Safety Classification of Mechanical Components for Fusion Application

13rd International Symposium on Fusion Nuclear Technology

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Oral Session 1-2: Nuclear System Design (1)

OA1-2.4

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IAEA
International Atomic Energy Agency

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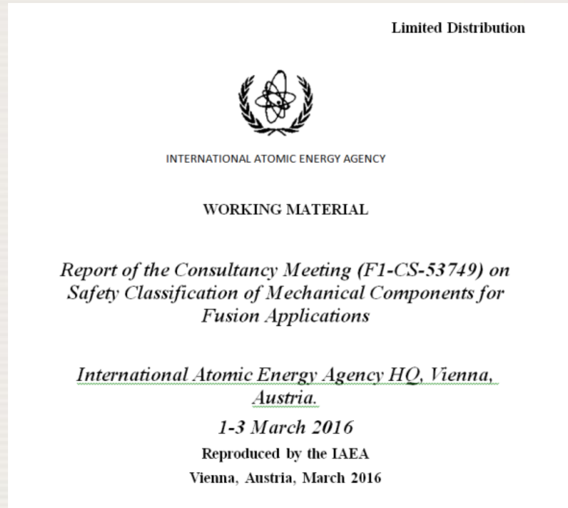
Outline

- Developing Guidelines and Standards for Fusion Applications
- Safety Classification of Mechanical Components – TECDOC
- Fusion Portal
- Conclusions

Consultancy meeting on Safety Classification of Mechanical Components for Fusion Applications

- Output: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INTERNATIONAL ATOMIC ENERGY AGENCY

WORKING MATERIAL

Report of the Consultancy Meeting (F1-CS-53749) on Safety Classification of Mechanical Components for Fusion Applications

International Atomic Energy Agency HQ, Vienna, Austria.

1-3 March 2016

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Vienna, Austria, March 2016

Production of a TECDOC on Guidelines for Safety Classification of Mechanical Components for Fusion Applications was recommended

- Chair: Nawal Prinja (UK). 6 participants from France, F4E, India, Italy and ITER

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TECDOC: Purpose

- Experts meetings held at IAEA to provide guidance on safety classification of mechanical components for fusion applications:

Name	Organisation	Country
Nawal Prinja (Chair)	Clean Energy, Amec Foster Wheeler plc	UK
Mario Gagliardi	F4E	Spain
Stefano La Rovere	NIER Ingegneria S.p.A.	Italy
Didier Perrault	IRSN	France
Neill Taylor	CCFE	UK

- **It was identified that the safety classification of SSCs used in nuclear power plants provided in various IAEA guides and other international standards is mostly aimed at the fission applications.**

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TECDOC: Purpose

- The IAEA Technical Document (TECDOC) provides further guidance on how to use the knowledge from the safety classification process to help design a component by selecting appropriate design codes and to help substantiate the design by knowing the failure modes and the allowable damage limits.

Safety functions

First step: **Identification of the required safety functions**

- **Development of a full list of safety functions + all required supporting functions.**

A safety function is a specific purpose that must be accomplished for safety for a facility or activity to prevent or to mitigate radiological consequences of normal operation, anticipated operational occurrences and accident conditions.

Some safety functions that are defined for a fission reactor are absent in a fusion plant: reactivity control, needed to avoid a criticality event in a fission reactor, and emergency cooling needed to avoid a core melt event**, are not relevant in a fusion plant.**

Safety functions

The principal safety functions in a fusion system are:

- **The confinement of radioactive material**

  to prevent mobilisation and dispersal of radioactive material within the plant, and the avoidance of the leakage of any part of this radioactive inventory to the environment.

- **Limitation of exposure to ionizing radiation**

  to minimize occupational radiation exposure of personnel arising from radiation from all radiation sources including mobile source terms.

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Safety functions

List of safety functions and supporting functions, as adopted in the conceptual design studies for a European DEMO plant.

