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Materials Data Requirements For High Power Target Design

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ESS Target Division

4th HPTW

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Outline

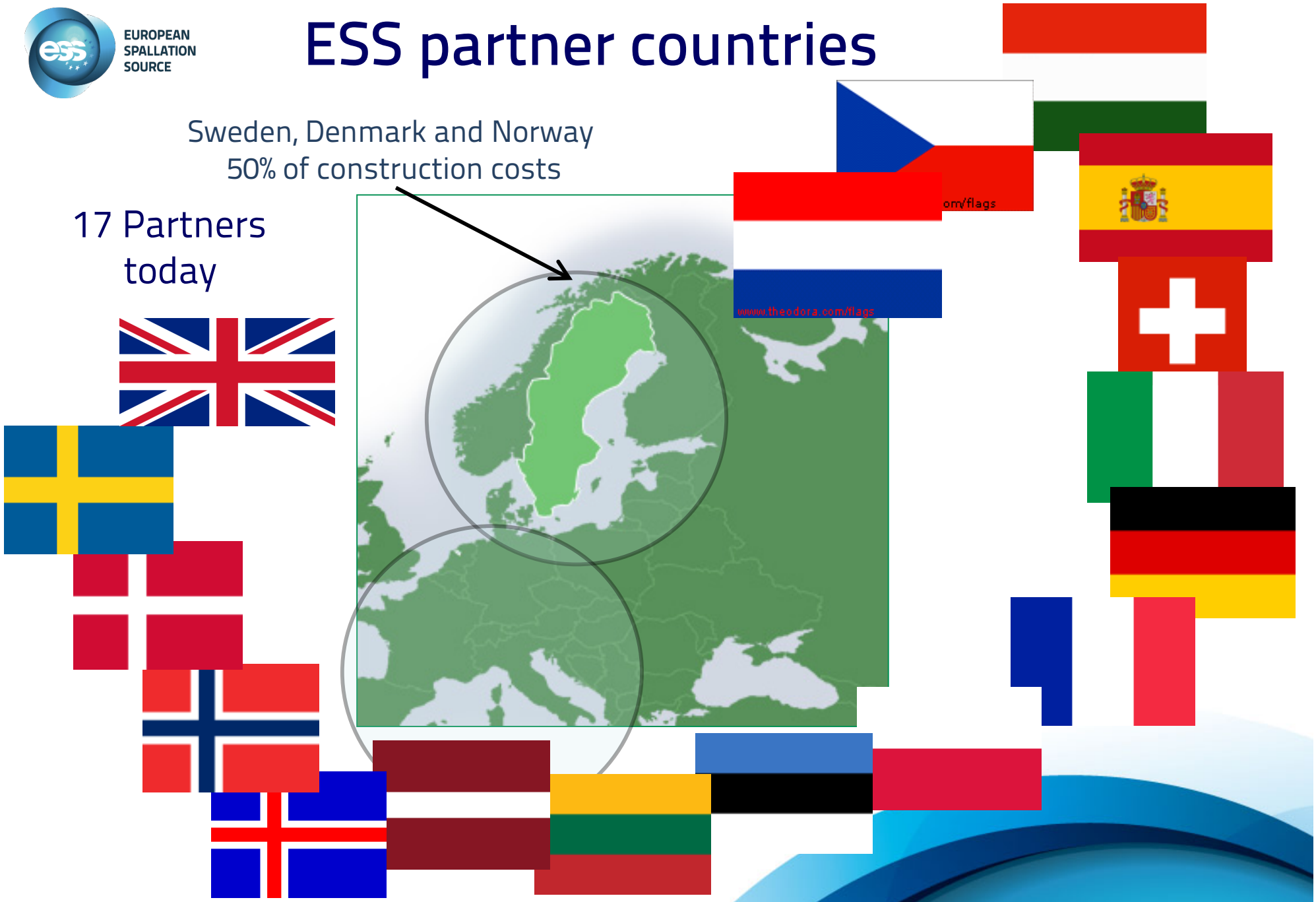
- ESS Baseline Parameters
- Irradiation environments
- Motivation for engineering design codes
- RCC code description
- Adding material data to code

