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Application of TRLs in NNL

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Background

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In 2013, as part of an initial UK Government National Programme in Nuclear, the National Nuclear Laboratory (NNL) undertook a study into the TRL levels for

- Fuels,
- Cladding &
- Associated manufacturing capability

Although some of the results have been presented at conferences etc, the report itself has yet to be published.

Study does cover ALL Fuels not just ATF.

TRLs for Fuels

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- TRL assessment for advanced fuels and claddings relevant to:
  - Current & near term (Generation II / III / III+ / LWSMRs)
  - Advanced reactors (Generation IV)

- The assessment incorporated the results from:
  - An extensive literature review
  - Conference attendance
  - Relevant facility visits
  - Discussion with key contacts in the international nuclear industry

- Manufacturing technologies for advanced fuels and claddings were considered integrally to each type.

As ever, however, the process remains subjective, even when backed by evidence.

TRLs for Fuels

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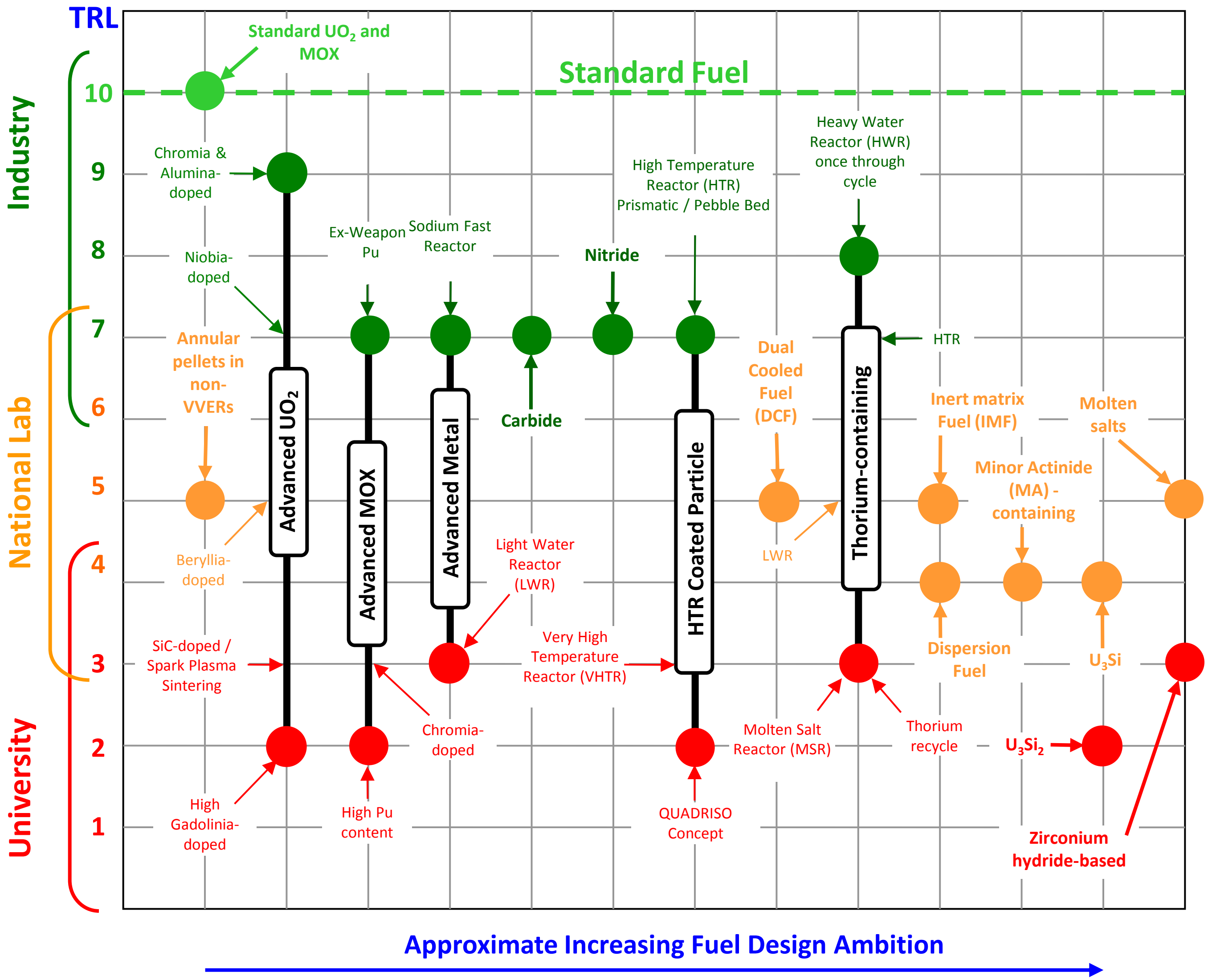
TRL	Definition & Description
10	**Widespread, Reliable, Long Term Operation of Many Actual Systems** *e.g. long term use of a fuel within a commercial reactor fleet / fleets i.e. many thousands of hours operating experience and data*
9	**Successful Operation of Actual System** *e.g. fuel assemblies successful after irradiation in large quantities i.e. reload quantities (roughly one third of a full reactor core)*
8	**Actual System Constructed and Commissioned** *e.g. assemblies fabricated in reload quantities*
7	**Prototype is Successfully Demonstrated** *e.g. lead test assemblies successful in a prototype or commercial reactor*
6	**Prototype Construction (much more representative than the basic system)** *e.g. lead test assemblies have been fabricated and irradiated in a prototype or commercial reactor but with only limited success*
5	**Basic System is successfully demonstrated** *e.g. test rods have been irradiated and performed successfully in a test reactor*
4	**Integration of Components into a Basic System** *e.g. representative assembly sections have been manufactured and subjected to out-of-reactor tests and/or test reactor irradiation trials of individual rods have been conducted with only limited success*
3	**Basic components are fabricated and successfully demonstrated** *e.g. fuel and/or cladding components have been manufactured and tested out-of-reactor and/or irradiated as a component only*
2	**Practical applications are suggested and concepts are formulated** *e.g. fuel, cladding and/or fuel assembly designs have been established*
1	**Research identifies the basic principles that underlie the technology** *e.g. promising materials and/or geometry have been identified*

