Irradiation facilities for fusion materials development

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Outline

- Introduction
- DEMO characteristics
- Facilities description
- Facilities evaluation
- Conclusions

Introduction

- One of the significant steps between present fusion machines (ITER, NIF, …) and DEMO is the neutron dose rate (typically a factor higher) and the total EOL dose (typically a factor of 100) in the elements close to the plasma
- Besides this, radiation effects of fusion-like neutrons can be significantly different to radiation effects induce by other neutron sources
- This induce a very important uncertainty in the behaviour of materials, materials systems and components, that must solve before being able to design and built up DEMO

- The **development, testing and qualification of structural (and functional) materials** suitable to design and construct the in-vessel components of fusion machines (breeding blankets and divertors in the case of magnetic fusion) is one of the important missions for the next decades

Materials Development Path vs. Facilities needed

Step	Objectives and Tasks	„Facilities“
Materials <u>Development</u>	**Development (design) of materials** **Properties analyses & irradiation “stability”** **Fabrication & Joining: Proof of principle** **Modelling (basic sience, microstructure)**	
Demonstration of Material <u>Performance Limits</u>	**Evaluation-modification cycle to optimize performance** **Database for conceptual design** **Demonstrate proof-of-principle solutions, design methodology** **Modelling (meso to macro-scale)**	
Materials <u>Qualification</u> – ***full demonstration of performance***	**Complete database for final design & licensing** **Demonstrate life time goals (including He issue)** **Modelling (interpretation & transferability)**	
Materials <u>Performance</u> ***<u>under component specific loading</u>***	**Demonstrate solution to concept-specific issues** **Performance under complex loading history (T, stress, multi-axial strain fields & gradients) & environmental conditions** **Modelling (macroscopic phenomena)**	

Based on **E. Diegele**

In order to progress in the DEMO design it is needed to study high-dose radiation effects using other irradiation sources.

The ones typically considered are Fission reactors, Ions, Electrons, Spalation neutron sources and Fusion-like neutron sources (like IFMIF)

How they can be compared?

Focus on two of them: The triple beam ion irradiation facility included at theTechnoFusión center and IFMIF

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Comparison criteria

Radiation effects in materials are very complex processes that can strongly depend on many parameters (total dose, dose rate, irradiation temperature, time from irradiation, material characteristics,…).

The comparison is based in the initial phases of interaction of radiation particles with the material:

- i) scattering of particles. This is measured with **the parameter "dpa"-total dose and dose rate-** and with **W(T) –damage function-** (a parameter that describes in a qualitative way the "type" of damage in the material)

- ii) Nuclear reactions, giving rise to "new" ions not previously in the matrix. In the case of fusion-like neutrons the main impurities induced are He and H. This is measured with the **He/dpa, H/dpa ratios** and other impurities production.