ESS baseline parameters

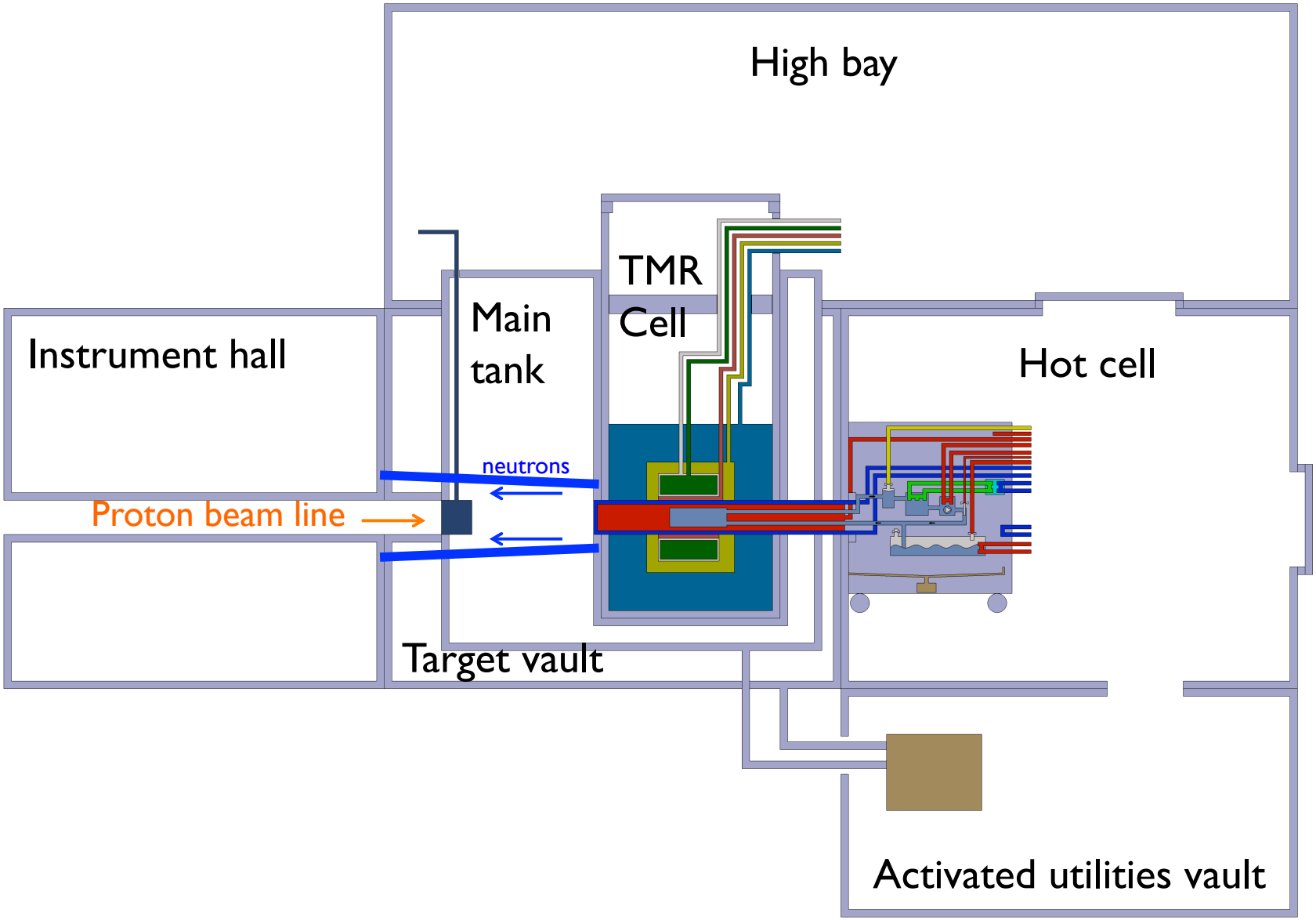
ESS partner countries

Sweden, Denmark and Norway
50% of construction costs

17 Partners
today

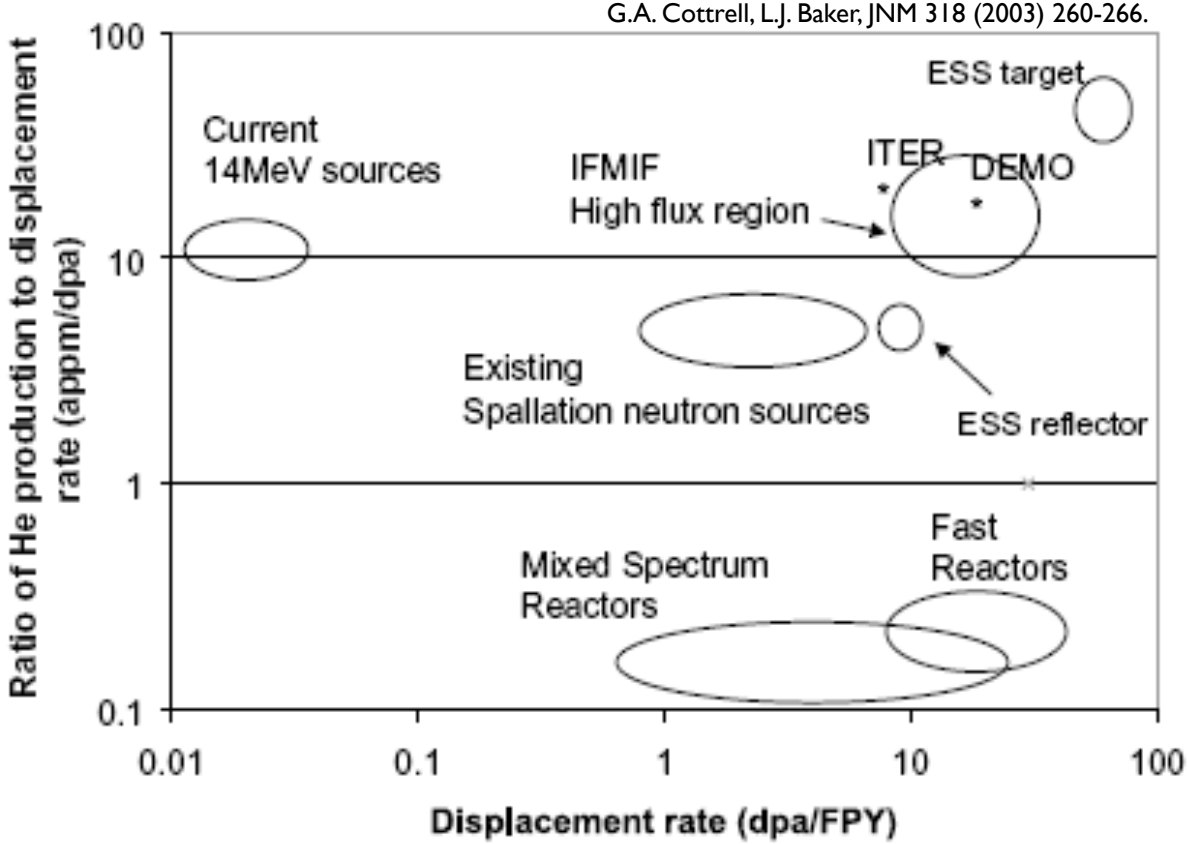


ESS target station sketch (LBE)



Irradiation environments

G.A. Cottrell, L.J. Baker, JNM 318 (2003) 260-266.



	dpa	H & He	Temperature	Corrosion	Pulsed	Codes & Standards
Spallation Source	+	+	-	+	+	–
ADS	+	+	+	+	–	–
Fusion	+	–	+	–	+	+
F.R. (Na)	+	––	+		–	+

