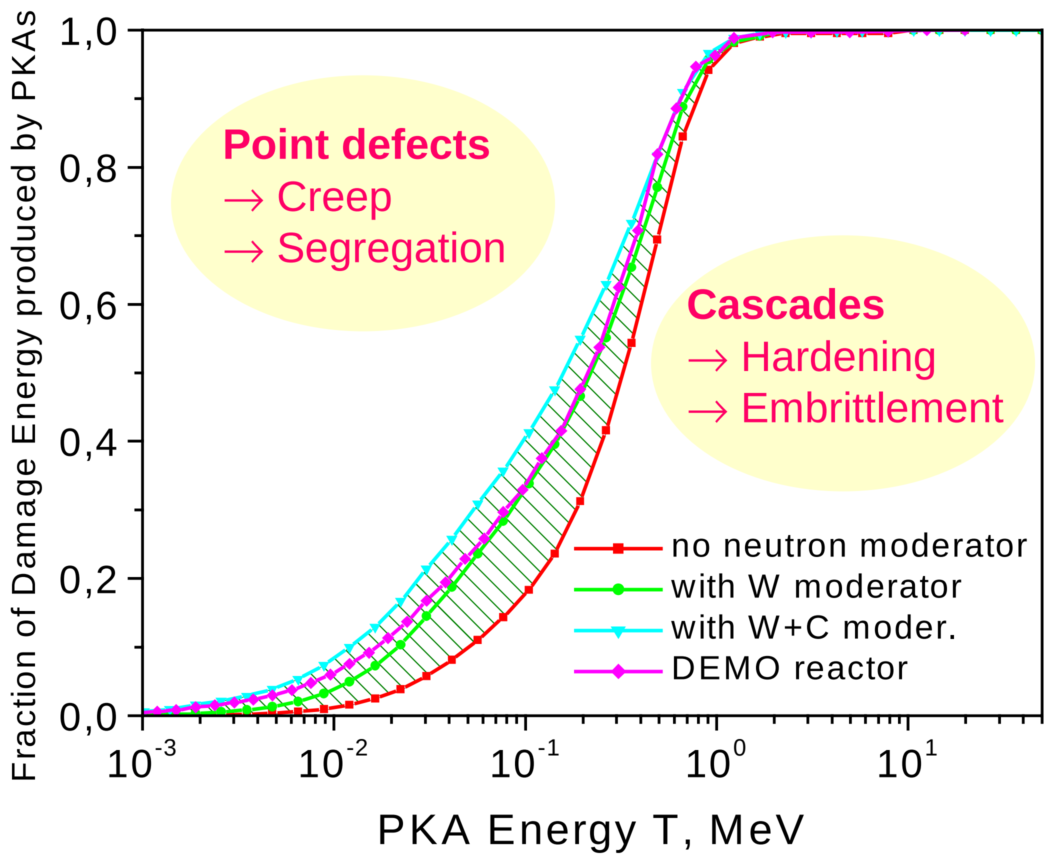
Requirements for an Intense Neutron Source
(*IEA-Workshop in San Diego 1989*)

1. **Neutron flux/volume relation:** Equivalent to 2MW/m^2 in 10 L volume
   [1 MW/m^2 $\cong$ 4.5x10^{17} n/m^2s; E = 14 MeV, 3x10^{-7} dpa/s for Fe]
2. **Neutron spectrum:**
   - Should meet FW neutron spectrum as near as possible
   - Quantitative criteria are: Primary recoil spectrum (PKA)
   - Important transmutation reactions (He, H)
3. **Neutron fluence accumulation:**
   Demo-relevant fluence 150 dpa_{NRT} in few years
4. **Neutron flux gradient:** ≤10%/cm
5. **Machine availability:** 70%
6. **Time structure:** Quasi continuous operation
7. **Good accessibility** of irradiation volume for experiments & instrumentation

1 MWy/m^2 $\cong$ 10 dpa_{NRT} for Fe

Charakterization of PKA spectra

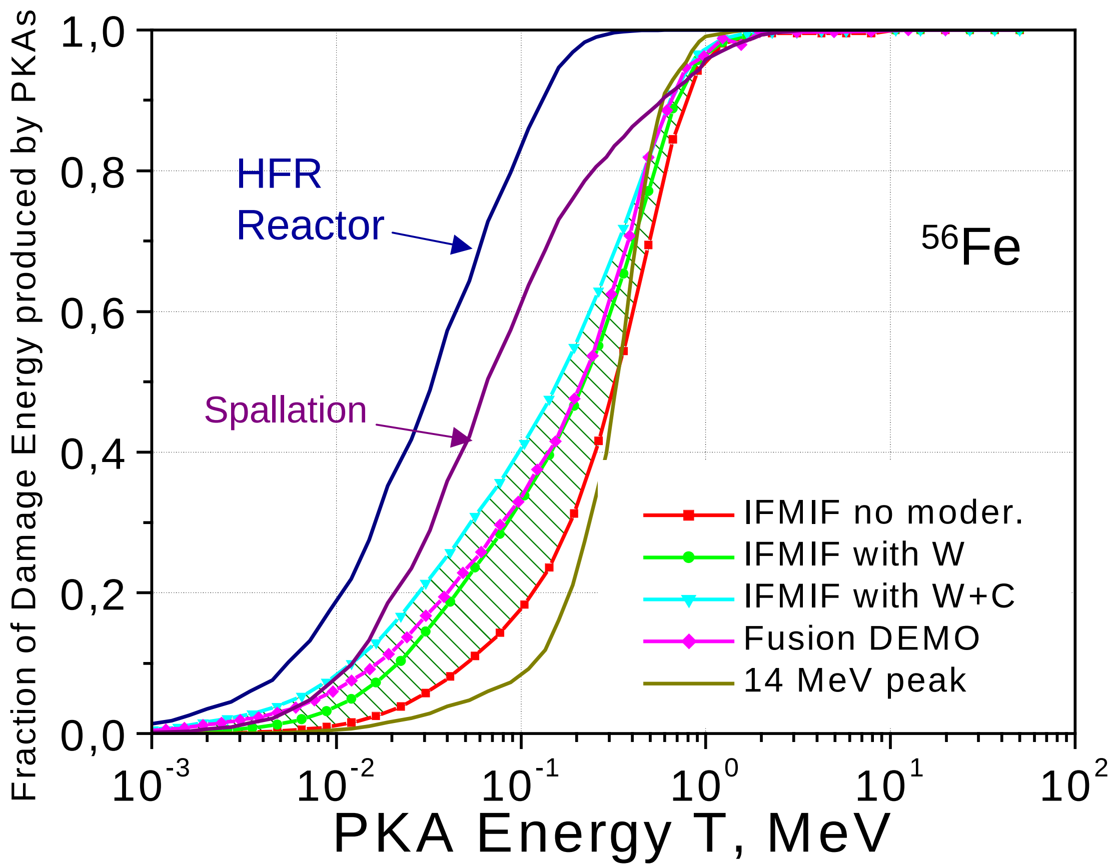
IFMIF High Flux Test Module



DEMO-relevant PKA spectra can be perfectly adjusted with neutron moderators & reflectors

