Lessons learnt on Tritium and workers in Fusion devices

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OUTLINE

- Feedback from Tritium in Fusion installations
- Radioprotection approach in ITER
- Means for Tritium confinement
- Safety objectives for ITER
- Conclusions

Safety background in the Fusion Community

Fusion Machines:2 machines have used tritium for fusion

- **JET** 1991 → 1.7 MW fusion power

  1997 → 16 MW fusion power (DTE1) (maximum value)

  2003 → Traces

  Safety case →UK requirements and standards followed

  →Dismantling included in UKAEA decommissonning

- **TFTR** 1993 → + 3 years DT campaign 11.5 MW Fusion power (maximum value)

  PSAR → approved in 1978 USDOE

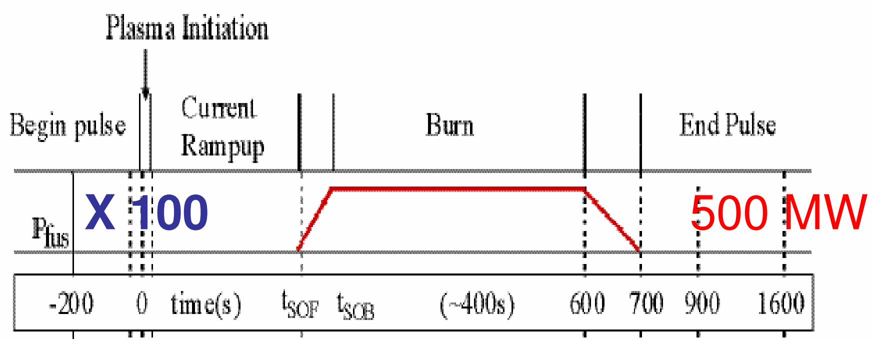
  FSAR → approved in 1992 for DT operation

  → Dismantling and safe disposal 2002 (in time and cost)

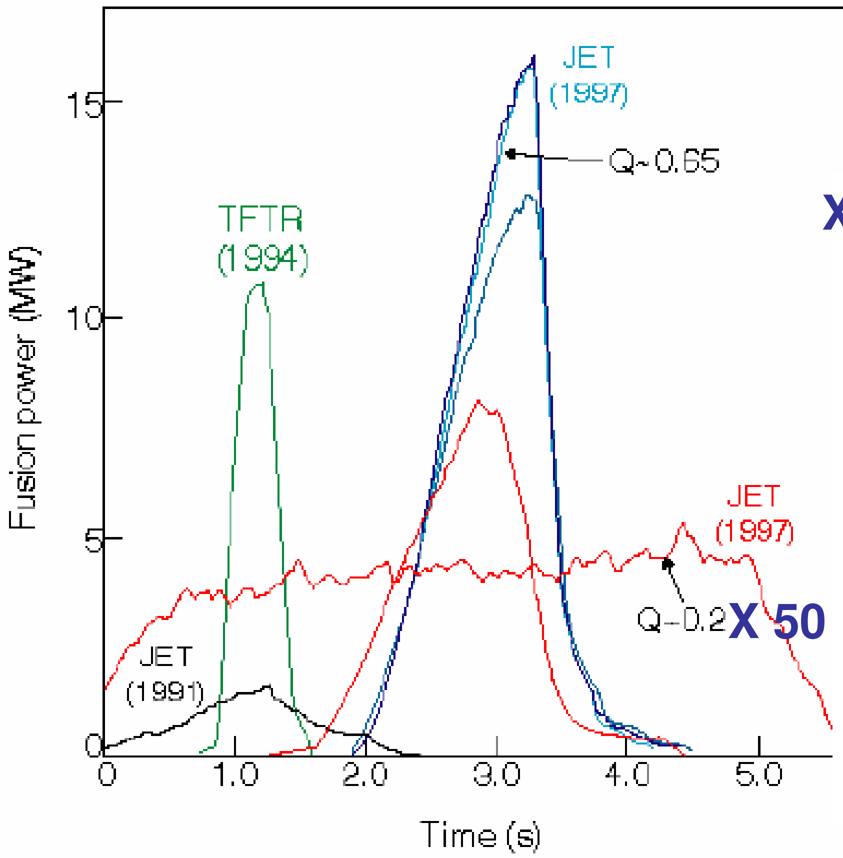
Existing machines ITER

pulse sequence

Fusion power gain Q=Pfus/Padd



X 100 ~600 s of fusion reaction from Q<1 to Q~1



Other installations relevant for fusion using or producing or reprocessing tritium

Tritium laboratories

Relevant for ITER tritium plant

- Active Gas Handling System at JET (maximum inventory 20 g)
- Tritium Laboratory Karlsruhe (maximum inventory 40 g)
- Tritium Process Laboratory at Naka (maximum inventory 60 g)
- Tritium Systems Test Assembly at Los Alamos (TSTA) (maximum inventory 100 g)
- Tritium Laboratory at Valduc

