Desafíos de la Fusión para la Seguridad Nuclear y la Protección Radiológica

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DE ESPAÑA

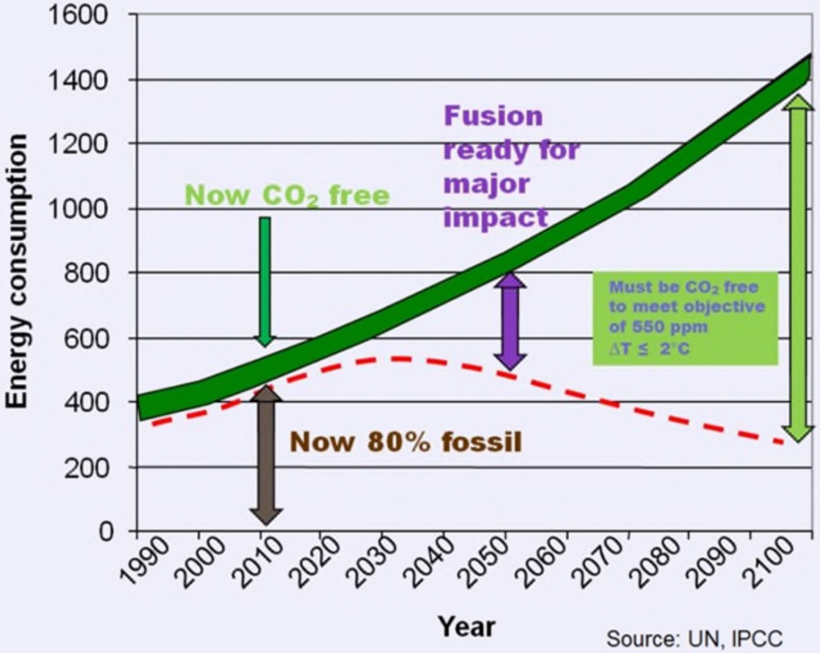
MINISTERIO
DE CIENCIA
E INNOVACIÓN

Ciemat
Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

Jornada de I+D
"Una actividad estratégica para el CSN"
Consejo Seguridad Nuclear
17 diciembre 2021

Niveles de CO_2 en los últimos 400.000 años

The energy challenge



Source: UN, IPCC

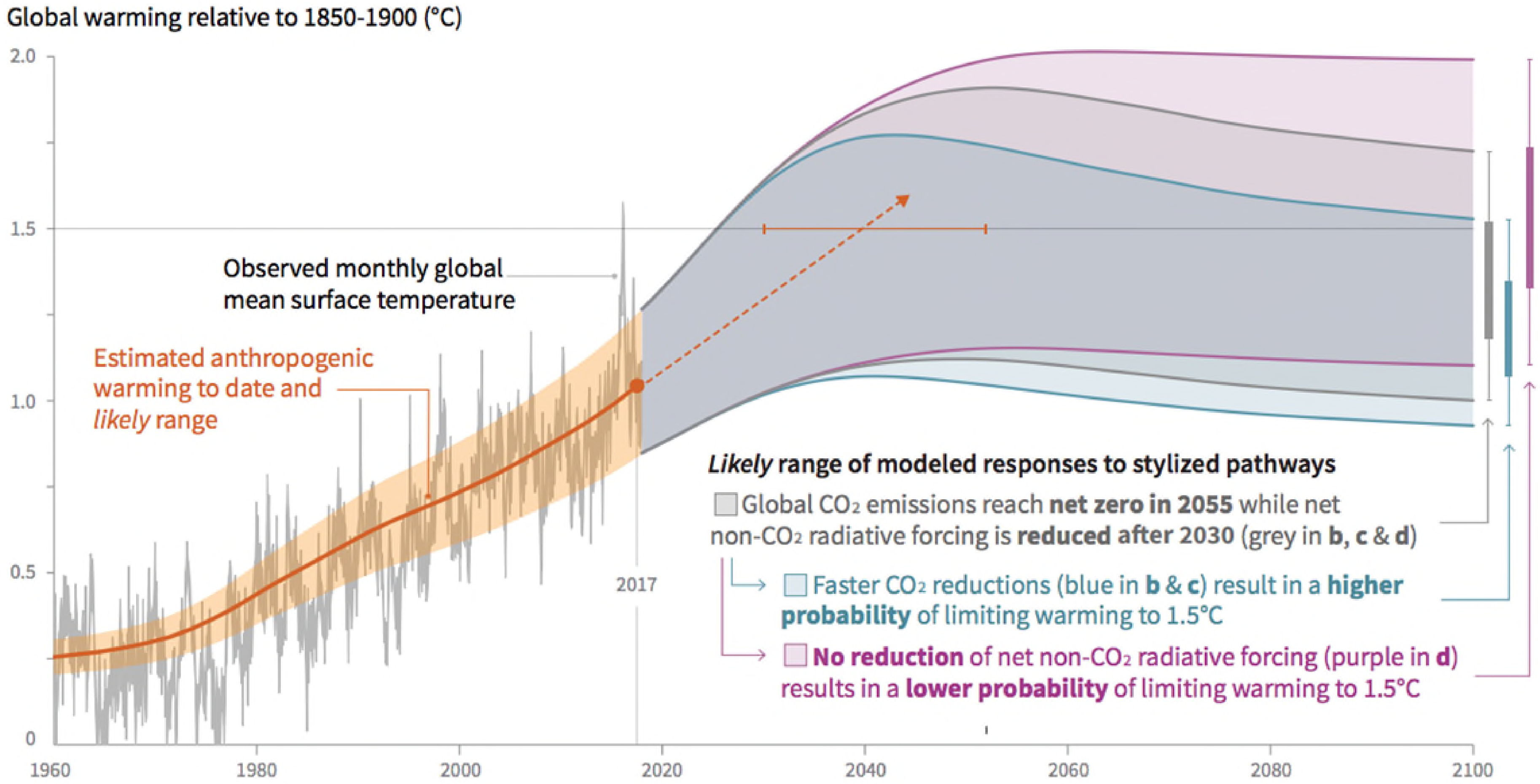
- **World energy consumption is growing continuously and it is predicted to grow at least twice by 2030 with respect to 90’s.** *(International Energy Agency - IEA)*

Options for the future

- **Fossil fuels : develop and deploy CO_2 capture and storage**
- **Renewables: seek breakthroughs in production and storage**
- **Nuclear fission: acceptability issue**
- **Fusion: must demonstrate scientific and technological feasibility**

We need to produce carbon-free energy on a massive scale !

Realidad - Proyección



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Combustible Fusion

La materia prima de una planta de fusion es agua y litio*

40 Toneladas de carbón

≈

45 litros de agua

+

Batería ordenador

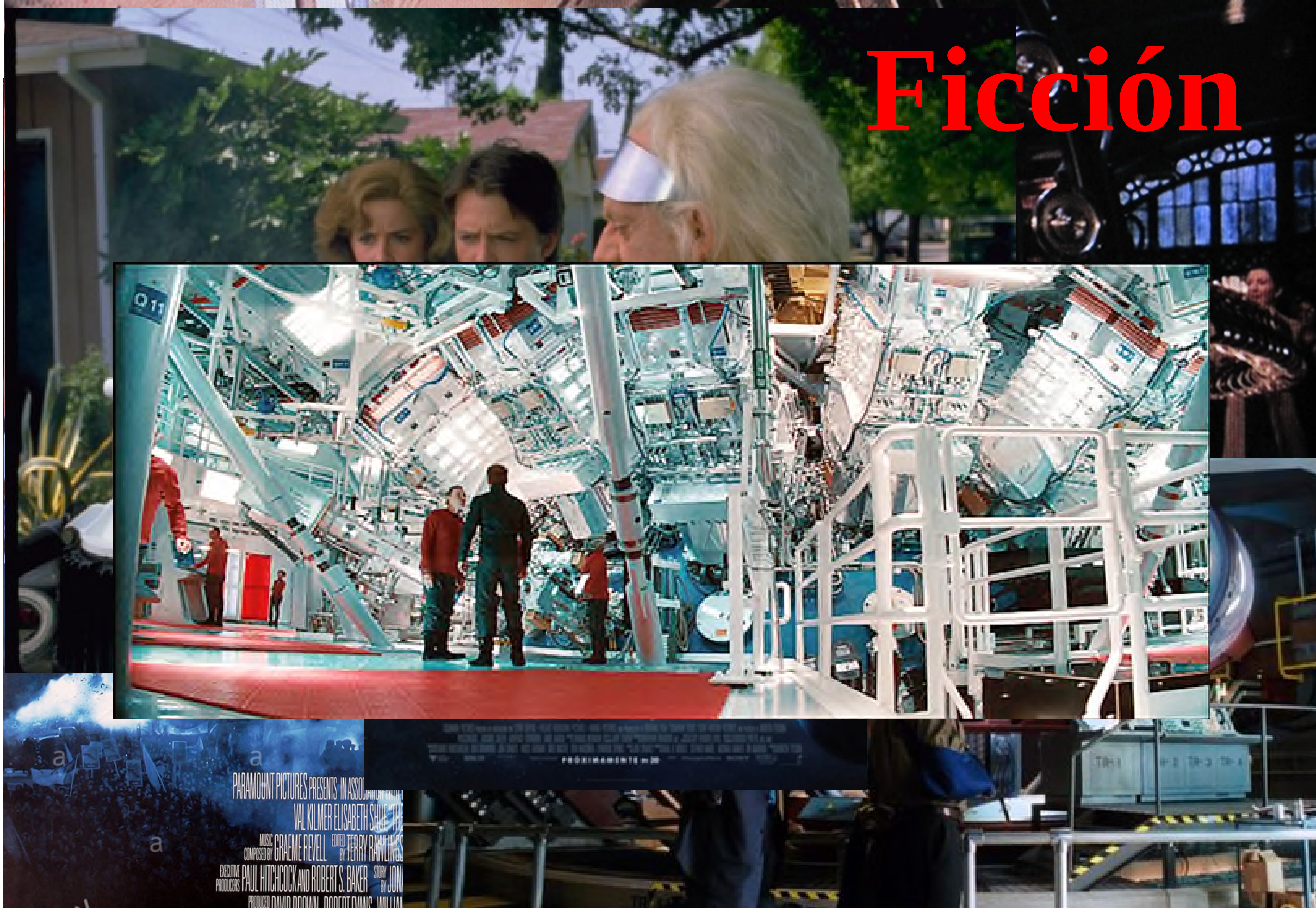
Litio en una bateria de un ordenador portàtil + media bañera de agua **(-> un dedal de agua pesada) puede producir** 200,000 kW-hora ≈ consumo promedio de un español durante 45 años