+ other obvious comparison criteria like irradiated volume,…

DEMO characteristics

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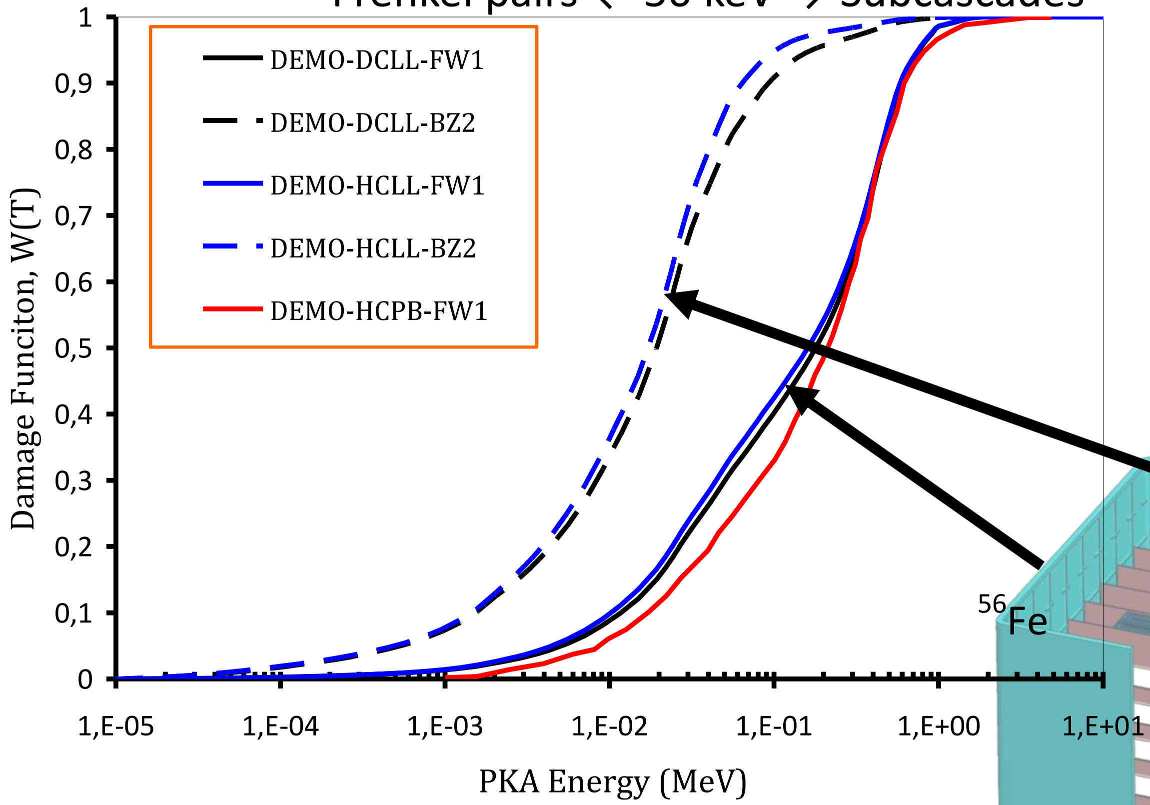
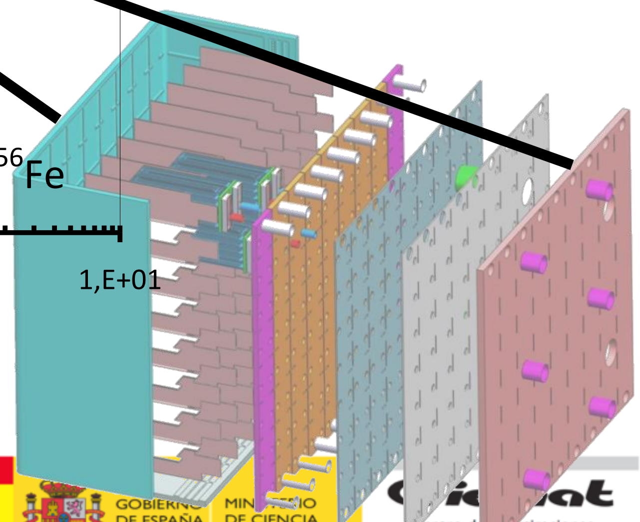
2) W(T)

Frenkel pairs ← 50 keV → Subcascades