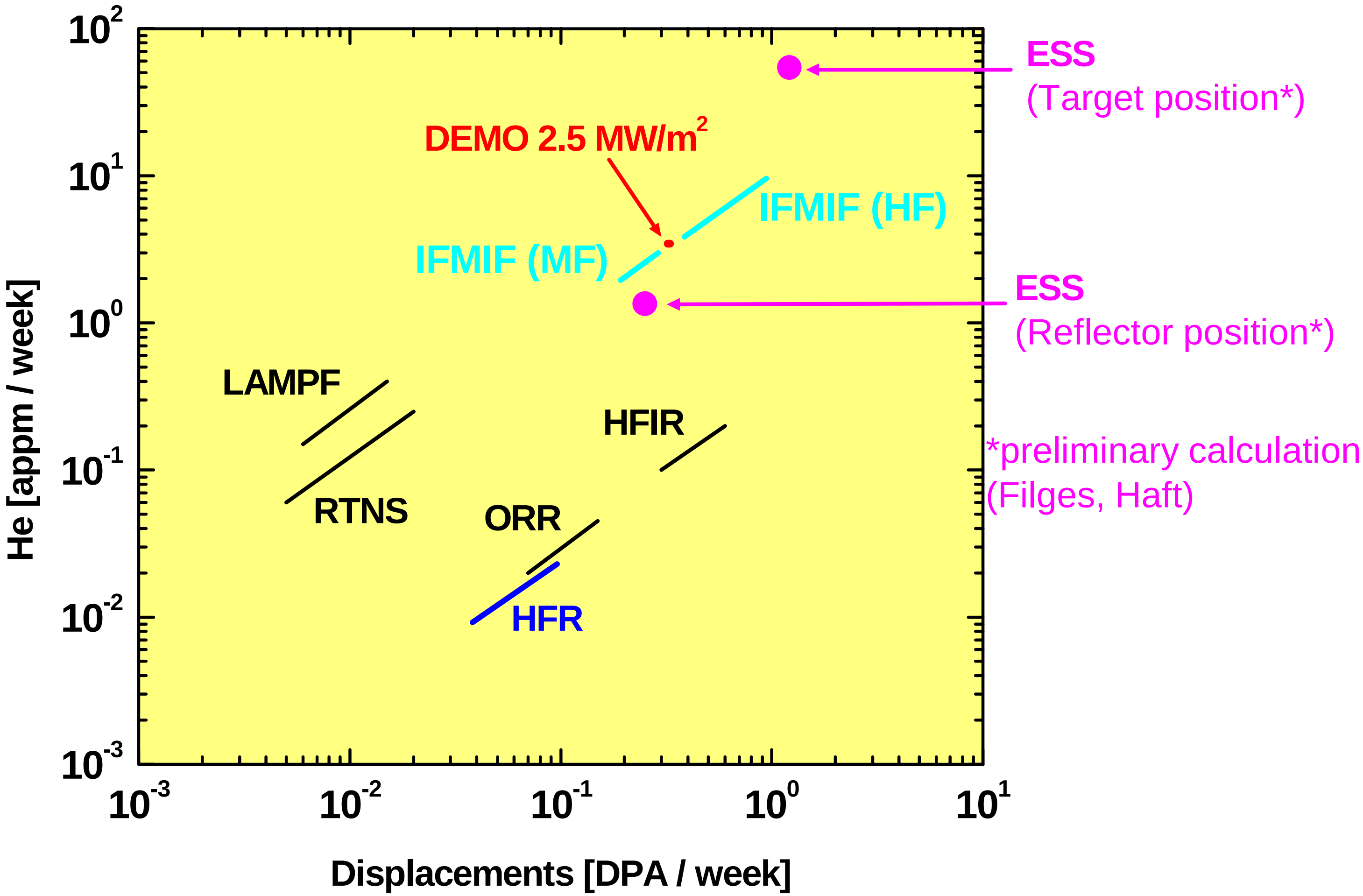
Sensitivity of damage to PKA spectra

Comparison of different neutron sources



IFMIF (hatched area) meets perfectly the conditions of DEMO-reactor blankets

Helium and DPA Production



Damage and Transmutation Calculations

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

Irradiation parameter		ITER*	DEMO*	IFMIF HFTM**	IFMIF MFTM***
Total neutron flux	[n/(s cm^2)]	4×10^{14}	7.1×10^{14}	4×10^{14} - 10^{15}	3.8×10^{14}
Hydrogen production	[appm/FPY]	445	780	1000 - 2500	300
Helium production	[appm/FPY]	114	198	250 - 600	78
Damage production	[dpa/FPY]	10	19	20 - 55	9
H/dpa ratio	[appm/dpa]	44.5	41	35 - 50	33
He/dpa ratio	[appm/dpa]	11.4	10.4	9.5 - 12.5	9
Nuclear heating	[W/cm^3]	10	22	30 - 55	9
Wall load	[MW/m^2]	1.0	2.2	3 - 8	1

* Outboard blankets ** Dependent on the exact position inside the HFTM ***Presently improved