Fundamental Safety Functions	**Confinement of radioactive and hazardous materials** **Limitation of exposure to ionizing and electromagnetic radiation** **Limitation of the non-radiological consequences of conventional hazards** **Limitation of environmental legacy**
Supporting Functions	**Functions in support of confinement:** Control of plasma energy Control of thermal energy Control of confinement pressure Control of chemical energy Control of magnetic energy Control of coolant energy **Functions to support personnel and the environmental protection:** Limitation of radioactive and toxic material exposure to workers Limitation of airborne and liquid operating releases to the environment Limitation of electromagnetic field exposure to workers Limitation of other industrial hazards **Supporting functions to limit environmental legacy:** Limitation of waste volume and hazard level Facilitation of clean-up and the removal of components

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Safety Classification Process

- **Classification is a top down process that begins with a basic understanding of the plant design, its safety analysis and how the main safety functions will be achieved**. On the basis of the classification, a complete set of engineering rules must be specified which then dictate the codes and standards that are used by the designers.
- **Close collaboration between the design team and the safety team.** The design team has to provide the knowledge of the plant and its SSCs, under normal and accidental conditions. The safety team has to provide the expertise required by the deterministic and probabilistic safety demonstration. Specific expertise could be required about external hazards (e.g. seismic, flood).

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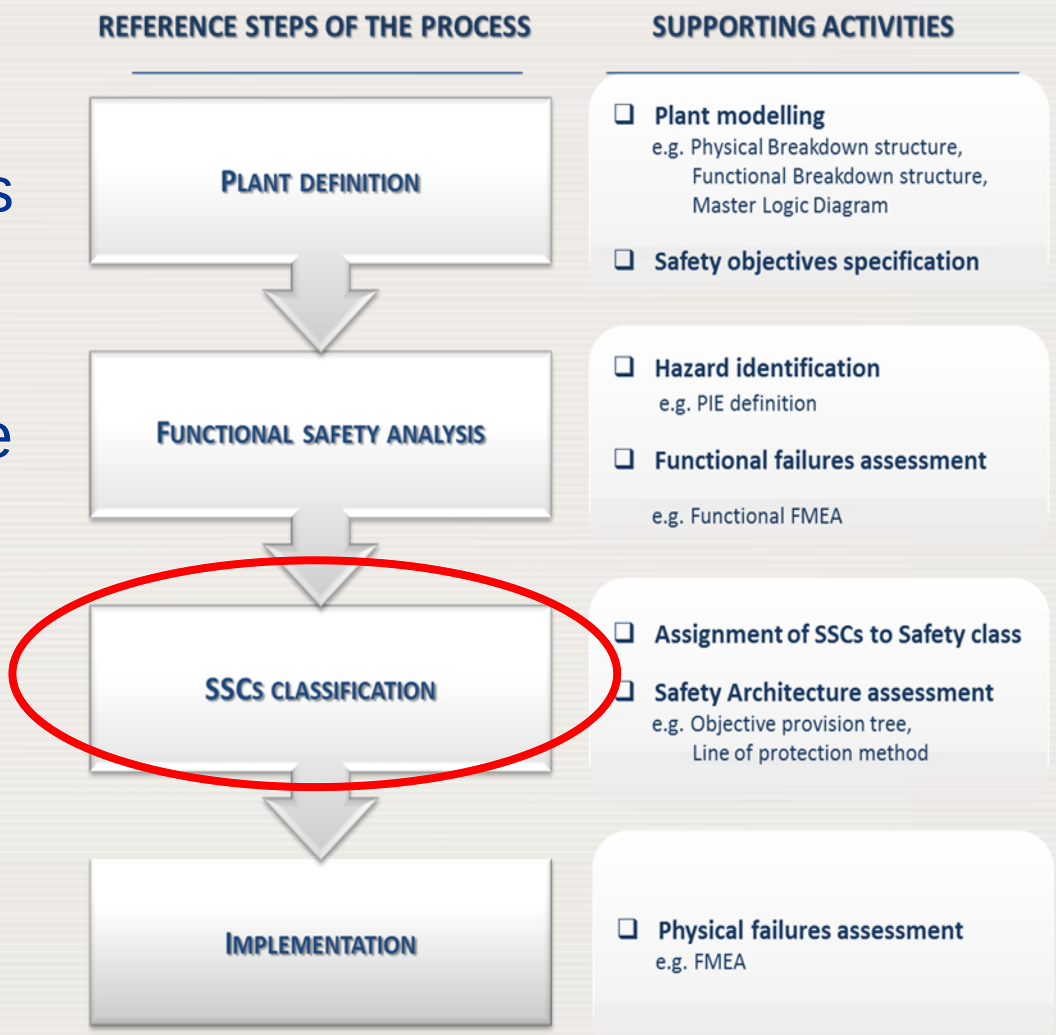
Safety Classification Process

Safety classification of mechanical Structures, Systems and Components (SSCs) of fusion installations.