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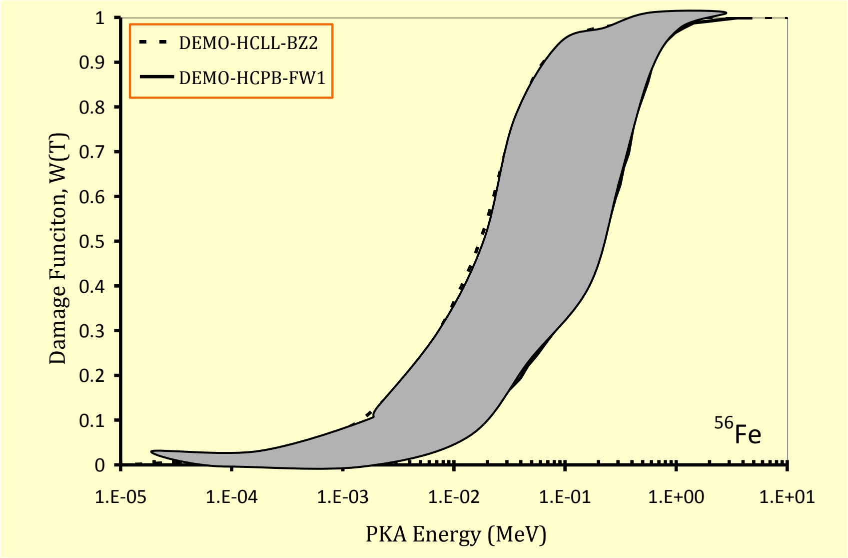

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DEMO characteristics

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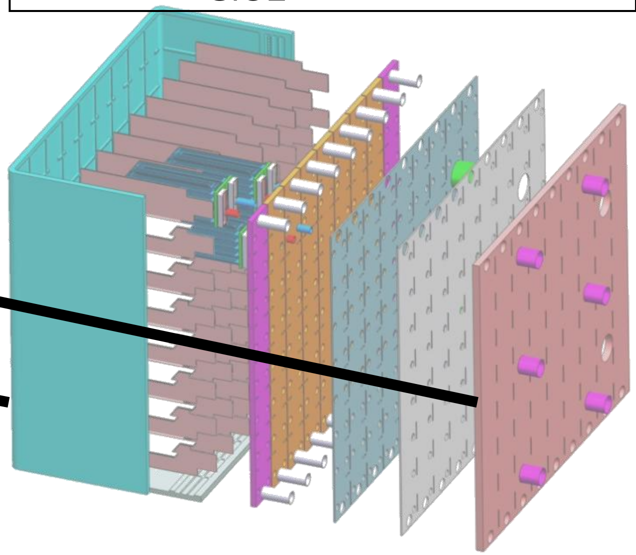
2) W(T)