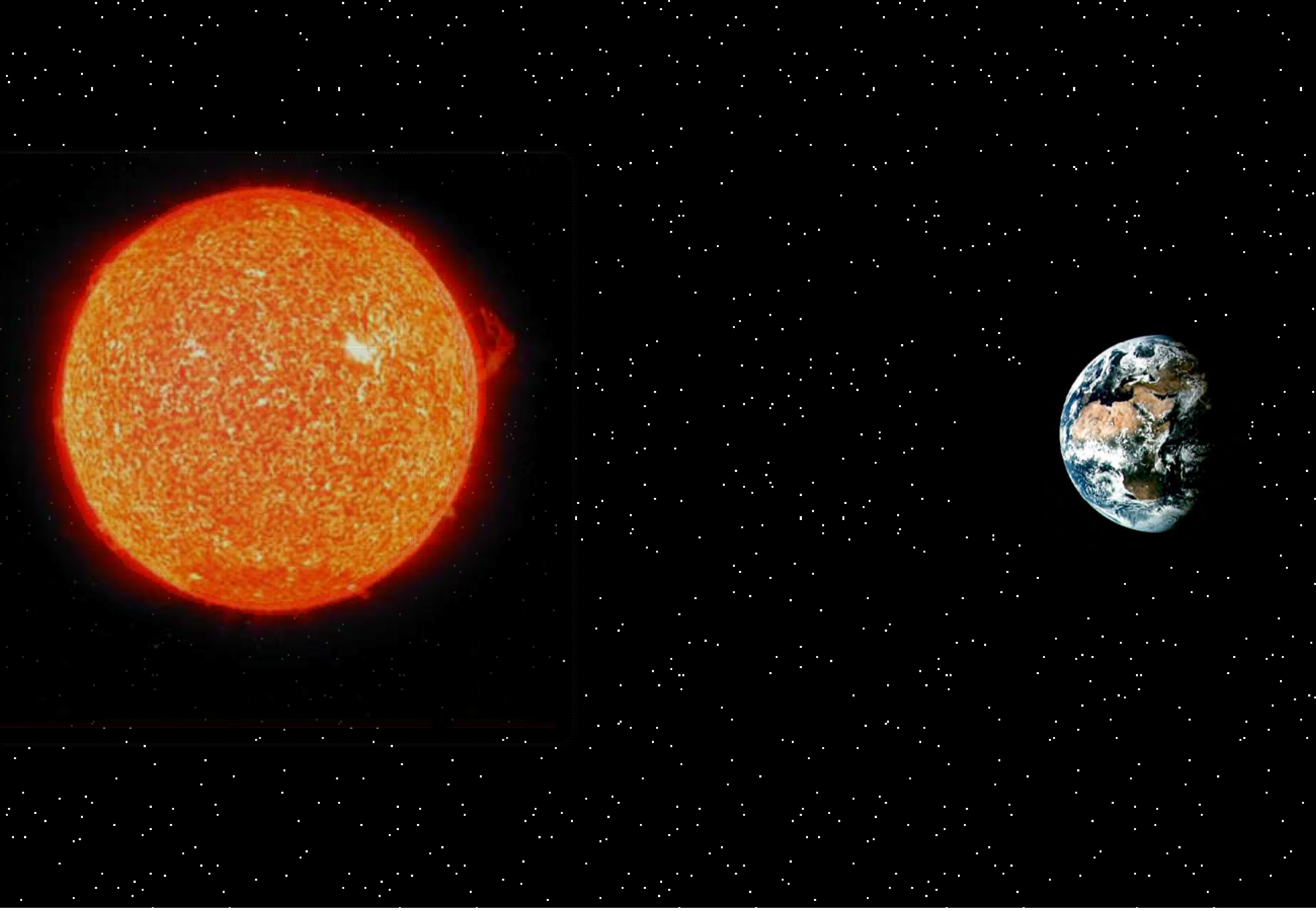
* ***Deuterio**/hydrogeno = 1/6700*

+ tritio de: neutron (de fusion) + litio □ tritio + helio

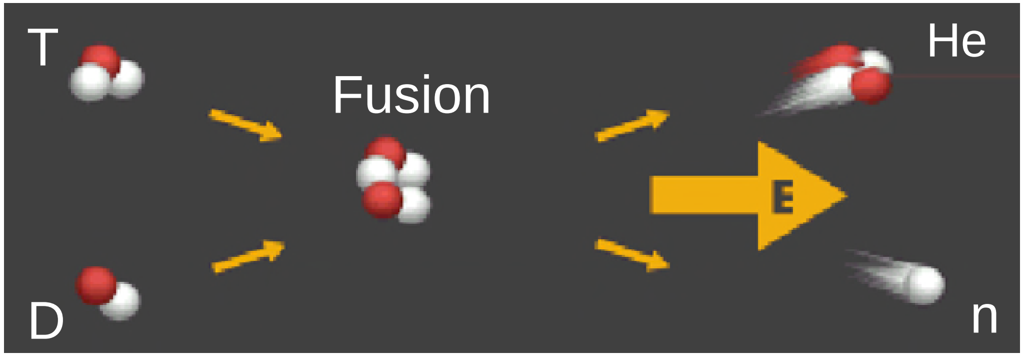
¿Ciencia o Ficción?

Ficción


PARAMOUNT PICTURES PRESENTS IN ASSOCIA
VAL KILMER ELISABETH SHUE
MUSIC COMPOSED BY GRAEME REVELL EDITED BY TERRY RAWLINGS
EXECUTIVE PRODUCERS PAUL HITCHCOCK AND ROBERT S. BAKER STORY BY JON
PRODUCED DAVID BROWN ROBERT EVANS WILLIAM
PRÓXIMAMENTE en 3D
Q11



La Fusión en nuestro Planeta“... *no es la misma que en el Sol*“



+ 20% de Energía (3.5 MeV)

+ 80% de Energía (14.1 MeV)

- **La reacción de fusión más sencilla de conseguir en condiciones terrestres:**

$^{2}D + {}^{3}T \Rightarrow {}^{4}He\ (3.5\ MeV) + {}^{1}n\ (14.1\ MeV)$

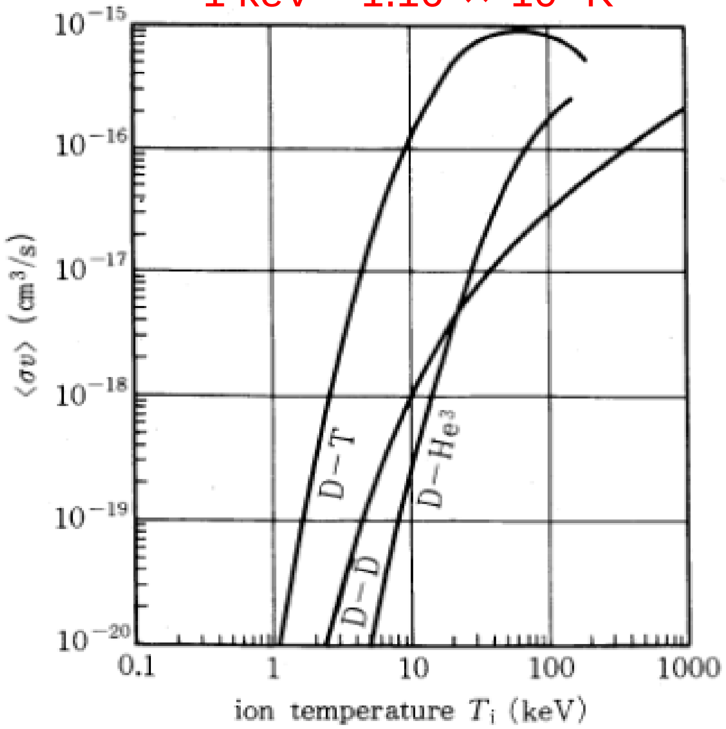
- **Otras dos reacciones importantes para la fusión DT son:**

