EUROfusion

SAFETY APPROACH FOR FUSION MACHINE

Joelle Elbez-Uzan

Head of Safety Office -DEMO Central Team

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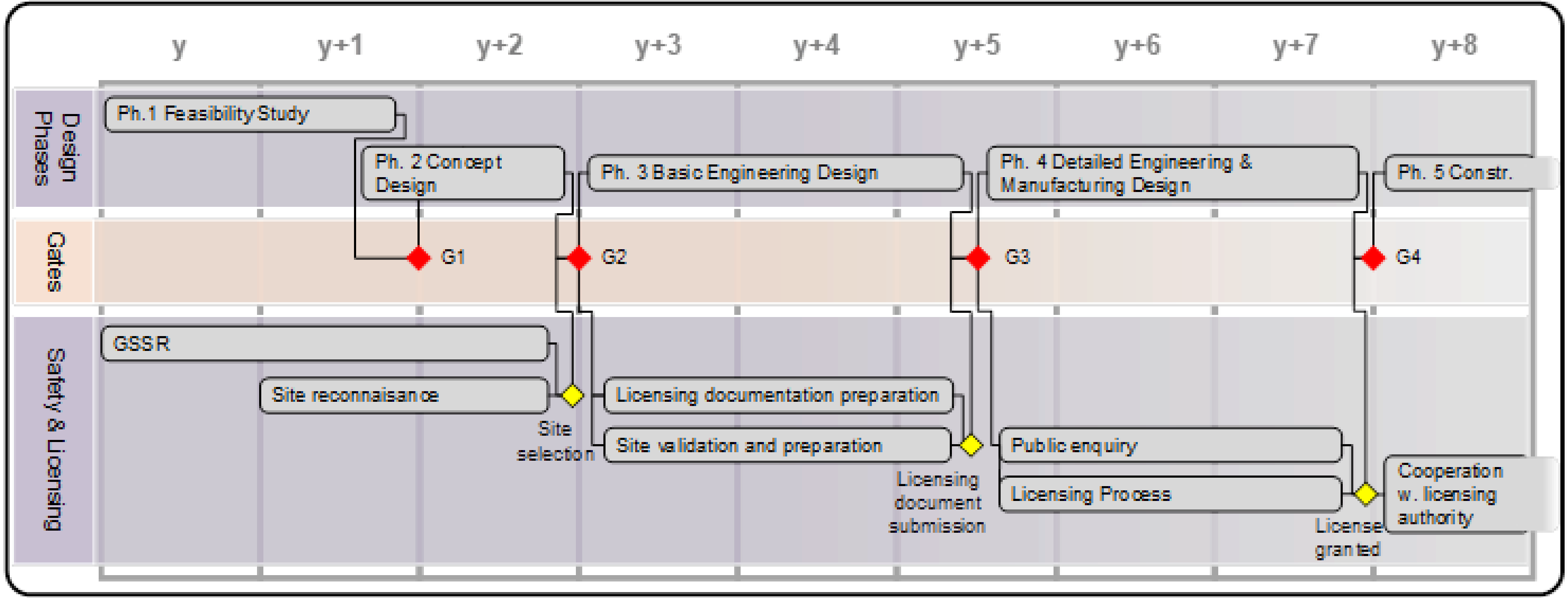
OUTLINE

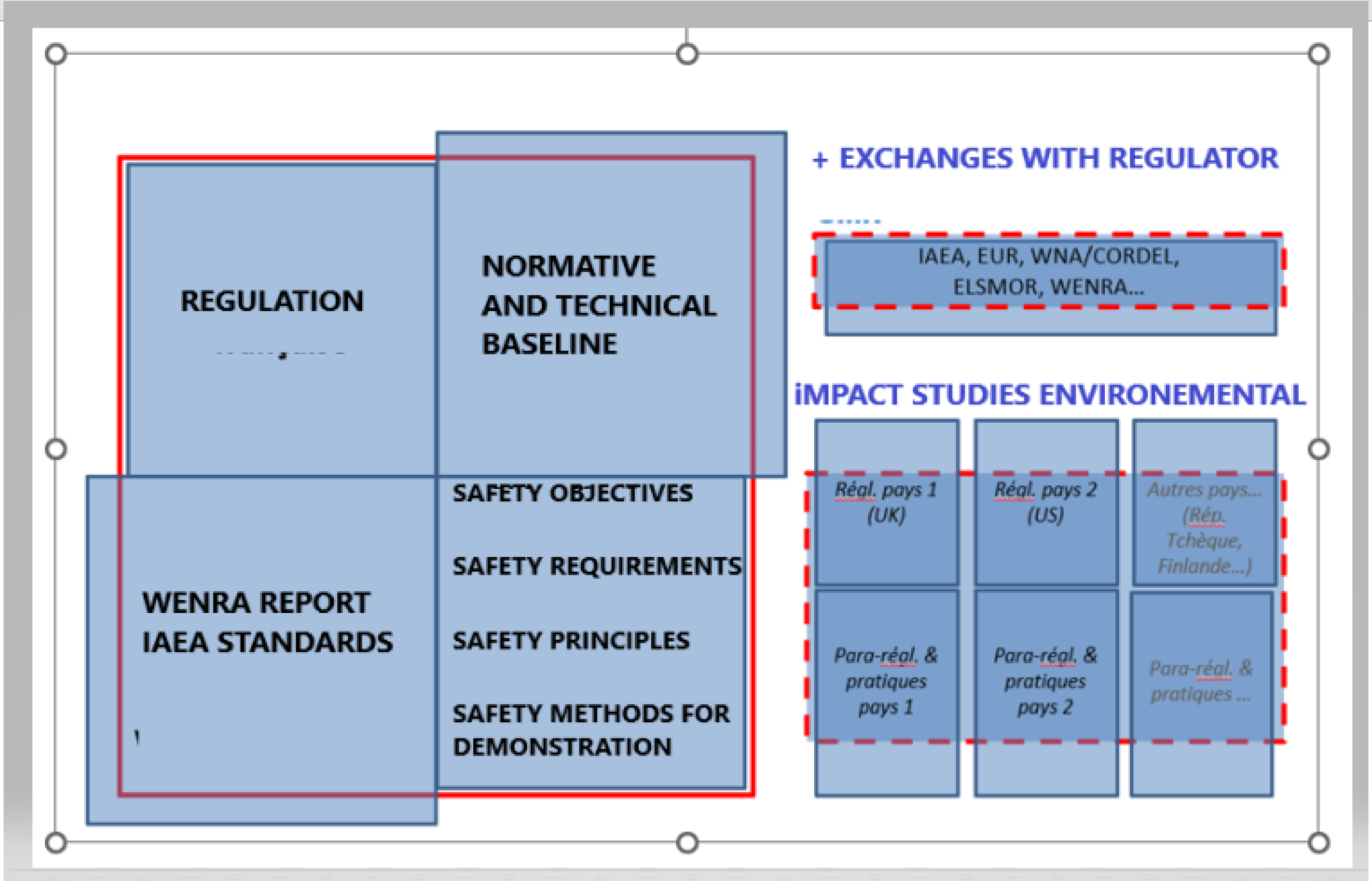
- Licensing process
- Safety approach and objectives
- Radioactive wastes
- Safety design engineering
- Qualification process
- Maintenability