3) He/dpa and H/dpa ratios

dpa/fpy appm/fpy		DEMO HCLL (4000MW)			
		FW (front)	FW (back)	BZ (middle)	BZ (back)
Fe-56	*dpa*	30	29	8	2
	H	982	870	53	4
	He	270	241	16	1
SiC	*dpa*	20	20	8	3
	H	1053	939	62	5
	He	2596	2304	144	11
SiO2	*dpa*	48	49	21	8
	H	929	827	53	4
	He	1477	1319	87	7

$(He/dpa)_{Fe}$ 10 - 0.5
$(He/dpa)_{SiC}$ 130 - 4
$(He/dpa)_{SiO2}$ 30 - 1

$(H/dpa)_{Fe}$ 30 - 2
$(H/dpa)_{SiC}$ 50 - 2
$(H/dpa)_{SiO2}$ 20 - 0.5



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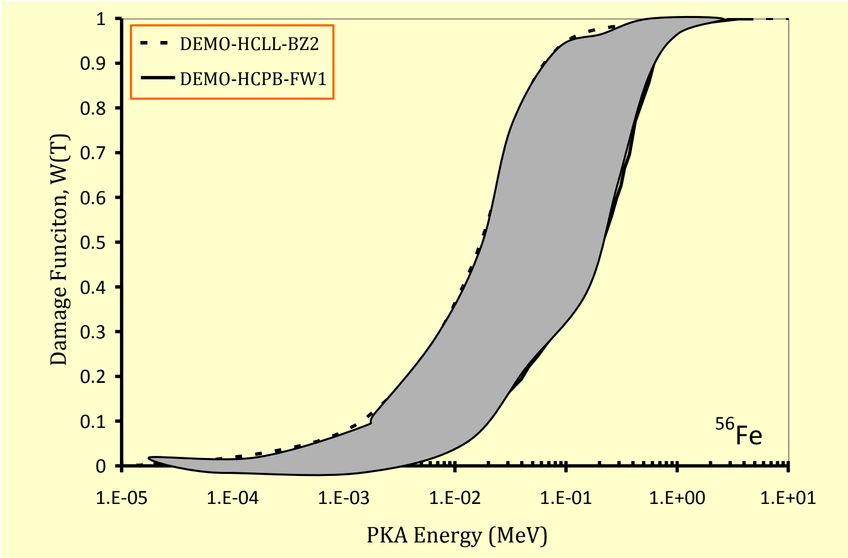

3) He/dpa and H/dpa ratios

$(He/dpa)_{Fe}$	**10** - 0.5	$(H/dpa)_{Fe}$	**30** - 2
$(He/dpa)_{SiC}$	**130** - 4	$(H/dpa)_{SiC}$	**50** - 2
$(He/dpa)_{SiO2}$	**30** - 1	$(H/dpa)_{SiO2}$	**20** - 0.5

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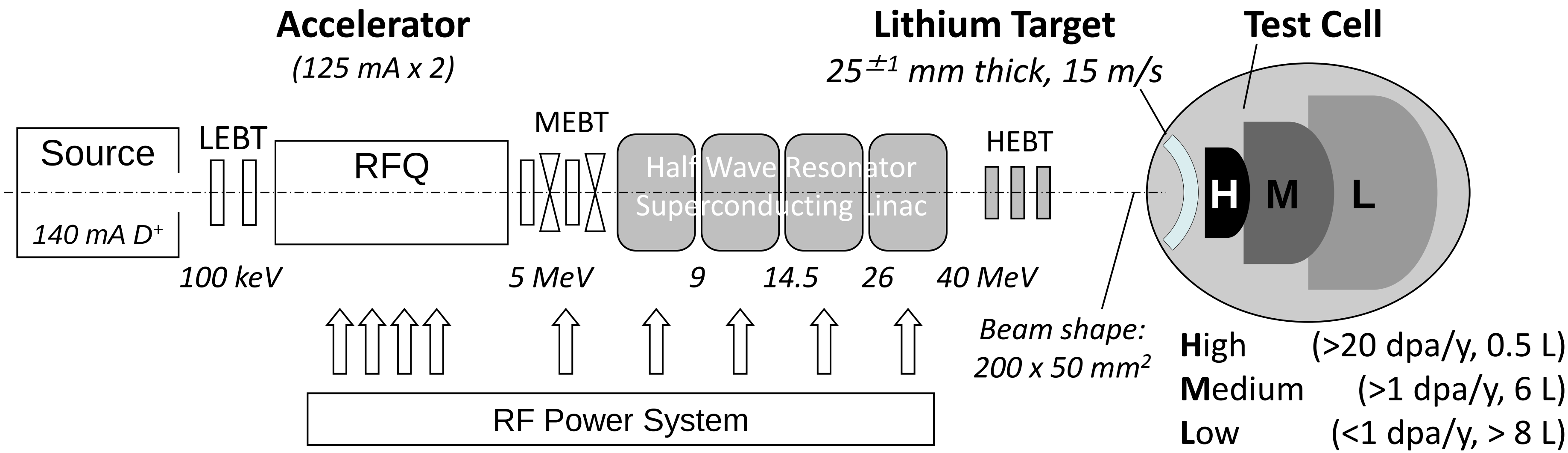
Facilities description