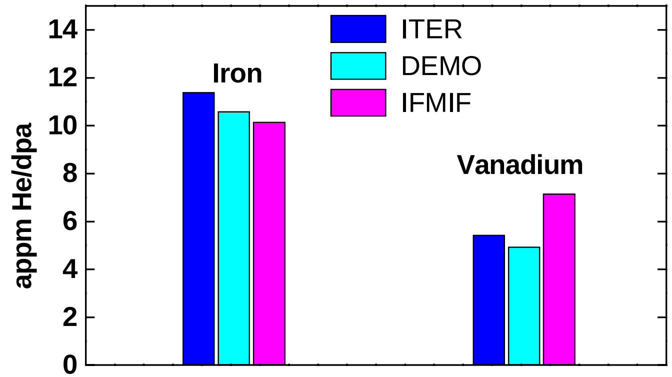
Damage and Transmutation Calculations

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

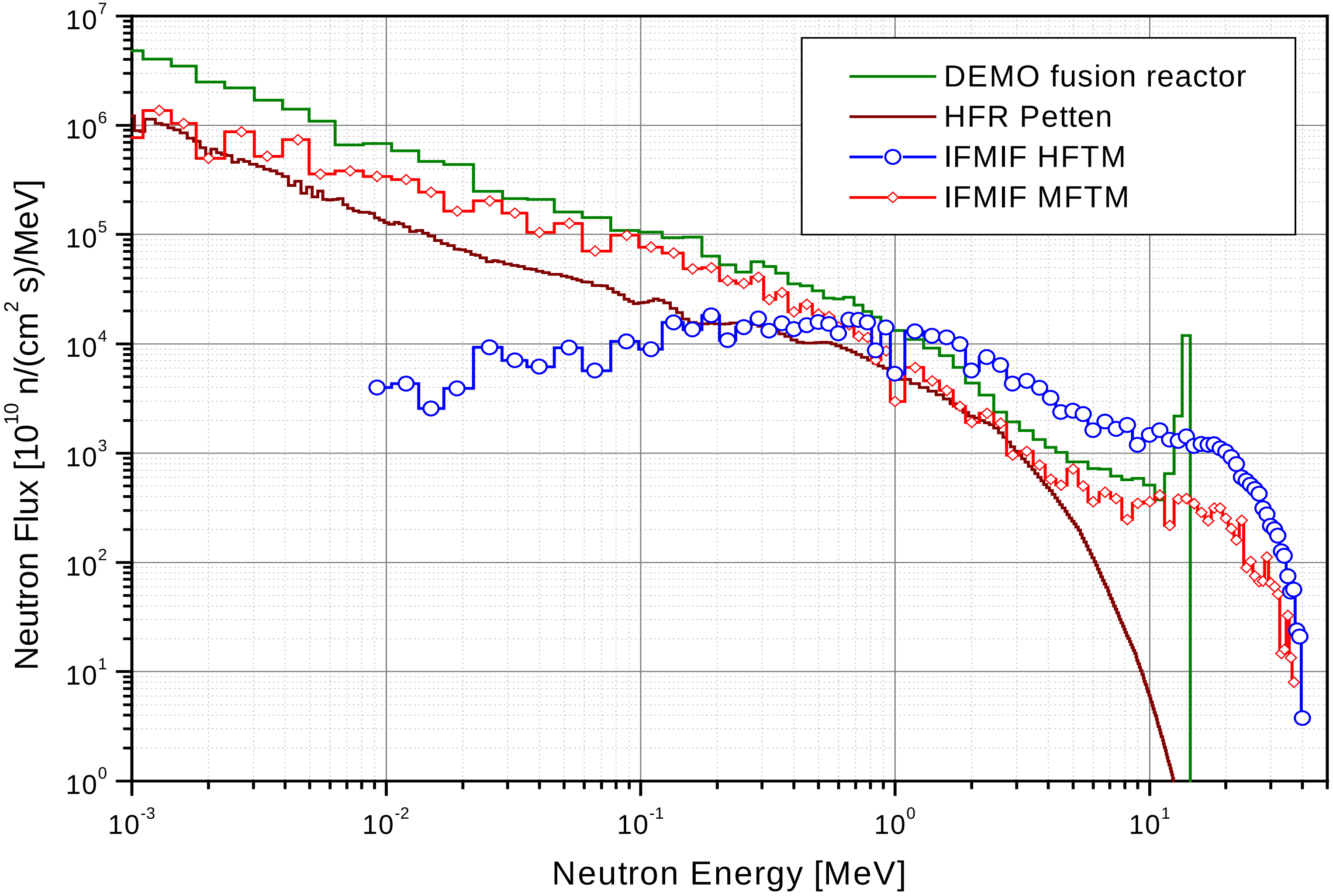
Irradiation parameter		ITER*	DEMO*	IFMIF**	GDT-NS
Total neutron flux	[n/(s cm^2)]	4×10^{14}	7.1×10^{14}	4×10^{14} - 10^{15}	5.8×10^{15}
Hydrogen production	[appm/FPY]	445	780	1000 - 2500	707
Helium production	[appm/FPY]	114	198	250 - 600	167
Damage production	[dpa/FPY]	10	19	20 - 55	14.4
H/dpa ratio	[appm/dpa]	44.5	41	35 - 50	49.1
He/dpa ratio	[appm/dpa]	11.4	10.4	9.5 - 12.5	11.6
Nuclear heating	[W/cm^3]	10	22	30 - 55	18
Wall load	[MW/m^2]	1.0	2.2	3 - 8	1.8