CANDU's

Relevant for T procurement for ITER

- About 100 g tritium is produced per year in a standard fission unit

Further Confinement Inertial Fusion installations like LMJ

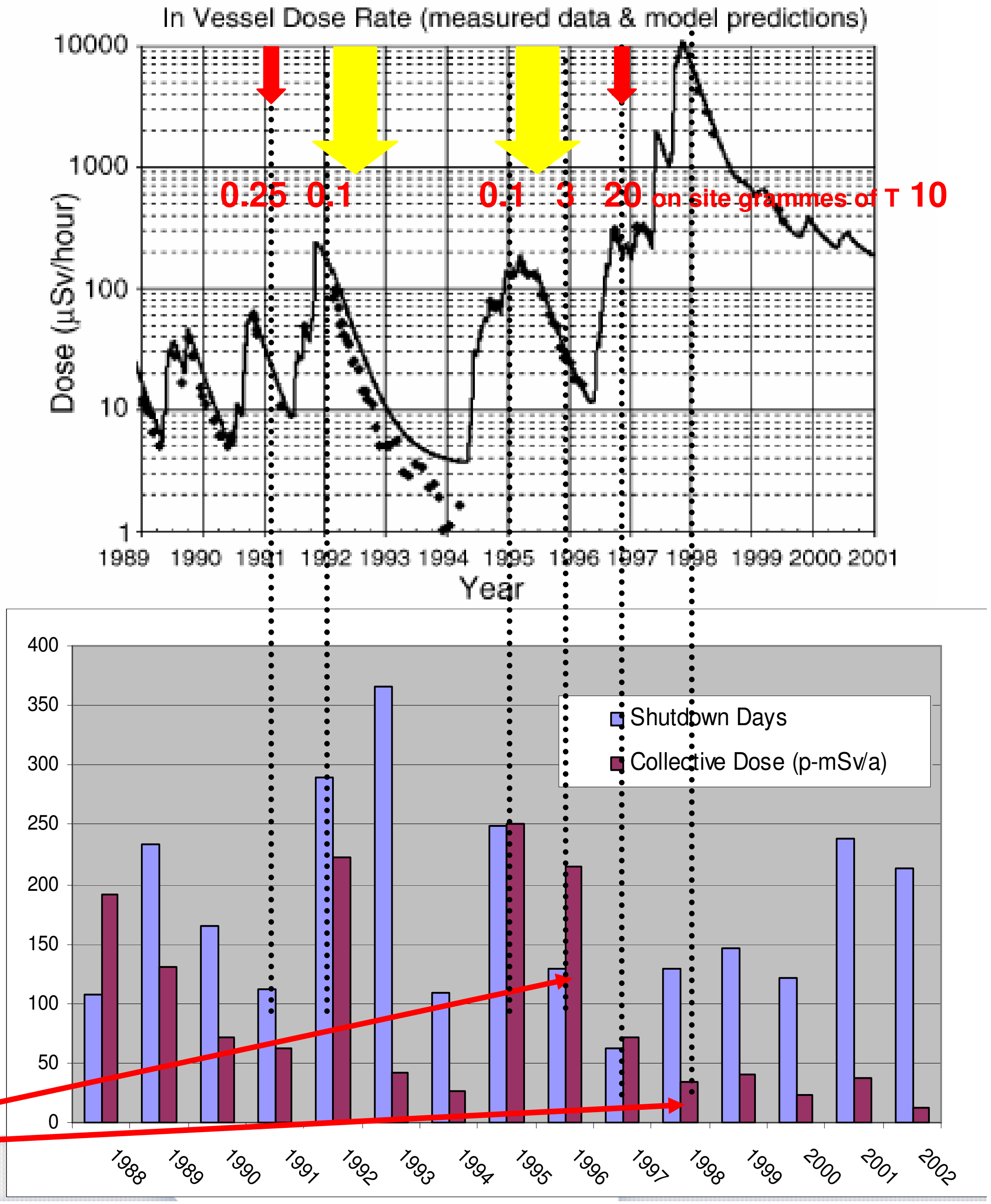
Relevant for similarities in fusion reactions and activation products
T retention and T breeding

Joint European Torus-JET: Tritium on site

Operational Phase	Year	Tritium on site
Hydrogen	1984	0
D-D	1986	0
D-D plus Be	1989	0
D-T (PTE)	1991	0.25g
Divertor Shutdown	1992	0.1g
AGHS trace tritium commissioning	1995	0.1g
AGHS full tritium commissioning	1996	3g
D-T (DTE1)	1997	20g
Trace Tritium Experiment	2003	<10g

Occupational dose: lessons learnt at JET

From JET data collection and analysis on occupational doses versus in Vessel Dose rate



The maintenance by Remote Handling (RH) plays a fundamental role in reducing occupational radiation exposure.

Maintenance at JET

Before 1997
•long-term average collective dose 96 p-mSv/a
•average individual worker dose ~0.150 mSv/a.

After 1997
•average collective annual dose 30 p-mSv/a
•average individual dose 0.058 mSv/a