Licensing process

LICENSING PROCESS - REMINDER



BUILD A SAFETY BASELINE – SAFETY ASSETS OF FUSION



REGULATION

NORMATIVE AND TECHNICAL BASELINE

WENRA REPORT
IAEA STANDARDS

SAFETY OBJECTIVES

SAFETY REQUIREMENTS

SAFETY PRINCIPLES

SAFETY METHODS FOR DEMONSTRATION

+ EXCHANGES WITH REGULATOR

IAEA, EUR, WNA/CORDEL, ELSMOR, WENRA...

iMPACT STUDIES ENVIRONEMENTAL

Réal. pays 1 (UK)

Réal. pays 2 (US)

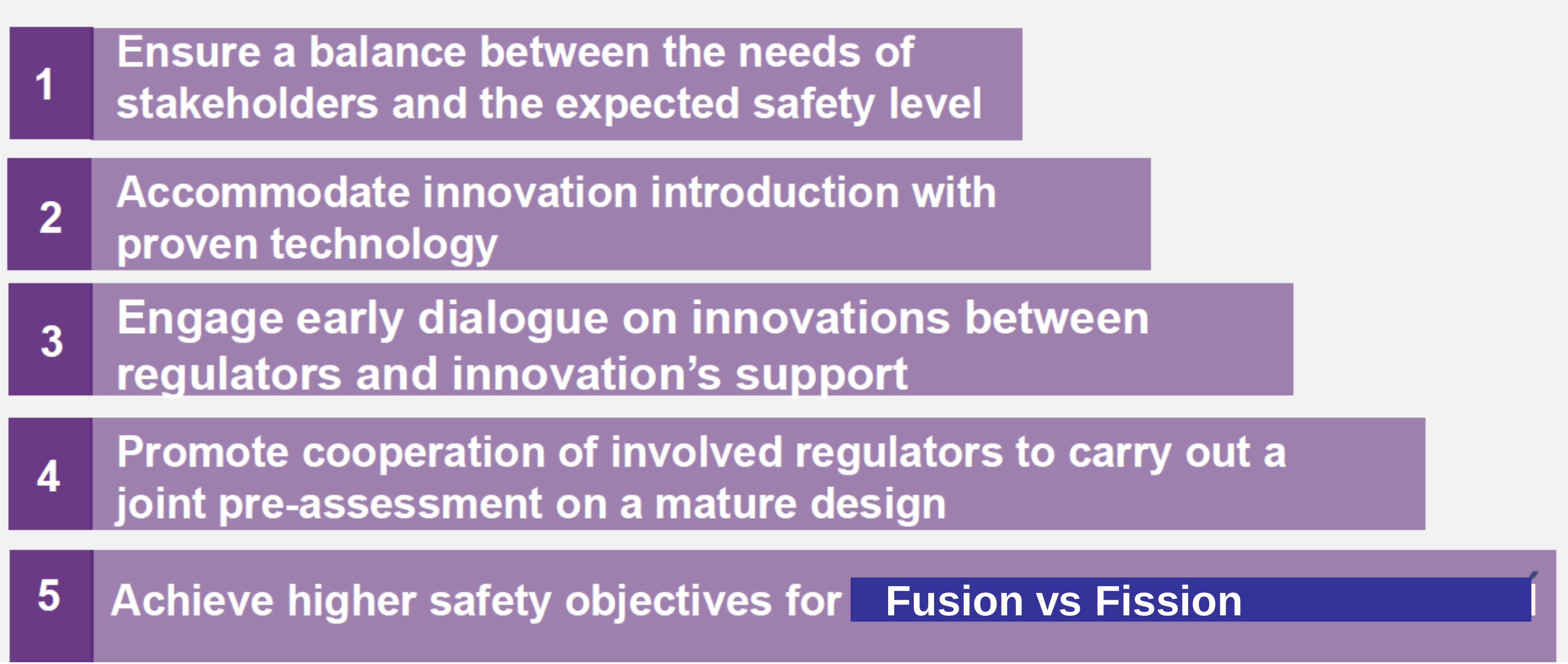
Autres pays... (Rép. Tchèque, Finlande...)

Para-réal. & pratiques pays 1

Para-réal. & pratiques pays 2

Para-réal. & pratiques ...

KEY ASSETS FOR A SUCCESSFUL LICENSING PROCESS



1. Ensure a balance between the needs of stakeholders and the expected safety level
2. Accommodate innovation introduction with proven technology
3. Engage early dialogue on innovations between regulators and innovation’s support
4. Promote cooperation of involved regulators to carry out a joint pre-assessment on a mature design
5. Achieve higher safety objectives for Fusion vs Fission

Safety approach and objectives

A SAFETY APPROACH TAILORED TO THE SAFETY CHALLENGES

- A safety approach is **deterministic** aiming to assess causes and consequences of events without **probabilistic** (to be developed in second stage)

- It shall be a **safety demonstration from normal operation to hypothetical accidents including incidents and accidents**

- **Compliance with these safety requirements shall be demonstrated:**
  - **Safe conditions**
  - **Impact below safety objectives and criteria**
  - **Using and adapting safety rules (defence in depth principle, single failure criterion, common mode failure…)**

SAFETY OBJECTIVES FOR FUSION REACTORS

ADDED VALUE FROM FUSION REACTORS IN TERMS OF SAFETY OBJECTIVES

GRADUATED APPROACH, BASIC PRINCIPLE FROM NUCLEAR REGULATION

- **Lower radiotoxic inventory** (reduces impact and allows to use a graded approach)

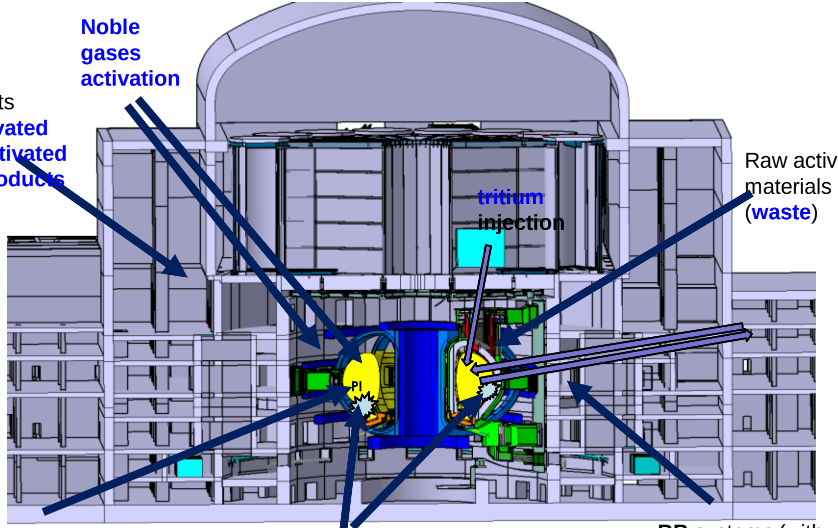
- **Limited long-term consequences of accident scenarios and higher passive safety**

