

Safety and Environmental Guidance for Fusion Conceptual Design Studies

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Purpose

- Assemble thoughts and guidance with regard to safety and environmental (S&E) issues for the fusion conceptual design communities in MFE and IFE.
- Review highlights from ITER safety and environmental activities and the development of the US DOE fusion safety standard
- Discuss how to integrate these lessons learned and new requirements in future fusion conceptual design studies.
- The Fusion Safety Program at the INEEL wants to support and work with the community to improve conceptual designs from an S&E perspective.

Outline

- DOE Fusion Safety Standard Requirements
- Design Basis vs. No-evacuation Assessments
- Safety/Design Implementation Examples in ITER
- Other Safety Issues (N-stamping, passive safety)
- Waste Minimization, Recycle, Reuse and Clearance
- Role of Safety R&D

The US DOE fusion safety standard

Written to develop the safety and environmental requirements for a large-scale magnetic fusion energy device. The highest level requirements stem from DOE policy, namely:

- The public shall be protected such that no individual bears significant additional risk to health and safety from the operation of those facilities above the risks to which members of the general population are normally exposed.
- Fusion facility workers shall be protected such that the risks to which they are exposed at a fusion facility are no greater than those to which they would be exposed at a comparable industrial facility.
- Risks both to the public and the workers shall be maintained as low as reasonably achievable (ALARA).

In addition to these requirements, two additional fusion-specific requirements were developed:

- The need for an off-site evacuation plan shall be avoided
- Wastes, especially high-level radioactive wastes, shall be minimized

Safety Functions for Magnetic Fusion

**Public Safety Function:
Confine Radioactive &
Hazardous Materials**



Potential Safety Concerns:

- Ensure Afterheat Removal
- Provide Rapid Plasma Shutdown
- Control Coolant Internal Energy
- Control Chemical Energy Sources
- Control Magnetic Energy
- Limit Routine Airborne and
- Liquid Radiological Releases

**Worker Safety Function:
Control of Operating
Hazards**



- Limit Radiation Exposures
- to Workers
- Limit EM Field Exposures
- Control Other Industrial Hazards

Safety Principles have also been established to provide a framework within which safety can be implemented at a level commensurate with the risks of the facility.