* Outboard blankets ** Dependent on the exact position inside the HFTM

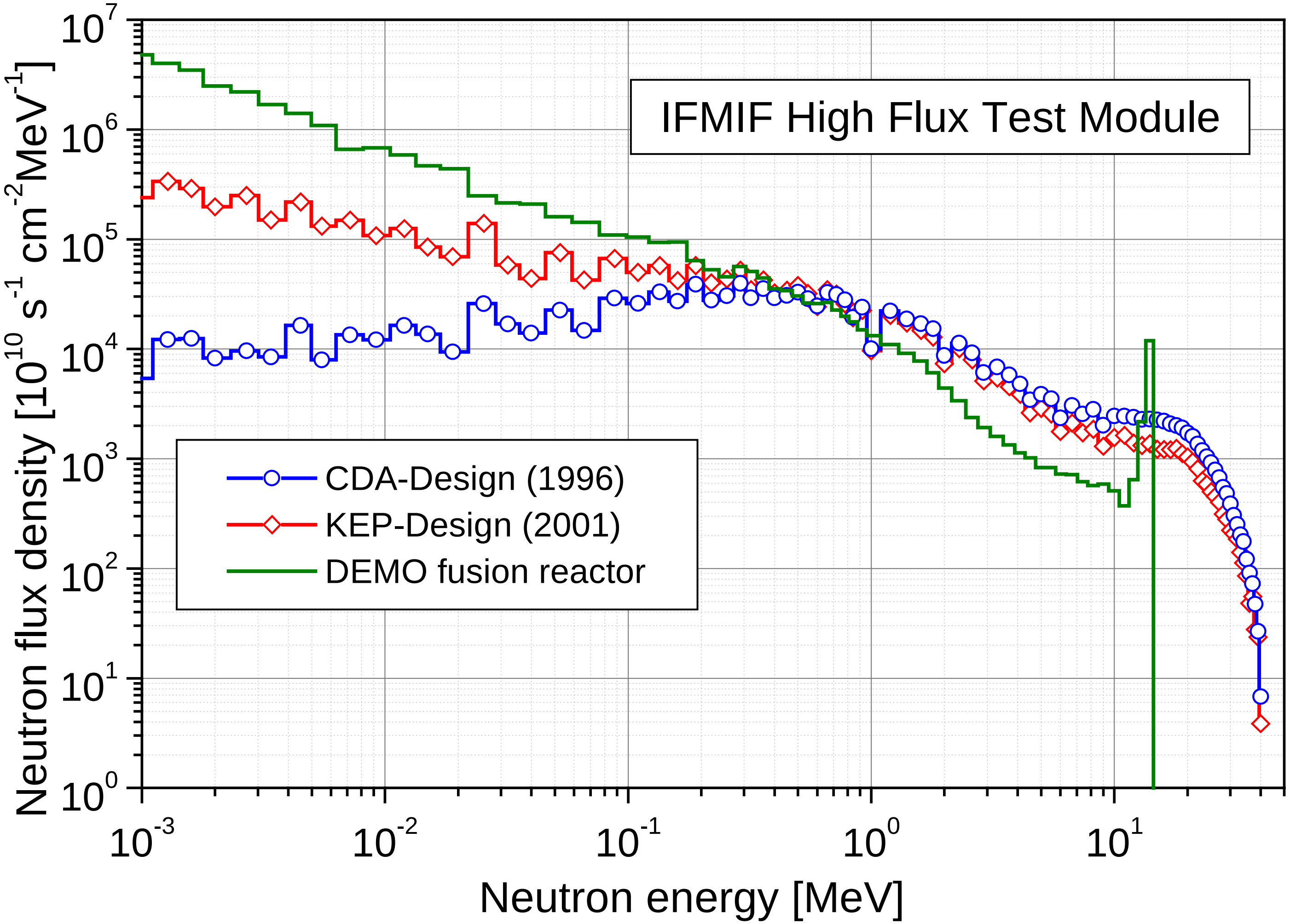
- **Correct scaling of H, He and dpa production in all facilities**
- **IFMIF: Accelerated irradiation in limited volume**



