

Input to the Expert Group meeting on ATF for LWR's

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STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

- Non-standard LWR fuel R&D
 - Thoria-based MOX fuels: since 1999 (design, fabrication, irradiation*, PIE, performance assessments, radiochemical analysis)
 - CERMET (FeCr & Mo + PuO₂) fuels: since 2006 (design, fabrication, irradiation°, performance assessment)
 - Fuel performance code modifications:
 - oxide, carbide, nitride & CERMET fuels
 - zircaloy, austenitic steels, SiC
- Irradiation capacity in BR-2
 - Cladding & materials
 - Fuel
- "MAX" phases research
 - Scoping studies collaboration with universities
 - Development in 7th FP MATISSE (+ KUL, KIT, KTH, CIEMAT, ENEA)

(*) various burnup levels, up to 40 GWd/tHM

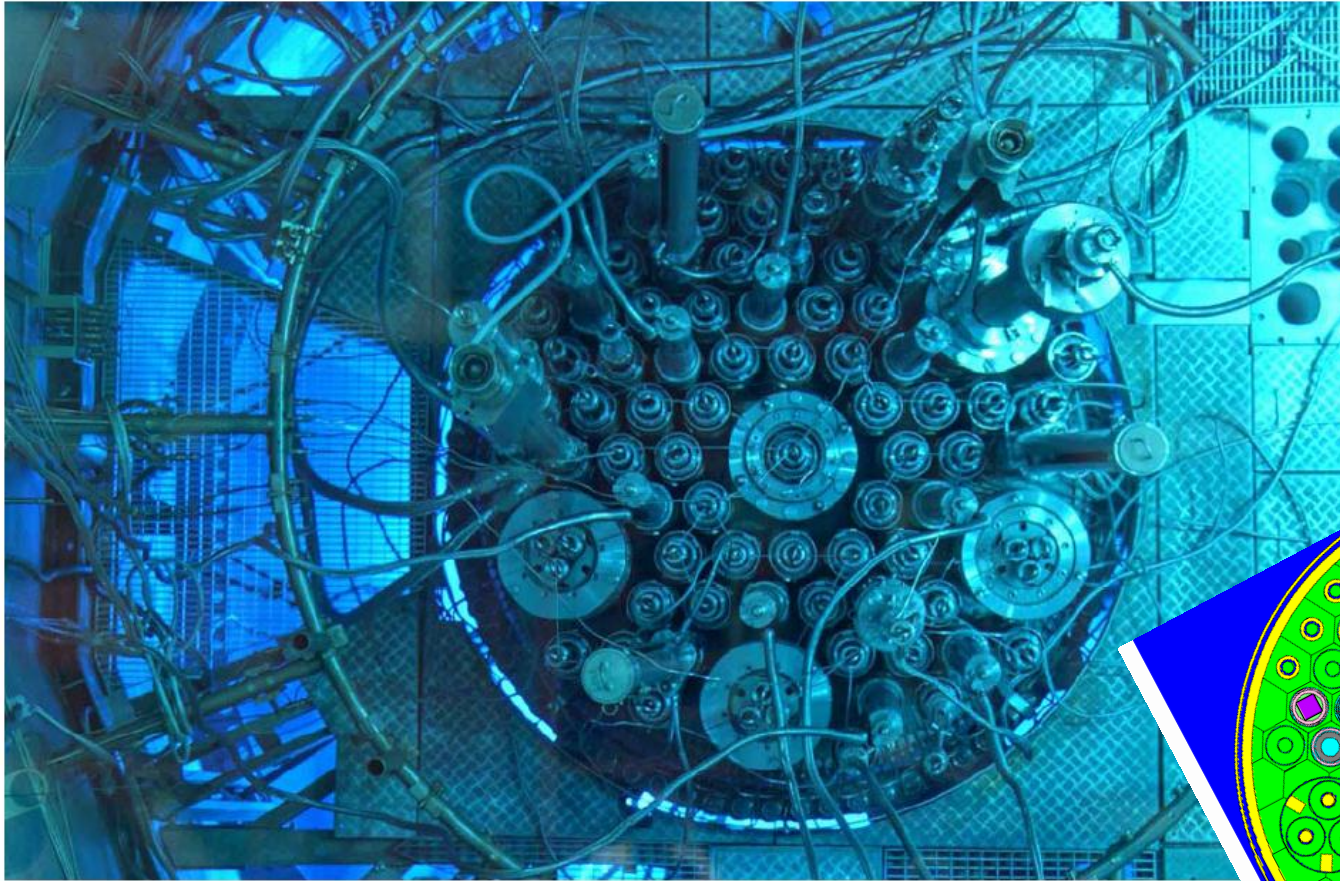
(°) up to 15 GWd/tHM

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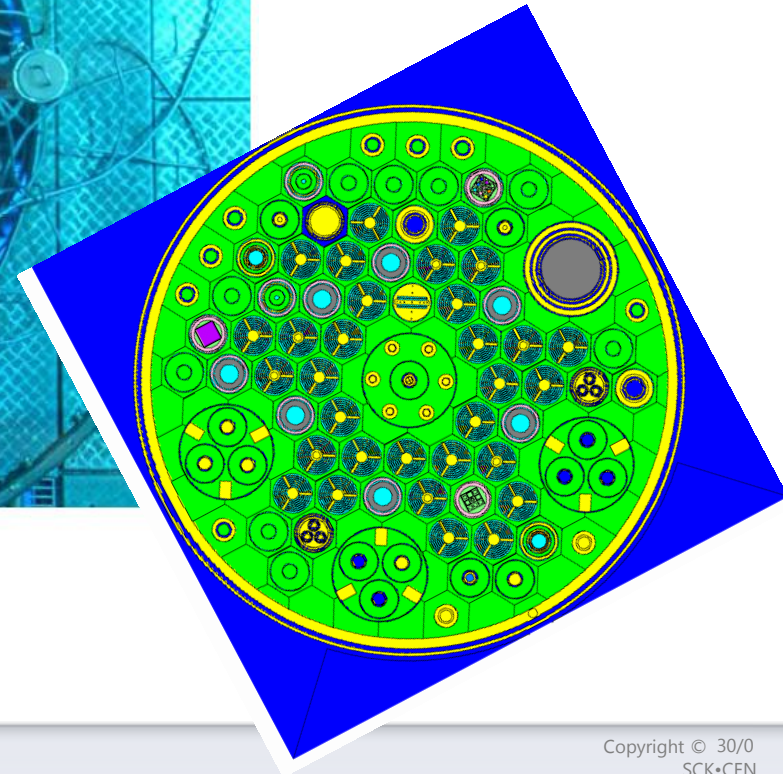
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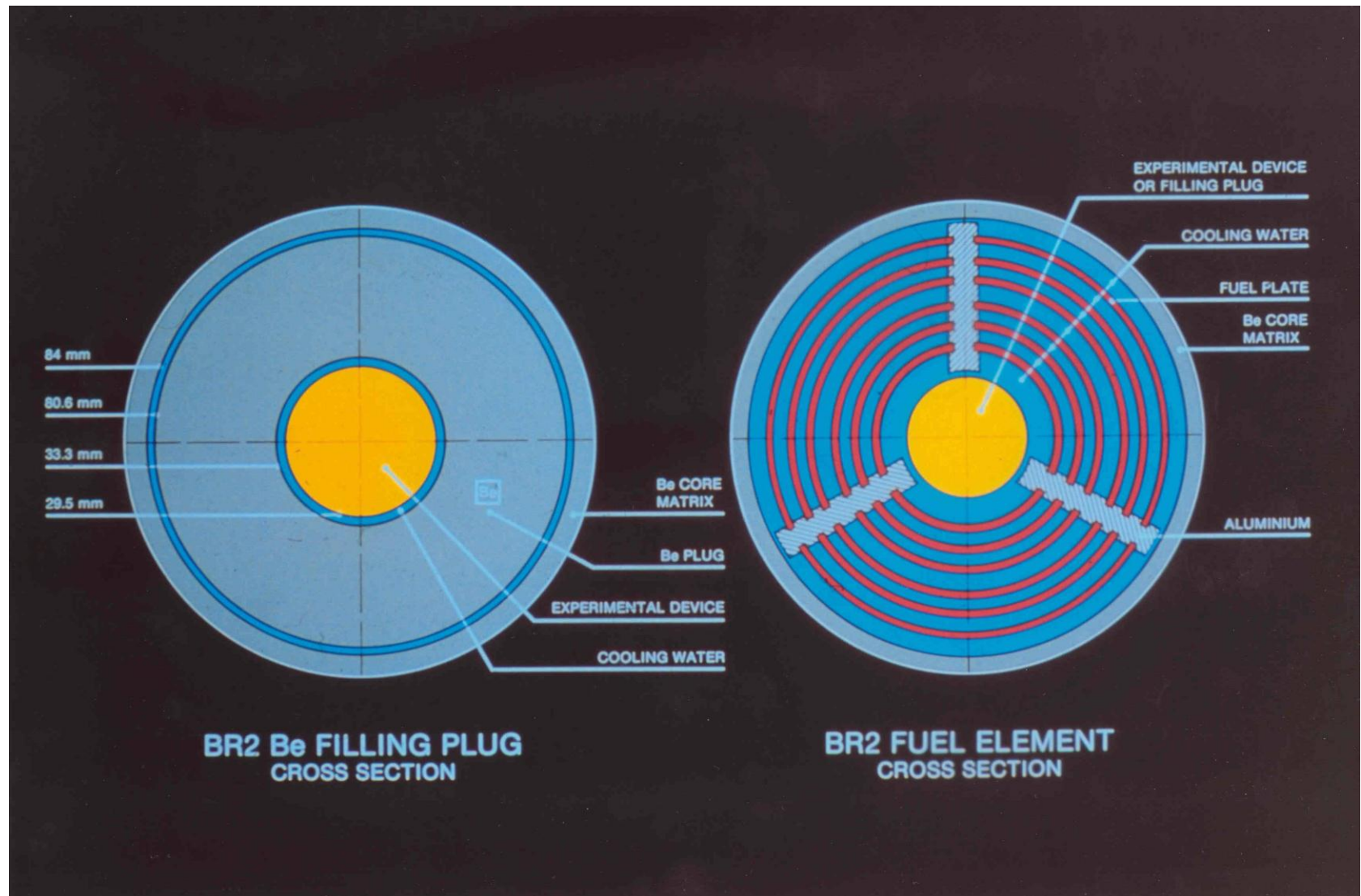
BR-2 top cover & core cross section view