Advanced Fuel TRLs



Fuel TRL vs Reactor type

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		Generation	II	II–III+	IV					
		Specific reactor	**AGR**	**L/HWR**	**SFR**	**HTR / VHTR**	**LFR**	**SCWR**	**GFR**	**MSR**
		Outlet temperature	650°C	~325°C (PWR)	550°C	650 – 1000°C	480 – 800°C	510 – 625°C	850°C	700 – 800°C
Advanced Fuel Categories	**Standard**	UO_2	10	10		7		3		
		MOX		10	8	7	5	3	3	
	New geometries	Annular pellets in non-VVER		5						
		Dual Cooled Fuel (DCF)		5				2		
	Evolutionary	Advanced UO_2	3	TRL9 – TRL2		2		2		
		Advanced MOX		TRL7 – TRL2	4	2	4	2	2	
		Advanced Metals		3	7		4			
	New compounds	Carbide		3	7	3	4	2	3	
		Nitride		3	7	3	4	2	3	
		U_3Si		4				2		
		U_3Si_2		2				2		
	Including new elements	Thorium		TRL8 – TRL5	3	7	3	2	2	3
		Minor Actinides (MAs)		3	4	3	3	2	3	3
	Including inert material	Inert Matrix Fuels (IMFs)		5	5		3	2	3	
		Dispersion fuels		4				2		
		Zr hydride-based		3				2		
		Coated particle-based				TRL7 – TRL2			2	
	Molten salt -based	FLiBe salt containing U								5