- **Lower environmental impact and legacy** (no high level wastes)

RISKS IDENTIFICATION – GRADUATED APPROACH

To show **the risks** have been properly **quantified** and the defense in depth principle is applied with **proportionally**

- Risks associated with radioactive materials (tritium, Activated dusts, activated corrosion products, …)
- Risks associated with toxic materials
- Risks associated with other hazardous materials (hydrogen isotopes, flammable materials, helium…)



Noble gases activation

Cooling circuits
Tritium, **Activated products, Activated corrosion products**

tritium **injection**

Raw activated materials (**waste**)

tritium adsorbed in dust and surfaces

Activated dust

Liquid effluents

BB systems (with **activated materials** and potentially traces of actinides and fission products)

Analysis of off-normal situations

The following situations are studied

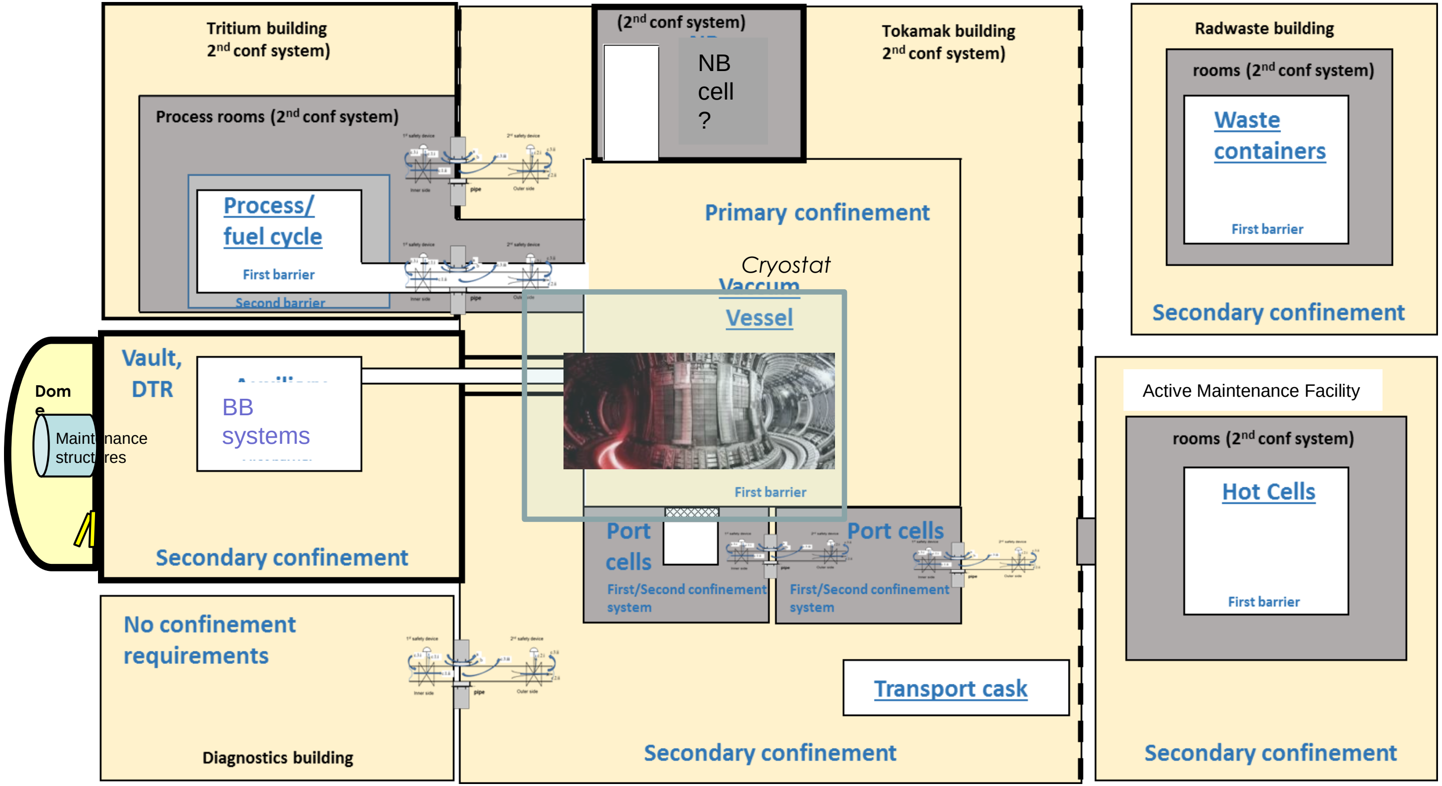
- **Degraded situations:** partial failure of a function (e.g. degradation of a flow rate, increase of pressure, of temperature, etc.)
- **Internal Events:** incidental or accidental events associated with the process (e.g. break of pressurised water pipes, break of helium lines…)
- **Internal hazards:** incidental or accidental situations from specific conditions inside the buildings (e.g. fire, explosion, flooding…)
- **External hazards:** incidental or accidental situations from specific conditions outside the buildings
  - Man induced hazards: airplane crash, rupture of an external tank,
  - Environmental hazards: earthquake, flooding, extreme climatic conditions…

SAFETY BOUNDARY CONDITIONS FOR FUSION FACILITIES

- **In terms of maximum inventories** or concentration (tritium, ACP, activated dust, activated blanket materials, others) able to be released inside/from:
  - ✓ Processes (cooling loops, BB, fuel cycle, etc.)
  - ✓ rooms
  - ✓ fire sectors
  - ✓ Buildings

- **In terms of maximum loading conditions** in processes, rooms and buildings (pressure, temperature, radiations, etc.), for normal, incidents and accidents, potentially combined with other incident/accident cases