$^{1}n + {}^{6}Li \Rightarrow {}^{4}He + {}^{3}T + 4.8\ MeV$

$^{1}n + {}^{7}Li \Rightarrow {}^{3}He + {}^{3}T + {}^{1}n - 2.5\ MeV$

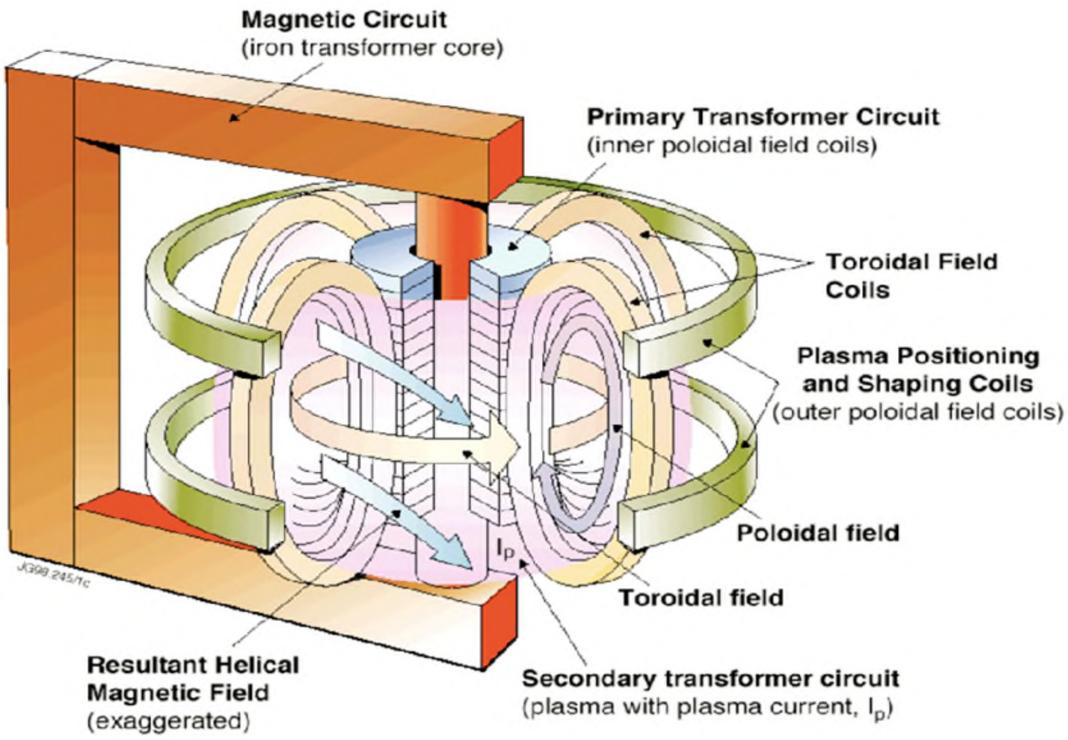
  - Estas reacciones permitirán a un reactor de fusión generar tritio

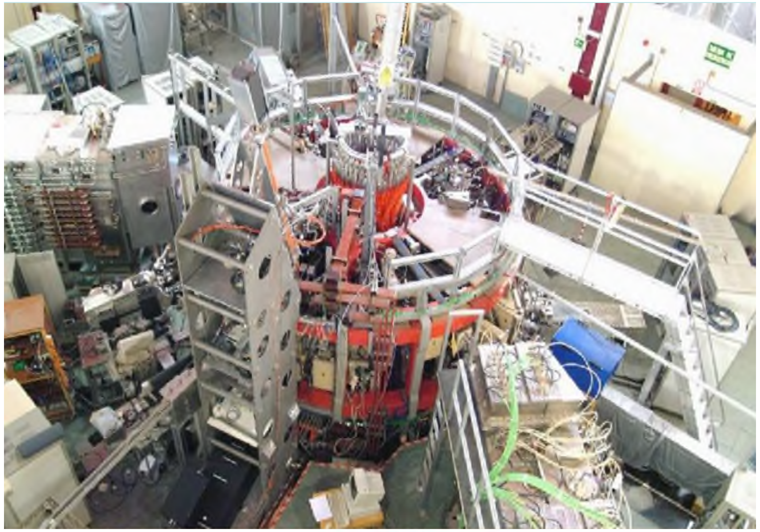
1 keV = 1.16 × 10^{7} K



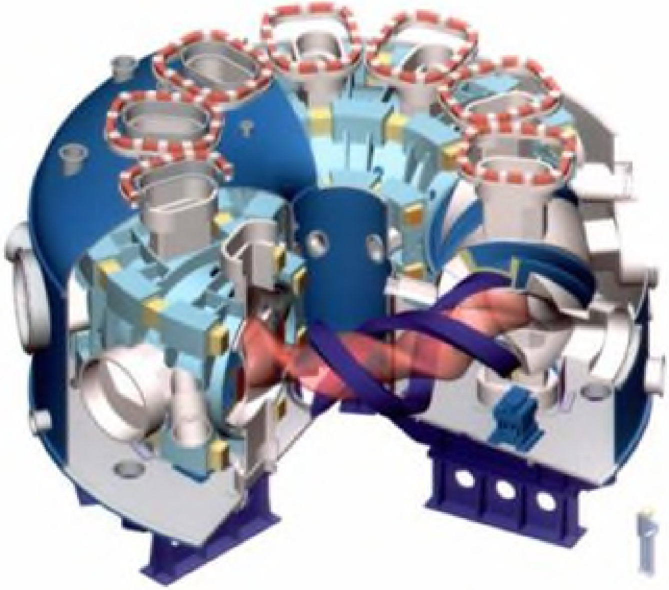
Las Botellas: Tokamak y Stellarator

"тороидальная камера в магнитных катушках" (*toroidal'naya kamera v magnitnykh katushkakh*) — toroidal chamber in magnetic coils (Tochamac)).

