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Fusion Specific Technology Readiness Levels

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Technology Readiness Levels (TRLs) give a good idea of maturity of new technology and are used by industry and government organisations worldwide. Nine TRLs exist ranging from initial ideas at Level 1 where basic principles are observed to fully robust technologies validated for application in industry at Level 9. TRLs can be further subdivided into Readiness Levels for system, materials, methods, manufacturing and instrumentation as shown in Figure 1. The main TRLs were originally devised by NASA and also used by ESA for aerospace industry. DOE 1 in USA produced a guide on TRL assessment for wider application. EU H2020 2 and NDA (UK) [3] also produced TRL guides out which the one defined by the NDA(UK) is perhaps the most relevant to the nuclear industry but it was specifically written for nuclear decommissioning sector. This paper presents a case to develop definitions of fusion specific TRLs.

The 1 to 9 TRL scale is an ordinal scale. The effort or time needed to move from one point to another may not be linear. TRLs are time specific and most importantly context specific. TRLs should not be used to measure progress, risk, cost or duration. Technologies with low TRL can mature more quickly and technologies with high TRL can stagnate and never mature as is shown in Figure 2. TRLs of individual items say nothing about whether the whole system will work together. The integration and interfaces need to be assessed separately. TRLs are for individual technologies not for a system requiring integration of many. There will be a need to breakdown a complex system into sufficient number of sub-systems to apply TRLs. Furthermore, a technology which is mature in one sector may not be mature for fusion application and vice versa. All this has to be analysed in the case of Fusion technologies

Benefits of TRLs are that they can help decide whether a technology is ready for implementation and can help plan its further development. For cost-effective development of a technology, a better definition of TRLs is needed as it will help focus the resources. The example shown in Figure 1, indicates the target TRLs to be achieved by a project and a stage gate review indicates the current status which highlights the areas where development effort needs to be invested. A good TRL definition and assessment will help produce a cost-effective development plan, and it not available for fusion so far.

The need for fusion specific TRLs arises from the fact that technology requirements in the nuclear sector are different from other industry sectors. Furthermore, there are some notable differences between the fission and fusion. The IAEA Tecdoc 1851 [4] highlights these differences. For example, in the fusion applications, there

is no reactivity control or emergency cooling requirements and no core melt conditions to be addressed. Prevention of core meltdown is not a safety related function for fusion reactors. Most of the main parameters like the safety functions, consequences of failure, fault frequencies, contributing to the safety classification process in fission applications are different for the fusion applications. Yet, the fusion industry has mostly relied on existing codes, standards and industrial practices developed for fission. Fusion technology challenges are also different if not more demanding. In the fusion nuclear facilities there are many kinds of accidents that can be postulated due the fact that a tokamak is a complex and dense zone with many different energy source terms. In addition, the first confinement barrier, which is surrounded by those energy source terms, has a very complex boundary and is subjected to a combination of extreme loads not seen in other industry sectors. E Surrey et al [5] have acknowledged inadequacy of the existing TRLs for fusion and proposed an alternative methodology that allows a quasi-numerical analysis by a combination of three quantities: unmitigated probability of failure, severity and probability of failure detection.