Non-prescriptive functional requirements

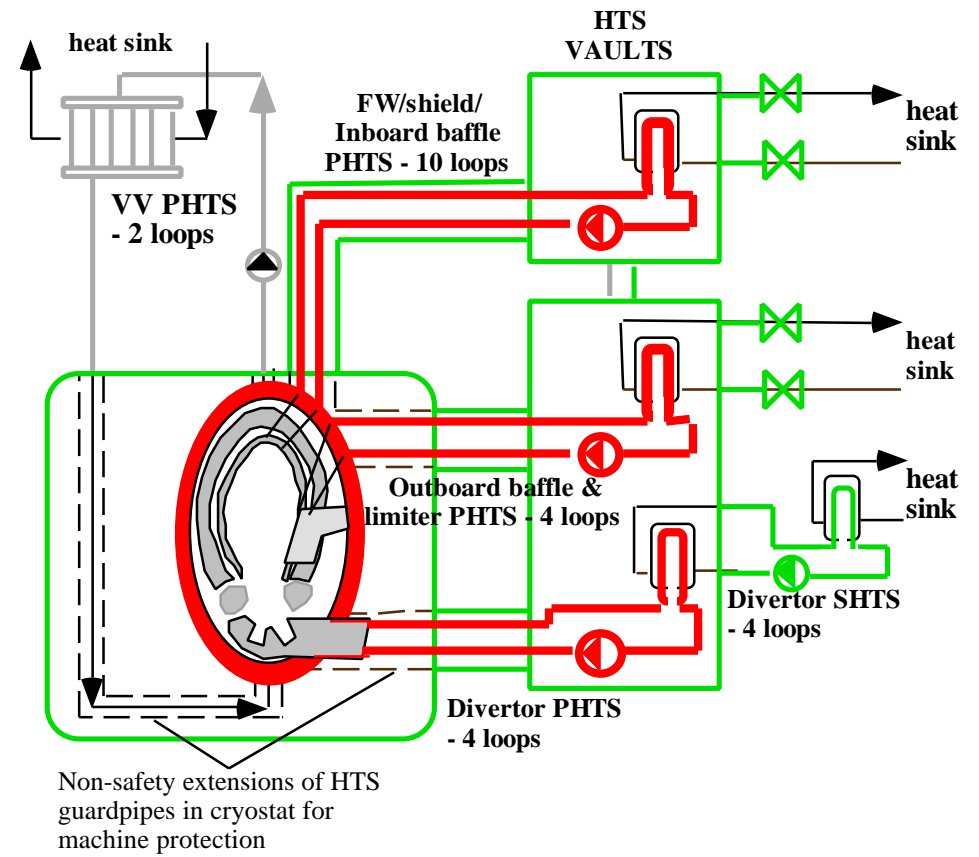
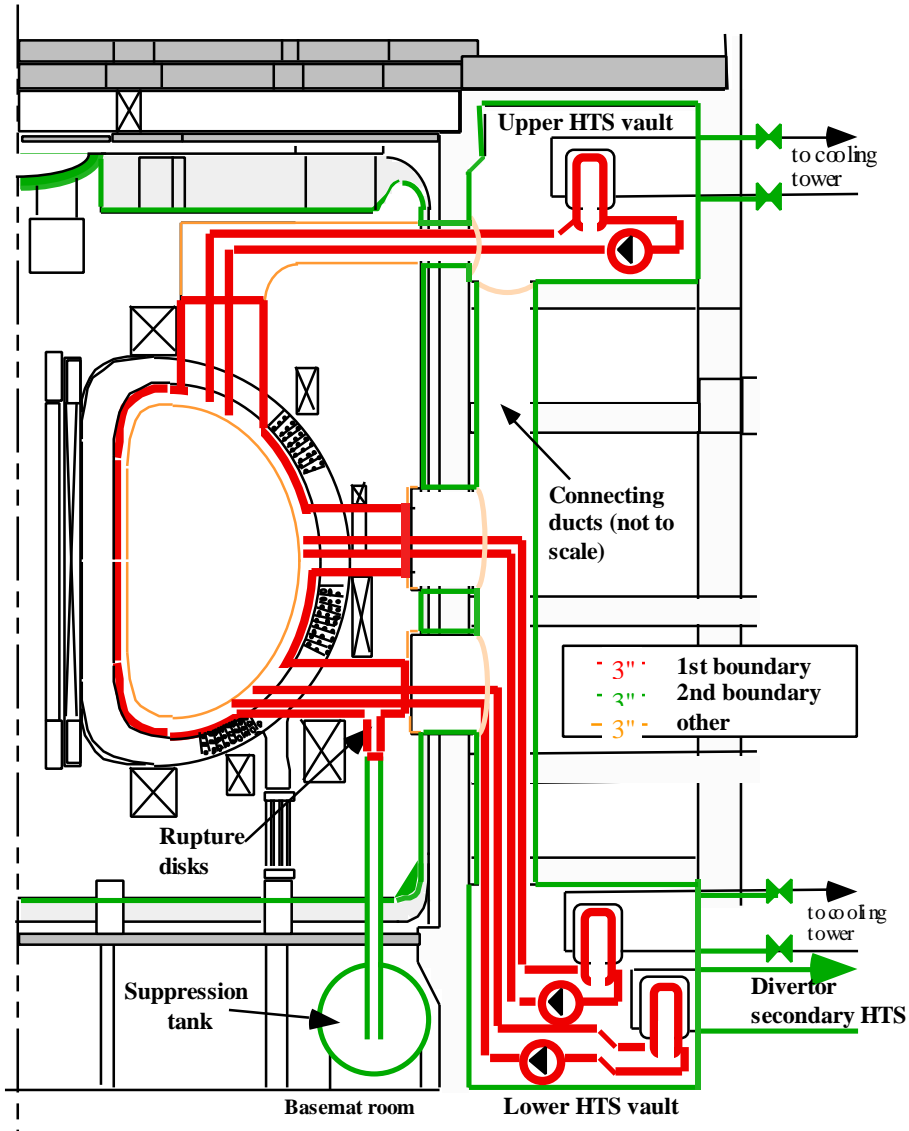
Safety and Environmental Principles