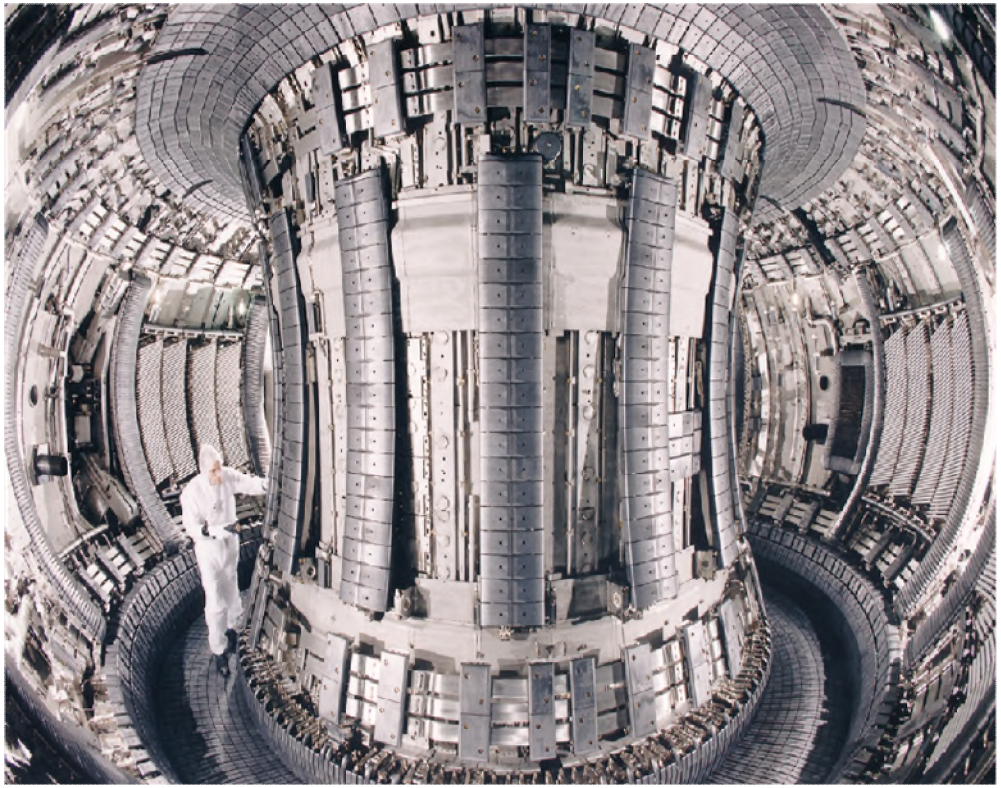




TJ-II
CIEMAT

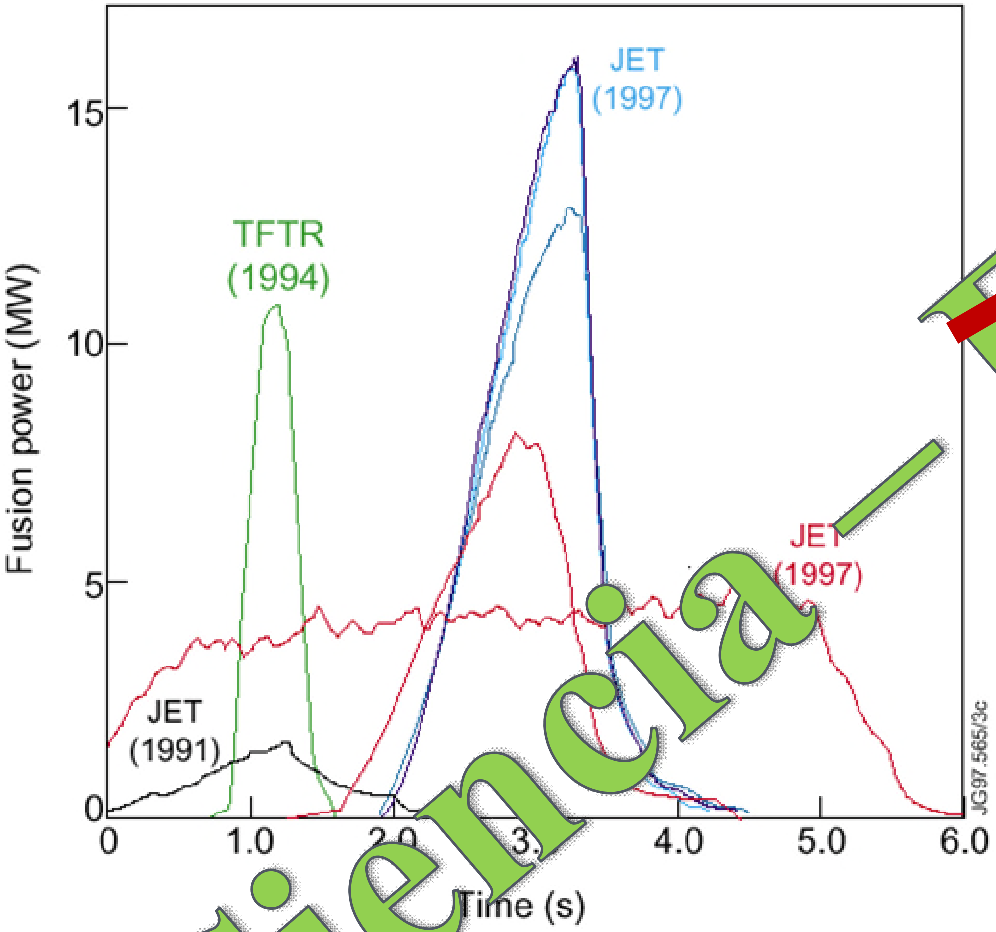


LHD
Japón



La “botella”de Fusión Nuclear mayor del mundo: JET

Records Obtenidos



Ciencia – ~~Ficción~~

Plasma fusion performance

Temperatura - T_i: *1-2 × 10^8 K (10-20 keV)*
(~10 × temperatura del centro del Sol)

Densidad - n_i: *1 × 10^{20} m^{-3}*
(~10^{-6} densidad atmosférica)

Tiempo confinamento energía- τ_E: unos segundos ($\propto$ corriente × radio^2)
(duración pulso plasma ~1000s)

Fusion power amplificación: $Q = \dfrac{\text{Fusion Power}}{\text{Input Power}} \sim n_i T_i \tau_E$

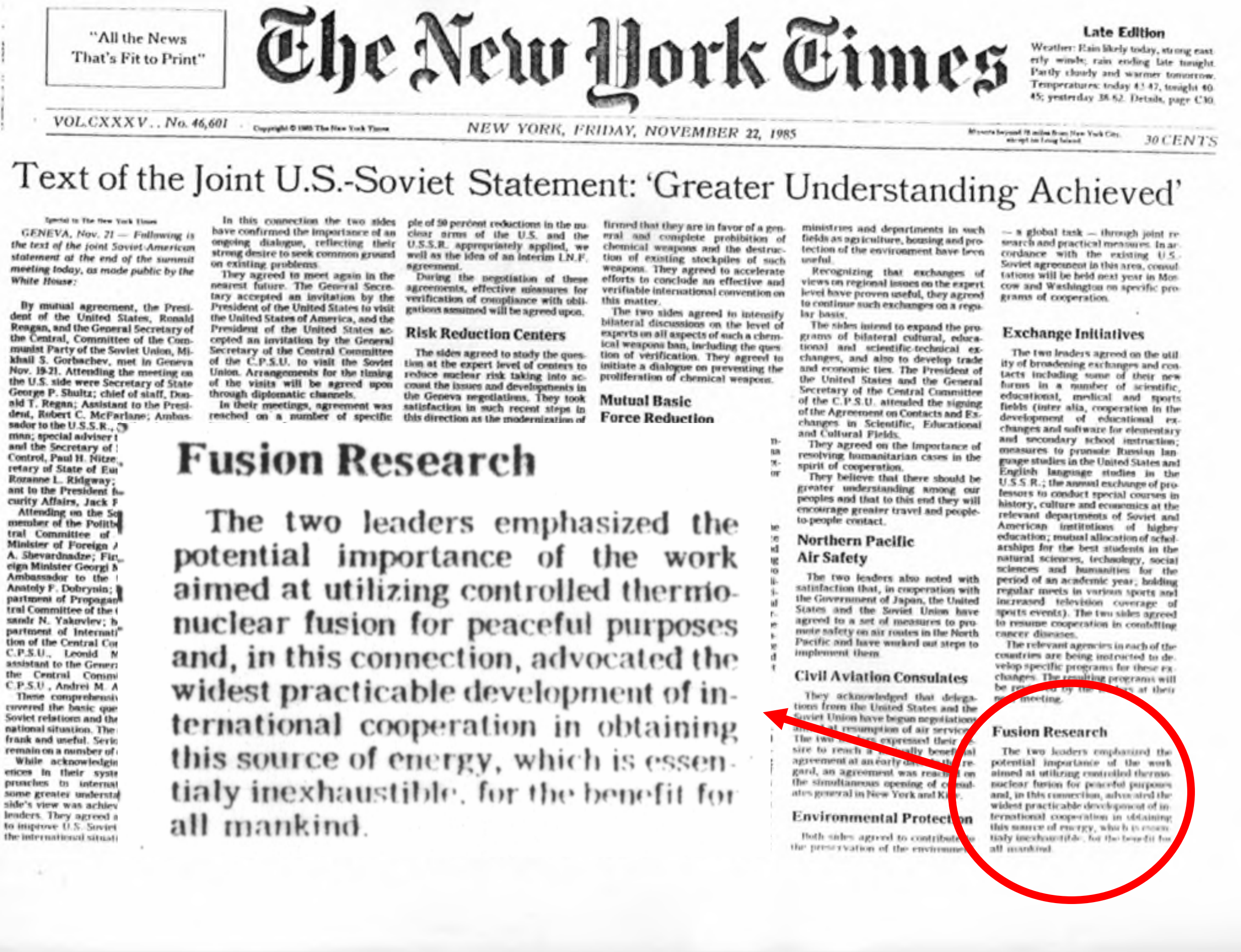
⇒ Dispositivos actuales : Q ≤ 1

 ⇒ ITER: Q ≥ 10

⇒ Ignición controlada': Q ≥ 30

The Way to Fusion Power – The ITER Story

The idea for ITER originated from the Geneva Superpower Summit on November 21,1985, when the Russian Premier Mikhail Gorbachev and the US-President Ronald Reagan proposed that an international Project be set up to develop fusion energy "as an essentially inexhaustible source of energy for the benefit of mankind".



"All the News
That's Fit to Print"

The New York Times

Late Edition

Weather: Rain likely today, strong easterly winds; rain ending late tonight. Partly cloudy and warmer tomorrow. Temperatures: today 43-47, tonight 40-45; yesterday 38-62. Details, page C30.