DEMO CONFINEMENT CONCEPT DIAGRAM

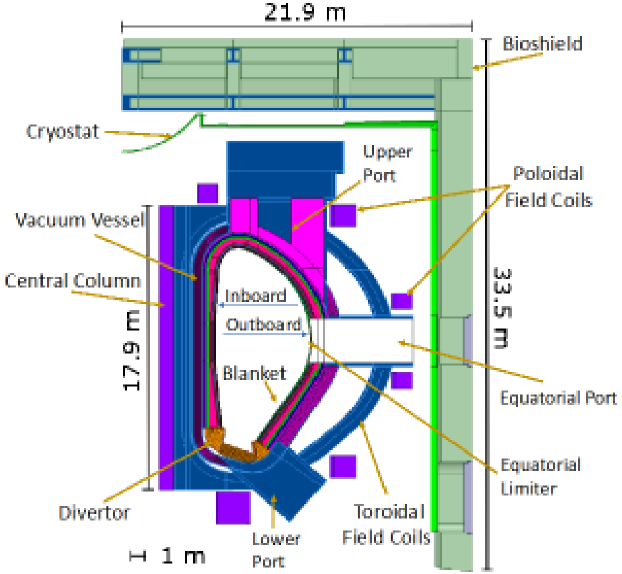


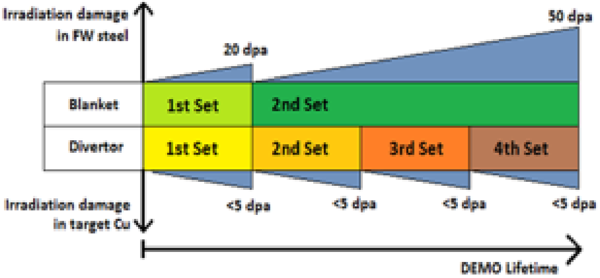
Radioactive wastes

DEMO - Baseline model

- 22.5deg DEMO_2017 baseline model for heterogenous WCLL and heterogeneous HCPB Blanket design concepts.
- The DEMO plasma source is equivalent to the fusion power of 1998 MW or 7.094×10^{20}n/s
- Irradiation is divided into two phases: Phase 1 with 20 dpa of damage and Phase 2 with 50 dpa of damage.

Water-cooled lithium lead (WCLL)	
Structural material	EUROFER97
First wall	W
Tritium breeder	Pb-15.7%Li
Neutron multiplier	
Helium-cooled pebble bed (HCPB)	
Structural material	EUROFER97
First wall	W
Tritium breeder	Advanced ceramic breeder pebbles (Li_4SiO_4 + 35%mol Li_2TiO_3) KALOS ((KArlsruhe Lithium OrthoSilicate)
Neutron multiplier	$Be_{12}Ti$ hexagonal prismatic blocks





RADIOACTIVE WASTES AND FUSION ASSETS

Most Ex-vessel components, except the Lower and Shield ports, can be disposed of as LLW within a few decades after shutdown.

All the in-vessel components in the reactor are only suitable for disposal as ILW, as it would take more than 100 years for the components to be accepted in any LLW repositories.

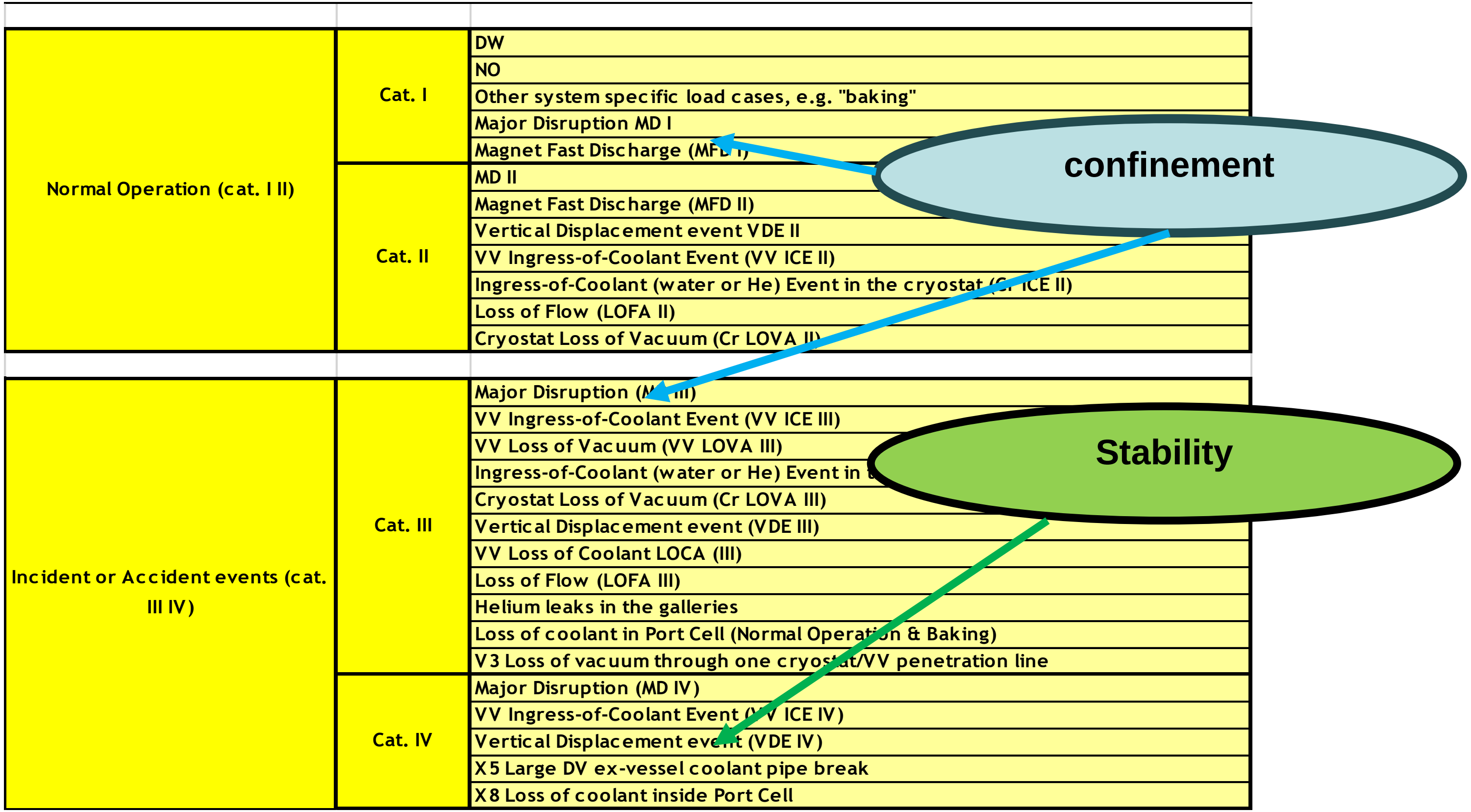
If a tritium removal rate of 99% is achieved, breeder blankets can be disposed of as ILW within 20 years of reactor shutdown. This time to disposal can be reduced further with the post-processing of the waste.