BR2 at normal reactor operating power



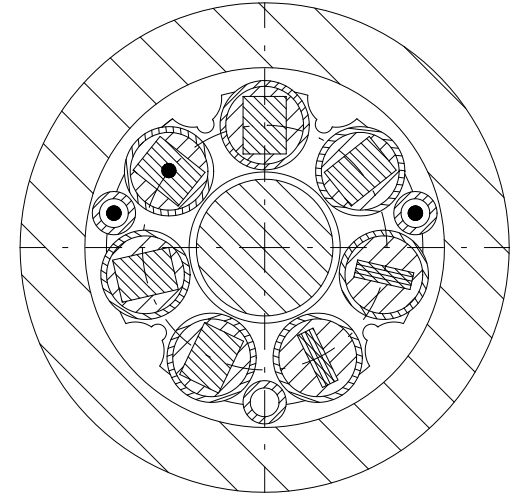
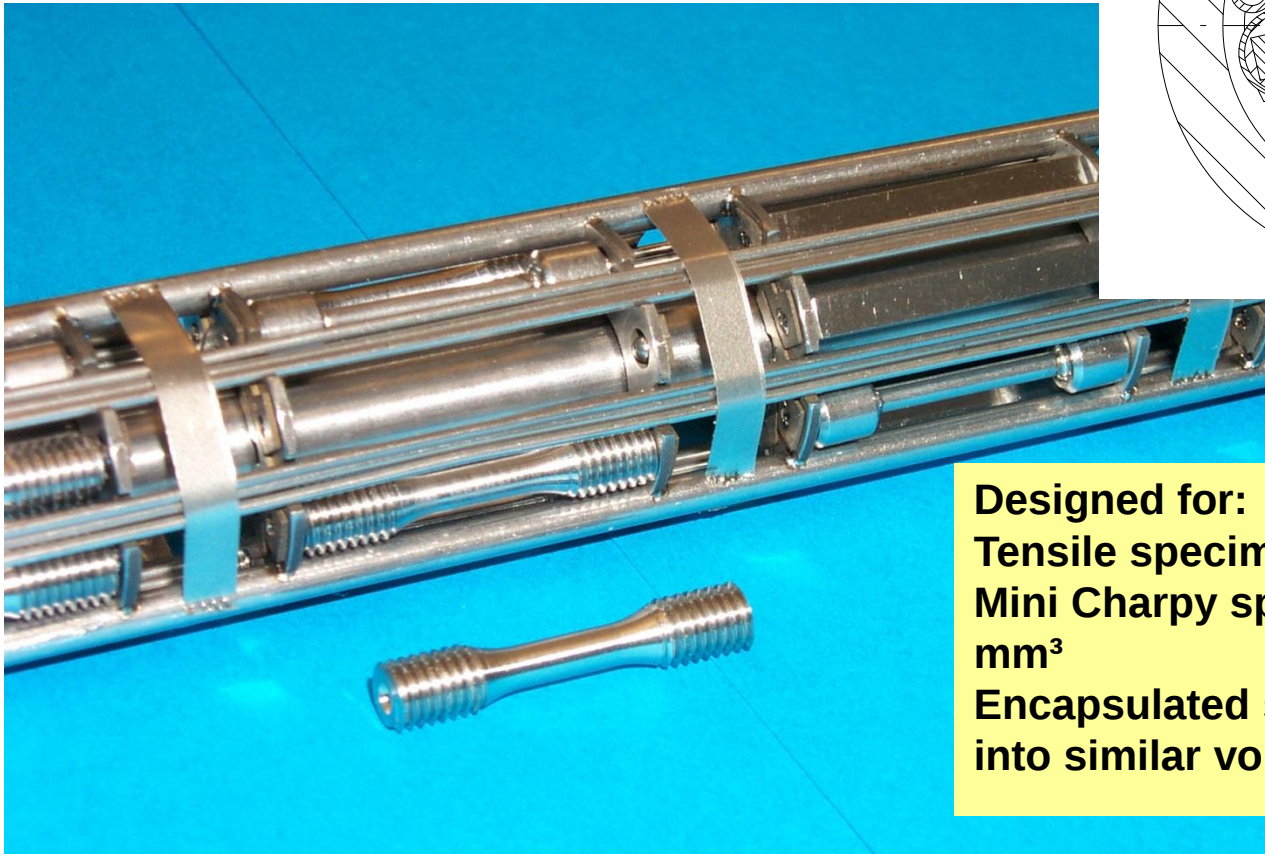
Standard irradiation positions



MISTRAL

Small specimens in a temperature controlled device

Total length 480 mm



Designed for:
Tensile specimens 5 mm Φ x 27 mm
Mini Charpy specimens 3 x 4 x 27 mm³
Encapsulated specimens must fit into similar volume