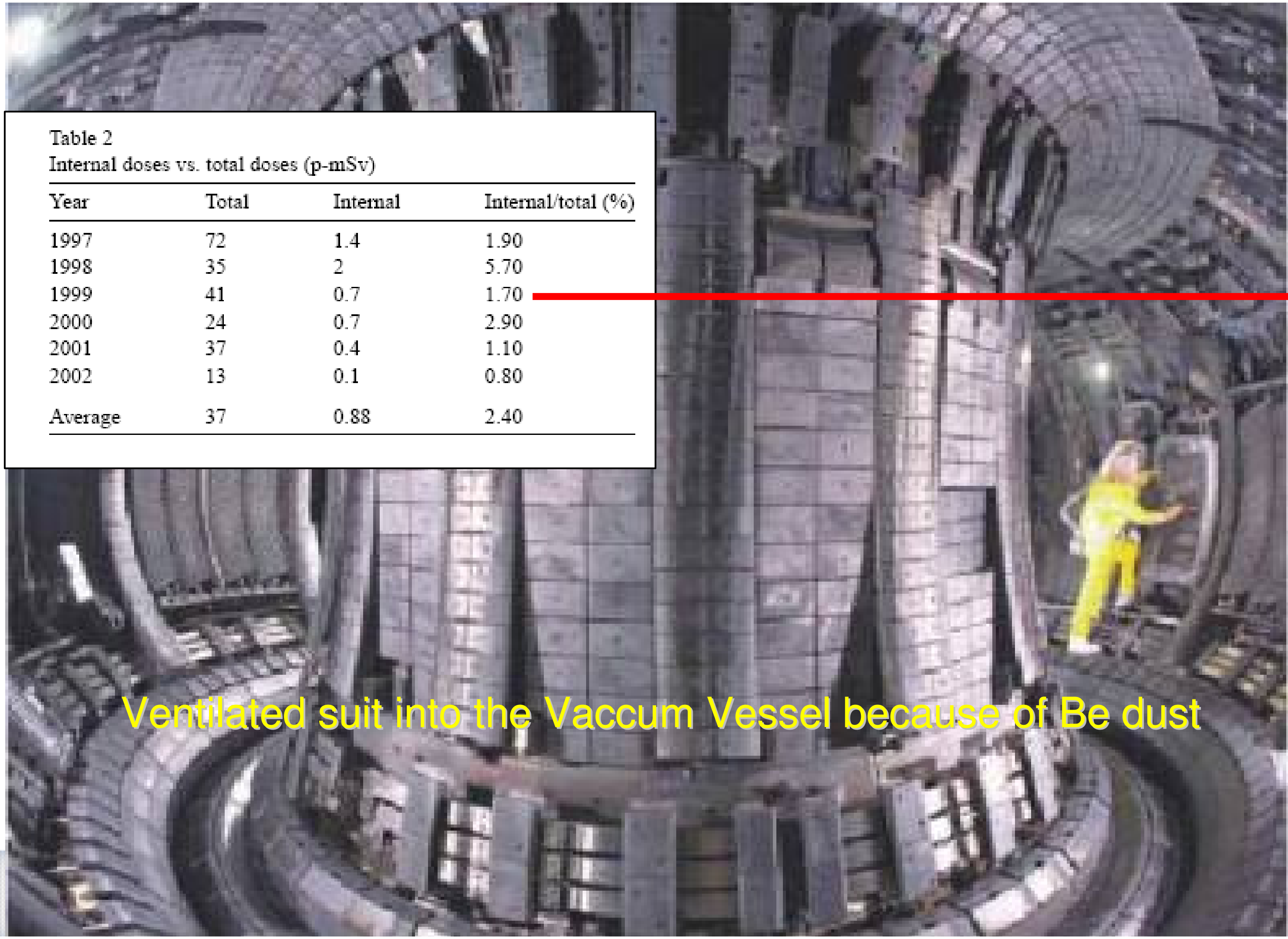


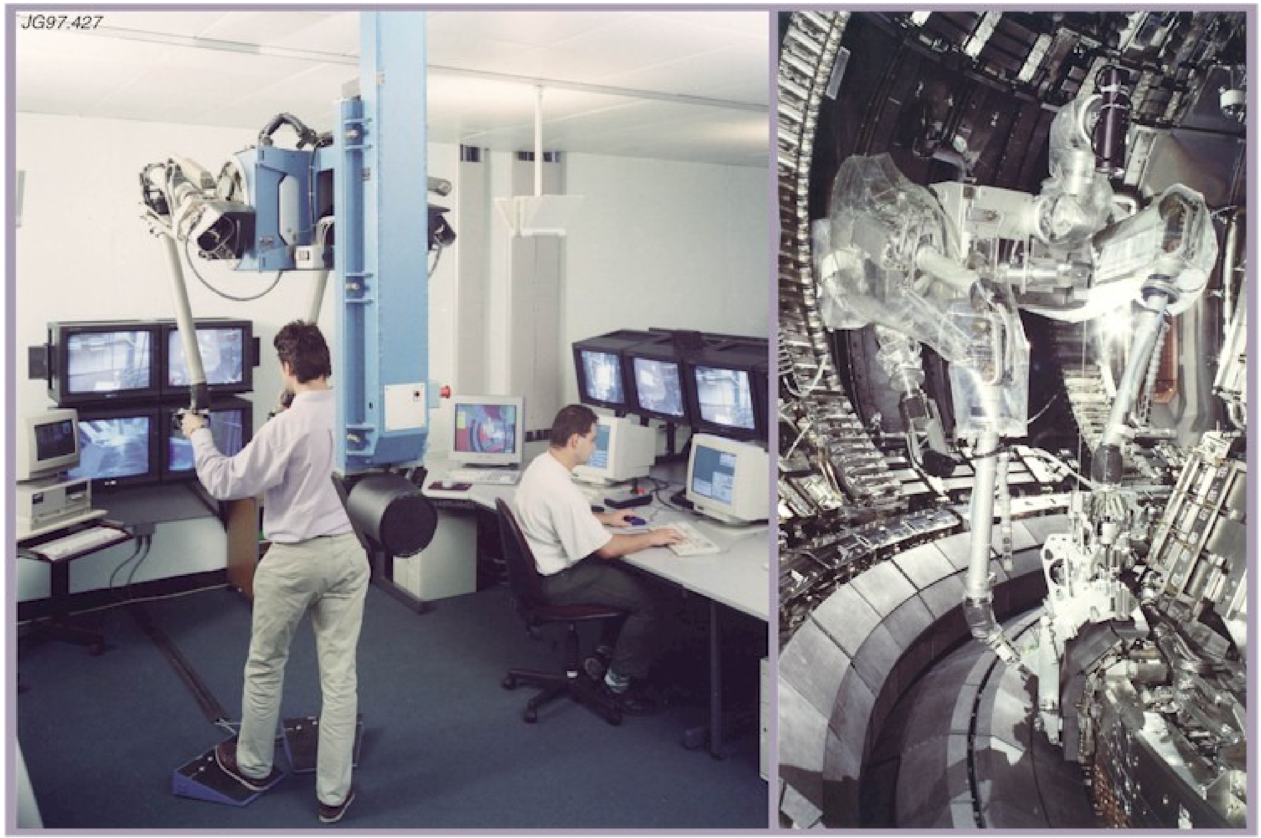
Table 2
Internal doses vs. total doses (p-mSv)

Year	Total	Internal	Internal/total (%)
1997	72	1.4	1.90
1998	35	2	5.70
1999	41	0.7	1.70
2000	24	0.7	2.90
2001	37	0.4	1.10
2002	13	0.1	0.80
Average	37	0.88	2.40

Since 1998 Remote handling has been used for maintenance

Remote Handling: an essential tool in ALARA process

– At JET RH techniques allows **in-vessel maintenance work** to be **carried out fully remotely**
– RH tasks are mainly carried out by: MASCOT master-slave units, Tile Carrier Transfer and Articulated Boom