- Defense in Depth
- Identification of Items Required to Implement Safety
- Design Basis
- Design for Reliability
- Fail-safe and Fault-tolerant Design
- Human Factors
- Remote Maintenance
- Quality Assurance
- Codes and Standards
- Safety Analysis
- Verification and Validation
- Special Considerations for Experimental Use
- Waste Recovery and Recycling
- Cleanup and Site Restoration
- Emergency Planning
- Operating Safety Requirements

Safety Implementation in Design

- ITER has shown that implementation of the safety design criteria early in the design process was key to the safety of ITER.
- The ITER EDA also taught us how important design can be at addressing critical safety concerns.
- The safety team and designers in ITER worked together to solve critical safety issues which resulted in low radioactive releases during postulated accidents and helped demonstrate the safety potential of fusion.
 - * ITER Radiological Confinement Scheme
 - * Vacuum Vessel Pressure Suppression System
 - * Decay Heat Removal by the VV Heat Transport System

ITER Confinement and Decay Heat Removal Schemes



What is the difference in a no-evacuation assessment and the classical design basis safety analysis needed for siting and regulatory approval?

Radiological Release Limits

Different sets of radiological release limits have been adopted in the fusion safety standard: regulatory limits that are required by federal law and fusion requirements that are tied to other safety goals such as no-evacuation.

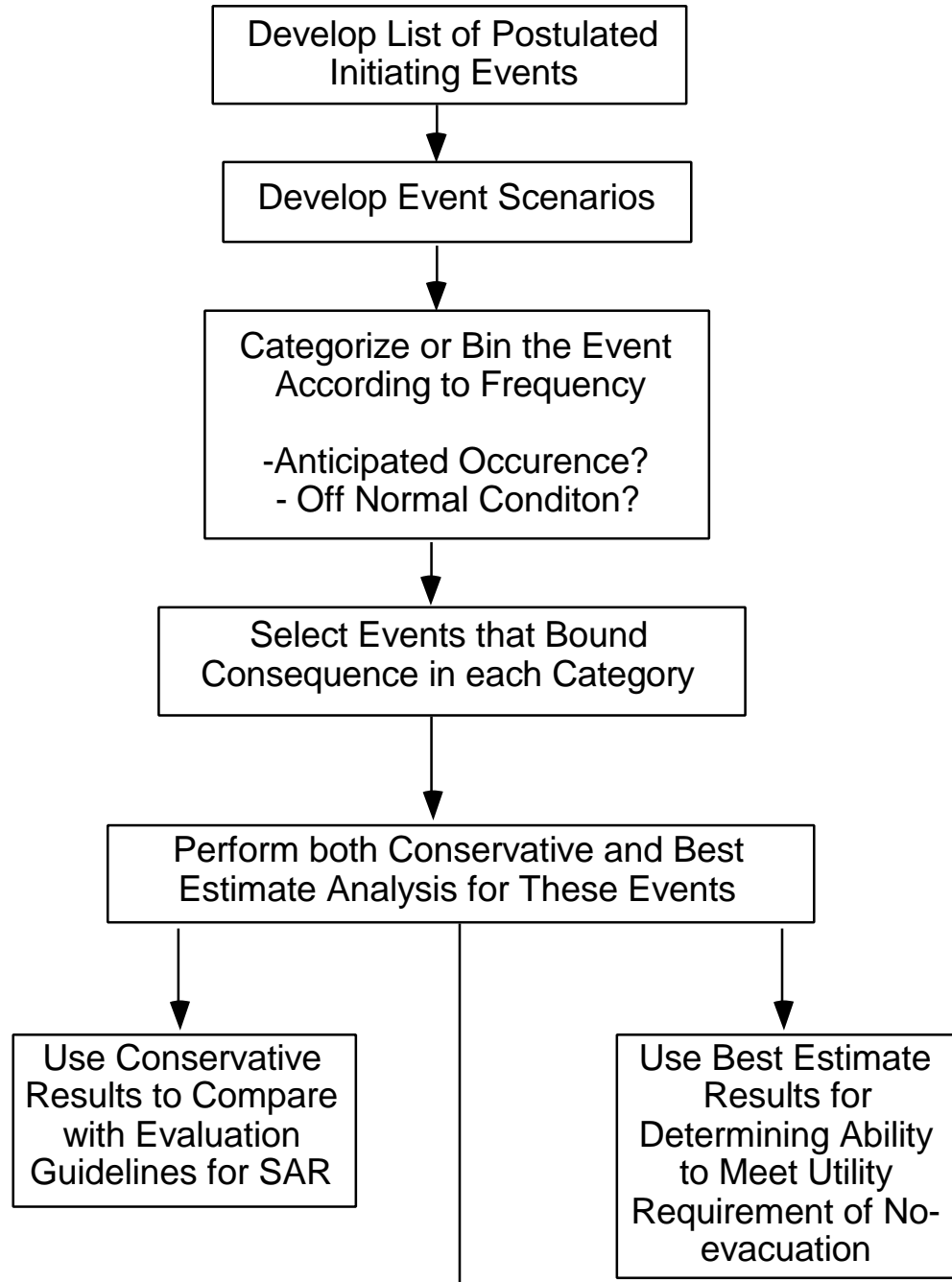
Release limits for two different categories: normal operation and anticipated operational occurrences, and off-normal conditions.