MAX Phases: Introduction

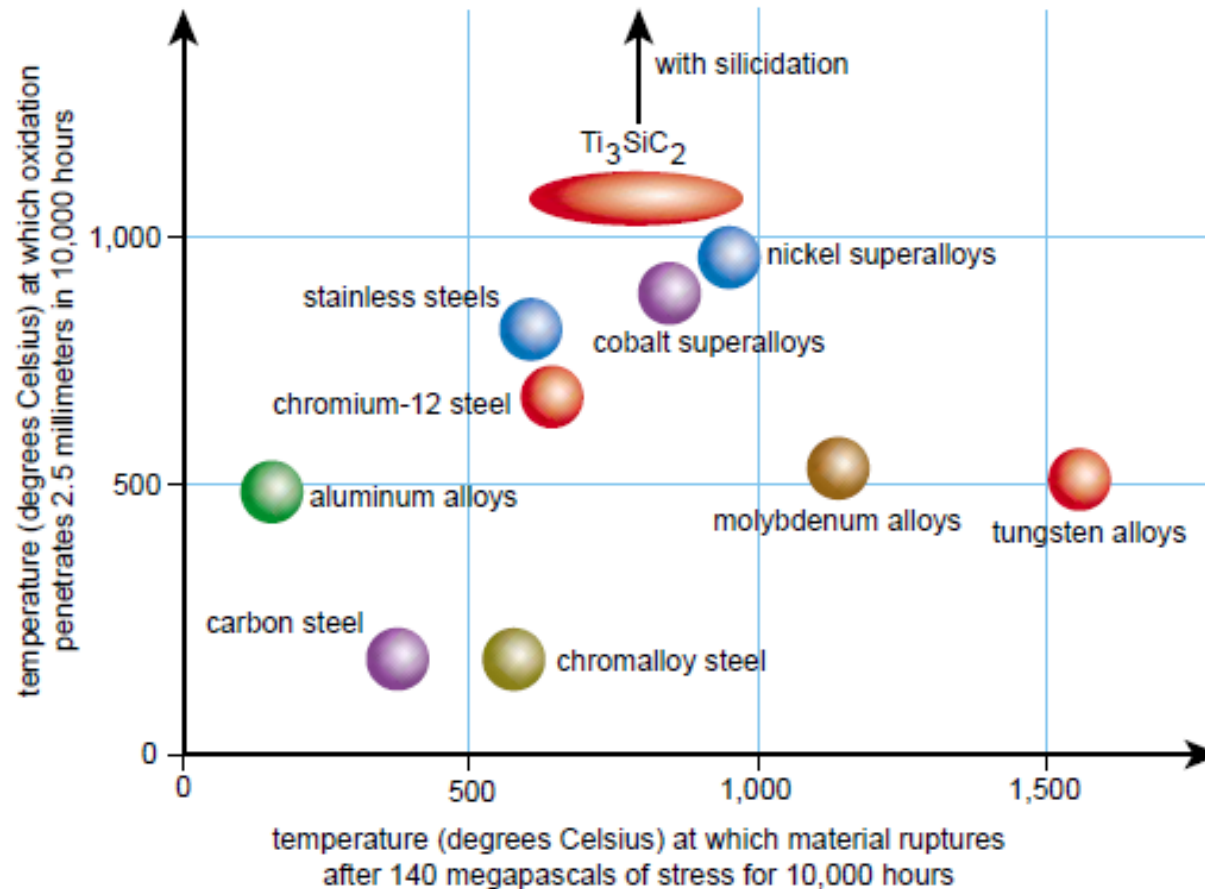
- MAX Phases: ternary carbide and nitride compounds described by general formula $M_{n+1}AX_n$, where $n = 1, 2, 3$

IA	IIA											IIIA	IVA	VA	VIA	VII	VIIIA
		H															He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Unq	Unp	Unh	Uns	Uno	Une									

M early transition metal
 A group A element
 X C and/or N

(M.W. Barsoum & T. El-Raghy, *American Scientist* **89** (2001) 334-343)