Lessons learnt and guidelines for developing a RH system

– **Trials** for remote operation (full size mock-up on the in-vessel environment for operator training)
– **Prototype** and its upgrades to make it ready for operational
– **Reliability** of a RH equipment tested during a 1000 hour trial
– Control system hardware and software, design of the tooling, spare parts policy, viewing and use of **virtual reality**…

Occupational dose: lessons learnt at JET

- *The tritium dose has been of the order of 2 % of the total worker dose*

- *The group responsible for all machine maintenance and repair work has been the most exposed group*

- *75% of collective dose was due to maintenance*

- *1/3 of collective dose on non-maintenance workers*

➔ **Radiation protection measures for reducing the tritium dose**

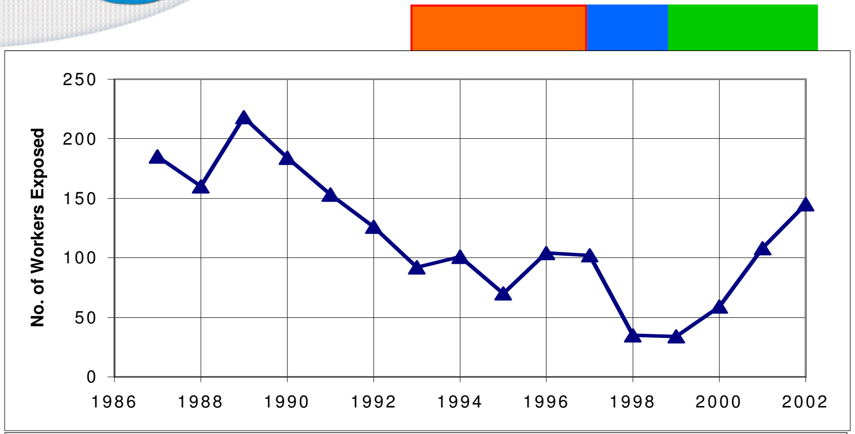
- **ALARA in operation**
- **Remote handling**
- **Radiological zoning**
- **Ventilation/detritiation**
- **Protection suits**
- **…**

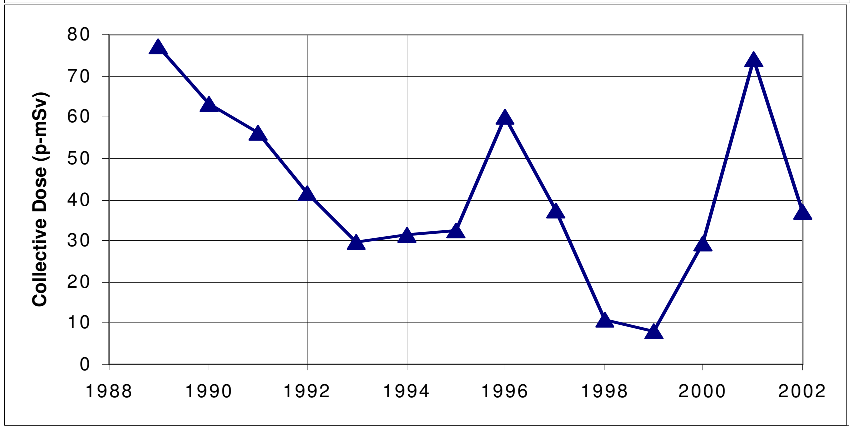
Tokamak Fusion Test Reactor –TFTR

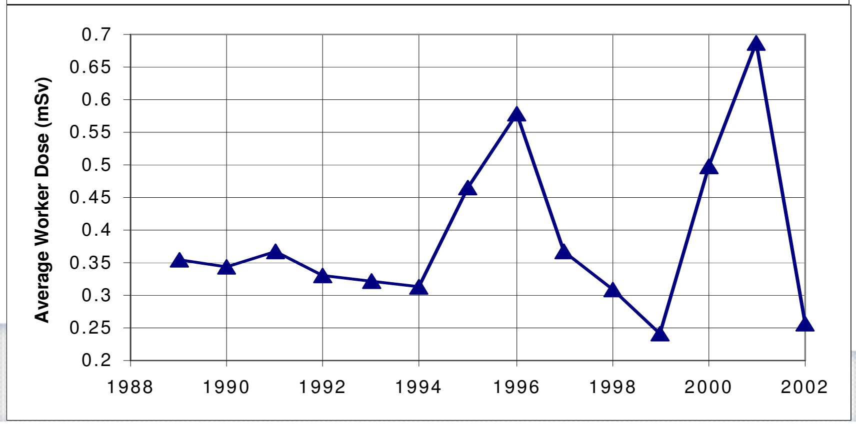
Princeton- USA

- For 3 years, about 37 PBq of tritium (100 g) had been processed
- Site limit 5g
- During the last 3 months of TFTR operation, the tritium was processed on site, with a tritium purification system
- During this time and also during the post operation shutdown, the radiation doses to Princeton Plasma Physics Laboratory workers were maintained at pre-tritium levels
- The key factors, which allowed this safety record, were thorough documentation of the installed hardware and careful planning of all activities.
- The TFTR Decontamination and Decommissioning (D&D) Project started at the beginning of October 1999. The last commitment of the TFTR Project was the removal and safe disposal of the TFTR device. The TFTR D&D Project was completed in three years in time and cost.