Waste assessment for each component in the HCPB DEMO model

Components	Subdivision	Set	Time to disposal as ILW (years)		Time to LLW (years)
			Without tritium removal	after 99% tritium removal	
Lower Port			0.00285		>100
Shield Port			0.00285		>100
Vacuum vessel	Inboard		1		>100
	Outboard		1		>100
	Shell		1		>100
Blanket	Inboard	1	35	12	>100
		2	45	16	>100
	Outboard	1	40	13	>100
		2	50	17	>100
Limiter		1	13		>100
		2	12		>100
		3	12		>100
		4	12		>100
Divertor		1	20		>100
		2	19		>100
		3	19		>100
		4	19		>100

Safety Engineering Design

Correspondence Loads/Safety Requirements/Service Level C&S



Normal Operation (cat. I II)	Cat. I	DW
		NO
		Other system specific load cases, e.g. "baking"
		Major Disruption MD I
		Magnet Fast Discharge (MFD I)
	Cat. II	MD II
		Magnet Fast Discharge (MFD II)
		Vertical Displacement event VDE II
		VV Ingress-of-Coolant Event (VV ICE II)
		Ingress-of-Coolant (water or He) Event in the cryostat (Cr ICE II)
		Loss of Flow (LOFA II)
		Cryostat Loss of Vacuum (Cr LOVA II)
Incident or Accident events (cat. III IV)	Cat. III	Major Disruption (MD III)
		VV Ingress-of-Coolant Event (VV ICE III)
		VV Loss of Vacuum (VV LOVA III)
		Ingress-of-Coolant (water or He) Event in t
		Cryostat Loss of Vacuum (Cr LOVA III)
		Vertical Displacement event (VDE III)
		VV Loss of Coolant LOCA (III)
		Loss of Flow (LOFA III)
		Helium leaks in the galleries
		Loss of coolant in Port Cell (Normal Operation & Baking)
		V3 Loss of vacuum through one cryostat/VV penetration line
	Cat. IV	Major Disruption (MD IV)
		VV Ingress-of-Coolant Event (VV ICE IV)
		Vertical Displacement event (VDE IV)
		X5 Large DV ex-vessel coolant pipe break
		X8 Loss of coolant inside Port Cell

General approach DEMO Code & Standards

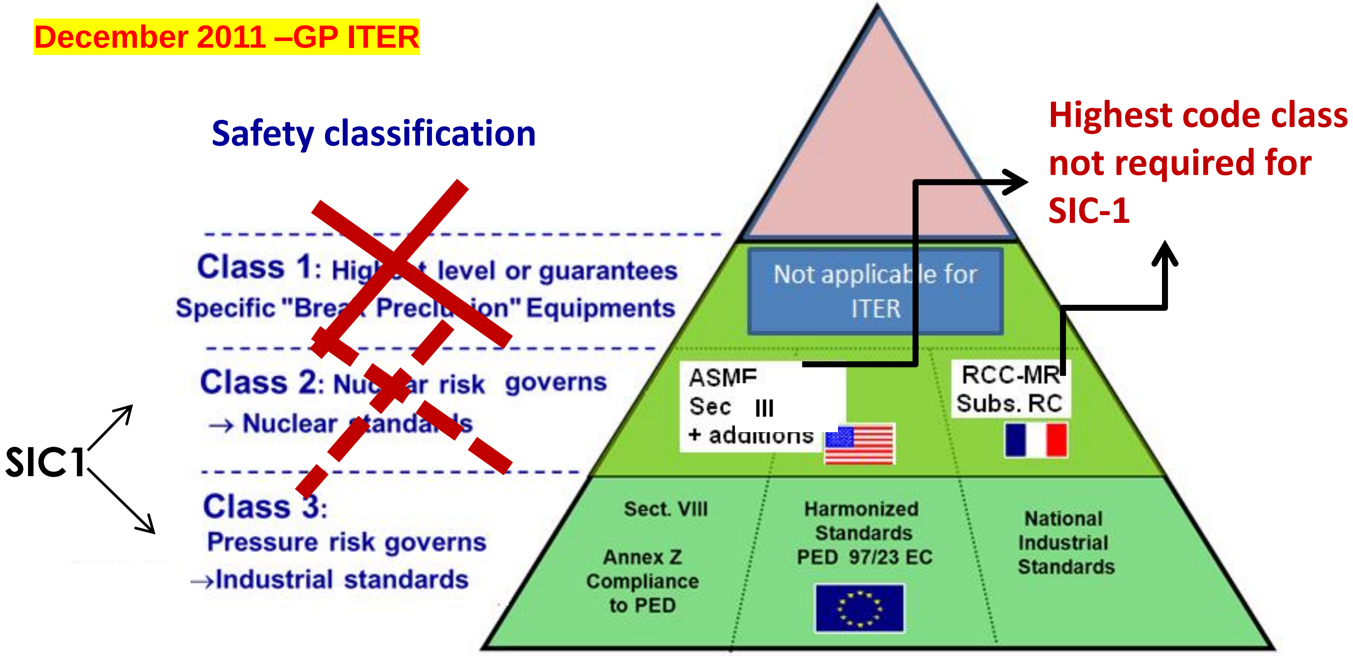
- Codes & Standards (C&S) shall be identified and used to **ensure coherency between design, manufacturing, inspection and testing** for the mechanical systems, structures and components.

- Selection of C&S for a specific component is based on the **comprehensive assessment** of
  - The C&S features,
  - The facility operational conditions,
  - The facility functional requirements and safety requirements.

- Ex of **existing industrial** C&S:
  - ASME codes,
  - RCC-MRX,
  - EU Harmonized Standards.

Codes and standards- Safety Classification

December 2011 –GP ITER



Safety classification

~~**Class 1**: Highest level or guarantees~~
~~Specific "Break Preclusion" Equipments~~

~~**Class 2**: Nuclear risk governs~~
~~→ Nuclear standards~~

Class 3:
Pressure risk governs
→Industrial standards

SIC1

Highest code class not required for SIC-1

These codes are not regulatory texts, they do not replace regulations but are **industrial tools** that can be usefully used as a basis for **meeting regulatory requirements**.

Codes and standards for future fusion facil

Recent working group on licensing fusion facility launched by EURC shown one important topic for future fusion facilities : **the need to have a specifi s and standards managing the design and the safety of fusion facilit o capture the specificities of fusion as well as to integrate in a safe way t ent of fusion provisions**

- **Internationally verified and validated analysis co** e developed to ease the acceptability of simulation by local authorities pics for which international databases are needed to consider the specifi hall be assessed, in particular with regards to data on fusion technolog ating modes as well as to fusion material nuclides effects and complex r activities.

- Codes and standards, developed cilities, are used by designers, regulators and operators of nuclear pla odes and standards (e.g. ISO, IEC) should consider fusion specificiti **of these fusion specificities should be established, topic by t to identify the nuclear and/or industrial codes and standards tha able, non-applicable, to be newly created and necessitating ad** is has to be conducted with regards to materials specific to fusion, fusic s and safety methodologies.