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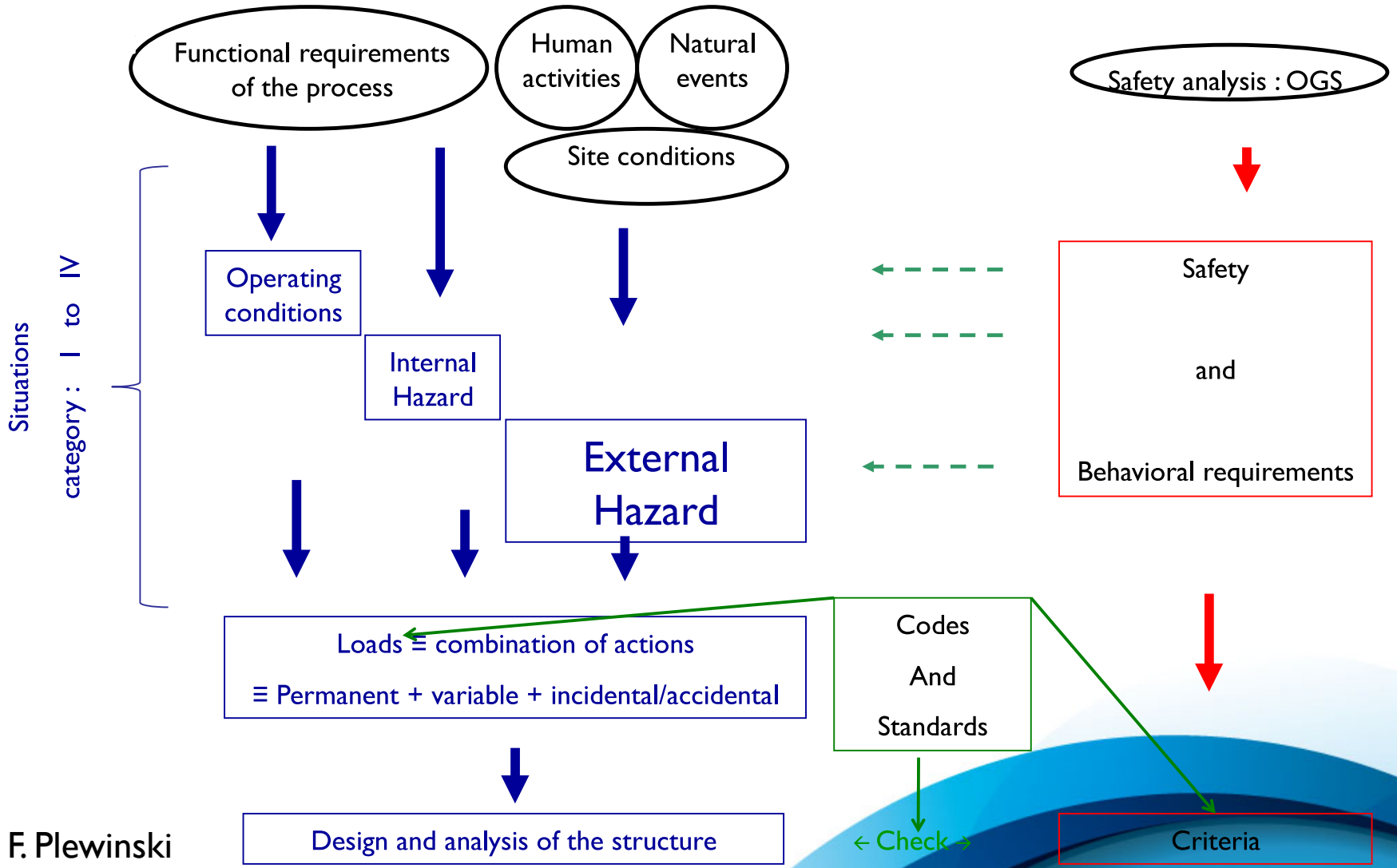
Motivation for design codes

- *Basic design requirements:*
  - Safety
  - Reliability of components
- *Motivation for codes and standards:*
  - Contractual: client/contractor/supplier
  - Consistency: tendering/safety authorities
  - Efficiency: documents/practices simplification
  - Sharing applied practice: tech. transfer/localisation of manufacturing/ international exchange.
  - Integration of industrial experience.

Safety considerations



F. Plewinski

RCC code description

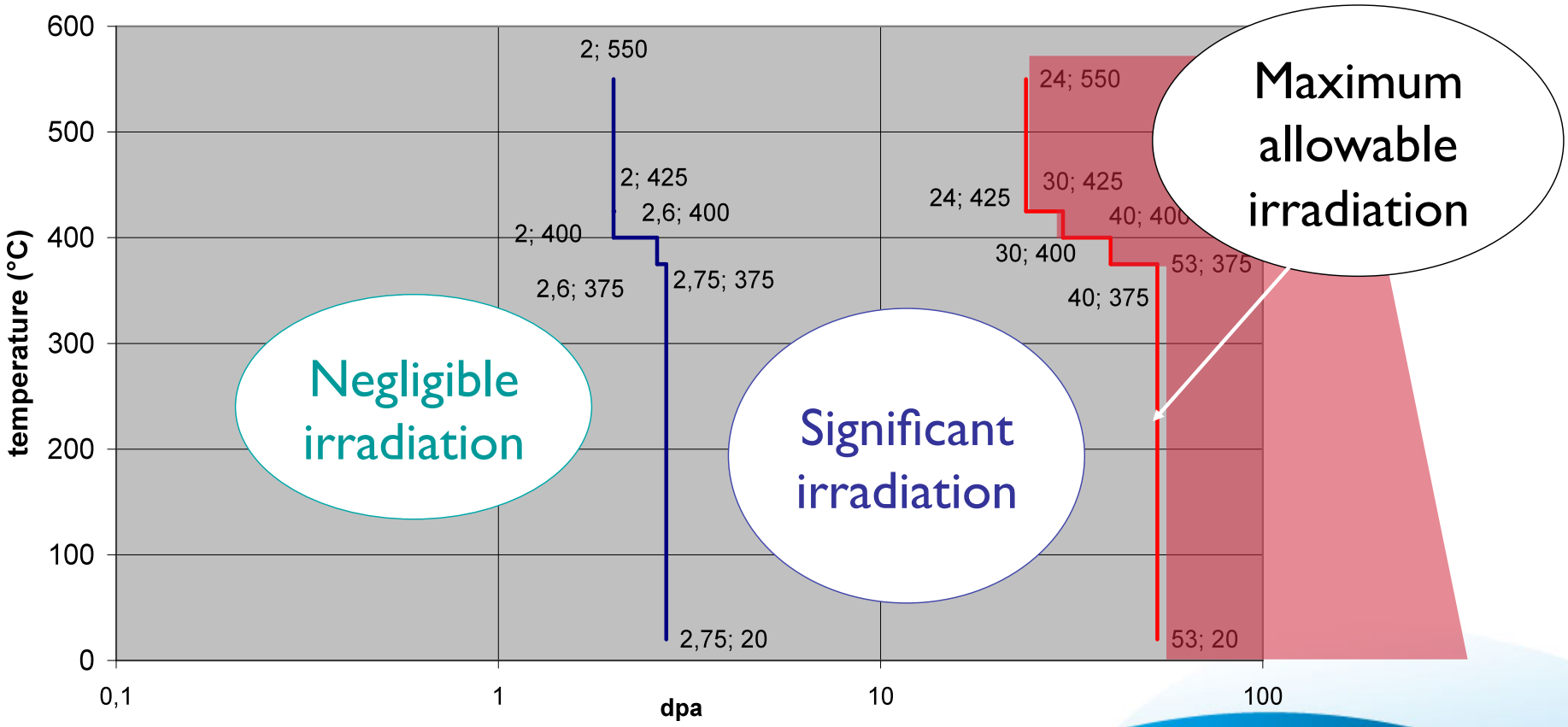
- *The RCC-MRx:*
  - Merging of RCC-MR with RCC-MX.
  - RCC-MR: equipments for use at nuclear installations (also ITER, except PWR): 12 materials.
  - RCC-MX: mechanical equipment at research reactors (JHR): Aluminium and Zirconium alloys specific.
  - RCC-MRx: Planned release 2012.