TFTR - Annual Worker Dose Summary







Tritium operations

Dormancy period

Dismantling

Available values of tritium doses

Year	Tritium dose (person-mSv/a)	Total dose (person-mSv/a)	Tritium dose/ total dose (%)
1994	4.75	31.6	15
1995	1.34	32.5	4
1996	4.03	60.2	7
Average	3.37	41.4	9

- **No RH available in TFTR**
- **T reprocessing during the 3 last months of TFTR operation**

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Radioprotection approach in ITER

- **As Low As Reasonably Achievable** (ICRP 60) (extended to chemical exposure risk of Be)
  - **in the design**
  - **in operation**
- **For internal exposure ➔ confinement system**
- **Individual and collective doses below statutory doses limit and ITER objectives**
- **Calculation of activation for dose rates taken at the end of life of ITER**
- **Material choice for reducing contribution to the dose to operators**
- **Activation for exposure conditions leading to radioprotection zoning taken at the end of life of ITER**
- Maintenance activities in locations around the tokamak wait **11.5 days** after shutdown (10E+6 seconds)➔**Dose rate behing bioshield <10 µSv/h**
- Activities in the Tokamak Cooling Water System (TCWS) vault wait 5 days after shutdown (<10 µSv/h)
- **Activities in port plug and VV by Remote handling**
- **Optimizing of human intervention in other areas**
- Controlled access and circulation of personnel and radioactive materials
  - **No access to Tokamak building during operation**
  - No access during remotely operated cask transfers

Order of 15 may 2006 ; radiological zoning (3)

E potential effective dose in 1 hr, DR dose rate,
H equivalent dose in 1 hr

	regulated zones				
			Specially regulated zones		
	Whole body				
Zone without regulation	**Supervised zone**	**Controlled zone green**	**Controlled zone yellow**	**Controlled zone orange**	**Restricted zone red**
- Dose D< 80 µSv / month	E< 7,5 µSv	E< 25 µSv	E< 2 mSv & DR < 2 mSv/h	E< 100 mSv & DR < 100 mSv/h	E> 100 mSv
- Radiological surveillance for zones adjoining regulated areas, if there is a contamination risk	Extremities				
	H_T< 0,2 mSv	H_T< 0,65 mSv	H_T< 50 mSv	H_T< 2500 mSv	H_T> 2500 mSv

Order of 15 may 2006 ; radiological zoning

- **Air Contamination**
  - –No reference values in the decree
  - –Equivalence between internal and external doses
  - –Zoning should be determined without the use of individual protection devices
  - –Proposed operational derived value

➔the average equivalent dose rate (on the duration of the operation) < 25 µSv/h

➔"Operational Derived Value" (ODV) < 25 µSv/h

⇐➔Limit between green and yellow zone

Air Concentrations ; Operational Derived Value

- **Air concentration for HTO**

	supervised	controlled	controlled	controlled	controlled Resctricted
HTO, **Bq.m-3**	< 2.3E5	< 7,7E5	< 6.2E7	< 3.9E9	> 3.9E9
HTO ODV	< 0.3	< 1	< 80	< 4000	> 4000

- **Calculation**

1 ODV = 25E-6 [Sv/h] / (1.2 [m3.h] * 2.7E-11 [Sv/Bq])= 7.7E5 [Bq.m-3]

Dose coefficient takes into account the skin transfer

2.7E-11 = 1.8E-11*1.5 (inhalation dose coeff 1.8E-11 Sv/Bq from directive 96/29)