- IFMIF

- TechnoFusión triple beam

Principle of IFMIF



Typical reactions

$^{7}Li(d,2n)^{7}Be$

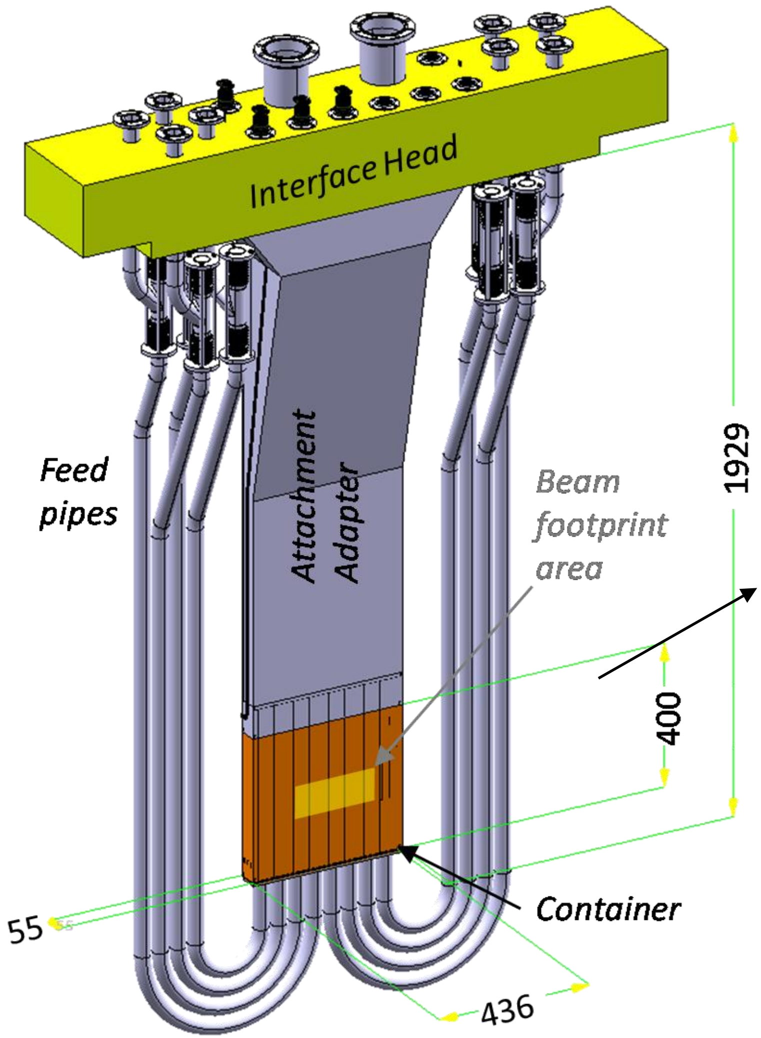
$^{6}Li(d,n)^{7}Be$

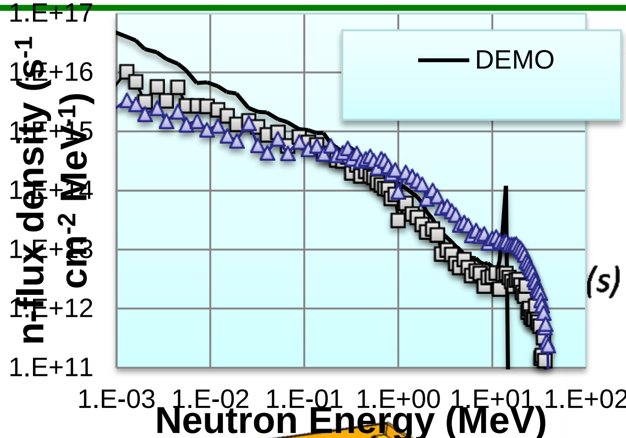
$^{6}Li(n,T)^{4}He$

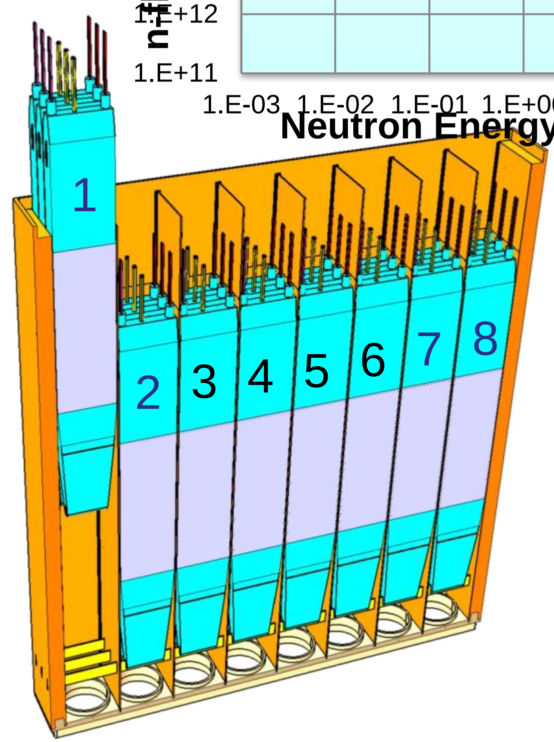
Engineering design presently being developed in the framework of the EU-JA Broader Approach Agreement (IFMIF-EVEDA Project)