VOL. CXXXV . . No. 46,601 — NEW YORK, FRIDAY, NOVEMBER 22, 1985 — 30 CENTS

Text of the Joint U.S.-Soviet Statement: 'Greater Understanding Achieved'

Special to The New York Times

GENEVA, Nov. 21 — Following is the text of the joint Soviet-American statement at the end of the summit meeting today, as made public by the White House:

By mutual agreement, the President of the United States, Ronald Reagan, and the General Secretary of the Central Committee of the Communist Party of the Soviet Union, Mikhail S. Gorbachev, met in Geneva Nov. 19-21. Attending the meeting on the U.S. side were Secretary of State George P. Shultz; chief of staff, Donald T. Regan; Assistant to the President, Robert C. McFarlane; Ambassador to the U.S.S.R.,
mnn; special adviser t
and the Secretary of
Control, Paul H. Nitze;
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Rozanne L. Ridgway;
ant to the President f
curity Affairs, Jack F
Attending on the So
member of the Politb
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Minister of Foreign A
A. Shevardnadze; Fir
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Ambassador to the
Anatoly F. Dobrynin;
partment of Propagan
tral Committee of the
sandr N. Yakovlev;
partment of Internati
tion of the Central Co
C.P.S.U., Leonid
assistant to the Gener
the Central Commi
C.P.S.U., Andrei M. A
These comprehensi
covered the basic que
Soviet relations and the
national situation. The
frank and useful. Seri
remain on a number of
While acknowledgin
ences in their syst
proaches to internat
some greater understa
side's view was achiev
leaders. They agreed
to improve U.S.-Soviet
the international situat

In this connection the two sides have confirmed the importance of an ongoing dialogue, reflecting their strong desire to seek common ground on existing problems.

They agreed to meet again in the nearest future. The General Secretary accepted an invitation by the President of the United States to visit the United States of America, and the President of the United States accepted an invitation by the General Secretary of the Central Committee of the C.P.S.U. to visit the Soviet Union. Arrangements for the timing of the visits will be agreed upon through diplomatic channels.

In their meetings, agreement was reached on a number of specific

ple of 50 percent reductions in the nuclear arms of the U.S. and the U.S.S.R. appropriately applied, as well as the idea of an interim I.N.F. agreement.

During the negotiation of these agreements, effective measures for verification of compliance with obligations assumed will be agreed upon.

Risk Reduction Centers

The sides agreed to study the question at the expert level of centers to reduce nuclear risk taking into account the issues and developments in the Geneva negotiations. They took satisfaction in such recent steps in this direction as the modernization of

firmed that they are in favor of a general and complete prohibition of chemical weapons and the destruction of existing stockpiles of such weapons. They agreed to accelerate efforts to conclude an effective and verifiable international convention on this matter.

The two sides agreed to intensify bilateral discussions on the level of experts on all aspects of such a chemical weapons ban, including the question of verification. They agreed to initiate a dialogue on preventing the proliferation of chemical weapons.

Mutual Basic Force Reduction

ministries and departments in such fields as agriculture, housing and protection of the environment have been useful.

Recognizing that exchanges of views on regional issues on the expert level have proven useful, they agreed to continue such exchanges on a regular basis.

The sides intend to expand the programs of bilateral cultural, educational and scientific-technical exchanges, and also to develop trade and economic ties. The President of the United States and the General Secretary of the Central Committee of the C.P.S.U. attended the signing of the Agreement on Contacts and Exchanges in Scientific, Educational and Cultural Fields.

They agreed on the importance of resolving humanitarian cases in the spirit of cooperation.

They believe that there should be greater understanding among our peoples and that to this end they will encourage greater travel and people-to-people contact.

Northern Pacific Air Safety

The two leaders also noted with satisfaction that, in cooperation with the Government of Japan, the United States and the Soviet Union have agreed to a set of measures to promote safety on air routes in the North Pacific and have worked out steps to implement them.

Civil Aviation Consulates

They acknowledged that delegations from the United States and the Soviet Union have begun negotiations [illegible] resumption of air services. The two [illegible] expressed their desire to reach a [illegible] beneficial agreement at an early [illegible] regard, an agreement was reached on the simultaneous opening of consulates general in New York and Ki[illegible]v.

Environmental Protection

Both sides agreed to contribute to the preservation of the environment

— a global task — through joint research and practical measures. In accordance with the existing U.S.-Soviet agreement in this area, consultations will be held next year in Moscow and Washington on specific programs of cooperation.

Exchange Initiatives

The two leaders agreed on the utility of broadening exchanges and contacts including some of their new forms in a number of scientific, educational, medical and sports fields (inter alia, cooperation in the development of educational exchanges and software for elementary and secondary school instruction; measures to promote Russian language studies in the United States and English language studies in the U.S.S.R.; the annual exchange of professors to conduct special courses in history, culture and economics at the relevant departments of Soviet and American institutions of higher education; mutual allocation of scholarships for the best students in the natural sciences, technology, social sciences and humanities for the period of an academic year; holding regular meets in various sports and increased television coverage of sports events). The two sides agreed to resume cooperation in combatting cancer diseases.

The relevant agencies in each of the countries are being instructed to develop specific programs for these exchanges. The resulting programs will be [illegible] by the [illegible] at their [illegible] meeting.

Fusion Research

The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentialy inexhaustible, for the benefit for all mankind.

Fusion Research

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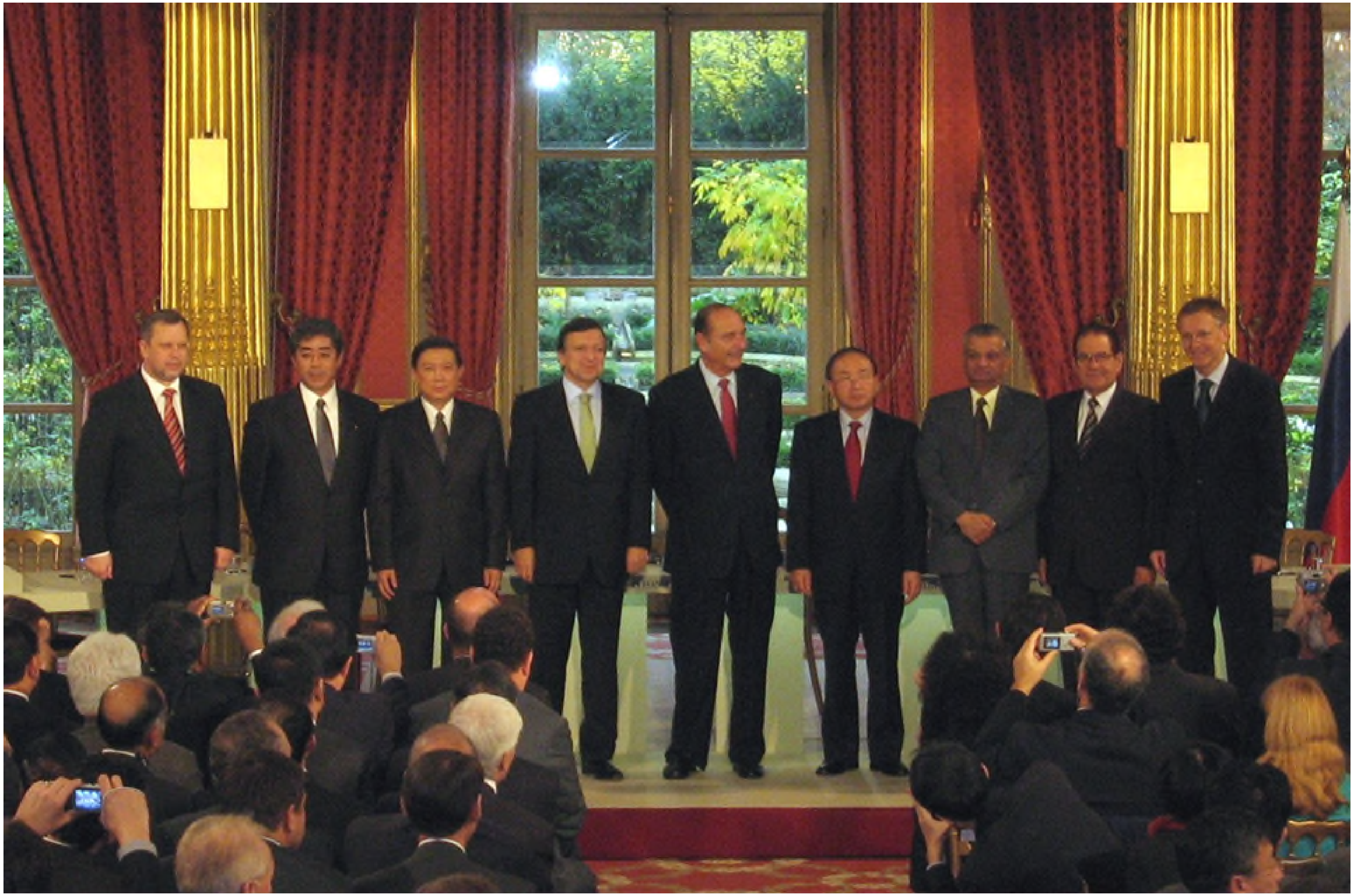
Collaboration is our greatest asset