Safety requirements for public exposure		
	Fusion requirement	Regulatory limit
Normal and anticipated operational occurrences	0.1 mSv/yr. (10 mrem/yr) (application of ALARA)	1 mSv/yr. (100 mrem/yr)
Off-normal conditions (per event)	10 mSv (1 rem) (No public evacuation)	250 mSv (25 rem) (Regulatory siting criteria)

What types of accidents should be considered?

- loss of coolant/decay heat driven transients
- confinement degradation/bypass events
- loss of flow
- ex-vessel events that require plasma shutdown
- plasma anomalies and transient overpower?
- loss of vacuum
- initiating events in the fueling and vacuum systems
- initiating events in the tritium system
- initiating events in balance of plant systems (e.g., loss of off-site power)
- operator errors
- external events

FLOWCHART OF SAFETY ANALYSIS PROCESS



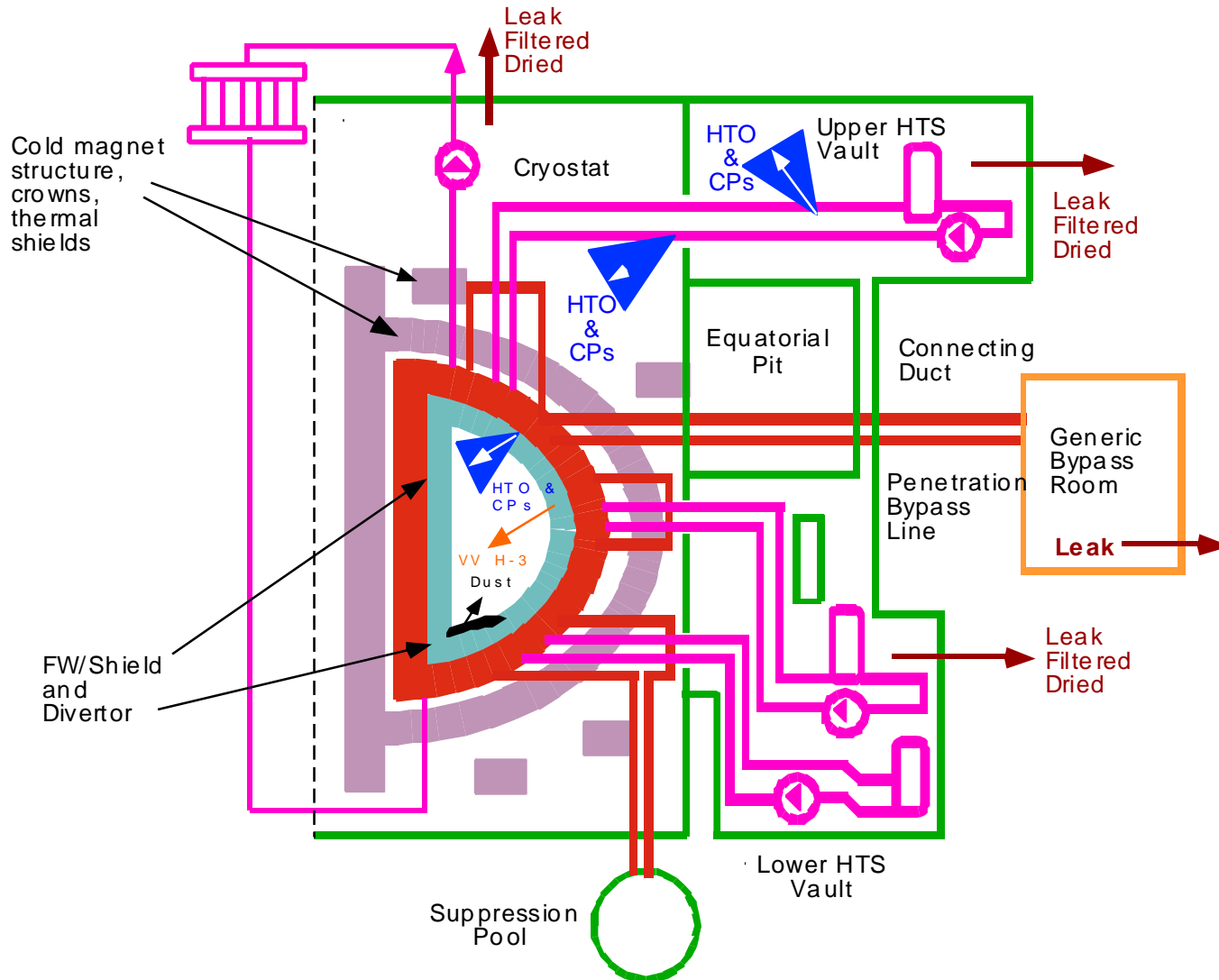
Design Basis Safety Analysis

- Use a subset of the identified event scenarios to form the design basis and undergo detailed quantitative safety analysis. Probabilistic and deterministic approaches may be used in the safety analysis. Rationale for probabilistic approaches should be documented.
- How low in risk space? NRC $10^{-4}/\text{yr}$;DOE and Advanced Fission Reactors $10^{-6}/\text{yr}$; For fusion, it is recommended to use $10^{-6}/\text{yr}$
- Conservative safety analysis calculations: meteorological conditions, release fractions and release timing, thermal response of the system, etc.
- The 250 mSv (25 Rem) siting criteria: plume passage dose to the maximum exposed individual which is either at the site boundary for a ground-level release or where the plume touches the ground for an elevated release.
- Need margin between the actual calculated accident dose and the 250-mSv (25-Rem) evaluation guideline as a result of the ALARA principle. ITER → a factor of 10 given the uncertainties involved. For conceptual design studies, where one assumes that such uncertainties should be smaller, a factor of 5 might be more appropriate.

What does “No evacuation” mean?