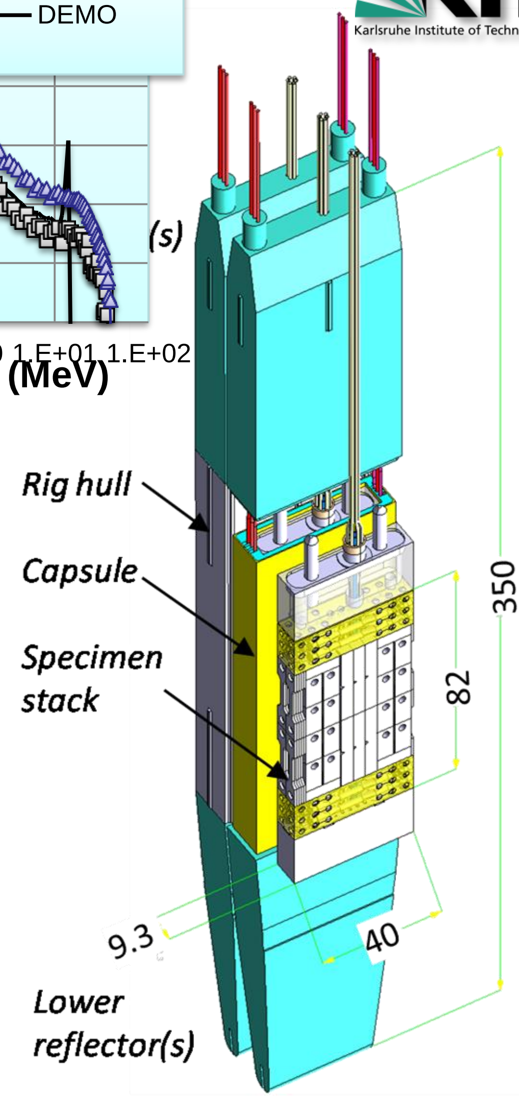
High Flux Test Module current design

About 1000 samples







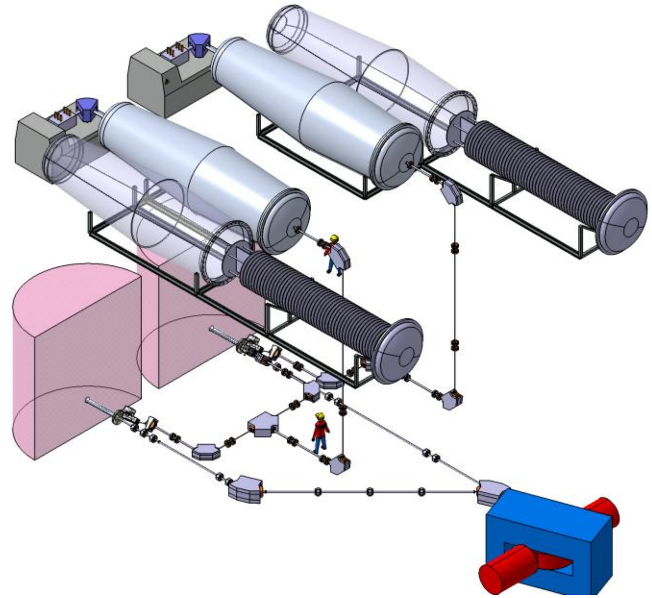


3,4,5,6: Irradiation Rigs

1,2,7,8: Companion Rigs

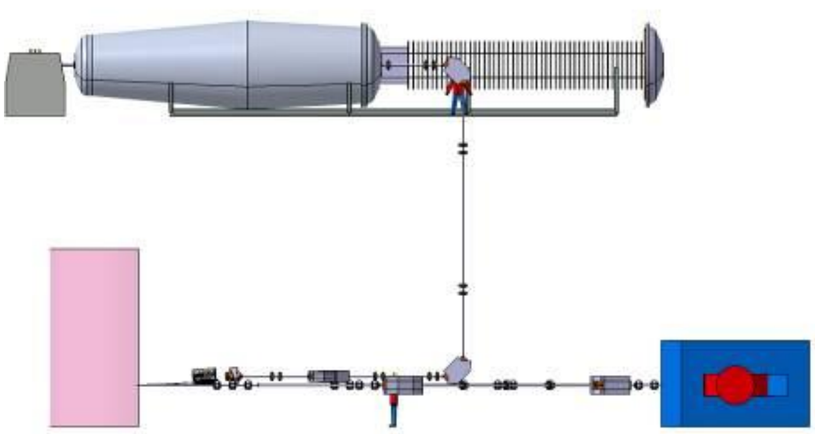
TF-triple beam facility

A Facility to allow the evaluation of radiation effects on fusion materials. Three simultaneous ion accelerators will emulate the neutron irradiation effect.



Includes:

- **Two light ions tandem-type, electrostatic accelerators (mainly for He and H irradiation)**
- **One heavy ion cyclotron (isochronous type) accelerator (Fe -400 MeV-, W -400 MeV-, Si -300 MeV-, C -100 MeV-, … and k = 110)**
- **Also experiments under high-field magnet**