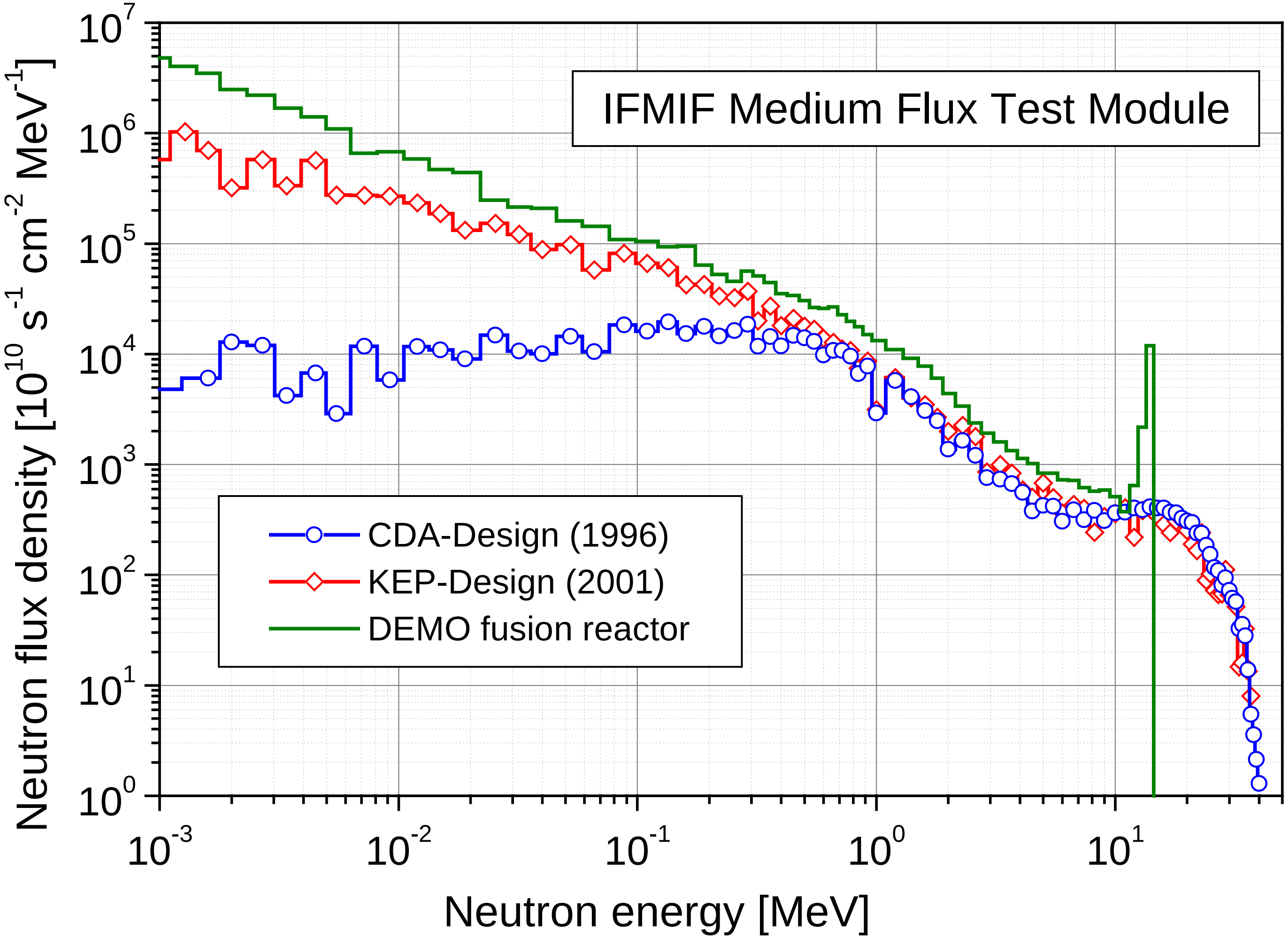
Comparison of different neutron spectra



Neutron spectra in high flux region

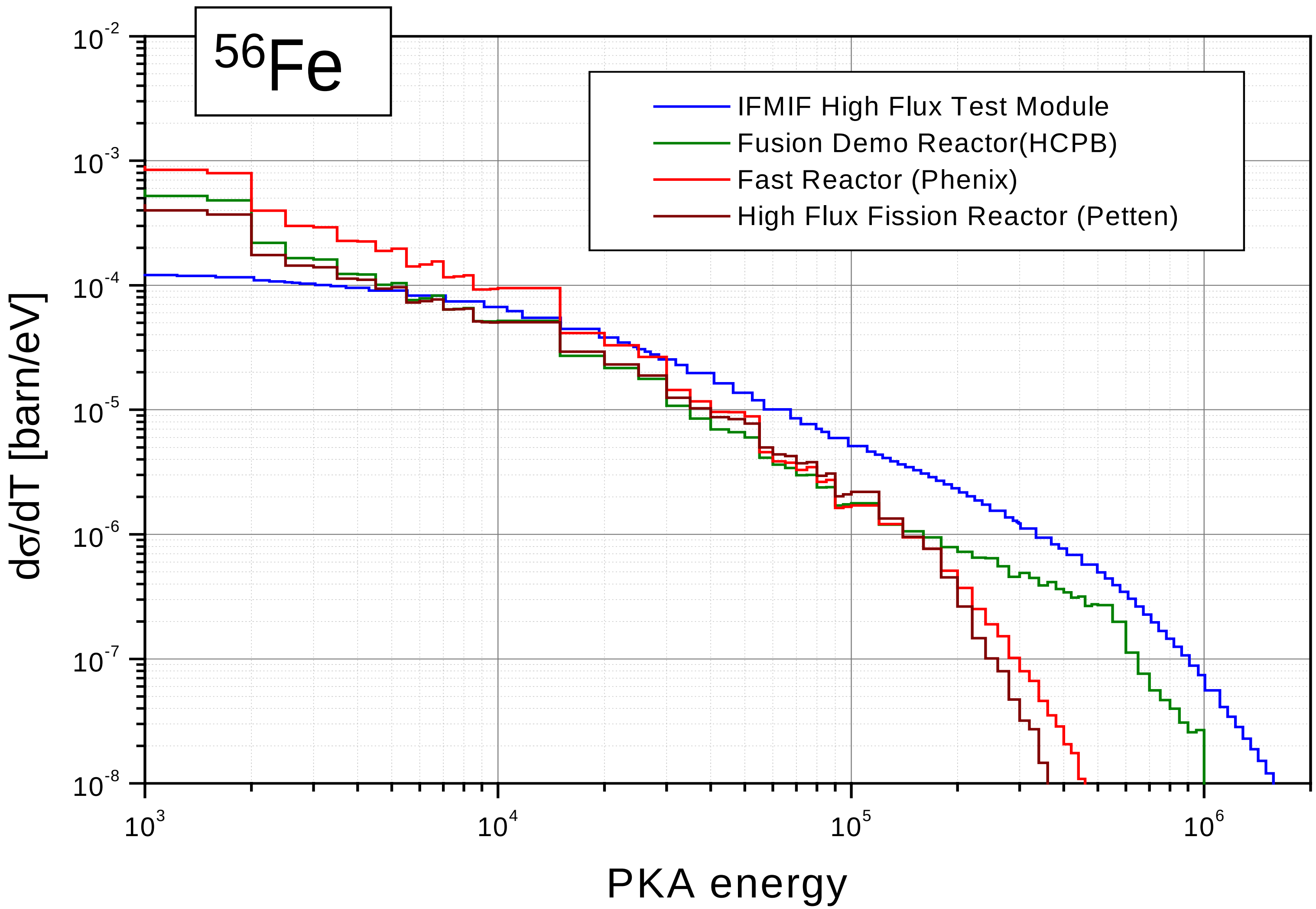


Neutron spectra in medium flux region



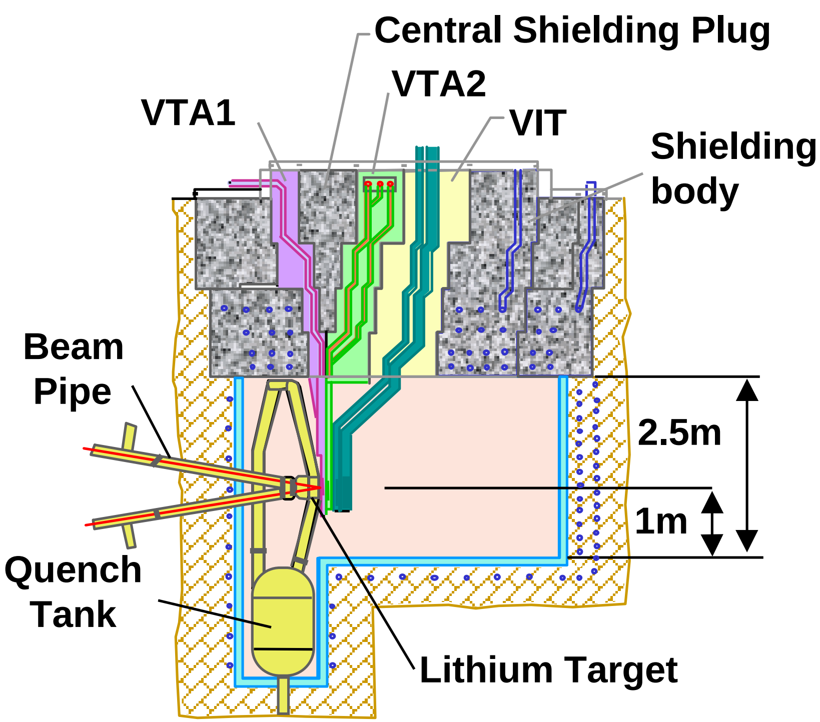
- Neutron spectra improvement: Substantial progress has been achieved very recently
- High and medium flux volumes can be irradiated practically under DEMO reactor conditions