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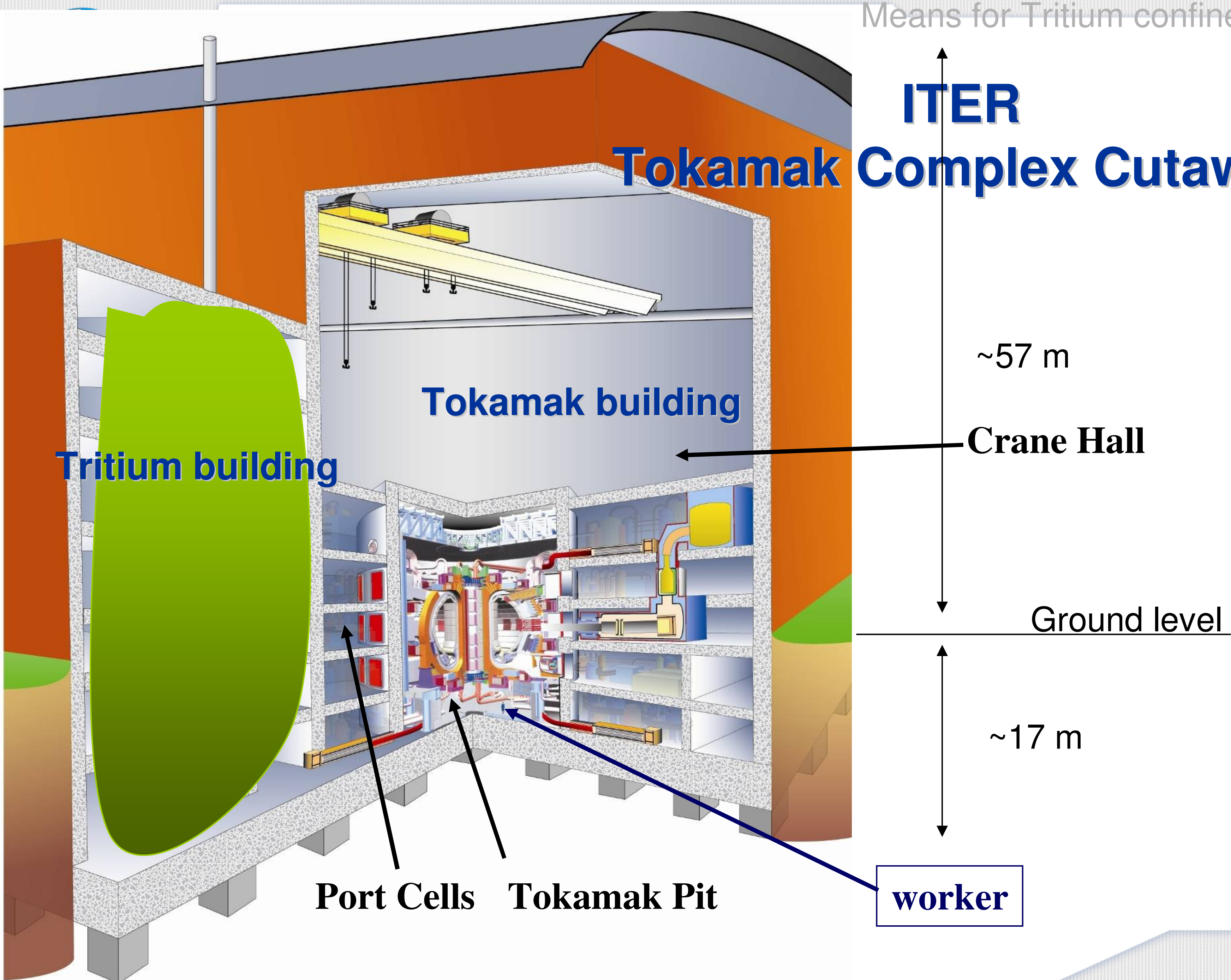
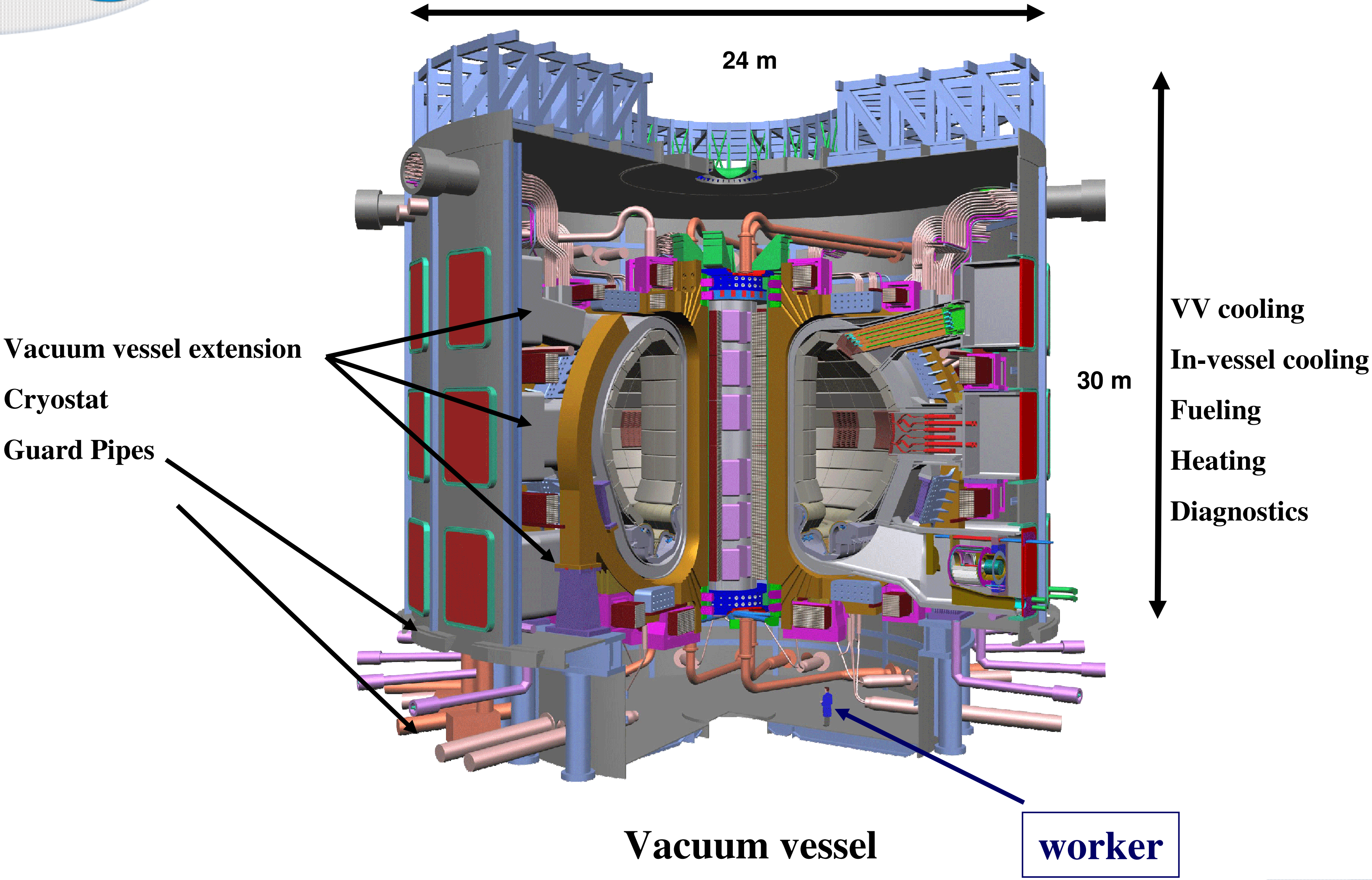
Tokamak Complex Cutaway