- *RCC describes requirements on:*
  - materials procurement.
  - design.
  - analysis.
  - construction qualification.
  - examinations.

RCC irradiation scales

- *Non-alloy and low-alloy steels:*
  - Fast neutrons > 1 MeV / cm^2.
- *Austenitic stainless steels:*
  - Displacements per atom using NRT model.
- *Aluminium alloys:*
  - % radiogenic silicon: conventional thermal neutron flux (0.0254 eV).
- *Zirconium alloys:*
  - Fast neutrons > 1 MeV / cm^2.

RCC irradiation range



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Material properties covered in code

RCC Properties Group		elastic	inelastic	Materials					
Physical properties	coefficient of thermal expansion	x	x	x (20-600C)	x (20-1000C)	x (20-1000C)	x (20-1000C)	x (20-1000C)	x (20-700C)
	Young modulus	x	x	x (20-600C)	x (20-700C)	x (20-700C)	x (20-700C)	x (20-700C)	x (20-700C)
	poisson'ratio	x	x	x	x	x	x	x	x
	density	x	x	x (20-600C)	x (20-800C)	x (20-800C)	x (20-800C)	x (20-800C)	x (20-700C)
	specific heat capacity	x	x	x (20-600C)	x (20-800C)	x (20-800C)	x (20-800C)	x (20-800C)	Not supplied
	thermal conductivity	x	x	x (20-600C)	x (20-800C)	x (20-800C)	x (20-800C)	x (20-800C)	Not supplied
	thermal diffusivity			x (20-600C)	x (20-800C)	x (20-800C)	x (20-800C)	x (20-800C)	Not supplied
border lines	negligible creep curve	x	x	x (T<375C)	x	x (20-700C)	x	x (T<425C)	Not supplied
	thermal ageing curve	x		Not supplied	x	Not supplied	Not supplied	Not supplied	Not supplied
	negligible irradiation curve	x	x	Not supplied	x (20-550C)	Not supplied	x (20-550C)	x (20-450C)	Not supplied
	maximum allowable irradiation	x	x	Not supplied	x (20-550C)	Not supplied	x (20-550C)	Not supplied	Not supplied
analysis data 1	conventional yield strenght at 0.2 % offset $R_{P0.2}$	x		x (20-600C)	x (20-700C)	x (20-600C)	x (20-550C)	x (20-550C)	x (20-550C)
	Tensile strenght R_m	x		x (20-600C)	x (20-700C)	x (20-600C)	x (20-550C)	x (20-450C)	x (20-550C)
	Values of S_m (linked with S in RCC)	x	x	x (20-600C)	x (20-675C)	x (20-600C)	x (20-550C)	x (20-550C)	x (20-550C)
	Values of S (linked with S_m in RCC)			x (20-500C)	x (20-575C)	x (20-550C)	x (20-550C)	x (20-500C)	x (20-550C)
	Tensile Stress-Strain curves: For plastic strain limited to x%	x	x	x (20-600C)	x	x (315-650C)	x	x (20-500C)	x (300-550C)
	Tensile Stress-Strain curves: For total strain attaining maximum elongation			No	x (20-700C)	x (316-650C)	x (20-500C)	Not supplied	Not supplied
	Cyclic curves	x	x	x (20-600C)	x (20-650C)	Not supplied	x (20-600C)	x (20-550C)	x (400C)
	Coefficient Kε			x (20-600C)	x (20-650C)	Not supplied	x (20-600C)	x (20-550C)	x (400C)
	Coefficient Kv	x		x (20-600C)	x (20-650C)	Not supplied	x (20-600C)	x (20-550C)	x (400C)
	Symmetrisation coefficient Ks	x	x	x (375,550C)	x	x	x	x	Not supplied
	Fatigue curves	x	x	x (20-600C)	x (20-650C)	x (20-650C)	x (20-650C)	x (20-450C)	x (20-700C)
	Values of J_{IC}	x	x	Not supplied	x (20-400C)	Not supplied	x (20-400C)	Not supplied	Not supplied
analysis data 2	THERMAL AGEING COEFFICIENT	x	x	Not supplied	x (20-700C)	Not supplied	x (20-700C)	x (T<450C)	Not supplied
	VALUES OF ST	x	x	x (425-650C)	x (20-700C)	x (425-700C)	x (20-600C)	x (425-650C)	x (550-700C)
	CREEP RUPTURE STRESS SR	x	x	x (425-675C)	x (20-700C)	x (425-700C)	x (20-600C)	x (425-650C)	x (550-700C)
	Creep strain rules: primary creep	x	x	x (375-600C)	x (20-700C)	x (427-704C)	x (20-600C)	Not supplied	Not supplied
	Creep strain rules: secondary creep	x	x	x (375-600C)	x (20-700C)	x (427-704C)	x (20-600C)	Not supplied	Not supplied
	FATIGUE-CREEP INTERACTION DIAGRAM	x	x	x	x	x	x	Not supplied	Not supplied
	MAXIMUM ALLOWABLE STRAIN DMAX		x	x	x	Not supplied	x	x	x
analysis data 3	conventional yield strenght at 0.2 % offset $R_{P0.2}$	x		Not supplied	x (550C)	Not supplied	x (450C)	Not supplied	Not supplied
	Tensile strenght R_m			Not supplied	x (550C)	Not supplied	x (550C)	Not supplied	Not supplied
	Values of S_{em}	x		Not supplied	x (550C)	Not supplied	x (550C)	Not supplied	Not supplied
	Values of S_{et}	x		Not supplied	x (550C)	Not supplied	x (550C)	Not supplied	Not supplied
	Ductility characteristics (after and before irradiation).			Not supplied	x (550C)	Not supplied	x (550C)	Not supplied	Not supplied
	Tensile Stress-Strain curves: For plastic strain limited to x%	x	x	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
	Tensile Stress-Strain curves: For total strain attaining maximum elongation			Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
	CYCLIC CURVES	x	x	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
	VALUES OF Kε	x	x	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
	VALUES OF Kv	x	x	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
	VALUES OF K_S	x	x	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
	Fatigue curves	x	x	Not supplied	x	Not supplied	x	Not supplied	Not supplied
	Values of J_{IC}	x	x	Not supplied	x (20-400C)	Not supplied	x (20-400C)	Not supplied	Not supplied
	Swelling	x	x	Not supplied	x	Not supplied	x	Not supplied	Not supplied
	growth			Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied

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Adding material data to code

- *Material* listed *in code*:
  - Data in (RCC standard) non-negligible irradiation domain needed.
  - Data in new irradiation needed.