- Public evacuation required if accident dose exceeds 1 rem.
- DOE, EPA and NRC guidance → a spectrum of accident scenarios should be considered including those somewhat more severe than design basis accidents, down to 10^{-7} to 10^{-8} /yr should be considered
- External events outside of the design basis should not be considered. More damage caused by the external event than the facility.
- Best-estimate calculations should be performed for these no-evacuation assessments. (e.g., weather, radioactivity release)
- EPA requirements and NRC guidance → Regulators need to know the expected response of the facility so that prudent emergency plans can be developed.

Schematic of Integrated MELCOR ITER Model



Passive vs. active systems

- The defense-in-depth principle emphasizes that passive systems are preferred to active systems.
- Greater simplicity and higher reliability are associated with passive systems
- Increasing emphasis in the US on passive safety.
- Further, there is a requirement to test all safety systems on a regular basis. Active systems are tested more frequently than passive ones and there is a cost and availability (downtime) impact on the facility.
- In practice, a spectrum exists when categorizing systems as active or passive; some systems have passive components or attributes but are not completely passive. For example, all systems need instrumentation and control to detect off-normal occurrences and these components need power, which makes them active components.
- The goal is still to use the most passivity possible.
- P.S. Because of the best-estimate nature of no-evacuation assessments, active systems can be used in the no-evacuation analysis if they would be used to mitigate the event under consideration.

N-stamping

Must nuclear grade components, that is, components meeting ASME nuclear fission standards, used for systems that implement safety functions in fusion facilities? Note: there are cost and in-service inspection concerns with nuclear grade equipment.