- There are 4 steps in the safety classification process



Safety Classification Process

- **1st step (Plant Definition):** providing the information required by the subsequent categorization of safety functions and safety classification of SSCs. It includes the definition of the safety objectives and the specification of the plant design concept and (physical and functional) breakdown(s).

- **2nd step (Functional Safety Analysis):** categorizing the safety functions implemented by the plant. This activity should be supported by the assessment of the plant's functional failures.

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Safety Classification: Physical breakdown

Plant Breakdown Structure (PBS) to be defined only at the highest levels at the start of a conceptual design process, and become defined at lower level as the design matures and becomes detailed. In the same way, safety classification may be done first at the top level, and later in progressively more detail at lower levels.

PBS level 1	Description
01	Magnet System
02	Vacuum Vessel
03	Divertor
04	Blanket and first wall
05	Limiter
06	Cryostat
07	Thermal Shields
08	Fuel cycle
09	Tritium Extraction from blanket
10	Electron Cyclotron (EC) System
11	Neutral Beam Injection (NBI) System
12	Ion Cyclotron (IC) System
13	Plasma Diagnostic & Control System
14	Primary Heat Transfer System
15	Vacuum vessel pressure suppression
16	Remote Maintenance System
17	Assembly
18	Radioactive Waste Treatment and Storage
19	Balance of Plant
20	Site Utilities
21	Cryoplant & Cryodistribution
22	Electrical Power Supply Systems
23	Buildings
24	Plant Control and Monitoring System
25	Auxiliaries

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Safety Classification: Functional breakdown

The functions that SSCs provide in the plant is the subject of a Functional Breakdown Structure (FBS). A function is a statement of a specific purpose or objective to be accomplished, without a description of how it is achieved.

FBS level 1	FBS level 2	FBS level 3	Description
1			To manage fuel
1	1		To supply fuel to the plant through external supplies
1	2		To recover tritium from breeding and multiplier materials
1	3		To recover unspent D-T from the tokamak exhaust
1	4		To recover unspent D-T from the tritiated process fluids
1	4	*1*	*To recover tritium from coolants*
1	4	*2*	*To recover tritium from cryogenic fluids*
1	4	*3*	*To recover tritium from inert gases*
1	5		To recover unspent D-T from the tritiated wastes
1	6		To store fuel gas (Hydrogen isotopes)
1	6	*1*	*To provide long-term storage of hydrogen isotopes*
1	6	*2*	*To provide short-term storage of hydrogen isotopes*
1	7		To supply fuel to fuel injection systems in plasma

Safety Classification: Functional safety analysis

Identification of the (fundamental and supporting) safety functions implemented by the plant and its SSCs.

- **Hazards identification studies**
  - A thorough identification of all hazards in a plant is an essential step in a complete safety analysis. Every identified hazard must be eliminated or reduced in frequency of occurrence, and its consequences must be minimized.
  - Hazard identification studies necessarily require a detailed design if they are to reveal the component-level failures that may lead to a safety consequence. Before the design is fully developed, or at least at the conceptual design stage, this is not possible.

Safety Classification: Functional safety analysis

- **Failures assessment**
  - The failures assessment should be performed iteratively throughout the plant design.
  - The results provided by the failure assessment should support the application of the construction code(s) selected for the SSCs fabrication; specifically, the analysis should provide the main failure modes to be taken as reference in the SSCs design, design justification and qualification, including any relevant degradation and aging phenomena.
  - The Failure Mode and Effects analysis (FMEA) is one of the earliest systematic methodologies for failures assessment.

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Safety Classification Process

- **3rd step (SSC classification):** classifying the SSCs according to the allocated safety functions and to their categorization.
  - It requires a representation of the relations between the SSCs and the implemented (safety) function, the unambiguous definition of the safety classes to be assigned, the results coming from the categorising of safety functions, and the assessment of the plant's SSCs failure.
  - At this stage, SSCs should be defined (at least) in terms of functions implemented and external (mechanical, electrical, hydraulic, pneumatic) interfaces. This activity shall be supported by the assessment of the SSCs failure from a functional perspective.

Safety Classification: SSCs classification process

- The safety classification of SSCs should consider their “role” within the safety architecture of the plant and the consequence of their failure during normal and off-normal operation.

- The complex physical and functional architecture of fusion machines suggest the definition of detailed criteria for the identification and classification of **Safety Important Component (SIC).**

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Safety Classification: SSCs classification process

- Three safety classes are proposed for the SIC, i.e. SSCs leading to or mitigating Anticipated Operational Occurrence (AOO) and Design Basic Accident (DBA):

  “SIC-1”, “SIC-2”, “SIC-3”.