- *Material not* listed *in code* (e.g. Ti alloy Ti6Al4V):
  - Data in negligible irradiation domain to be added.
  - Data in (RCC standard) non-negligible irradiation domain needed.
  - Data in new irradiation regime needed.

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Adding material data to code

- *Phase I:*
  - Identify origin of criteria for selection of data.
  - Clarify use of code for elastic/inelastic design.
  - Highlight applicability of code to ESS components.
  - Draft list of components that can be designed with RCC.

- *Phase II:*
  - Analyse damage modes for spallation environment.
  - Establish whether spallation materials data can be included in code.
  - Assess whether formal "modification request" can be drafted.

TMR structural materials environment

Neutrons
T < 100°C
e.g. Al6061

Reflector

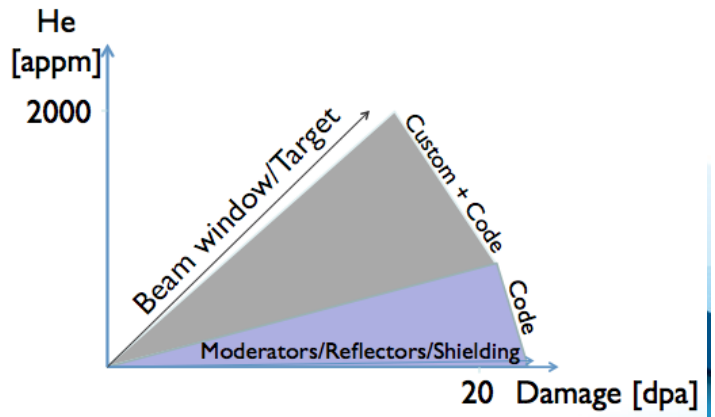
Moderator

Neutrons
-200°C < T < 100°C
e.g. Al6061, Zircaloy

protons

Target

Protons+Neutrons
30°C < T < 400°C
Low-cycle fatigue (beam trips, LBE target)
High-cycle fatigue (rotating target)
e.g. T91, SS316



Materials data requirements for high power target design
E. Noah, 4th HPTW, Malmö, SE, 2-6 May 2011

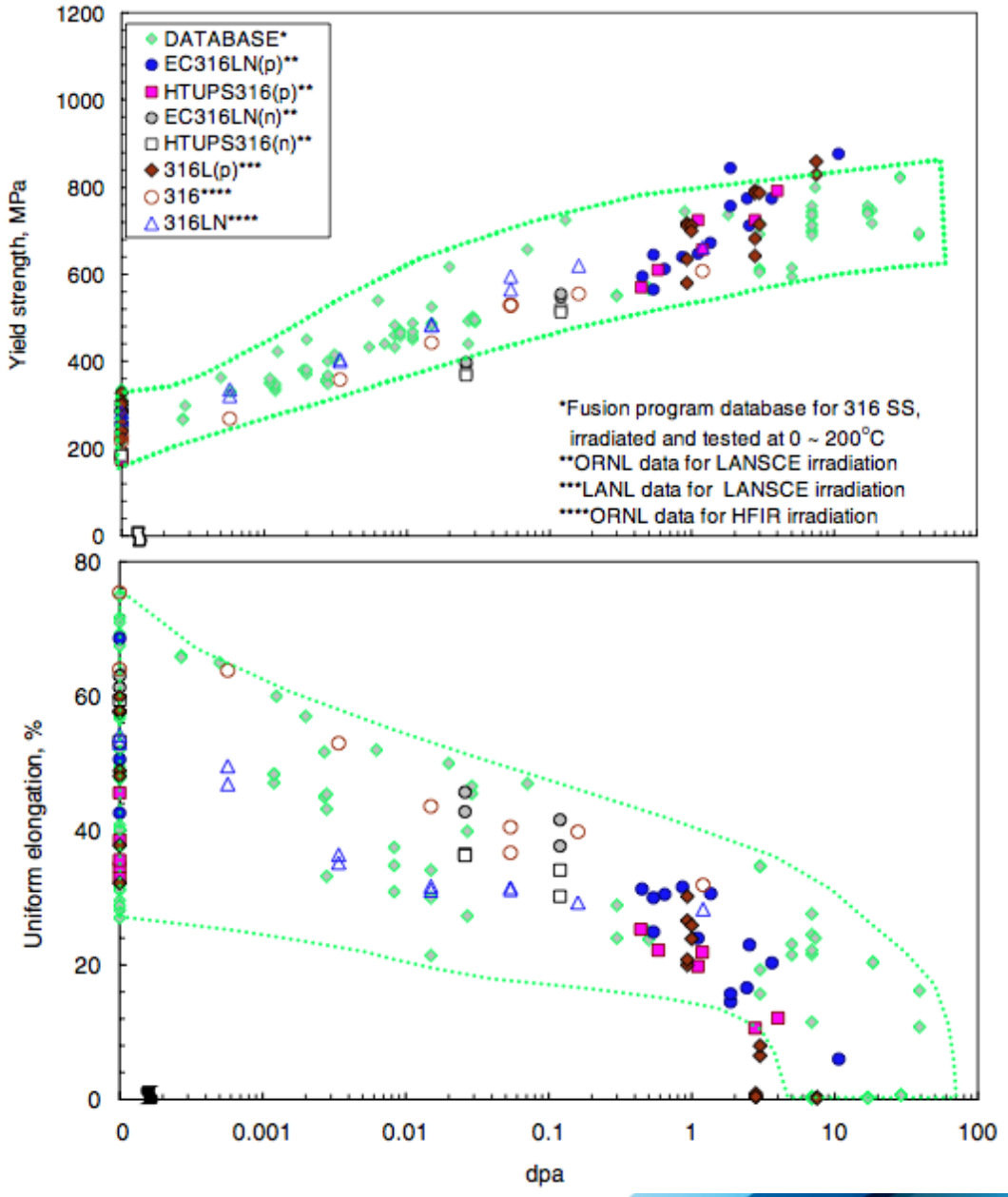
1.25×10^{16} protons/s
5.6×10^{17} neutrons/s