Ceremony ITER Agreement Signature, Elysee Palace, 21 November 2006

ITER

The ITER tokamak* is an experimental nuclear fusion reactor

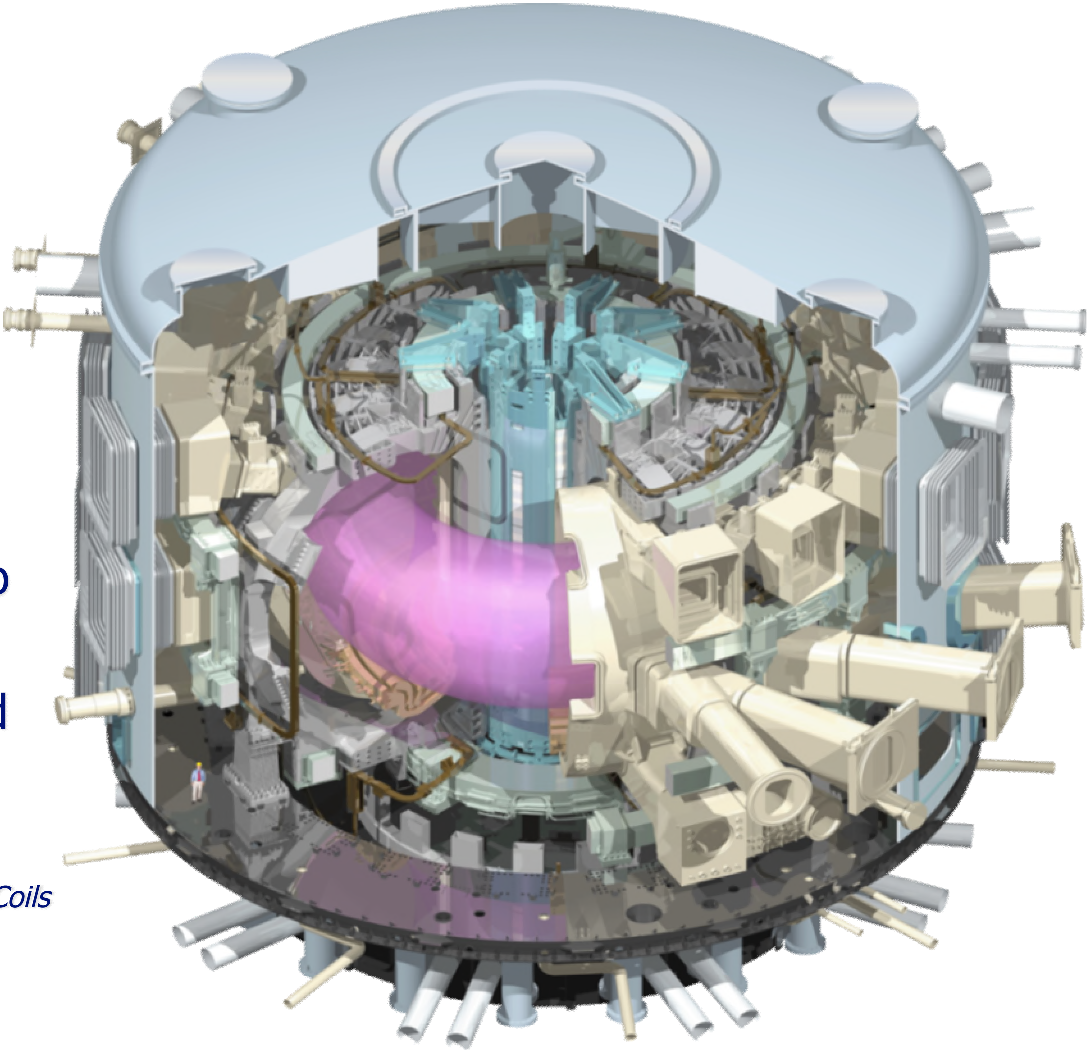
ITER plasma will generate 10 times more energy than it receives.

Input 50 MW – Output 500 MW

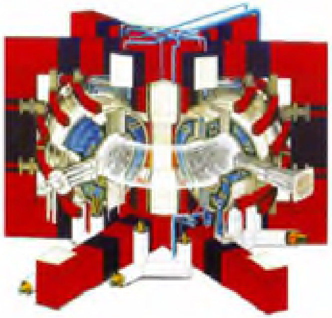
It is a necessary step on the way to commercial nuclear fusion energy.

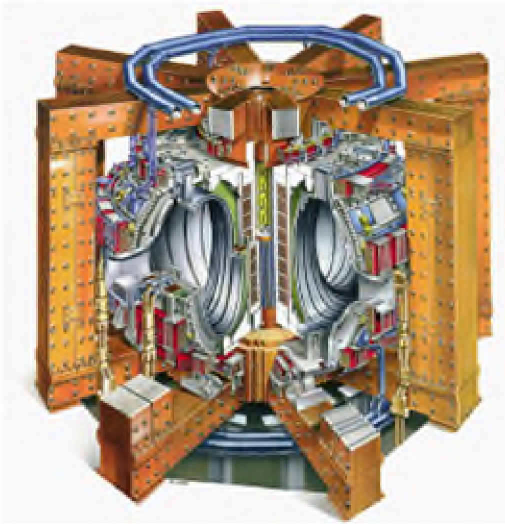
Will demonstrate the availability and integration of technologies essential for a nuclear fusion reactor

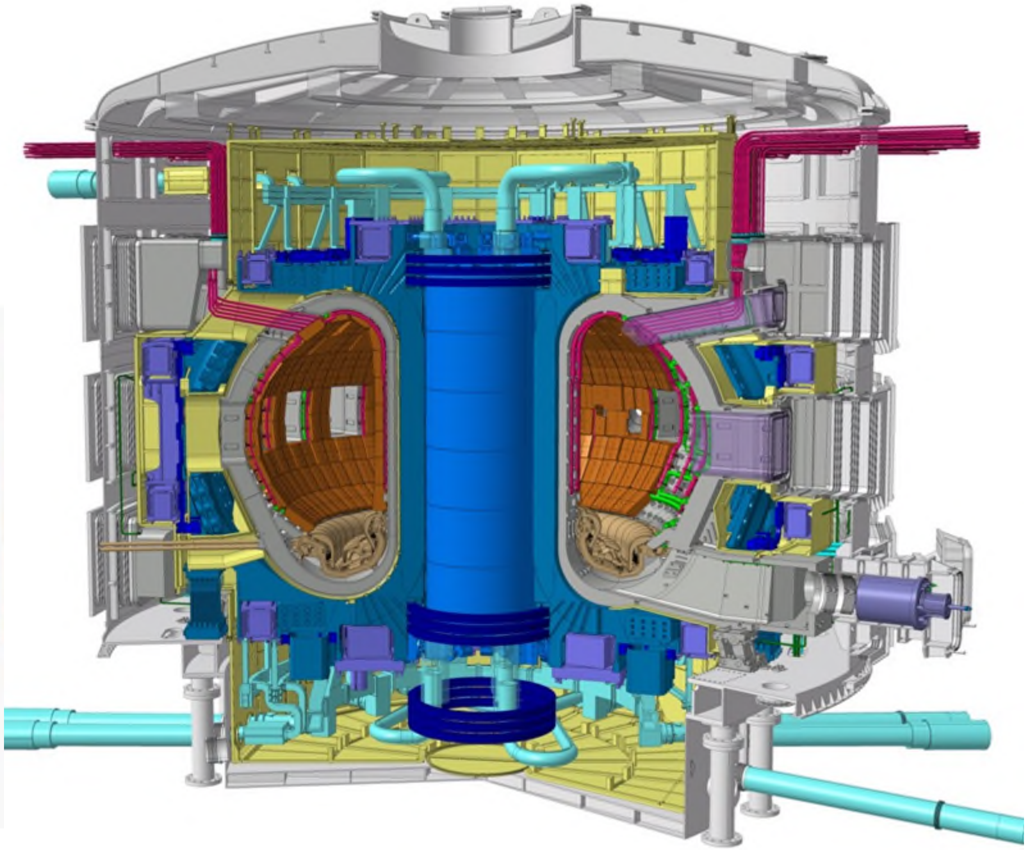
** Toroidal Chamber, Magnetic Coils*



El tamaño de ITER es el doble del mayor experimento existente

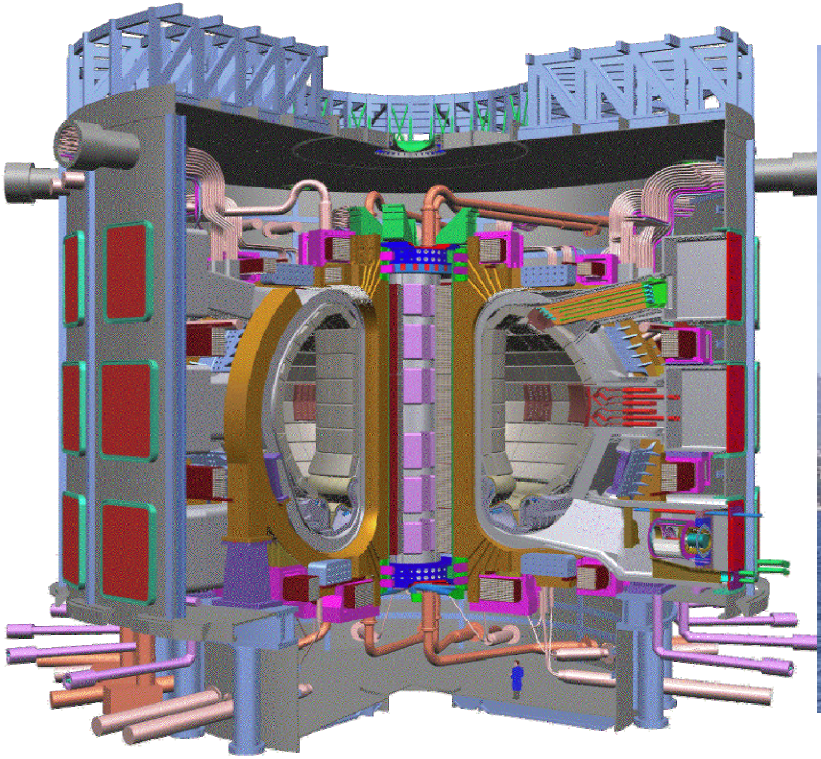






	Tore Supra	JET	ITER
V_{plasma}	25 m^3	80 m^3	830 m^3
P_{fusion}	~0	~16 MW, 2 s	~500 MW, ~400 s
T_{plasma}	~400 s	~30 s	~700 s