- A complementary class includes all the SSCs without any safety relevance: “Non-SIC”.
- A fourth safety class is proposed for the classification of the SSCs mitigating Design Extension Condition (DEC) and Beyond Design Basis Accident (BDBA) non-practically eliminated: “HCC” (Hard Core Component).
- A complementary class includes all the SSCs without any relevance: “Non-Hard Core”.

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Safety Classification: SSCs classification process

Criteria for the assignment to SIC-1 class	
SSC role	**Criteria**
Hazardous SSC	• **SSCs whose failure can result in high severity consequences, including:** **_failures without effective and/or reliable protection (to be mitigated)** *E.g. SSCs materializing the first confinement system (e.g. Vacuum Vessel and its extensions, e.g. Isolation valves), Tritium process safety-important SSCs, Cooling circuit with significant inventories of tritium and activated corrosion products.* **_failures without effective and/or reliable mitigation (to be practically eliminated).** *E.g. Catastrophic failure of Vacuum Vessel.*
Protection or mitigation SSC	• **SSCs implementing safety functions required to bring to and to maintain the plant in a controlled* or safe state after an incident or a design-basis accident (AOO or DBA), and whose failure (when challenged) can result in high severity consequences. (DiD L3)** *E.g. Vacuum Vessel, Pressure Suppression System, Detritiation system.* **A SIC-2 is required to bring to and to maintain the plant in a safe state*.
Supporting SSC	• **SSCs ensuring the capability, reliability and robustness required to (other) SIC -1.** *E.g. VV support, Emergency electrical power supplying for active SIC-1, Safety instrumentation and control for SIC-1.*
Passive SSC for shielding	• **Passive SSCs protecting** **_workers and public from harmful effects of radiation, and/or** **_safety-Important SSCs from damages due to internal or external hazards, and whose failure can result in high severity consequences**

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Safety Classification: SSCs classification process

- **Link SIC grading to code class**

➢ Once a SSC has been identified as a SIC, it is necessary to design it in order that it fulfills the missions which are allotted to it so that the plant's safety objectives are achieved

➢ Design studies of a component are made by associating with the safety requirements which arise from the safety analysis. On one hand acceptable damage limits are important and on the other hand the safety margins shall be tailored considering the frequency of the event and the safety function.

➢ The designers can choose the level of the code classification which is adapted to the damage limit and the safety classification of the component which were imposed by the safety analysis.

Safety Classification: SSCs classification process

- **Link SIC grading to code class**
  - The use of the adequate code for the design of equipment is worth quasi demonstration that the safety requirements will be satisfied
  - But these codes adapted for fission reactors cannot being for certain equipment of fusion reactors because the safety requirements are different, the materials are not the same one. Indeed, certain normal or accidental events are specific in fusion field, which results in having to take into account new operating conditions.
  - Fusion reactors are likely to have to cope with accidental events which do not exist in fission reactors, like disruptions of plasma, losses of superconductivity for magnetic coils, helium leaks at very low temperature, loss of vacuum. This resulting in having to take into account operating conditions for equipment different from those met in fission reactors: vacuum operation, electromagnetic loads, thermal shocks.

Safety Classification: SSCs classification process

- **Link SIC grading to code class**

➢ Before using a code dedicated to the design of fusion reactor equipment (metal joints, the penetrations, the isolation valves), to show the adequacy of the code with the safety requirements of the equipment to be designed is essential.

➢ If need be, the code can be revised, under reserves to bring the elements of demonstration necessary for that (studies, tests). Thus, for the design of ITER vacuum vessel, code RCC-MR, used before for fast breeder and high-temperature reactors, was supplemented by a specific appendix dedicated to ITER vacuum vessel.