ADAPTATION OF THE DESIGN CRITERIA (SERVICE LEVEL) TO THE FUSION CHALLENGE

Uncertainties/Margins & progressive start-up

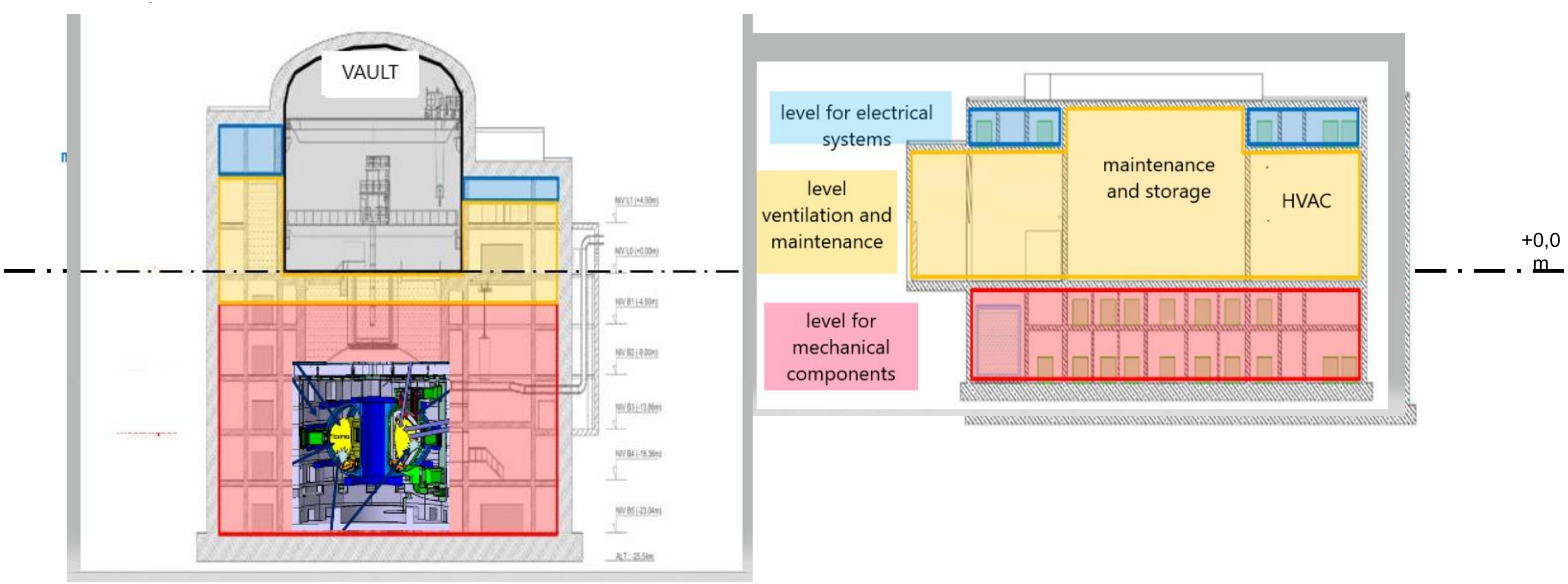
- The aim of the ITER facility's experimental program is to obtain scientific and technical information in order to prepare for the next steps in the development of a facility capable of generating electricity.

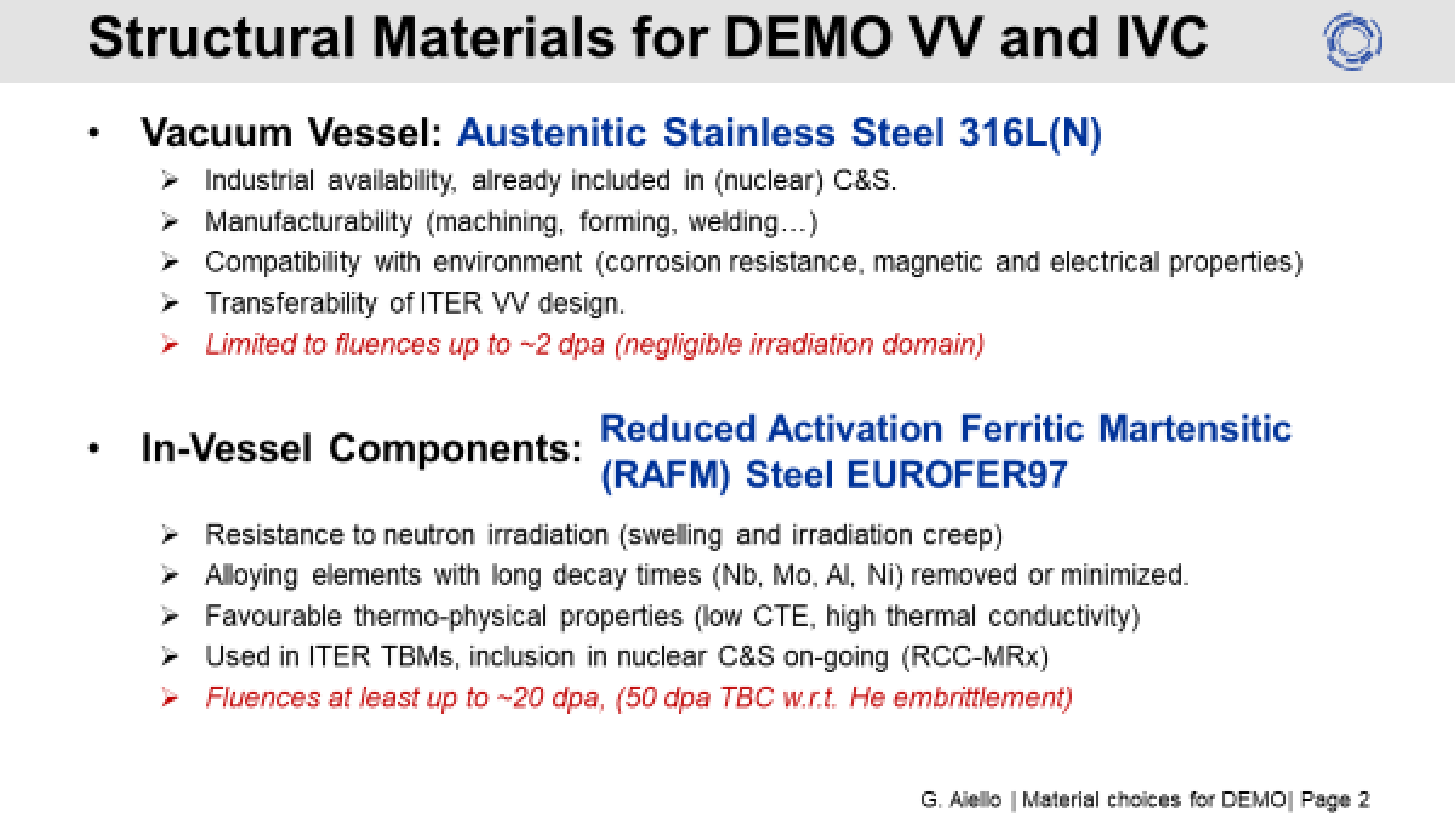
- Most of the data required to validate the safety analyses comes from existing databases from previous fusion facilities. **Nevertheless, some of this data can only be checked during operation and in particular during the progressive start-up of the facility**.