LBE target structural materials

LBE Target

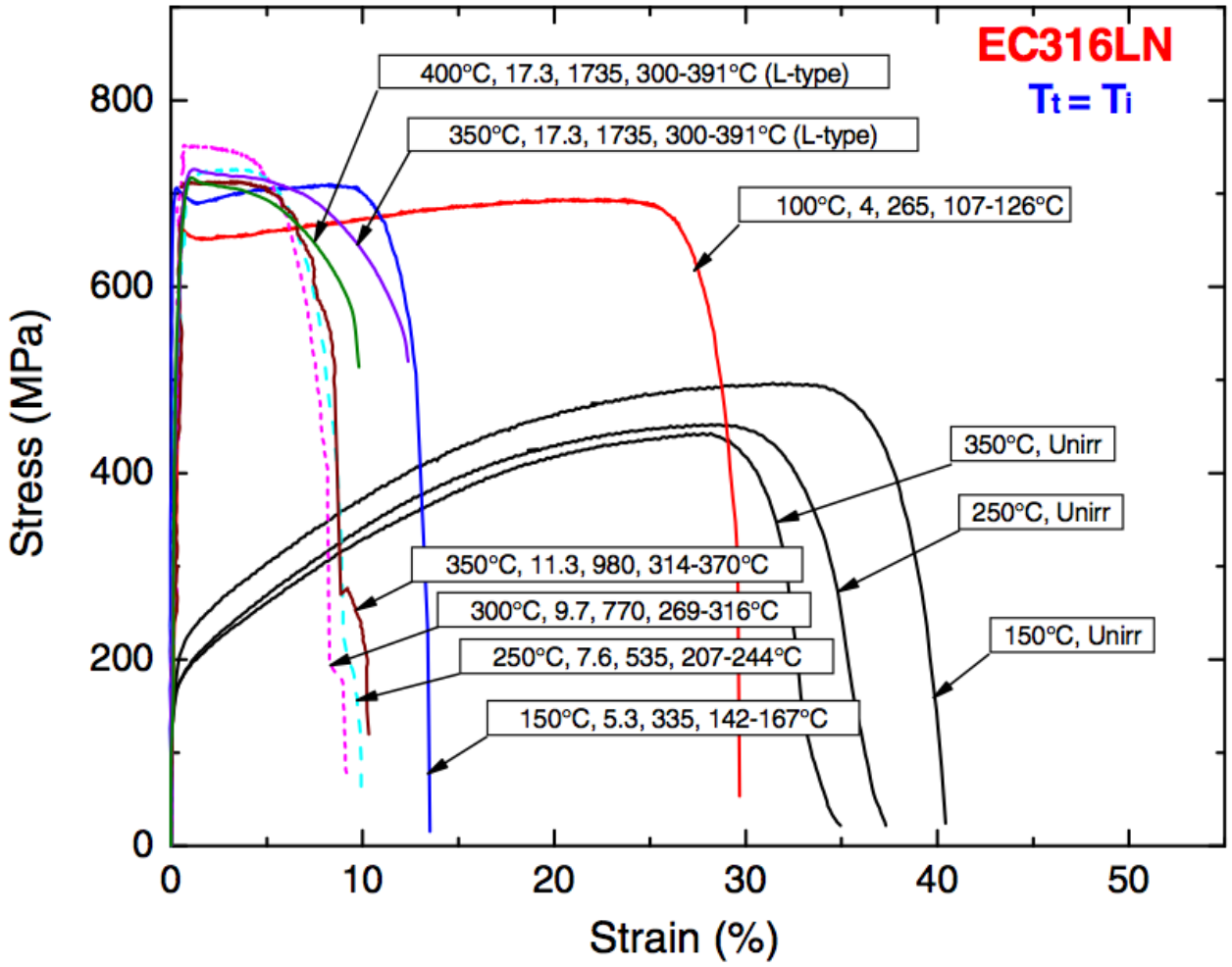
	Inner vessel	Middle vessel	Outer vessel
Materials			
Material - Reference	Martensitic steel T91	SS316	SS316
Material - Alternative 1		AlMg3	AlMg3
Physical characteristics and boundaries			
Thickness [mm]	3	3	3
Contact fluid inner/outer	liquid LBE/helium	helium/water	water/helium-or-vacuum
Operating temperature and pressure			
Operating temperature [°C]	200-400	20-400	20-400
Operating pressure [Bar]	10	5	5

Austenitic steel fission vs spallation



L.K. Mansur et al, JNM356 (2006) 1-15

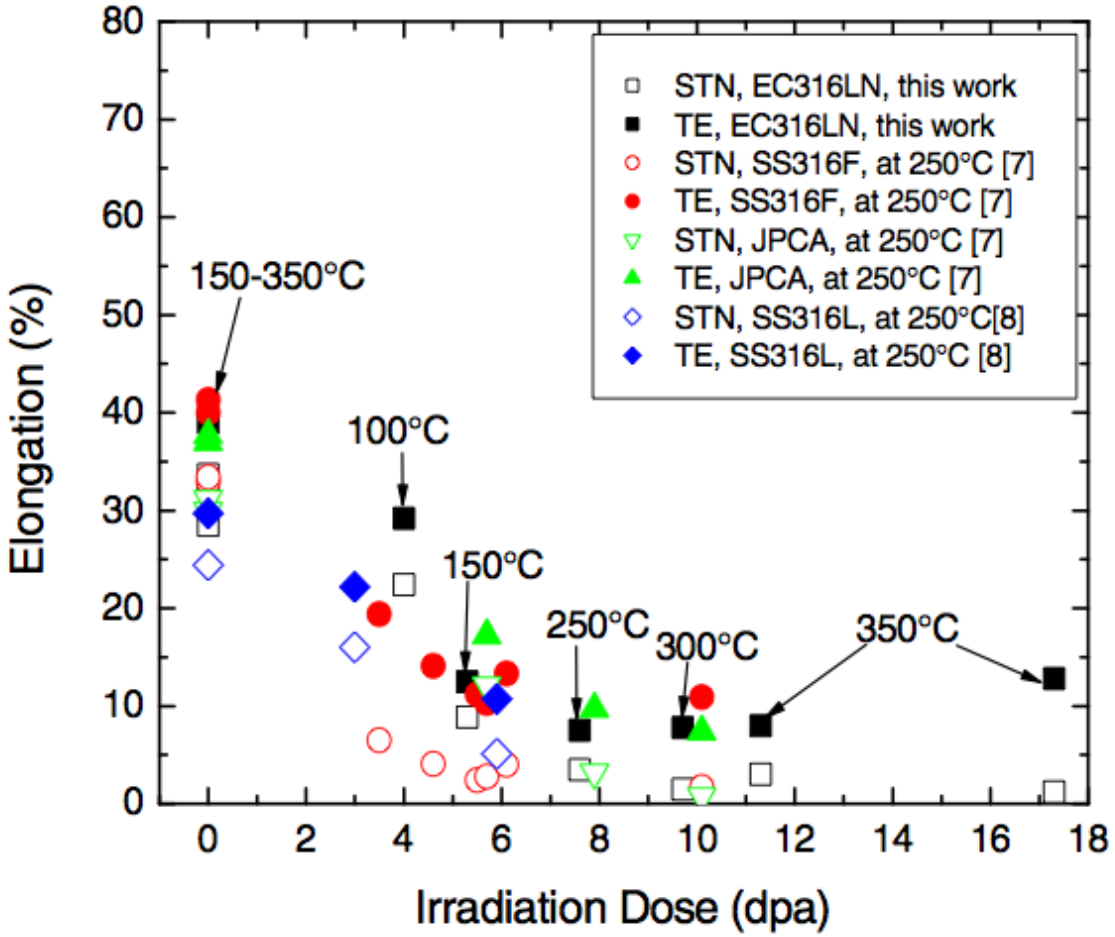
Austenitic steel spallation data



No substantial differences for 316-type steels between fission reactors (US fusion program DB) and spallation sources under these conditions, T > 100°C.