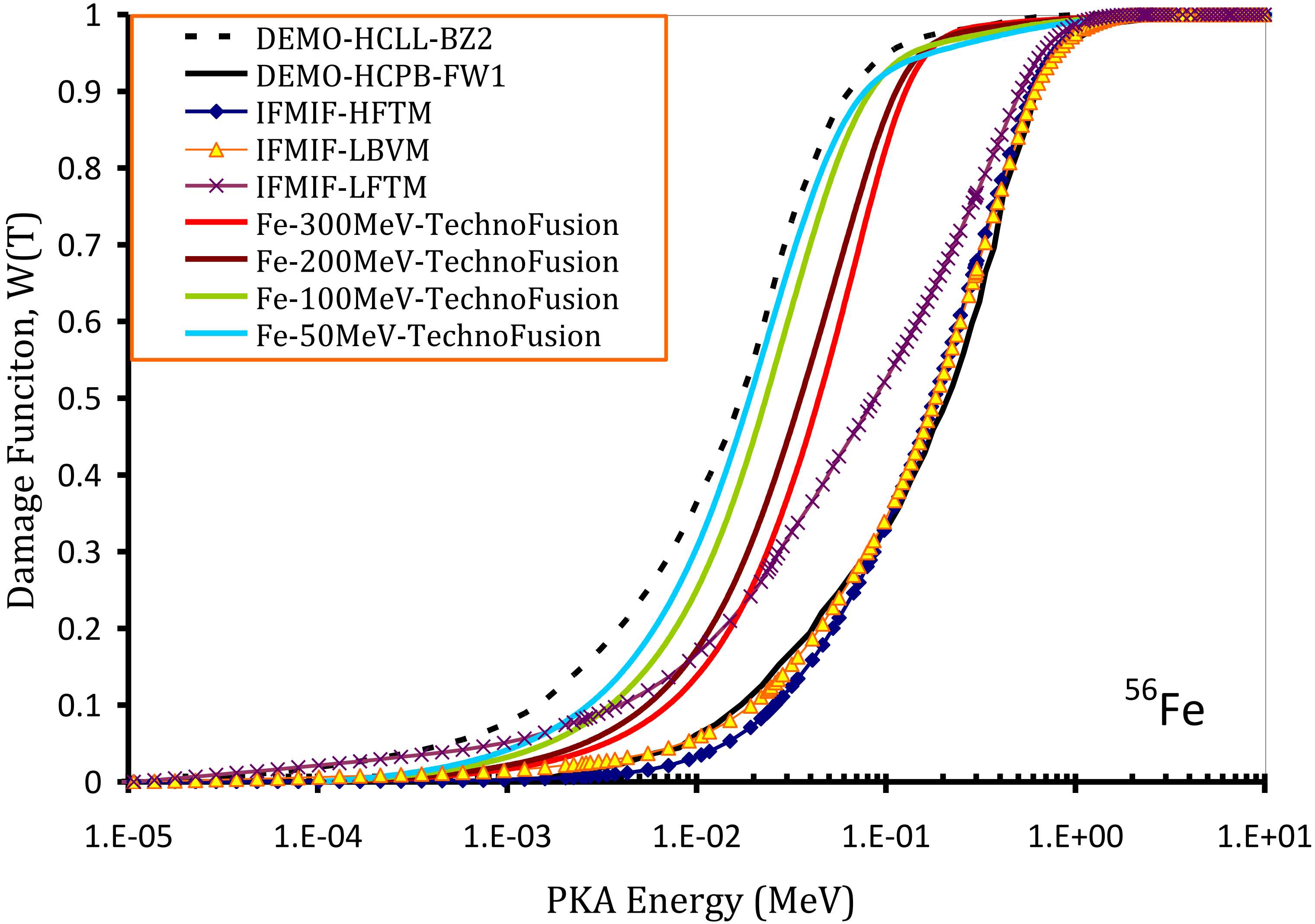


Small irradiation volume (but large surface)

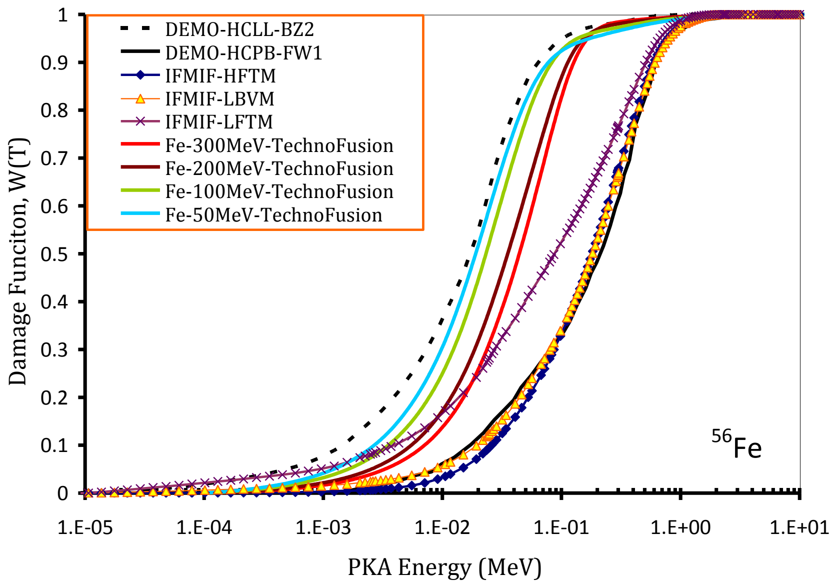
Accelerated testing (screening capability)