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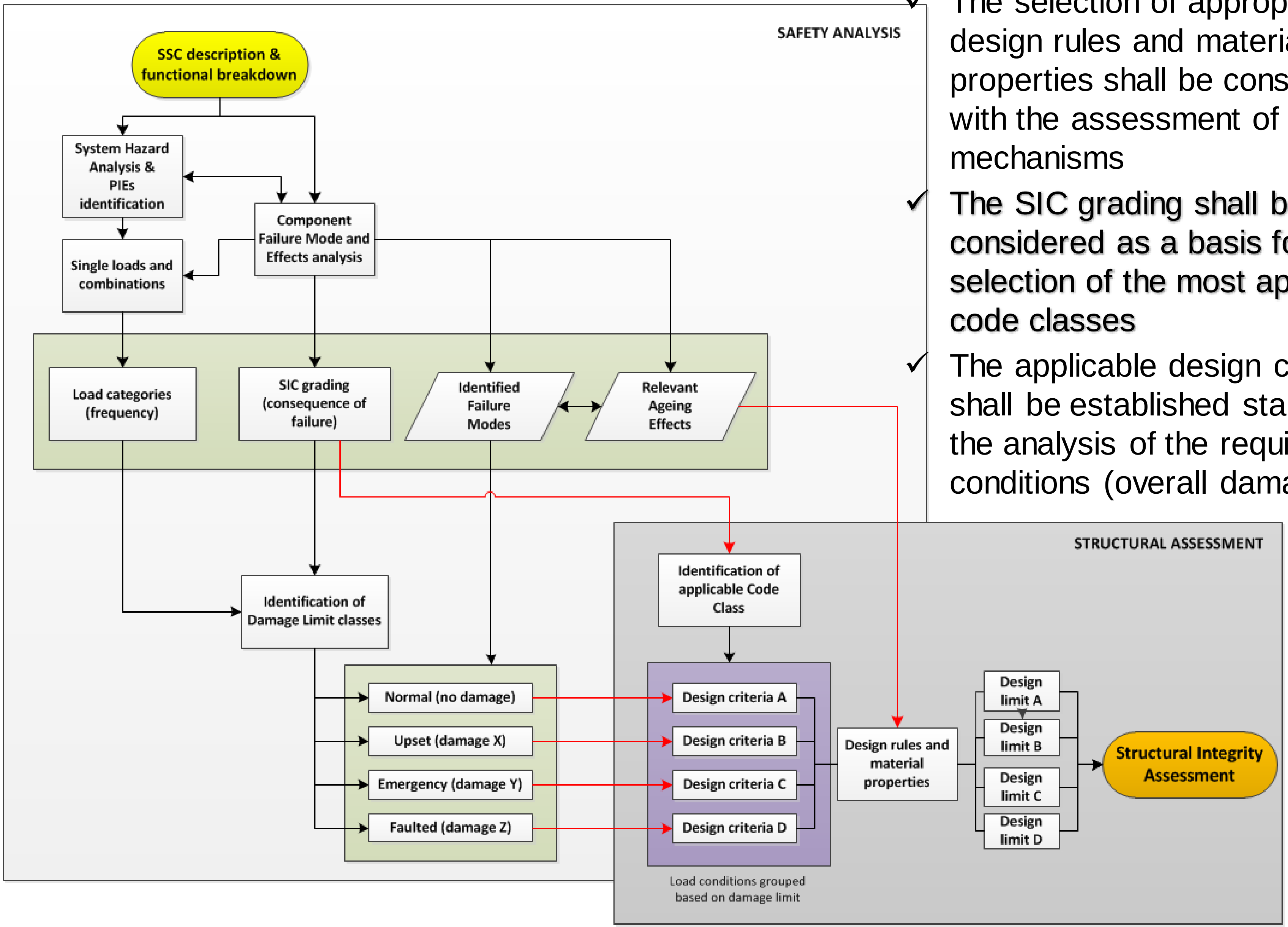
From Safety Analysis to Structural Integrity Assessment



- ✓ The selection of appropriate design rules and material properties shall be consistent with the assessment of ageing mechanisms
- ✓ The SIC grading shall be considered as a basis for the selection of the most appropriate code classes
- ✓ The applicable design criteria shall be established starting from the analysis of the required plant conditions (overall damage limits)

Safety Classification Process

- **4th step (Implementation):** includes the design, the design justification, the prototype qualification and the fabrication of the SSCs.
- All these activities should be supported by the detailed assessment of the failure modes of the SSC and its subparts. A Physical Failures assessment can be developed through the FMEA methodology.