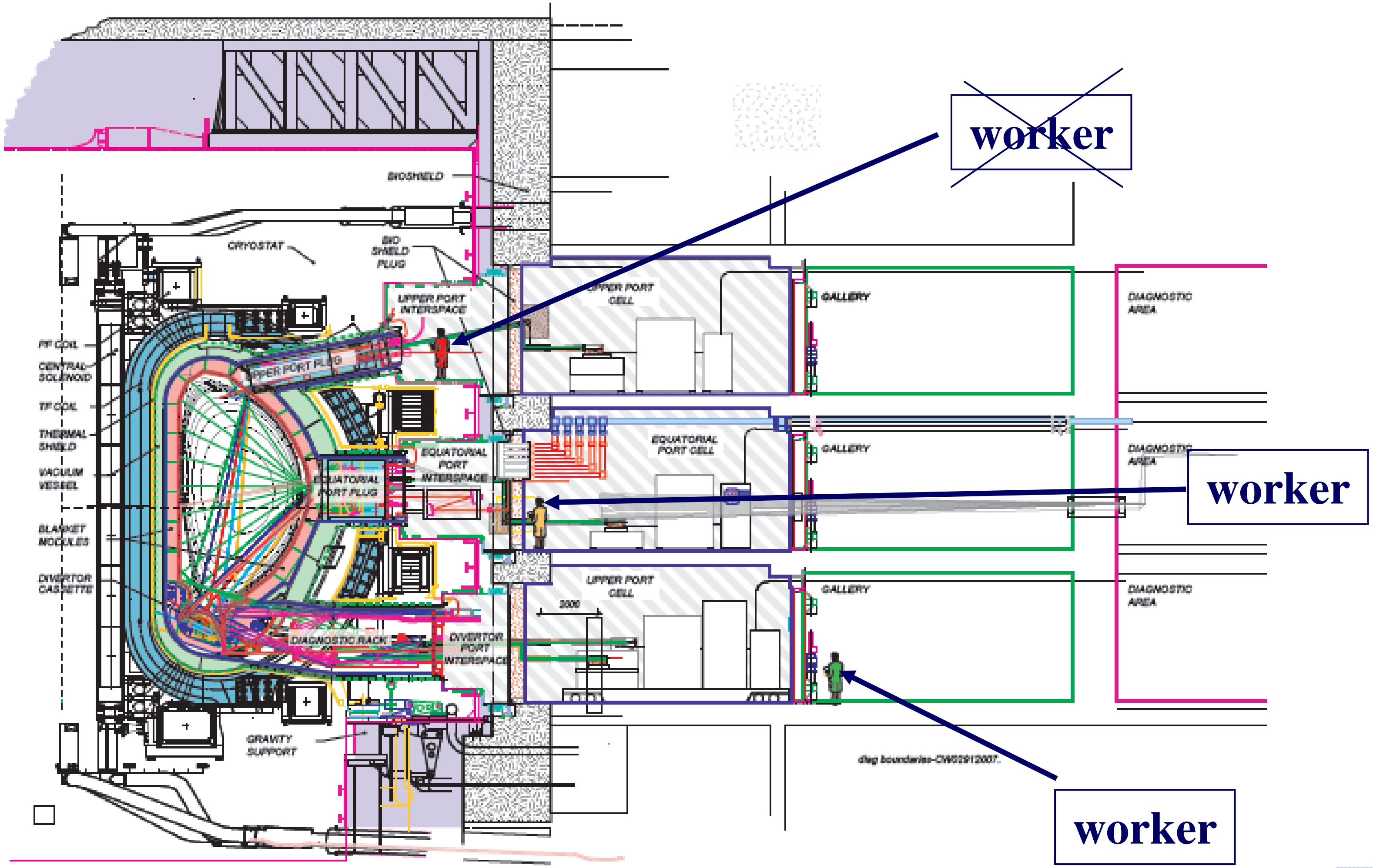


Tokamak Confinement Components



Workers in tokamak building

Mainly external exposure



Green area in the galleries

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Confinement Strategy Implementation for fusion devices

➔Collective protection against internal exposure

➔ Against the risk of spread of radioactive elements

Two confinement systems for each inventory at risk

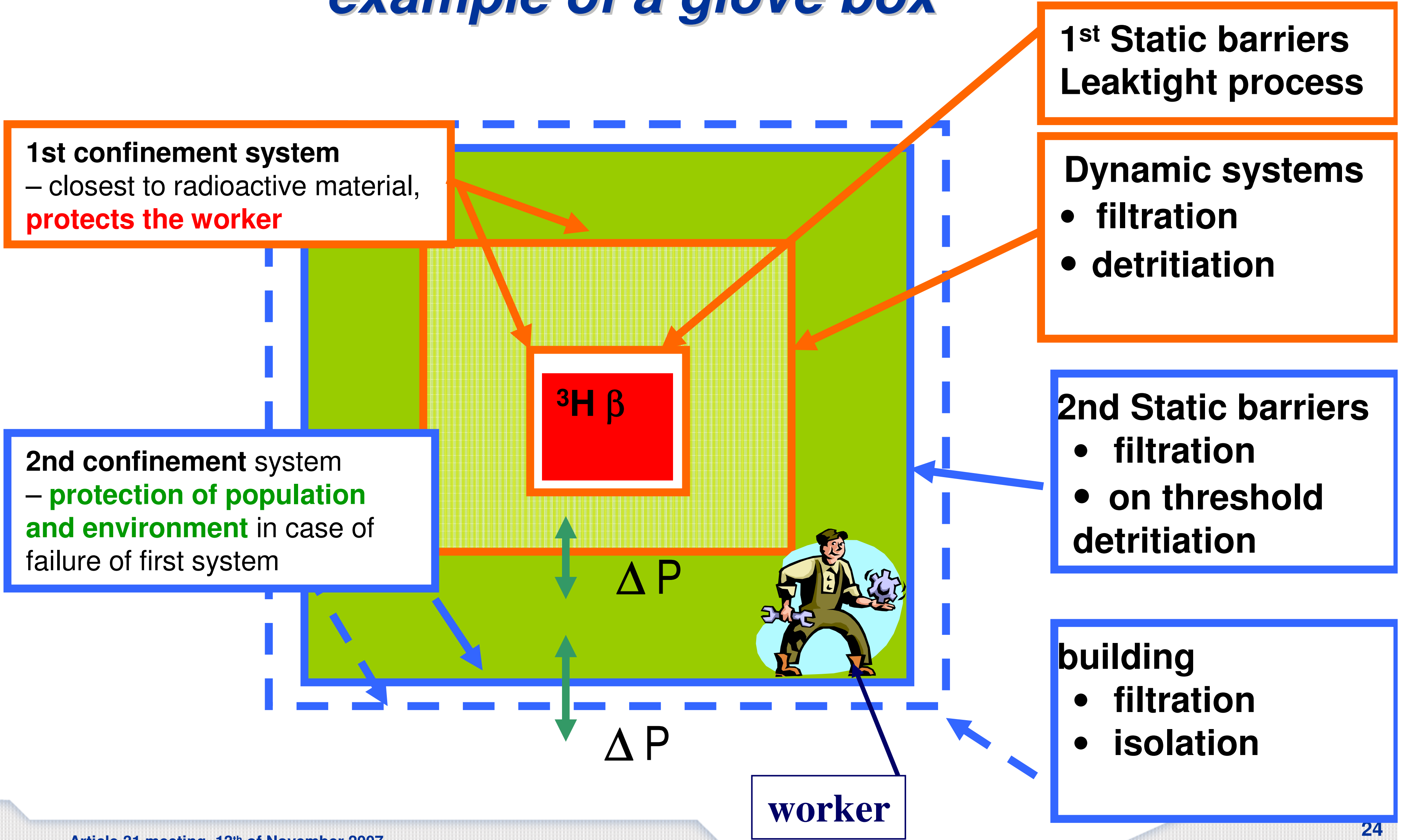
– 1st confinement system – process boundaries
  - » **Prevent onsite spread of contamination**
  - » **Normal facility conditions, e.g. operation, testing, and maintenance**
  - **➔Generally process equipment**
  - **➔Worker Protection**

