

Safety Analysis of Fusion Reactors with special reference to External Event initiators

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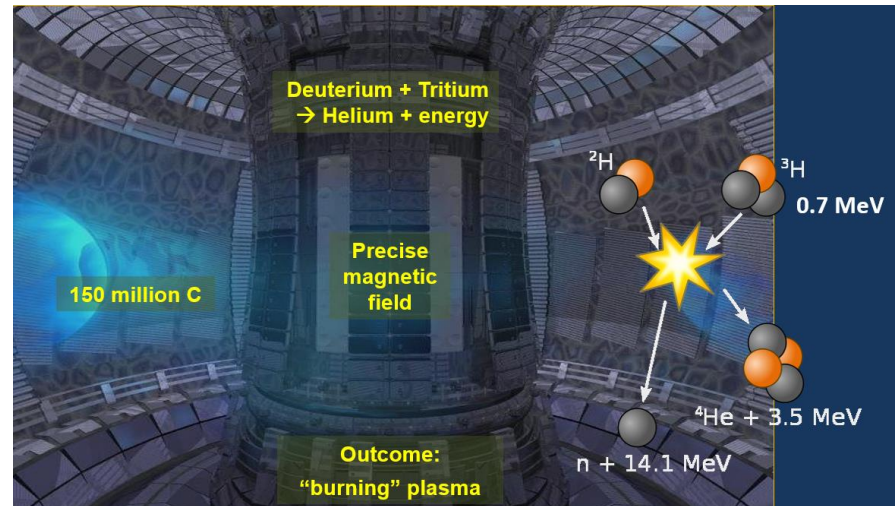
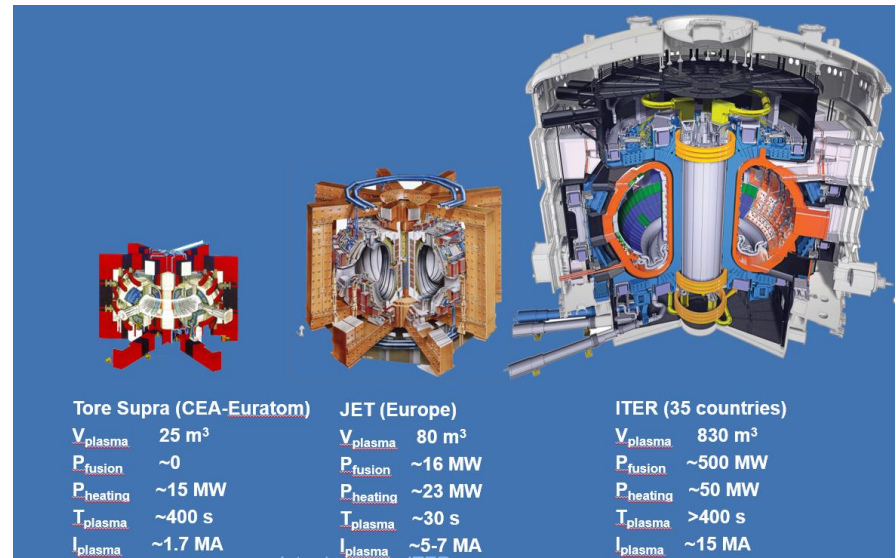
Introduction

- With over 450 fission nuclear power plants safely operating on the entire planet and with only a few incidents/accidents occurred in many decades we can easily say that the nuclear fission technology has reached a very high degree of safety.
- Despite the power plants being built and operated in different countries and under different regulatory frameworks, internationally known codes and standard are used to perform safety analyses in support to the licensing process and many lessons have been learned in the lifecycle of these power plants.



Introduction

- Nuclear fusion is in an advanced research and development phase with some fusion reactors being built and operated in the world. Among them, the ITER reactor, under construction in the south of France, is the most ambitious one with the target to achieve fusion plasmas with a ratio Q of fusion power produced to external power supplied (Q -factor ratio) bigger than 10.
- Many of the lessons learned in the fission industry are applied to ITER and many others lessons are being learned during the design/licensing/construction of ITER.



Safety analyses general points

- The Operator has to perform the safety analysis of the installation.
- Safety important functions and safety important systems, structures and components are then identified.
- These components guaranty that the safety functions deduced from the safety analysis are maintained in all the situations: what can be an accidental situation for the facility (e. g. a loss of offsite power) is a normal operation for the safety systems and components which must operate during and after such events.
- The general methodology adopted for the analysis of external hazards consists of:
 - Identifying hazards external to the facilities.
 - Characterizing the effects of the hazard (taking into account common mode failures and/or hazard sequences potentially initiated by the “source” hazard) and to identify the systems required to maintain or achieve a safe state of the facility. The source hazard is analysed taking into account direct and/or indirect impacts on the facility.
 - Demonstrating that the resulting bounding effects of the hazards will not generate accident situations with a significant radiological impact on personnel or the environment

External initiator events considered in the safety analysis

- The following external hazards are considered in ITER:
 - earthquakes,
 - extreme climatic conditions: notably severe heat, severe cold, snow, wind and lightning,
 - external flooding,
 - external fire,
 - hazards relating to human activities:
 - aircraft crashes,
 - hazards associated with the industrial environment and communication routes
 - primarily external explosions
 - accident in a nearby facility at the CEA Cadarache Centre site.
- In the following, as illustrative examples, the earthquakes and the fire are analysed in more detail.