Advanced Cladding TRL's

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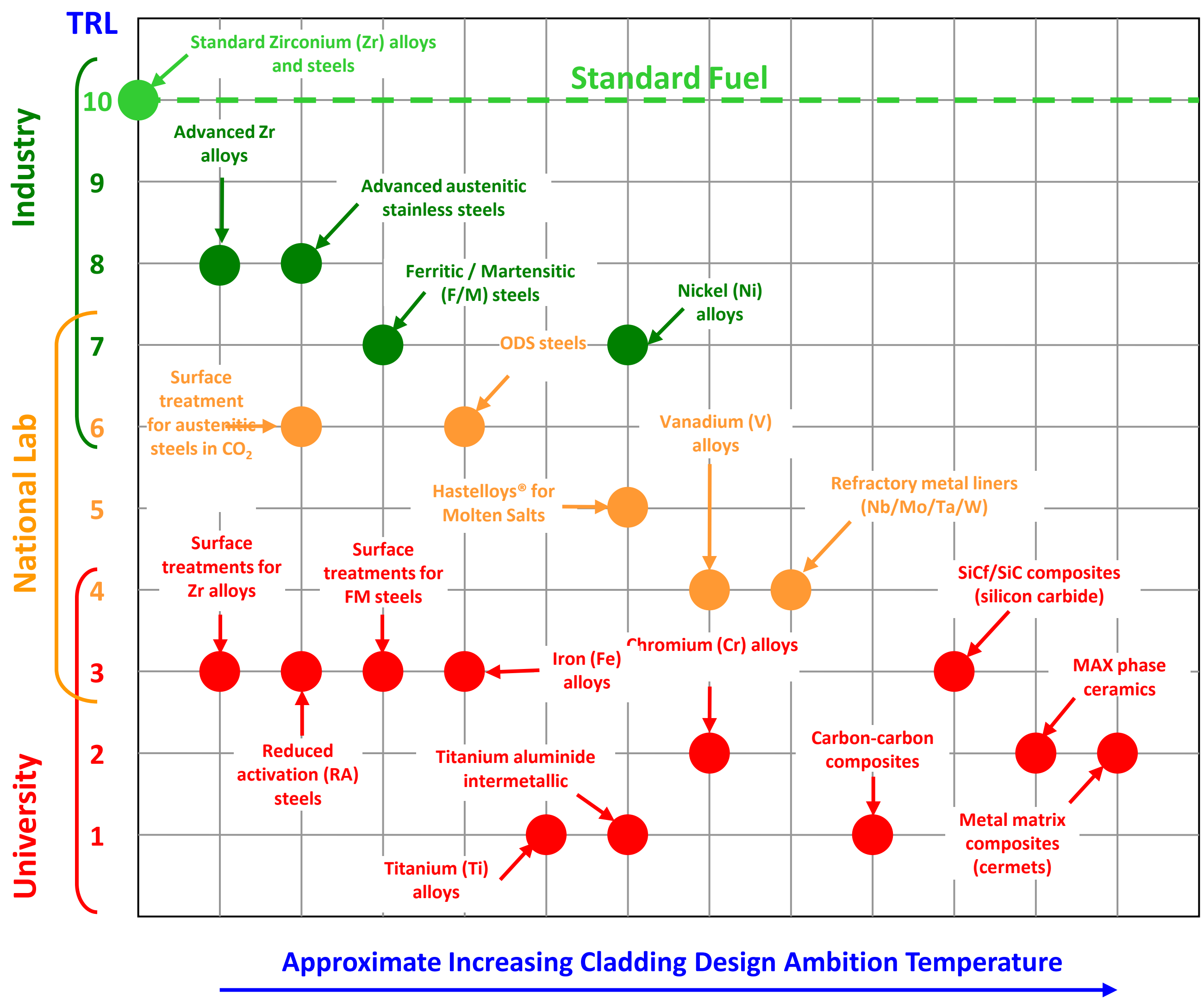

Cladding TRL vs Reactor types

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Approximate increasing ambition →

↓ Advanced Cladding Categories

	Generation	II	II–III+	IV					
	Specific reactor	**AGR**	**L/HWR**	**SFR**	**HTR / VHTR**	**LFR**	**SCWR**	**GFR**	**MSR**
	Outlet temperature	650°C	~325°C (PWR)	550°C	650 – 1000°C	480 – 800°C	510 – 625°C	850°C	700 – 800°C
Standard	Zirconium alloys		10				3		
	Austenitic stainless steels	10	8 (past standard)	6		4	3	3	
Zirconium development	Advanced zirconium alloys		8				3		
	Surface treatments for zirconium alloys		3				2		
Steels development	Surface treatments for austenitic stainless steels	6							
	Advanced austenitic stainless steels		6	8		4	3		
	Ferritic / Martensitic (F/M) stainless steels			7		4			
	Surface treatments for F/M steels					3			
	Oxide Dispersion Strengthened (ODS) steels			6		4	2	3	
	Reduced Activation (RA) steels			3		3	3		
Semi-refractory metals	Iron alloys (excluding steels)		3	2		2	2		2
	Nickel alloys			7			3	3	
	Hastelloy®								5
	Titanium / Titanium Aluminide alloys		1	1		1	1		
	Chromium alloys		2	2		2	2	2	
	Vanadium alloys			4		2		3	
Refractory metals (liner / coating only)	Niobium, Molybdenum, Tantalum or Tungsten alloys			4		3		3	
Ceramic-based	SiCf/SiC		3	3	(coated particles assessed with fuels)	3	2	3	
	MAX phase		2	2		2	2	2	

Conclusions

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- For advanced reactor designs, a significant level of further development of the fuel and cladding will be required before commercial application.

- Advanced claddings were found in general to have lower TRLs than fuels. Therefore claddings may be a limiting factor in deploying advanced reactors.

- Further down-selection of the more promising candidate advanced fuel and cladding materials is proposed to prioritise UK research.