Fusion Specific Technology Readiness Levels

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NEED FOR FUSION SPECIFIC TRL

- 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 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

Phase	TRL	Stage	Description
Operations	TRL9	Operations	The technology is being operationally used in an active facility
Deployment	TRL8	Active Commissioning (radioactive)	The technology is undergoing active commissioning
	TRL7	Inactive Commissioning	The technology is undergoing inactive commissioning. Works testing and factory trials on the final designed equipment using inactive simulants comparable to that expected during operations. Testing at or near full throughput will be expected
Development	TRL6	Large Scale	Undergoing testing at or near full-scale size. The design will not have been finalised and the equipment will be in the process of modification. It may use a limited range of simulants and not achieve full throughput
	TRL5	Pilot Scale	Undergoing testing at small to medium scale size in order to demonstrate specific aspects of the design
	TRL4	Bench Scale	Starting to be developed in a laboratory or research facility.
Research	TRL3	Proof of Concept	Demonstration in principle that the invention has the potential to work.
	TRL2	Invention and Research	A practical application is invented or the investigation of phenomena, acquisition of new knowledge or correction and integration of previous knowledge.
	TRL1	Basic principles	The basic properties have been established

Four phases of nuclear specific rating scale in nuclear decommissioning

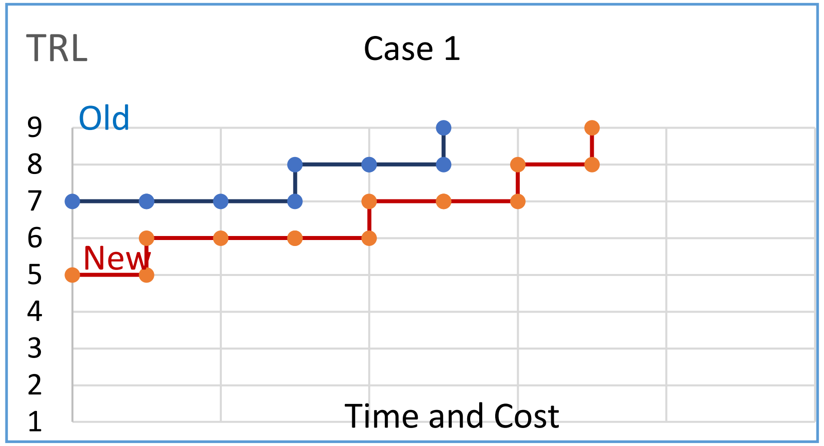
FUSION TECHNOLOGY REQUIREMENTS

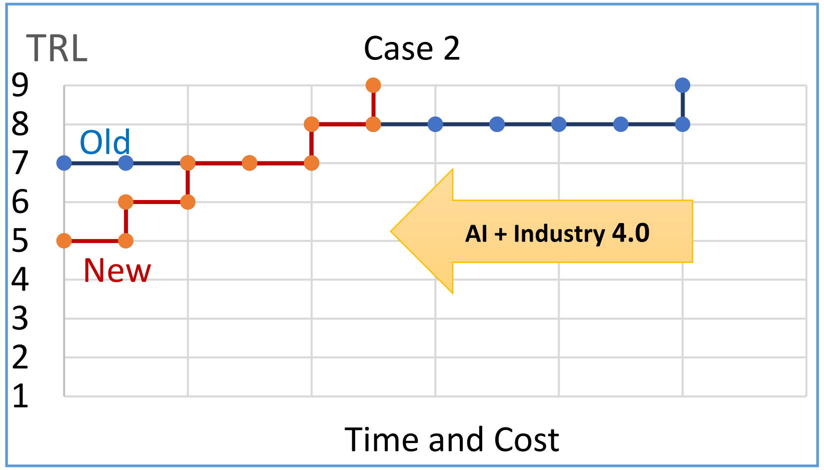
Fusion power is fast becoming a reality. ITER is the first industrial scale fusion reactor expected to achieve its first plasma in December 2025. It has to be followed by building of fusion power stations that bring the following six big science and engineering challenges that will require new technologies:

i. **Plasma science:** need to confine and control the hot plasma
ii. **Plasma exhaust:** exhaust system to deal with the intense heat
iii. **Materials science:** developing materials that can withstand high neutron dose and the attendant nuclear heating
iv. **Fuel handling:** need to breed and handle tritium fuel to power future commercial fusion reactors
v. **Remote maintenance:** advanced robotics to work under demanding conditions to maintain the reactor remotely
vi. **Advanced manufacturing:** new advanced manufacturing techniques to economically produce complex components with precision

NEED TO DE-RISK AND ACCELERATE TECHNOLOGY DEVELOPMENT

- Fusion sector needs to **de-risk and accelerate its technology** development programmes. Normally, when building a complex system, it is expected that using the existing off-the-shelf old technology will achieve TRL9 earlier compared to using new technology as shown in case 1 of the figure
- Note that technologies with low TRL can mature more quickly and technologies with high TRL can stagnate and never mature as is shown in case 2 of the figure. Furthermore, new technologies can be accelerated by use of AI and Industry 4.0. Cases 1 and 2 in the figure illustrate that
- 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.
  - ❑ Technology with low TRL today need not be a risky choice.
  - ❑ Development plan can help reduce risk.
  - ❑ Innovation with Artificial Intelligence and Industry 4.0 can bring faster maturity





CONCLUSION

- There remain a number of science and engineering challenges to achieve commercial fusion power.
- New technologies need to be developed to economically build the complex components and systems for the future fusion power stations. **Technology Readiness Levels (TRLs) can give a good idea of maturity of new technology.**
- Definition of TRLs exist for use in the nuclear industry but these are more suitable for the nuclear fission technologies. Furthermore, a technology which is mature in one sector may not be mature for fusion application and vice versa. Therefore, there remains **a need to develop definitions of Fusion specific TRLs.**
- **The new TRL 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. The design and safety aspects can be integrated much earlier in the project as has been advised in the IAEA TECDOC 1851