Y. Dai et al, JNM377 (2008) 109-114

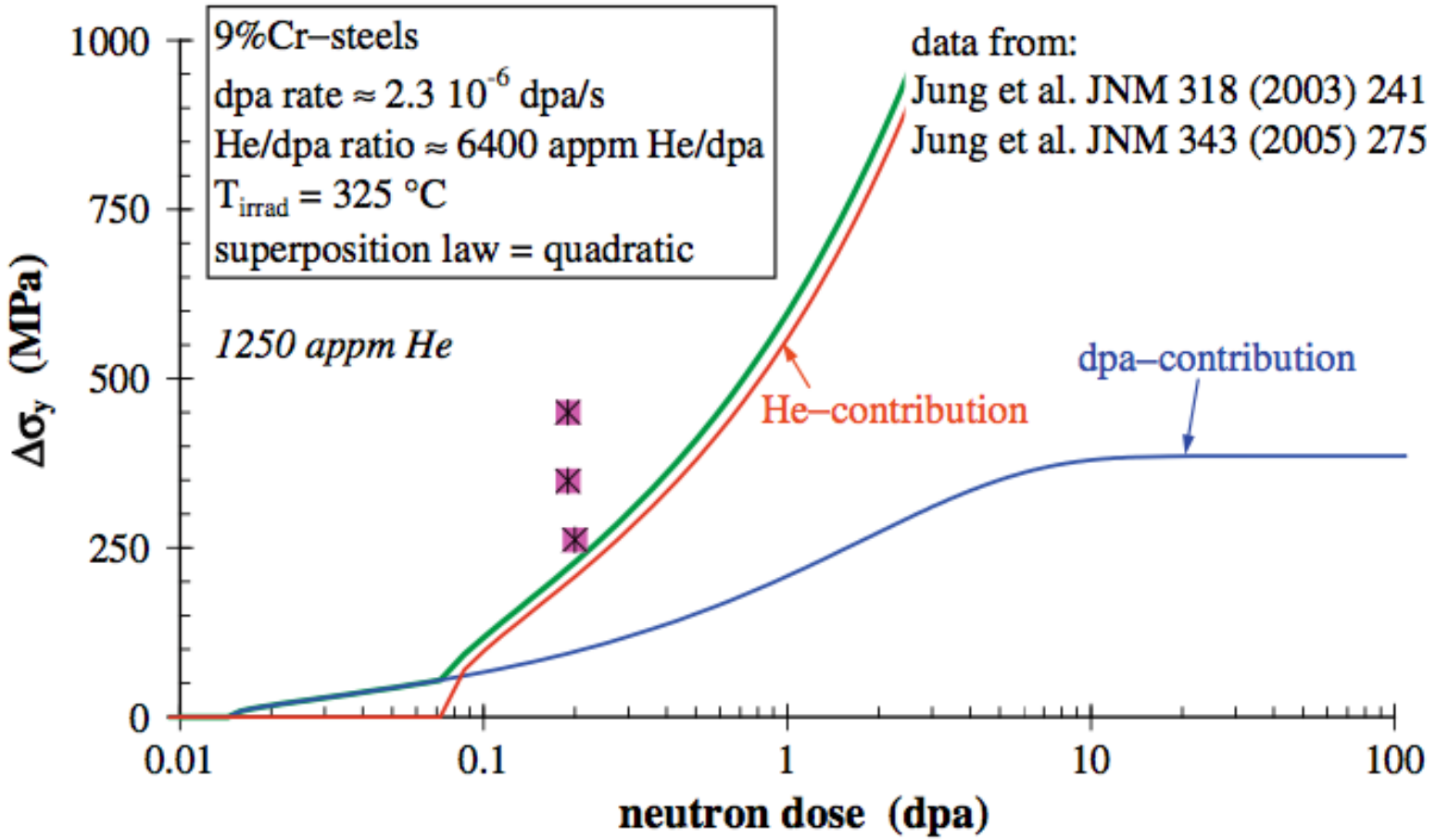
Austenitic steel spallation data



Saturation above 10 dpa?
Issue with TE margins for engineering design

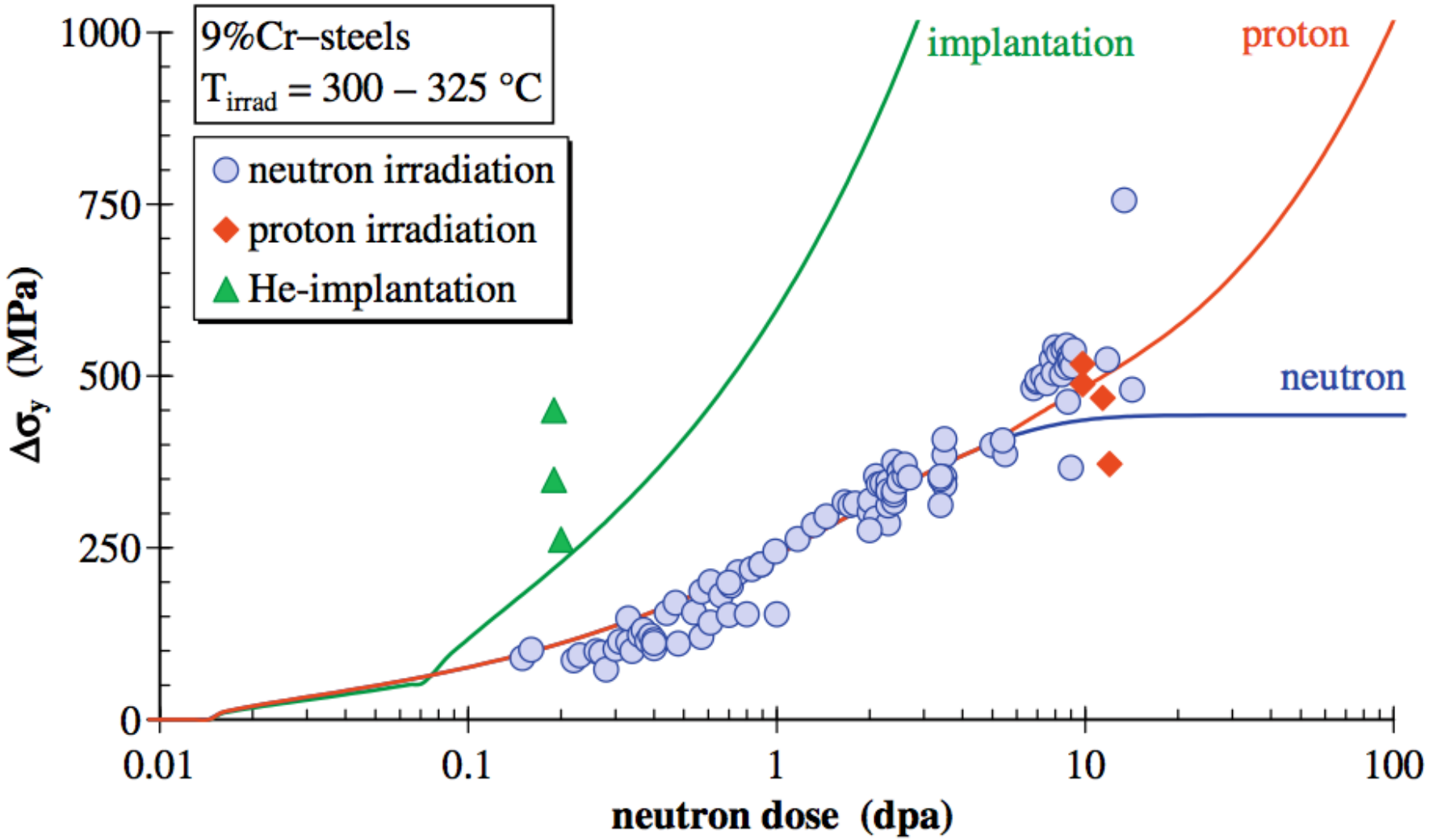
Comparison by Y. Dai et al, JNM377 (2008) 109-114
[7] S. Saito, JNM343 (2005) 253.
[8] J. Chen et al., JNM343 (2005) 236.

Martensitic steel spallation data



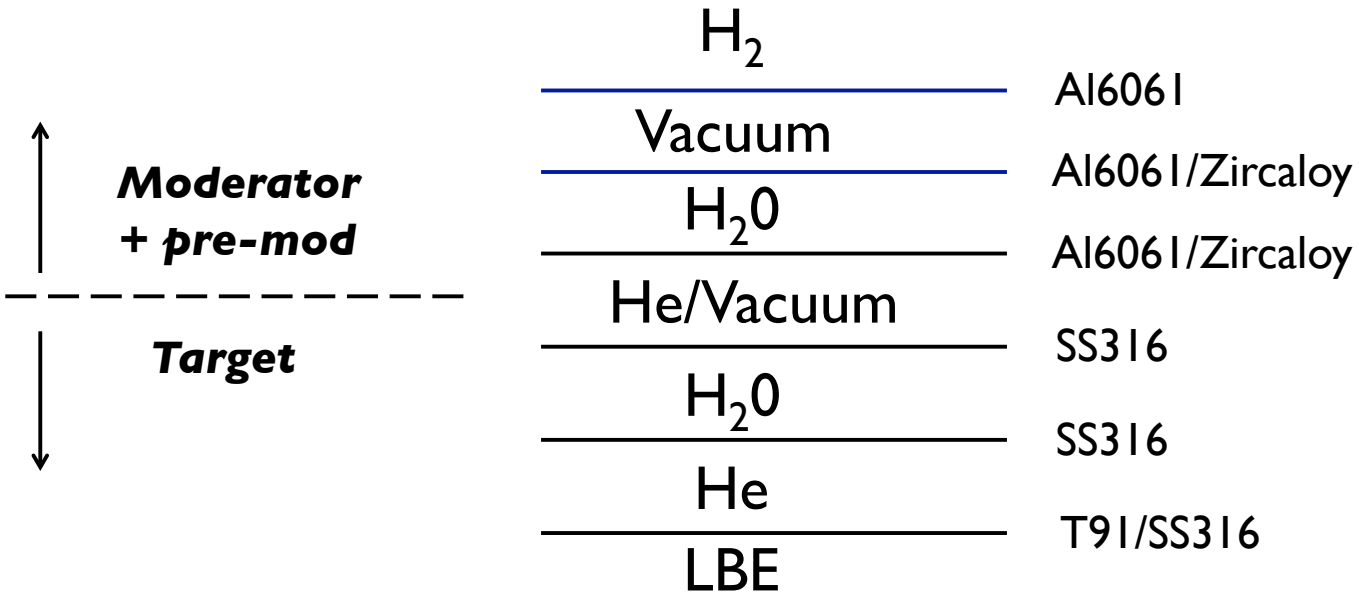
R. Chaouadi et al, JNM386-388 (2009) 544-549

Martensitic steel spallation data



R. Chaouadi et al, JNM386-388 (2009) 544-549

Elastic vs. inelastic design



- Seeking *less conservative* approach to:
  - *Reduce* typical *thicknesses* of *structural components*
- *Irradiation* leads to severe *embrittlement*
- Design code *not prescriptive*, only offers *guidelines*
- *Data* on *irradiated properties* for *inelastic design* are scarce

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Materials test requirements

- *Standards:*
  - Samples (geometry, composition, manufacturing).
  - Test procedures.
- *Environment:*
  - Radiation/Temperature/Mechanical loads/Fluids.
- *Mechanical properties:*
  - Tensile/Impact/Fracture toughness/Fatigue/Hardness/Swelling/Creep.
- *Activity & radiochemistry:*
  - Diffusion/release.
  - Gamma/alpha spectrometry.
  - H/He conc.
- *Microstructure:*
  - SEM/EDX, EPMA, TEM.

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Summary

- Use of *design codes* strongly motivated by *safety* and *reliability* of components.
- Large number of *ESS* target station *components* already *qualify* for use of *design codes*.
- *Critical components* subjected directly to *proton beam* currently *not covered* by *design codes*.
- Large amount of *data exists* on *structural materials* from *spallation community*.
- *Inclusion* of *spallation data* in *design code*:
  - Review criteria for data inclusion used by code
  - Assess existing spallation data
  - Draft code modification requests