Conclusions (i)

- For the safety classification of mechanical components for fusion applications the basic principles described in SSG-30 remain applicable but there are some important differences between the fission and fusion applications

Conclusions (ii)

- **It was found that there are still several areas where further work needs to be done for the fusion components**. Some of the important areas requiring future work where there is still lack of information and guidance are as follows:
  - Lack of processes and criteria for:
    - Classification of Shielding function.
    - Definition of Design pressure for vessel.
  - Lack of data for:
    - **Material properties for structural materials under fusion irradiation conditions (14 MeV neutrons)**
    - Material properties for ceramics, ceramic to metal joints in irradiated environment (with right spectrum)
    - Lack of reliability data for components
    - Uncertainty related with disruption loads and plasma stability

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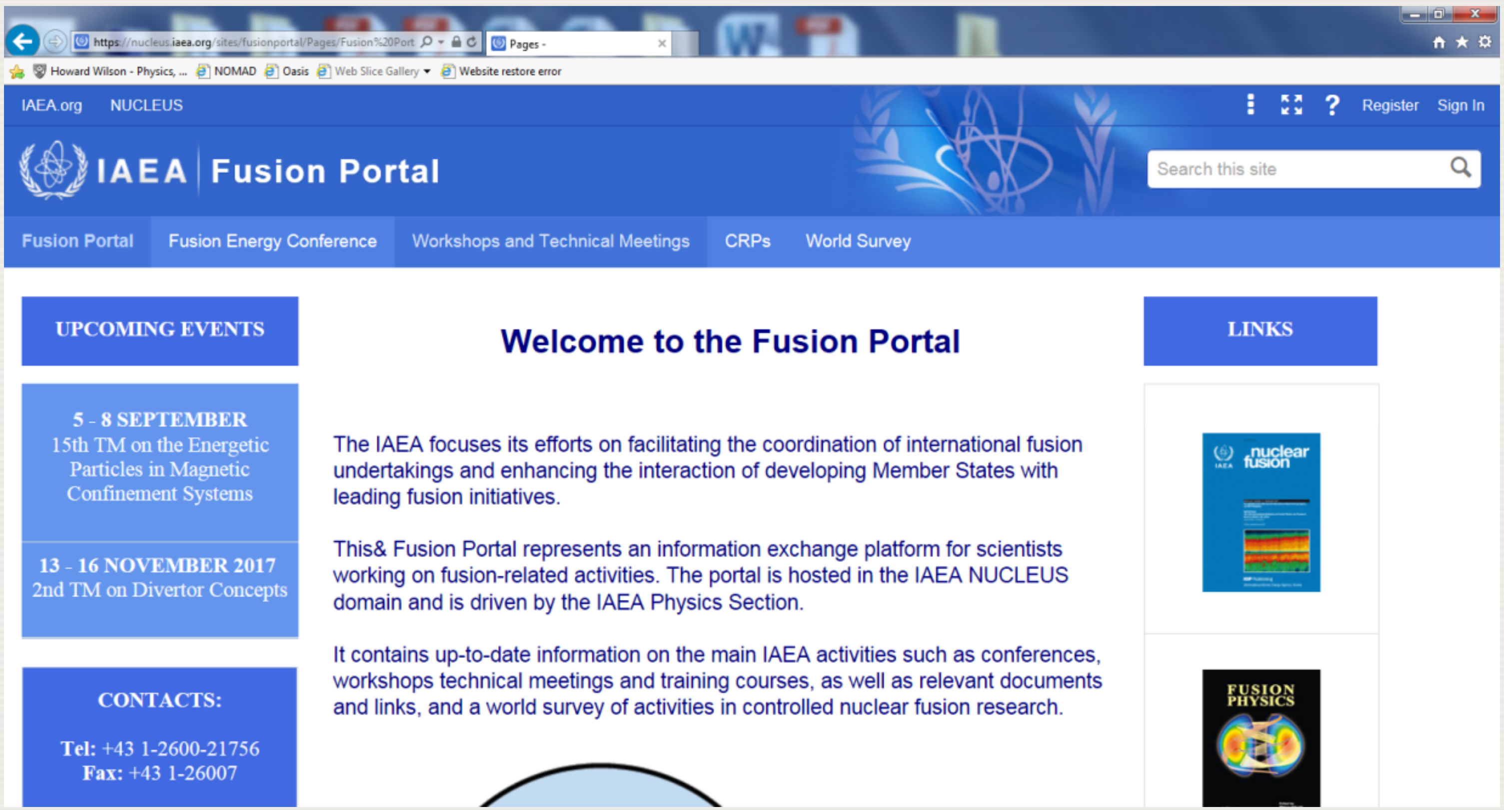
FUSION PORTAL

https://nucleus.iaea.org/sites/fusionportal/Pages/Fusion%20Portal.aspx



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TM Material

- Material is made available on the meeting web site

Presentations

Time for Questions

Thank you for your attention!

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