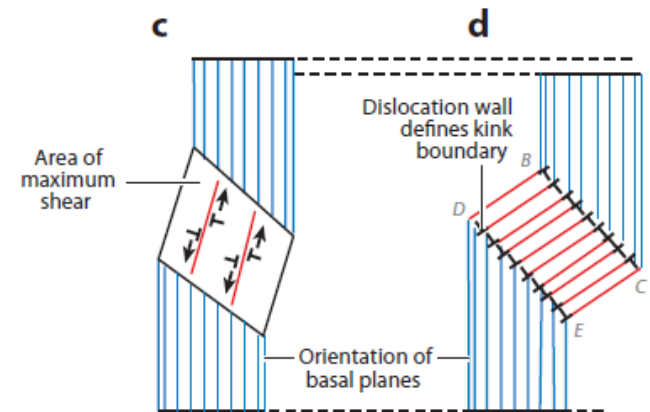
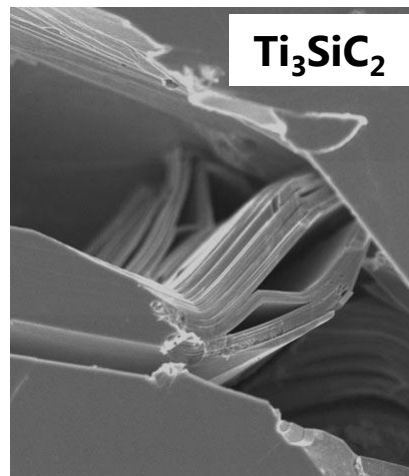
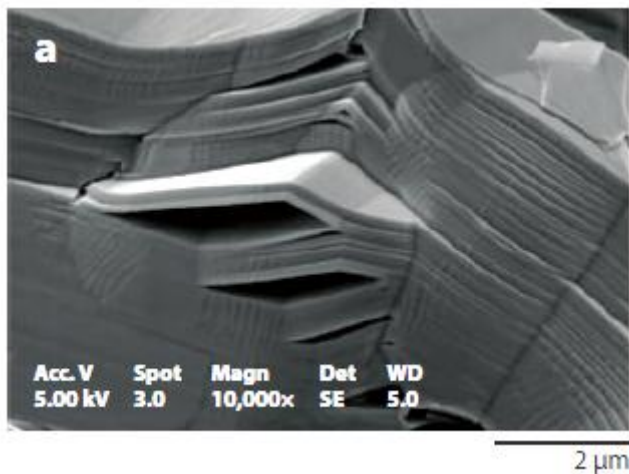
MAX phases: high temperature & oxidation resistant



(M.W. Barsoum & T. El-Raghy, *American Scientist* **89** (2001) 334-343)

MAX Phases: Properties

- Damage tolerance due to ability to deform by **kink band formation**
- Damage tolerance: result of *nano-laminated nature* of MAX phases



- Toughening mechanisms: **delamination** and **crack bridging**
- **Room temperature ductility** can be achieved, if large grains are highly oriented