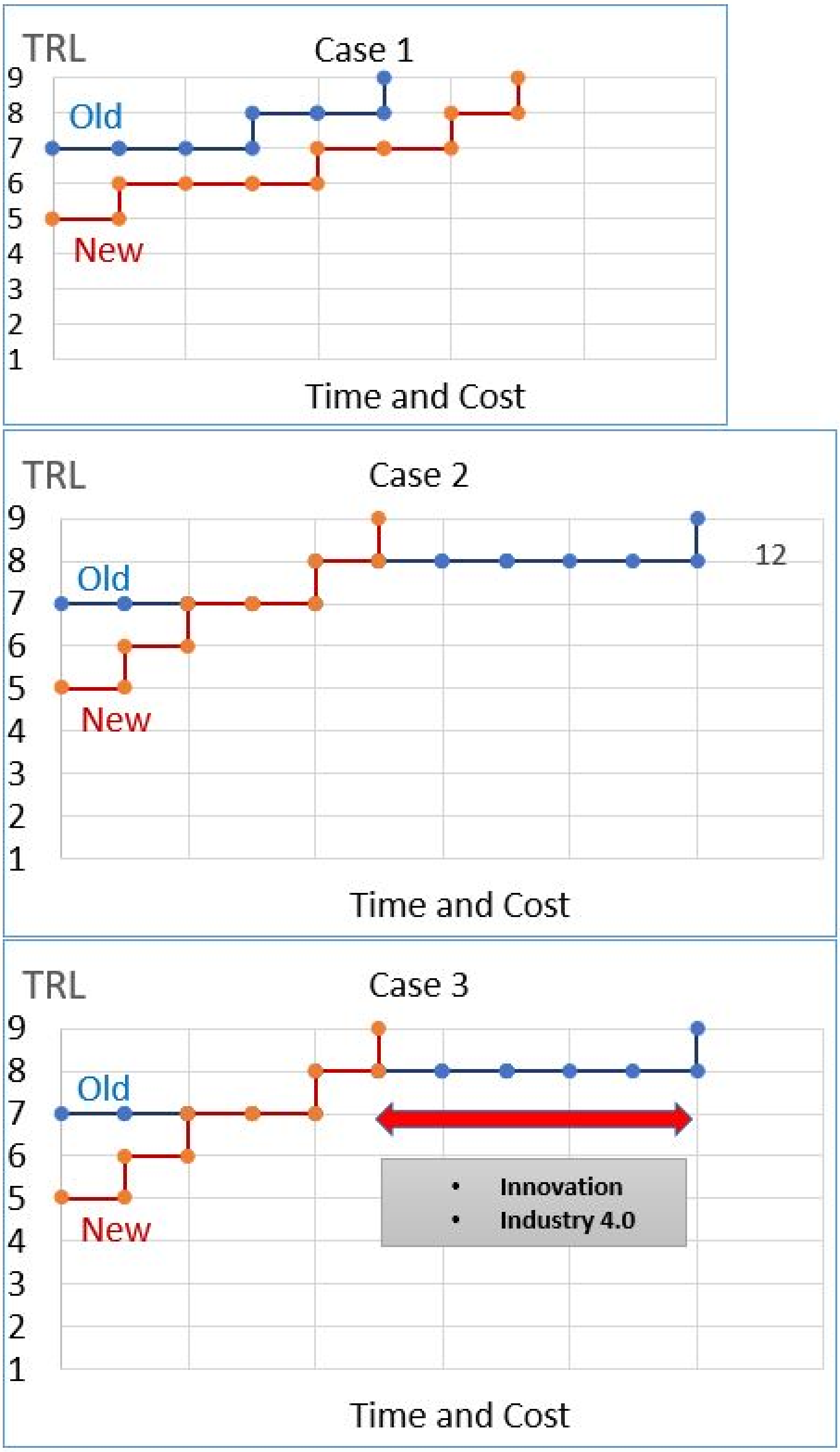
To help fusion technology achieve full industrialisation, it is prudent to consider internationally harmonised definitions for fusion specific TRLs and provide fusion specific definitions for all the 9 levels of TRL for system, materials, methods, manufacturing and instrumentation.

The new definitions can also take into account new approaches to design and validate a system, structure or component. For example, risk informed performance based probabilistic design methods can help produce cost-effective designs without compromising safety. The current design approach is to use allowable stress codes to design components that rely on experience-based safety factors which gives no idea of reliability or risk in design of the full system. The new approach can produce cost-effective design and give a good idea of the risk and probability of failure. This new approach is going to have wider scope and will be applicable to next generation of reactors.

TRL	System	Materials	Methods	Manufacturing	Instrumentation
9	Successful mission operation	Production ready material	Full production system demonstrated	Demonstrated over an extended period	Service proven
8	Test and demonstration	Full operational test	Release into Production Library	Significant run lengths	Demonstrated productionised system
7	Prototype demo in an operational environment	Evaluated in development rig tests	Validated for production usage.	Economic run lengths on production parts	Successful demonstration in test.
6	Prototype demo in a relevant environment	Validated via component and/or sub-element testing.	Agree integrated product is verified.	Process optimised for capability and rate using production equipment	Applied to realistic location/environment with low level of specialist support.
5	Partial system validation in a relevant environment	Methods for material processing and component manufacture	Partial validation of basic functionalities & specific models	Basic capability demonstrated using production equipment	Requiring specialist support
4	Validation in a laboratory environment	Design curves produced.	Models validation in stand-alone environment.	Process validated in lab	Lab demonstration of highest risk components
3	Proof of concept	Materials' capability based on lab scale samples.	Proof of concept.	Experimental proof of concept completed	Lab test to prove the concept works.
2	Technology concept	Agreed property targets, cost & timescales	Requirement Definition produced	Validity of concept described	Concept designed
1	Basic principles	Evidence from literature	Evidence from literature	Process concept proposed	Understand the physics

Project Target　　Current TRL

Figure 1: Typical example for practical use of TRL



- **Technology with low TRL today need not be a risky choice.**
- **Development plan will help reduce risk.**
- Innovation and Industry 4.0 can bring faster maturity

Figure 2: TRL comparisons

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3. Guide to Technology Readiness Levels for the NDA Estate and its Supply Chain, Nuclear Decommissioning Authority (NDA), 2014.
4. Integrated Approach to Safety Classification of Mechanical Components for Fusion Applications, IAEA Tecdoc 1851.
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