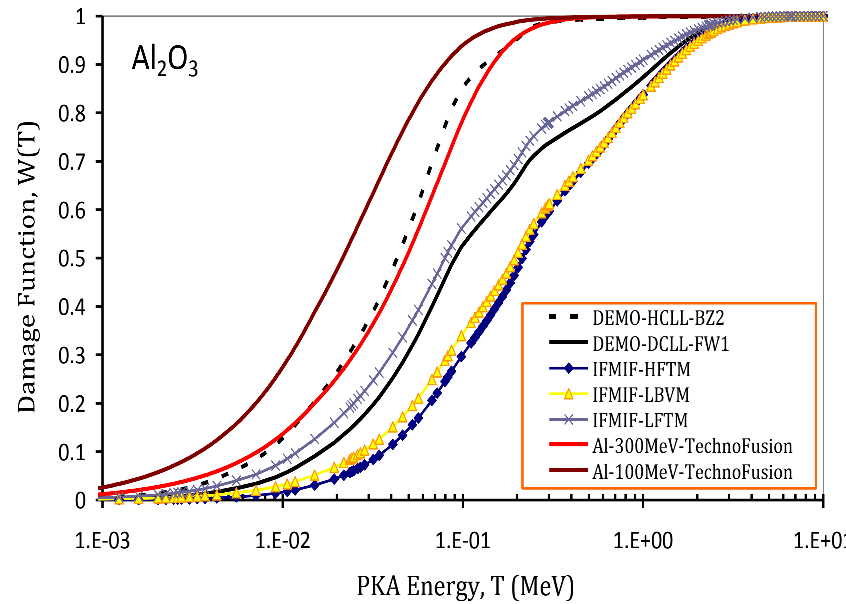
Facilities evaluation

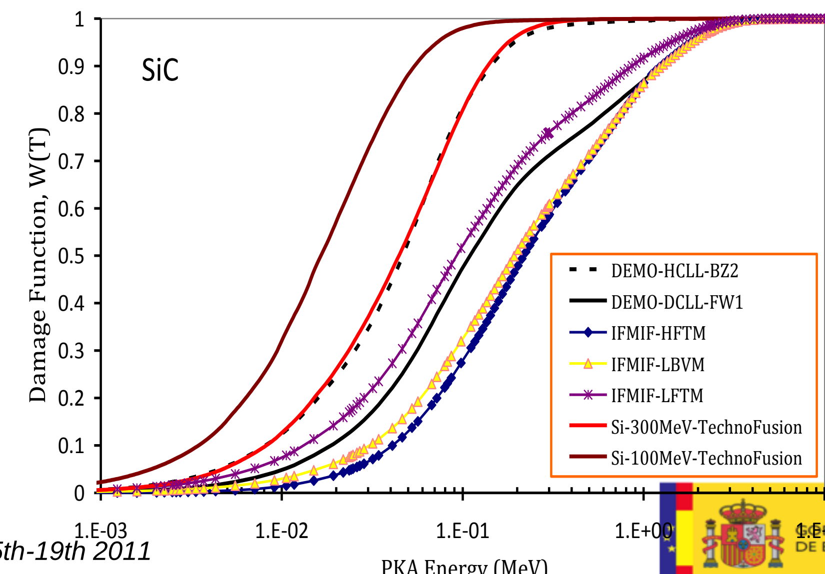
1.- Damage function in ^{56}Fe for DEMO, IFMIF and TechnoFusion Results



4.- Damage function for DEMO, IFMIF and TechnoFusion Results







DPA and gas production for DEMO, IFMIF.

dpa/fpy appm/fpy		DEMO HCLL (4000MW)				IFMIF				
		FW (front)	FW (back)	BZ (middle)	BZ (back)	HFTM (1)	MFTM (2)	MFTM (3)	ICR (4)	ECR (5)
Fe-56	*dpa*	30	29	8	2	31	2	13	7	2
	H	982	870	53	4	1329	87	605	201	33
	He	270	241	16	1	402	26	180	62	11
SiC	*dpa*	20	20	8	3	15	2	6	4	1
	H	1053	939	62	5	1330	85	589	208	37
	He	2596	2304	144	11	2707	178	1230	408	70
SiO2	*dpa*	48	49	21	8	34	4	14	9	3
	H	929	827	53	4	1182	77	530	183	32
	He	1477	1319	87	7	1709	108	752	270	50

$(He/dpa)_{Fe}$ 13 - 6
$(He/dpa)_{SiC}$ 180 - 80
$(He/dpa)_{SiO2}$ 50 - 15

$(H/dpa)_{Fe}$ 45 - 15
$(H/dpa)_{SiC}$ 90 - 40
$(H/dpa)_{SiO2}$ 50 - 10

Comparison table

DEMO		IFMIF	TF-triple beam	BOR60	HFR
		Fusion-like neutron source	**Ion beams irradiation**	**Fission reactor**	**Fission reactor**
15-25	**Dpa/y dose rate range**	50-1 range	Very high (>100 dpa/w)	around 15	Around 3
Fusion type	**W(T)**	First wall-range equivalent	Medium-range equivalent	Medium-range equivalent	Medium-range equivalent
10-0.5	**He/dpa ratio**	13-6	Adjustable wide range	0.2	0.5
30-2	**H/dpa ratio**	45-15	Adjustable wide range		
	Irradiation volume	Around 500 cm3	Penetration of tens of microns	High	high

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Available **Available**

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Materials <u>Development</u>	**Development (design) of materials** **Properties analyses & irradiation “stability”** **Fabrication & Joining: Proof of principle** **Modelling (basic sience, microstructure)**	**MTR** **Ion beam facilities** **Others**
Demonstration of Material <u>Performance Limits</u>	**Evaluation-modification cycle to optimize performance** **Database for conceptual design** **Demonstrate proof-of-principle solutions, design methodology** **Modelling (meso to macro-scale)**	**MTR** **IFMIF**
Materials <u>Qualification</u> – ***full demonstration of performance***	**Complete database for final design & licensing** **Demonstrate life time goals (including He issue)** **Modelling (interpretation & transferability)**	**IFMIF** ***ITER-TBM (partly)***
Materials <u>Performance</u> ***<u>under component specific loading</u>***	**Demonstrate solution to concept-specific issues** **Performance under complex loading history (T, stress, multi-axial strain fields & gradients) & environmental conditions** **Modelling (macroscopic phenomena)**	*IFMIF – like?* *CTF ?*

Based on **E. Diegele**

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Conclusions

- In order to solve the materials problem for DEMO and FPP, materials characterization and qualification using different irradiation sources is needed
- IFMIF is the only facility that can fullfil all the requirements needed to qualify the materials
- In spite of this, a number of other irradiation facilities, like ion accelerators are also very useful in order to understand the physics of radiation damage on materials
- Triple-beam ion accelerators has the unique feature that allows tuning of the He/dpa and H/dpa ratio

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Thank you!!!