ITER Tokamak – Mass Comparison



Charles de Gaulle mass:

~38000 t (empty)

856 ft (261 m) long

(Commissioned 2001)

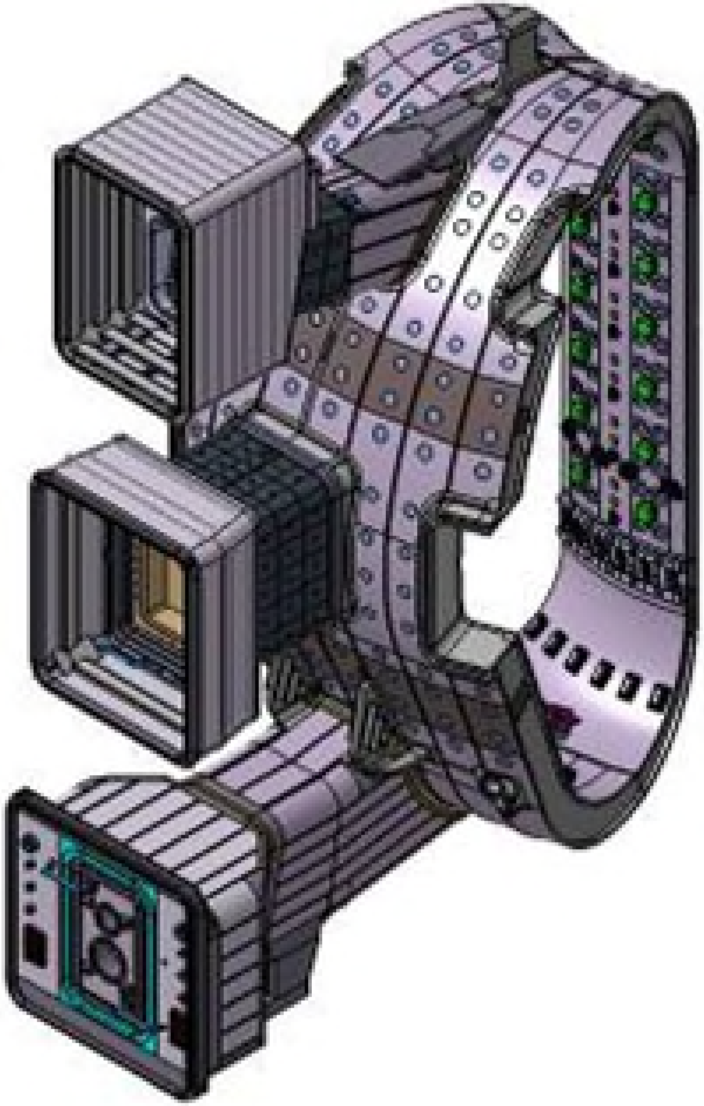
ITER Machine mass:

~23000 t

28 m diameter x 29 m tall

EU, KO, IN & RF

Vacuum Vessel



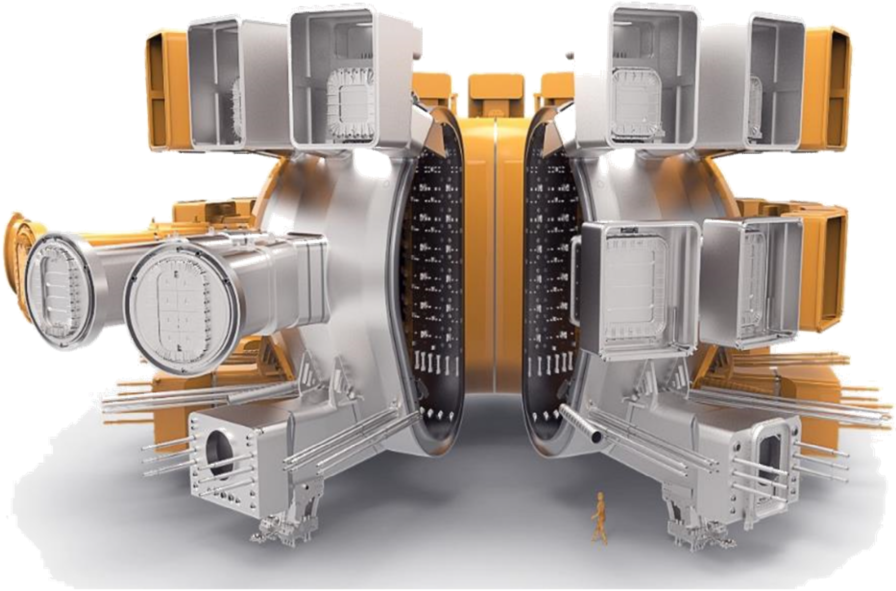
Facts

- SS 316 L(N)-IG
- ~5300 tons (VV, ports, shielding only)
- 19.4 m (63 ft) torus outer diameter
- 11.3 m (37 ft) torus height

Status

- VV sector and port Procurement Arrangements signed (EU, KO, IN, & RF)
- KO - VV & port contract awarded to Hyundai Heavy Industries
- EU - VV contract awarded