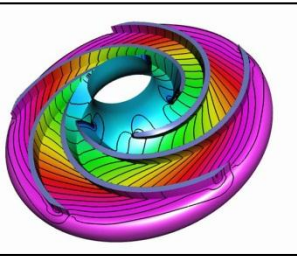


'Allowable' MAX elements as part of a fuel system

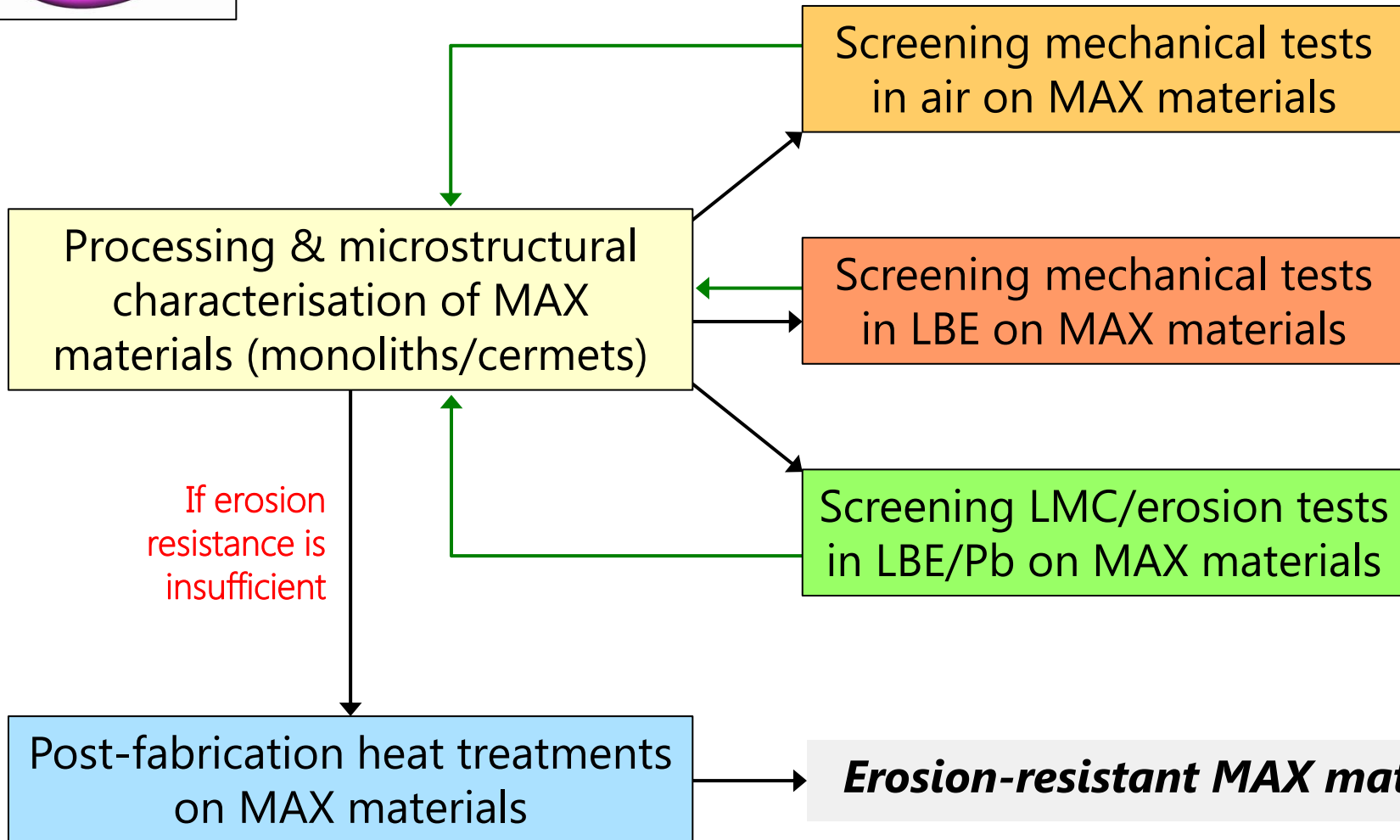
IA	IIA											IIIA	IVA	VA	VIA	VII	VIIIA
		H															He
Li	Be											B	C	N	O	F	Ne
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K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Unq	Unp	Unh	Uns	Uno	Une									

■ M early transition metal
■ A group A element
■ X C and/or N

- ✗ Unacceptable neutron cross-sections
- ✗ Long-lived activation products (OrigenArp)



On-going work on MAX phases



- Non-standard LWR fuel R&D

- Thoria-based MOX fuels: 1999-today (design, fabrication, irradiation*, PIE, performance assessments, radiochemical analysis)
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- Fuel performance code modifications:
 - Oxide, carbide, nitride & CERMET fuels
 - Zircaloy, austenitic steels, SiC

- Irradiation capacity in BR-2

- Cladding: MISTRAL, ROBIN, BAMI
- Fuel: PWC

- MAX phase research

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