It is important to note that there are no clear regulatory rules or precedents to follow in this regard. The use of nuclear grade components is not tied to any specific dose criteria or to whether or not the system is active or passive.

Many of the reactors in the DOE complex were not designed to nuclear grade codes because such codes did not exist when those facilities were constructed. Tritium plants around the world, with the exception of a facility at ISPRA, have never used such strict design criteria. Accelerator and other DOE energy research facilities (e.g., APS, RICK) do not use such standards.

For ITER, there was tremendous discussion about whether the vacuum vessel, the cryostat, and the heat transport system piping should be nuclear grade.

The ultimate decision rests with the regulators but a justification based on the low hazard of the facility, as demonstrated by meeting the no-evacuation criteria, should allow design to fusion appropriate standards rather than N-stamp.

DOE Fusion Safety Standard takes this approach

Worker Dose Limits

Proposal	Value	Comment
Limit for annual individual worker doses	50 mSv and 20 mSv averaged over 5 yrs	IAEA proposal. (Also consistent with EUR: European Utility Requirements for future fission plants. Similar to US DOE reqmts)

Administrative Guidelines

Proposal	Value	Comment
Administrative guideline for annual individual worker doses	5 mSv	Consistent with EUR. Typically Facility Limits are 10 times smaller compared to limits. (factor 4 smaller than ITER FDR)
ALARA threshold for activities with doses larger than	0.5 mSv/shift	Dose guideline for single shift should be 10 times smaller compared to annual dose guideline (factor 4 smaller than ITER FDR)
ALARA threshold for dose rates	100 micro-Sv/h	
Collective annual worker dose target averaged over life time of plant	0.5 man-Sv	EUR target: 0.7 man-Sv/GWe
ALARA review of all activities exceeding collective worker dose	30 person mSv/yr	Collective dose target for each activity

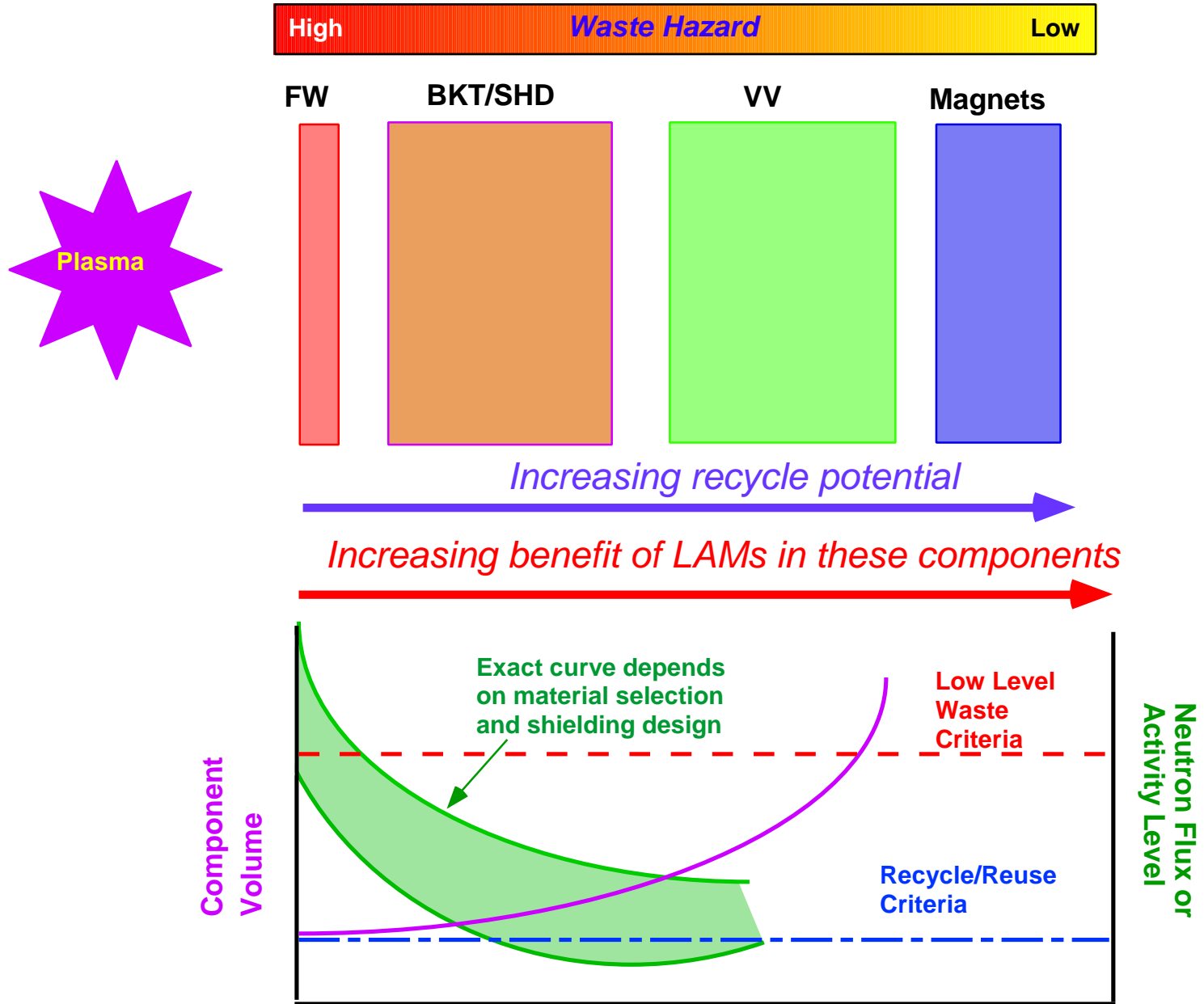
10 mSv = 1 Rem; 100 micro-Sv/hr = 10 mrem/hr