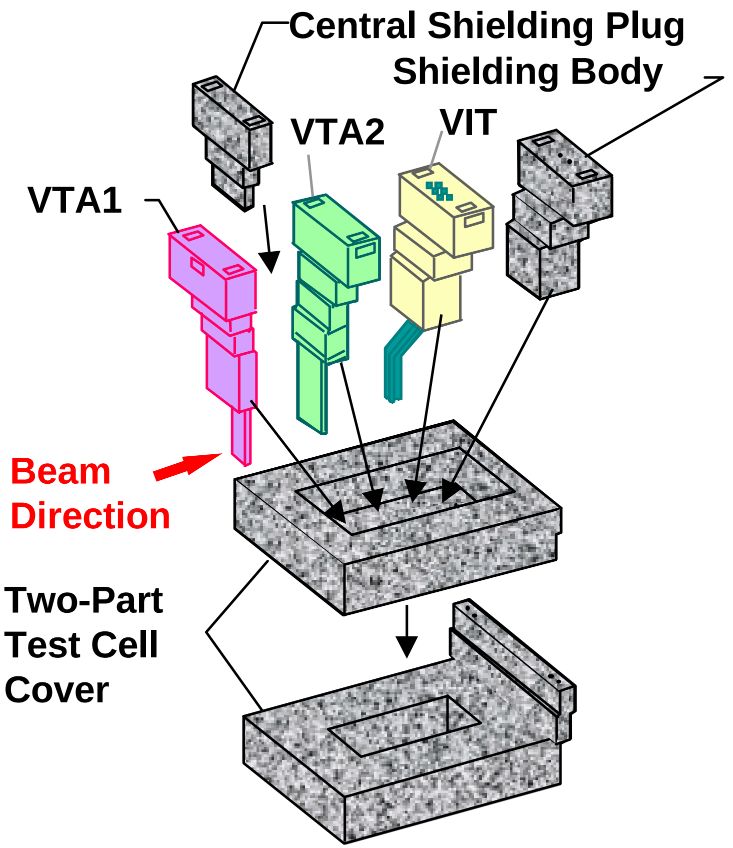
PKA spectra



56Fe
IFMIF High Flux Test Module
Fusion Demo Reactor(HCPB)
Fast Reactor (Phenix)
High Flux Fission Reactor (Petten)
10-2
10-3
10-4
10-5
10-6
10-7
10-8
dσ/dT [barn/eV]
103
104
105
106
PKA energy