– 2nd confinement system – process areas
  - » **Limit environmental releases in events during which the first confinement system fails**
  - » **Specified and credited leak rates**
  - » **Filtration and detritiation systems when needed**
  - **➔Public and environment Protection**

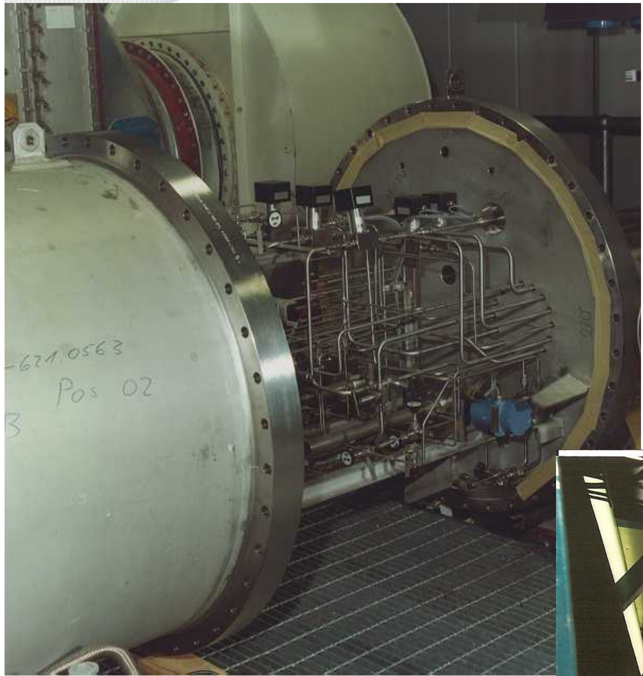
ITER Confinement Strategy Implementation

- One or more static or dynamic barriers for each system, e.g.:
  - Static barriers
    - Vacuum vessel
    - Cryostat
    - Process piping
    - Vacuum vessel pressure suppression system
    - Vacuum vessel drain tank
    - Process room walls, building walls, etc.
  - Dynamic systems
    - Depressurization ventilation systems and filtration systems
    - Detritiation systems (Atmospheric and water detritiation systems)
    - Isolation functions

Confinement
example of a glove box



JET Secondary Containment



ITER → Glove boxes

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General Safety Objectives for ITER

Condition	Personnel		Public and Environment	
	General Safety Objective •Dossier d'Options de Sûreté (DOS) reviewed by Safety Authorities November 2002 •Rapport Preliminaire de Sûreté (RPrS) 2008	Consequence Analysis	General Safety Objective (DOS and RPrS)	Consequence Analysis (preliminary up-date values)
Design Basis Situations	**Design Basis Situations**			
Normal (per year)	As Low As Reasonably Achievable, and in any case less than: < 10 mSv/a	< 5 mSv/a (project guideline)	ALARA and in any case ≤ 0.1 mSv/a	< .01 mSv/a
Incident (per event)	As Low As Reasonably Achievable, and in any case less than: < 10 mSv	Managed per event	< 0.1 mSv per incident.	<< .01 mSv per event
Accident (per event)	Consider occupational exposure management of accidents.	Managed per event	< 10mSv No restrictions on the consumption of produce or meat.	< 2 mSv Early dose at site boundary < 1 mSv Long-term dose at 2.5 km
Beyond Design Basis	**Situations beyond Design**			
Hypothetical Accidents	Consider occupational exposure in management hypothetical situations.		No cliff-edge effects; possible countermeasures limited in time and space.	< 10 mSv

ITER target: collective dose < 500 p-mSv/a

Dust in fusion devices

R&D studies

- JET particles study in vitro study for dust ➔the mean aerodynamic diameter expresses as radioactivity (AMAD) was around 4 µm
- Other studies mention the solubility in lung fluid simulant of tritium trapped in a variety of matrixes: TFTR particles, titanium, hafnium, beryllium, graphite, titanium, iron hydroxide and zirconium
- In the rats ➔ intratracheally instillation, hence by-passing the upper airways, where, according to the particle size, a remarkable fraction is retained through deposition.

Sv/Bq	HTO	OBT	Tokamak T- particles
Effective dose coefficient	1.8E-11	4.1E-11	2.7E-10

➔ Tritied dust are taken into account at the initial phase of ITER operation in radiological studies

➔In DT phase dust activity is dominated by dust activation ➔ end of life values are taken for dose calculations

➔Dust in confined into the process in normal operation➔ no impact on the workers

Conclusions

- The experience on Tritium and workers in fusion devices is available
  - Tritium had an impact of about 1-2% of the collective dose to the workers at JET
  - In fusion devices 20%-25% of the doses to the workers were on non-maintenance teams
- The key factors for low doses ALARA approach➔ radioprotection measures, remote handling, thorough documentation of the installed hardware and careful planning of all activities.
- Technologies for Tritium confinement and detritiation (atmosphere and water) system for Tritium recovery are well developed in for new devices.
- More feedback may be gathered from Tritium laboratories and CANDU reactors
- ITER will be the first fusion machine fully designed for operation with equimolar DT
- European and French regulation will be applied also for radioprotection
- No effect of tritiated particles have been reported on the workers, but their existence has to be taken in to account.
  - Technologies for particle confinement and filtration are classical
  - More R&D could be launched