- **Learning phase (non active)** to refine some assumptions and clarify the uncertainties

ITER Safety Report extract 2010

SAFETY INTEGRATION





Structural Materials for DEMO VV and IVC

- **Vacuum Vessel: Austenitic Stainless Steel 316L(N)**
  - Industrial availability, already included in (nuclear) C&S.
  - Manufacturability (machining, forming, welding…)
  - Compatibility with environment (corrosion resistance, magnetic and electrical properties)
  - Transferability of ITER VV design.
  - *Limited to fluences up to ~2 dpa (negligible irradiation domain)*

- **In-Vessel Components: Reduced Activation Ferritic Martensitic (RAFM) Steel EUROFER97**
  - Resistance to neutron irradiation (swelling and irradiation creep)
  - Alloying elements with long decay times (Nb, Mo, Al, Ni) removed or minimized.
  - Favourable thermo-physical properties (low CTE, high thermal conductivity)
  - Used in ITER TBMs, inclusion in nuclear C&S on-going (RCC-MRx)
  - *Fluences at least up to ~20 dpa, (50 dpa TBC w.r.t. He embrittlement)*

Qualification process

QUALIFICATION SAFETY COMPONENTS/FUNCTIONS

Qualification is a key parameter in the safety demonstration

Objective of qualification: demonstrate that the safety function can be achieved at any time to bring and maintain the safe state of the plant

CHALLENGE

Accommodate innovation introduction with proven technology

Qualification process overview

Design input

- Safety functions
- Mission time
- Environmental conditions
- Load and service conditions

Equipment qualification

- Qualification criteria and requirements
- Qualification methods
- Perform qualification
- Define installation and maintenance procedures, conditions and limitations
- Qualification documentation

Maintaining qualification

- Installation and maintenance control
- Replacement control (if any)
- Service condition monitoring
- Analysis of degradation and failures
- Operating experience feedback
- Training
- Documentation

Qualification standar[illegible]

Several qualification methods may [illegible] acceptable

Recommendations for ITER use

- RCCs, specially RCC-E f[illegible] electrical com[illegible]ents
- IEC 60780 for enviro[illegible]ntal qualificat[illegible]
- IEC 60980 for sei[illegible]c qualification
- NF64-001 fo[illegible] electrical co[illegible]nents submitted to harsh environme[illegible] without magne[illegible]elds
- Other[illegible]
  - [illegible]E (United Sta[illegible])
  - KTA (Germa[illegible]

STILL UNDER DEVELOPMENT

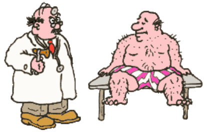
HUGE EFFORTS TO ADAPT THE CURRENT STANDARDS

Each metho[illegible] requires substantiation in order to ensure acceptabi[illegible].

Maintenability

MAINTENABILITY

Maintenance Strategy



SSCs working

SSCs out of order (failure or close to it)

Scheduled or Unscheduled but well defined

Preventive Maintenance

- Periodic Preventive Maintenance
  - Periodicity=F(number of units) - dpa, hours, km, cycles, etc
- Scheduled Preventive Maintenance
  - For DEMO Plant maintenance shutdown every 5 years
- Condition-Based Preventive Maintenance
  - Predictive maintenance actions based on NDT/ageing
- Regulatory or Statutory Inspections
  - SO to plan systematic and method inspection programme
- Preventive Maintenance of 1st level
  - Inspections rounds, routine action, readings of usage units

Unscheduled and undefined

Corrective Maintenance

- Curative Maintenance
  - Failure that have a "definitive" character
- Deferred Corrective Maintenance
  - Corrective action delayed in accordance with given rules
- Palliative Maintenance
  - Troubleshooting consisting of restoring the unit temporarily

Maintenance. The organized activity, both administrative and technical, of keeping structures, systems and components in good operating and safe condition, including both preventive and corrective (or repair) aspects.

MAINTENABILITY

- ROBUSTESS OF THE DESIGN (REASONABLE MARGINS) TO AVOID THE CHANGE OF KEY AND COMPLEX SYSTEMS

- DEVELOP THE INTERVENTION STRATEGY INSTEAD OF RELYING ONLY ON THE PREVENTIVE MAINTENANCE (EXCEPTIONAL OPERATION)

- SET UP A STRATEGY FOR ISI IN CONJONCTION WITH SAFETY DEMONSTRATION

- ESTABLISHMENT OF DATA BASE FAILURE RATES TO PREPARE ALSO THE PROBABILISTIC APPROACH

PERSPECTIVES and CONCLUSION

- **Safety commissioning for fusion**
  - Test methods (norms, standards), critical systems, validity domains

- **Progressive start up and safety tests**
  - Operational Limit Conditions

- **Qualification of the workers in nuclear environment**
  - Education/training

PERSPECTIVES and CONCLUSION

R1 - GOAL SETTING REGULATION

A regulatory approach should be adopted whenever possible for FPP design, construction, commissioning, operation, and decommissioning, to allow the operator to apply a proportionate approach to reflect the FFP hazard potential.

R2 - CRITERIA FOR EMERGENCY REFERENCE LEVELS IN REGULATIONS

A design objective for FPPs should be that no accident within the design basis should result in the release of radioactive materials that would require offsite emergency countermeasures or further restrictions of the civilian population outside the plant.

R3 - ENVIRONMENTAL CRITERIA FOR LARGER PUBLIC ACCEPTANCE

To encourage public acceptance of FFPs, transparency, education, and information of the public with respect to tritium discharges is necessary.

R4 - RADIOACTIVE WASTE PRODUCTION

Seek international agreement on the need for uniformity of waste acceptance, storage and disposal criteria and understanding of fusion specificities. Minimization of radioactive waste shall be of primary consideration.......

R5 - REGULATION OF FPP PRESSURIZED SYSTEMS

Specific European regulations on pressurized equipment shall be written for FPP or adapted from the existing set of the European Directives to consider fusion specificities.

R6 - INTERNATIONAL DATABASE

Internationally verified and validated analysis codes should be developed to ease the acceptability of simulation by local authorities. A list of topics for which international databases are needed to consider the specificity of FPPs shall be assessed, and operating modes as well as to fusion material nuclides effects and complex maintenance activities.

R7 - FUSION CODES AND STANDARDS

C&S, developed for fission facilities, are used by designers, regulators, and operators of nuclear plants. These codes and standards (e.g., ISO, IEC) should consider fusion specificities. A list should be established, topic by topic, to identify the nuclear and/or industrial codes and standards that are applicable, non-applicable, to be newly created.