IFMIF Test Cell System

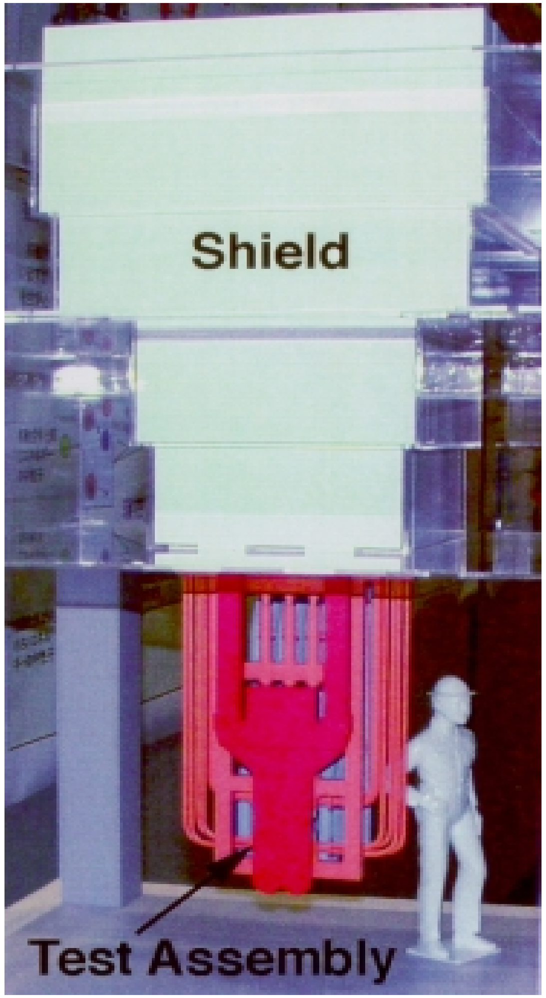


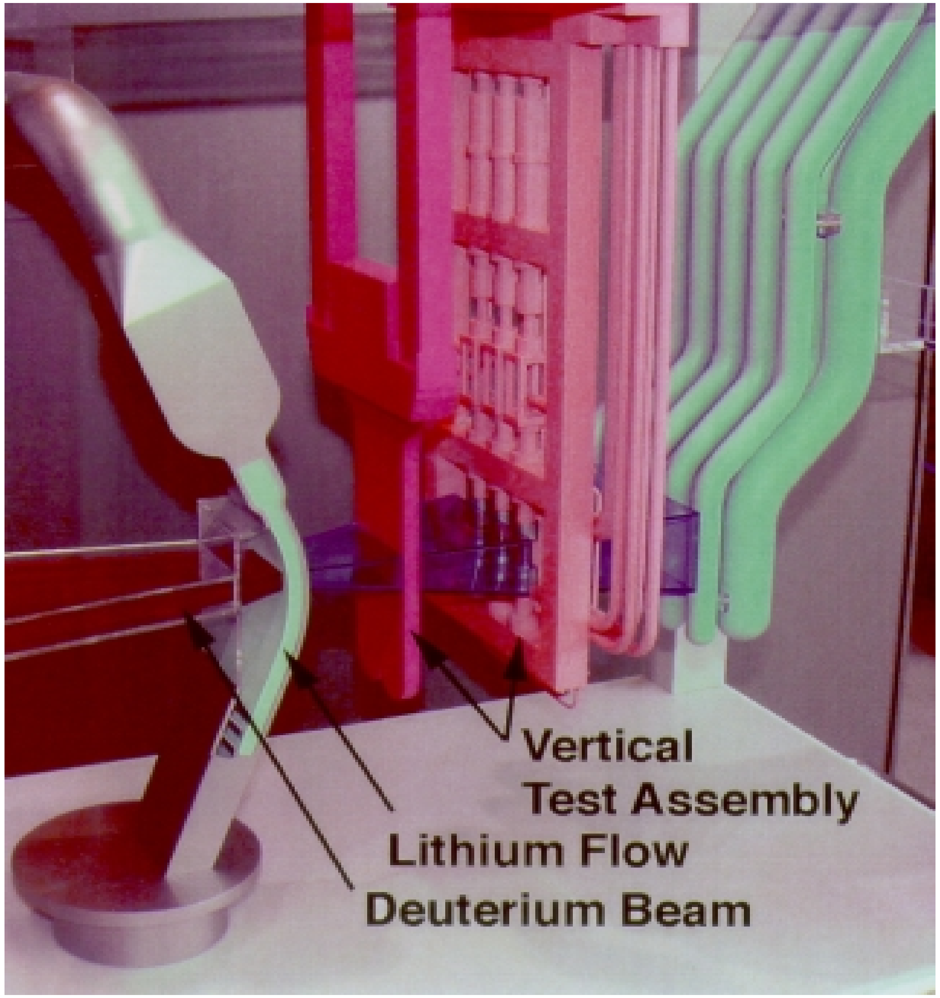


Baseline design concept:

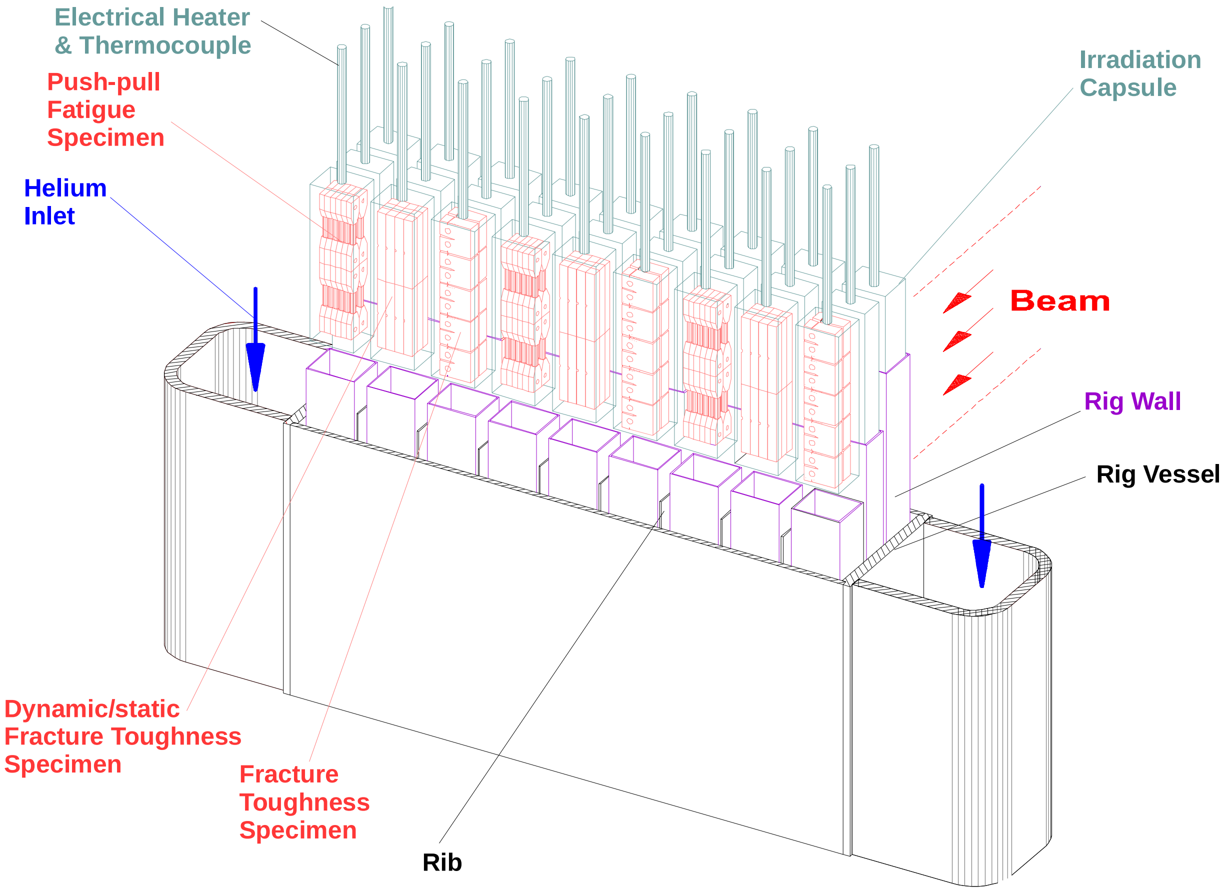
- Gas coolant systems for all test modules
- Modular and highly flexible
- Easy user access
- Capacity for upgrades