Waste Minimization and Clearance

Why should fusion care about recycle/reuse/clearance?

- The environmental advantages of fusion relative to other energy sources have long been emphasized, however these do not come automatically
- Avoiding high-level waste is desirable, however minimizing total waste for disposal is better
- There is significant justification in the US for minimizing waste given that opening repositories for radioactive waste has proven extremely difficult, and has been fraught with numerous delays in siting and/or opening repositories (e.g., Ward Valley, Yucca Mountain, and WIPP)
- Recent support in the US Congress and DOE for the Accelerator Transmutation of Waste project show reluctance in the US to dispose of waste with extremely long-lived isotopes
- Recycling/reuse/clearance are methods for reducing the amount of material that must be disposed of; there are tradeoffs associated with each that must be considered

Waste can be minimized not only by materials choice but also by design



The concept of clearance has been under discussion in many countries for years

- Clearance is the declassification of radioactive waste to non-radioactive waste (exemption refers to sources that never entered the regulatory regime) because of its low activity level.
- Clearance is a very sensitive for certain industries such as scrap metal recycle companies, metal manufacturers, and the photographic industry where even a small amount of radioactivity can be undesirable (e.g., when fabricating MRI equipment)
- Clearance limits proposed by Sweden and Great Britain correspond to very low levels of radioactivity, often lower than those naturally occurring in substances (e.g., lawn fertilizer)
- The IAEA has recommended clearance and exemption levels for fission reactors and nuclear fuel cycle facilities; these levels are under discussion, and are not, as of yet, internationally accepted
- Clearance levels in addition to waste disposal ratings should be used to help us classify the different types of activated material in fusion.

Role of Safety R&D

- Safety R&D is important because it improves experimental databases needed for safety analysis, increases our physical understanding of critical phenomena and processes, and reduces uncertainties surrounding critical safety issues. All of these have helped ITER safety analysis, increased the credibility of the safety case with regulators, and should contribute to the safety of future fusion activities.
- The FSP has tried to tailor its R&D activities to support fusion conceptual design studies. In the 1980s, extensive experiments were performed to understand the chemical reactivity of Li (also LiPb) and its safety implications because of promise of the Li/V blanket concept. Experiments were also performed on mobilization of activation products from fusion relevant materials and tritium permeation in materials.
- Most of the safety R&D in the 1990s supported the ITER CDA and EDA. It centered around characterization of the ITER source term for tritium and activation products, development of fusion safety computer codes for safety analysis, and measurement of the chemical reactivity of various forms of Be.
- As the Fusion Safety Program moves forward we plan on studying the safety issues of Flibe (both experimentally and analytically), improving our safety tools to deal with liquid walls, and providing general safety support to the conceptual fusion design community.