R8 - GRADED APPROACH TO SAFETY DEMONSTRATION

This graded approach applies as follows:

- no systematic application of the single failure criterion when the consequences of accident scenarios are low,
- acceptance of potential common mode failures when consequences of acc. scenarios are low,
- no systematic combination of loads when the consequences of accident scenarios are low,
- adaptation of design extension conditions to FPPs

R9 - DETERMINISTIC AND PROBABILISTIC APPROACHES

Safety demonstration shall be based on an initial deterministic approach (using conservative assumptions), with appropriate lines of defence that are proportionate to the hazard potential. This approach should be complemented by the application of a probabilistic approach...

R10 - CONSENSUS ON A REGULATORY FRAMEWORK FOR FUSION POWER PLANTS

Engage IAEA and members states to seek international agreement on what constitutes the basis of an appropriate legal and safety regulatory framework for FPPs that should be delivered by the national regulator.

R11 - IMPLEMENTING A LEGAL AND REGULATORY FRAMEWORK FOR FPPs

A new regulatory framework for future Fusion Power Plants should be consistent with the IAEA Fundamental Safety Principles and, preferably, technology neutral.

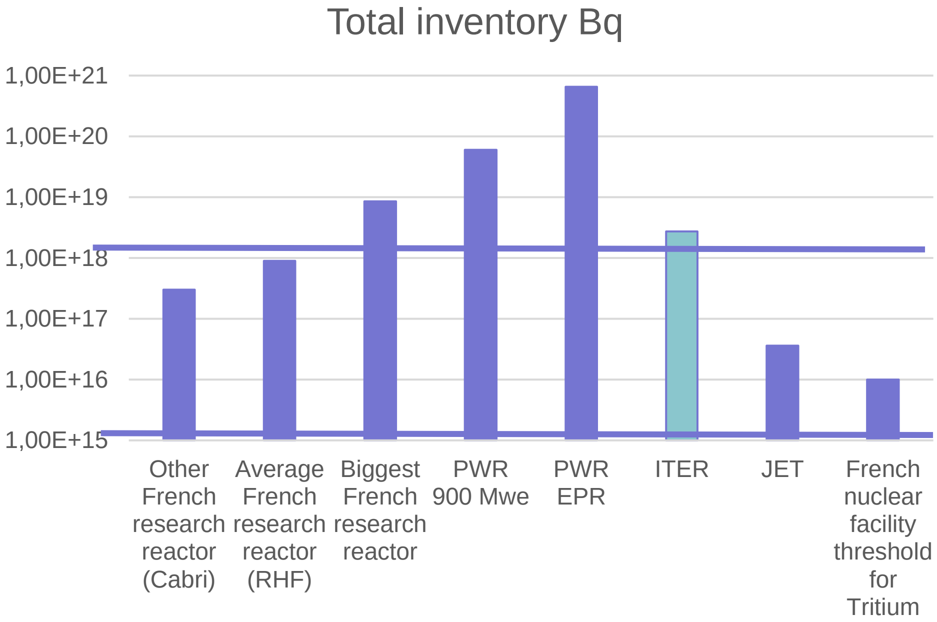
R12 - PRESCRIPTIVE REGULATORY FRAMEWORKS

For countries using a prescriptive approach to regulation, any regulatory requirements and regulations relating to the safety of Fusion Power Plants should be based on a graded approach and be proportionate to the hazard potential of a Fusion Power Plant

THANK YOU FOR YOUR ATTENTION !

FAIRNESS	OPENNESS	COMMITMENT	DIVERSITY
Transparency Collaboration Loyalty	Open doors Open hearts Open minds Open ears	Ownership Critical thinking Determination Respect	Cooperation Equal opportunities Inclusion

Back up



French nuclear facilities

Comparison with other recent nuclear facilities

Recent French nuclear research reactor (RJH)

RJH	Workers	Public:
routine	ALARA	ALARA
	5 mSv/y average	0.1 mSv/y
	10 mSv/y max	less than authorized limits
Incident	ALARA	less than authorized limits per event
	10 mSv/event max	0.1 mSv/event
Accident	constraints from accident/post-accident situations	No counter measures
		< 10 mSv
DEC		No cliff edge; counter measures limited in time and space

Collective dose < 500 h.mSv

Recent PWR (EPR)

EPR Finland	Workers	Public
Normal	10 mSv/y (total) and less than 0.5 mSv/y (internal)	Normal: 0.1 mSv/y
Incident	20 mSv/event	Cat 2: 1mSv/event
Accident	/	Cat 3-4: 5mSv
DEC	/	DEC: 20 mSv

Collective dose < 50 h.mSv for the 1st year of operation

EPR France	Workers	Public:
Normal	5 mSv	Normal: 1 mSv/y
Incident	20 mSv	Cat 2: 1mSv
Accident	/	Cat 3-4: 10 mSv
DEC	/	DEC: limited sheltering, no evacuation beyond close vicinity

Collective dose < 350 h.mSv

Comparison with other recent nuclear facilities

Future PWR (EPR2) (under discussion with the French regulator)

EPR2			**Public**
Accidents without core melt (DEC-A)			10 mSv effective dose
			50 mSv thyroid
Accidents with core melt (DEC-B)	24h		50mSv effective dose for the closest populations
	7 days	3 km	50 mSv effective: no evacuation above 3 km
		5 km	10 mSv effective: no shetering above 5 km
		5 km	50 mSv thyroid: no iodine ingestion above 5 km
	Long term		No food restriction above 5 km
			Dose due to deposits : less than 100 mSv, averaged over 5 y, after the 1st year

DEMO general safety objectives

	Workers	Public	Environment
Routine	ALARA	ALARA	Environment legacy: minimisation of waste No situation impacting environmental matrixes (ground, water, fauna, flora)
	5 mSv/y average	0.1 mSv/y	
	10 mSv/y max	less than authorized limits	
Incidents	ALARA	less than annual authorized limits per incident	
	10 mSv max per incident	0.1 mSv per incident	
DBA	Accidental doses less than 50 mSv (1) for emergency situations necessitating an intervention preventing others to receive doses	No immediate or deferred counter mesures (no sheltering, no evacuation)	No accident leading to exceed World health Organization food and water quality criteria
	Constraints from implementation of accident / post-accident management	< 10 mSv effective dose for both short term and long term situations for fence and most exposed populations	
DEC	Constraints from implementation of accident / post-accident management < 100 mSv (2)	No cliff edge effects; no sheltering; counter measures limited in time and space	

(1) IAEA objective in G.S.R part 7 (req 5.55) no emergency worker is subject to an exposure in an emergency that could give rise to an effective dose in excess of 50 mSv other than: (1) For the purposes of saving human life or preventing serious injury; (2) When taking actions to prevent severe deterministic effects or actions to prevent the development of catastrophic conditions that could significantly affect people and the environment; (3) When taking actions to avert a large collective dose.

(2) IAEA objective in G.S.R part 7 (lowest guidance values in table 1.1)

Radiotoxicity (Sv/Bq)