IFMIF Model of Li-Target and Test Assemblies



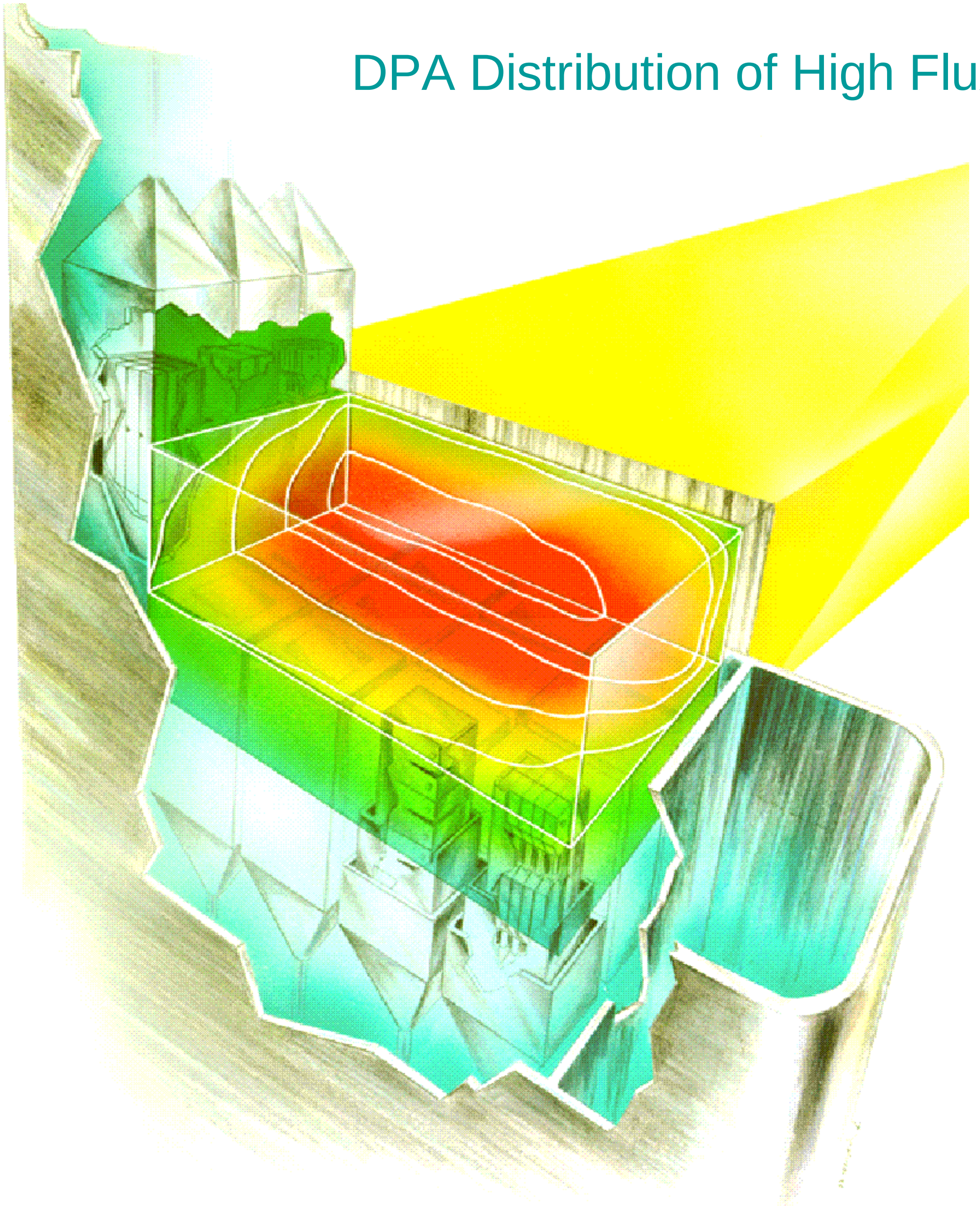


IFMIF   High Flux Test Module



- 27 rigs,
  He-gas cooled
- Individual rig temperatures (ohmic heating)
- T_{irr}:
  300 - 1000 °C
- SSTT:
  - 7 specimen types
  - 400-700 specimen
  - significant volume reduction (20-125 times)

DPA Distribution of High Flux Test Module



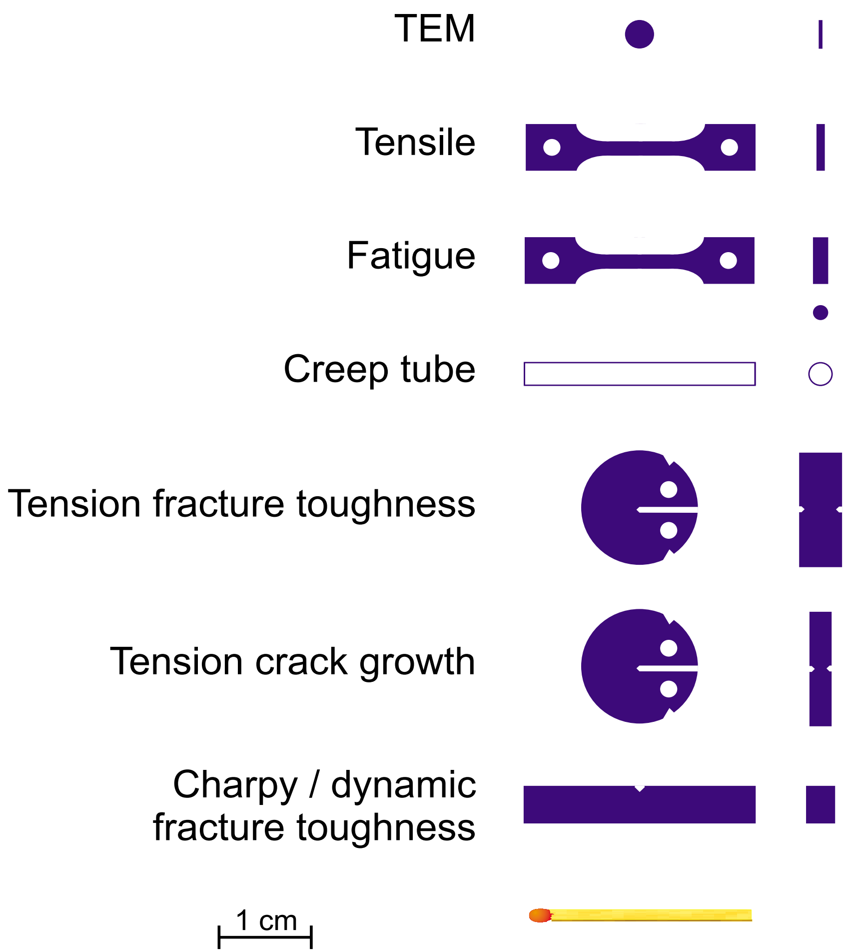
>40 dpa/fpy

>30 dpa/fpy

>20 dpa/fpy

Small Specimen Test Technology (SSTT)

Proposed specimen geometry



✔ development not necessary

✔ development completed;
YS, UTS and A_g independent on size;
generation of material intrinsic properties.

✔ development almost completed at FZK;
generation of material intrinsic properties;

X experience under irradiation is required;
potential for material intrinsic properties

X } Properties strongly size & geometry dependent
World wide efforts ongoing in US, JA, EU
Modelling includes presently:
- Master curve shift approach
- FEM modelling
- Micro-toughness modelling

X

✔X Charpy tests: KLST specimen has become quasi standard in IEA countries
Frac. toughness tests: R&D efforts ongoing

Irradiation devices and testing

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**