EARTHQUAKES

- For the ITER site, in compliance with basic safety rule RFS 2001-01, the analysis is performed using two spectra:
 - a spectrum derived from a review of historical seismicity over a period of approximately 1000 years called Séisme Majoré de Sécurité (SMS),
 - and the spectrum characterising paleoseismicity, based on the analysis of geological faults over a period of tens of thousands of years.
- The load specifications and spectra are calculated in the frequency range from 0.1 to 34 Hz, for different damping values. Rock and soft soil conditions are considered where appropriate.
- The reference earthquake for the design, called SL-2 or Safe Shutdown Earthquake (SSE), is the envelope of the SMS and the paleoseismic spectrum.
- The occurrence rate of the SL-2 level earthquake is considered to be a Category IV – extremely unlikely loading condition.

EARTHQUAKES

- The seismic classification of structures/systems and components is based on the safety objectives:
 - SC1 (SF) - seismic class 1-SF: structural stability and required functional seismic safety performance maintained in the event of an earthquake,
 - SC1 (S) - seismic class 1-S: structural stability maintained in the event of an earthquake, i.e. no rupture of piping, no collapse of structures or equipment, limited plastic strain, limited concrete cracking, support functions maintained,
 - SC2 – seismic class 2: non-damage to SC1 equipment: absence of damage to SC1 equipment for buildings and structures housing and protecting safety important components, or to buildings that can potentially damage such structures in the event of collapse, no other requirements regarding structural or functional performance in the event of an earthquake,
 - NSC – non-seismic category: no seismic requirements for safety.
- All risks associated to the SL-2 are taken into account in the safety analysis:
 - risk of damage to confinement in the different buildings, risk of displacement of shielding, risk of occurrence of initiating events potentially leading to accident situations, risk of damage to safety important components needed to mitigate risks induced by the earthquake, risk of damage to seismically designed buildings by other buildings, risks of induced internal hazards (fire, pipe break, load drop, etc.), risk of loss of external utilities, risks of induced external hazards (forest fire, external flood, etc.).

EARTHQUAKES

- When assessing seismic safety and design, the safety objective is to ensure that safety functions are maintained to prevent unacceptable releases to the environment or exposures that would exceed the ITER General Safety Objectives for accidents.
- The classification measures adopted ensure the following:
 - confinement of radioactive materials (at least one confinement system and capability to maintain depression in the rooms performing confinement function),
 - maintaining adequate shielding to prevent over-exposures,
 - shutdown of the facility and maintaining it in a safe state,
 - provision of filtration and detritiation to potentially contaminated rooms,
 - residual heat removal,
 - possibility to place handling equipment in a safe configuration prior to evacuation of work areas,
 - prevention of potential internal hazards: fire, flooding, load drop/impact that could lead to a release of radioactivity,
 - ensuring monitoring capability after an earthquake.

EXTERNAL FIRE

- The risk of external fire around the ITER facility is represented by the following:
 - forest fire,
 - possible presence of vehicles,
 - possible presence of flammable materials,
 - switchyard fires.
- External fire affecting the ITER facility could have the following consequences:
 - spread of fire within buildings, directly or indirectly by thermal radiation,
 - loss of integrity of radiologically controlled building support structures,
 - risk of smoke and diffusion of toxic gases within the radiologically controlled buildings or the back-up diesel generators building,
 - risk of loss of external services:
 - loss of external electrical power supply,
 - loss of water supply from CEA Cadarache Centre network/Canal de Provence.

EXTERNAL FIRE

- The main measures adopted with regard to the risk of fire are as follows:
 - the strength of the external walls of the radiologically controlled buildings and the absence of risk of propagation of fire inside the rooms, in application of Ministerial Order of 31/12/1999 (amended on 31/01/06, defining the general technical regulations for the prevention and limitation of detrimental effects and external hazards resulting from the operation of basic nuclear installations),
 - clearance of undergrowth and ‘deforestation’ of the area surrounding the facility,
 - the gas oil and oil storage tanks are designed in accordance with the order of 31/12/1999, they have required retention capacity and are located away from the other buildings taking into account this risk,
 - appropriate layout and design of ventilation air inlets in order to avoid propagation of external fire and smoke into the rooms,
 - temporary storage of flammable products is limited to predefined zones, at a distance from radiologically controlled buildings and equipped, in particular, with fire fighting measures close by,

EXTERNAL FIRE

- The main measures adopted with regard to the risk of fire are as follows (continued from previous slides):
 - the car park for personnel vehicles is located outside the facility,
 - Fire hydrants are distributed around the facility
 - geographical separation of safety important components (back-up diesel generators, tanks and associated electrical lines) induces:
 - Separation between redundant trains,
 - separation from combustion sources (combustible materials, etc.),
 - the installations are protected against the effects of lightning that could cause a fire of external origin.

CONCLUSIONS

- As it can be seen from the examples given in the previous slides, the most important lesson learned from the fission power plants is indeed implemented in ITER: the ultimate protection is the last confinement barrier which must withstand all loading conditions either coming from internal events or external ones.
 - In order to do that either the last confinement barrier is designed against the load, or the load is excluded by design (like it happens in ITER for the external flooding).
- The correct implementation of this lesson learned is also demonstrated by the fact that, when the stress tests following the Fukushima accident were performed in ITER, indeed, for the TKM building, the only resulting hard core components are the building last confinement walls (and the slab) and their penetrations toward the external environment.
- There are many other lessons learned from the fission power plants and also new lessons learned during the ITER project which could be shared during this meeting or following ones.