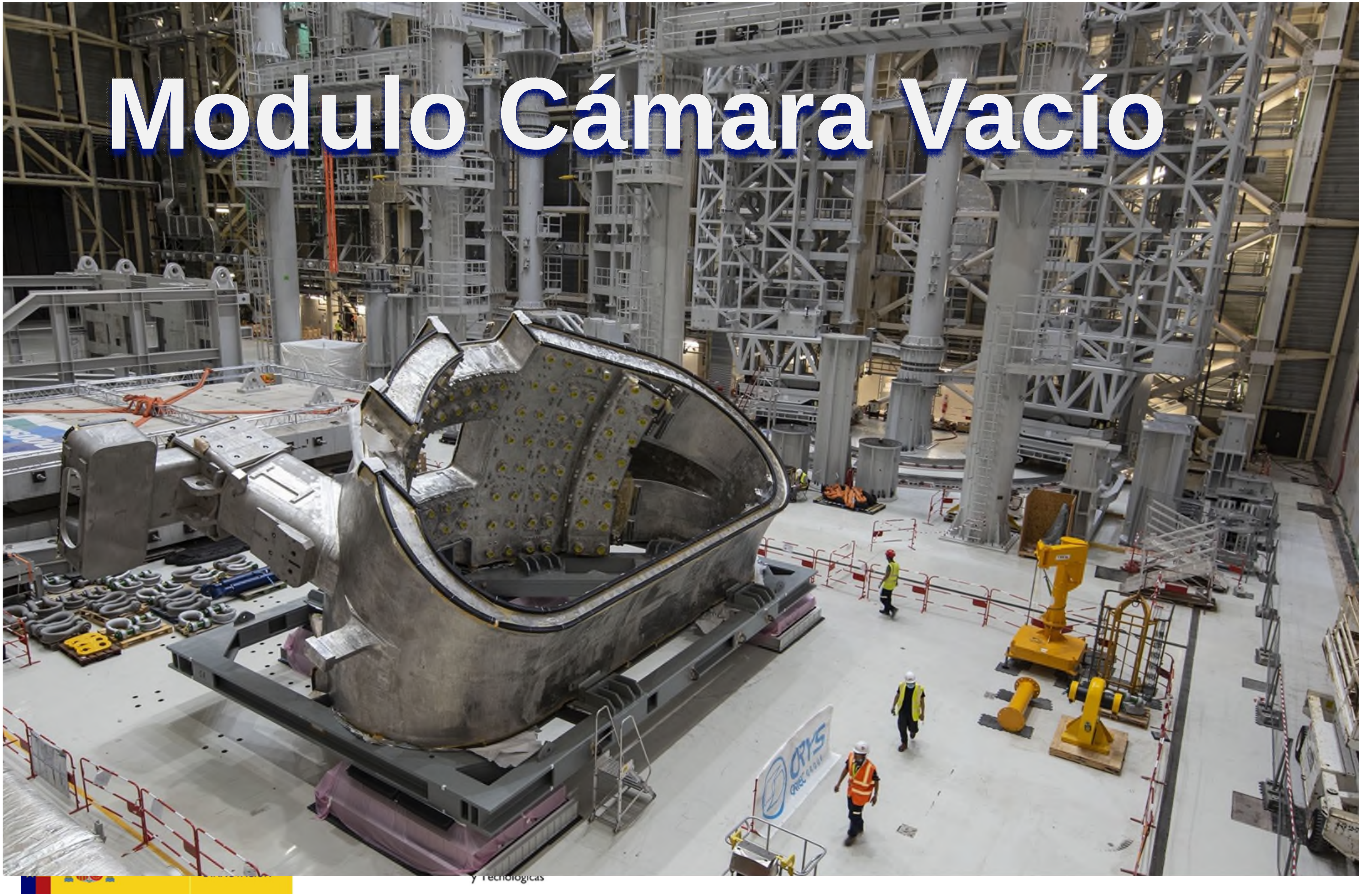
Vacuum Vessel Mass Comparison

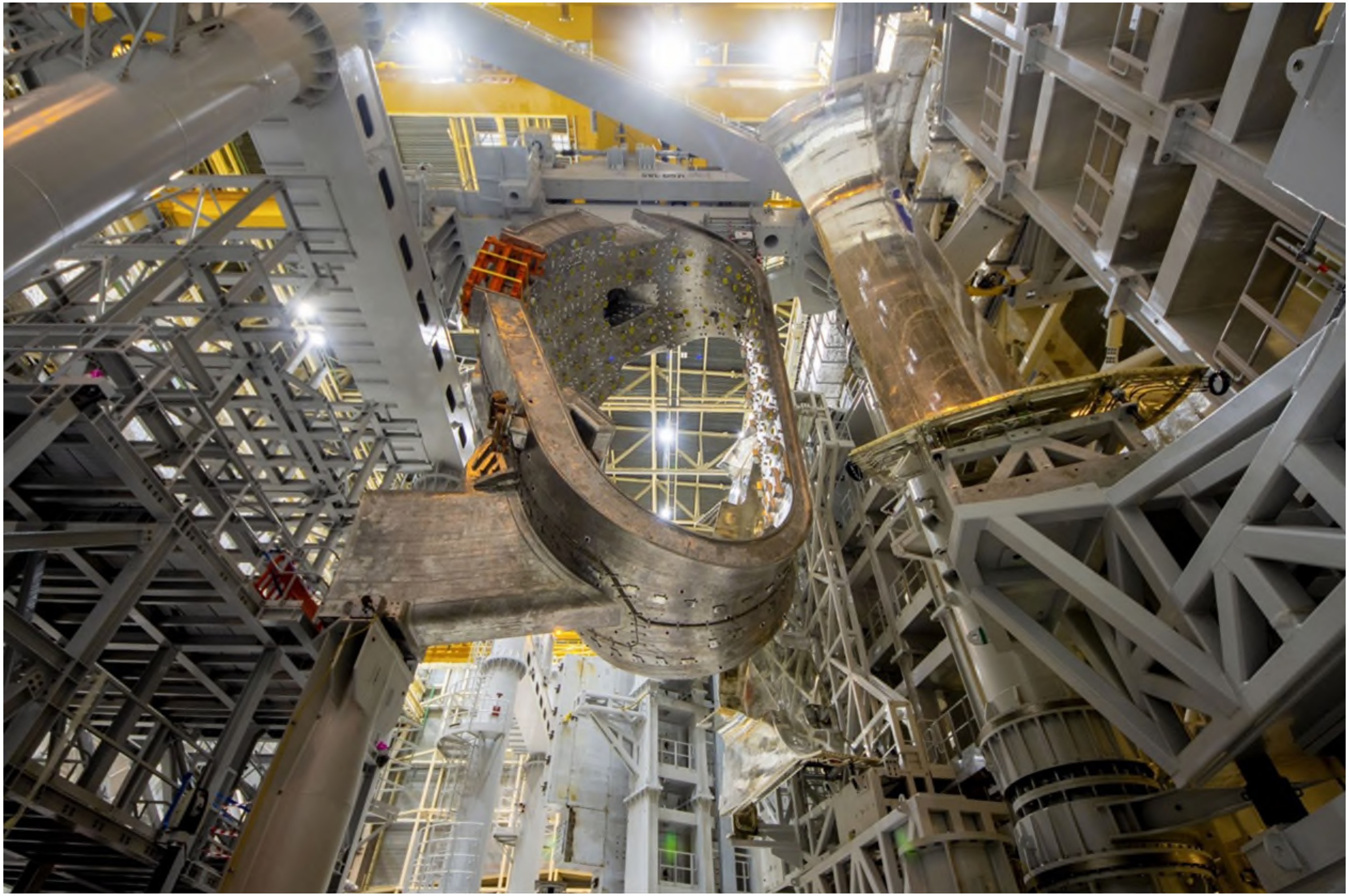


VV & In-vessel components mass:
~8000 t
19.4 m outside diameter x 11.3 m tall

Eiffel Tower mass: ~7300 t
324 m tall
(Completed 1889)

Modulo Cámara Vacío





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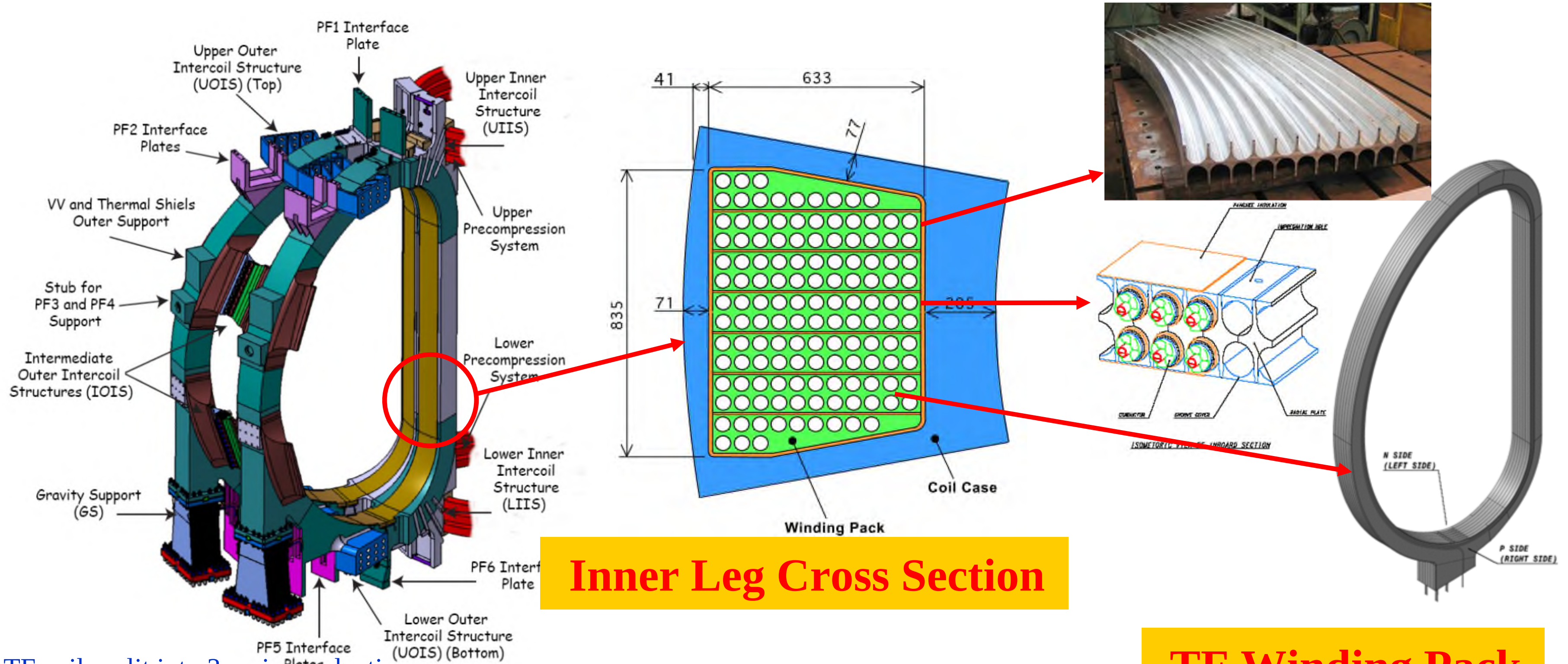
EU

TF Coils

JAPAN



Inner Leg Cross Section

TF Winding Pack

TF coils split into 3 main production areas

- TF conductors

  400t of Nb3Sn superconductor, assembled into 90km of high current 70kA conductor cooled by supercritical He, Shared by Europe, Russia, Japan, Korea, China and USA

- TF structures

  4500t of high precision stainless steel forgings and plates, assembled by welding in Japan

- TF windings and coils

  19 coils, 12T peak field, 20kV maximum voltage shared between Europe and Japan.

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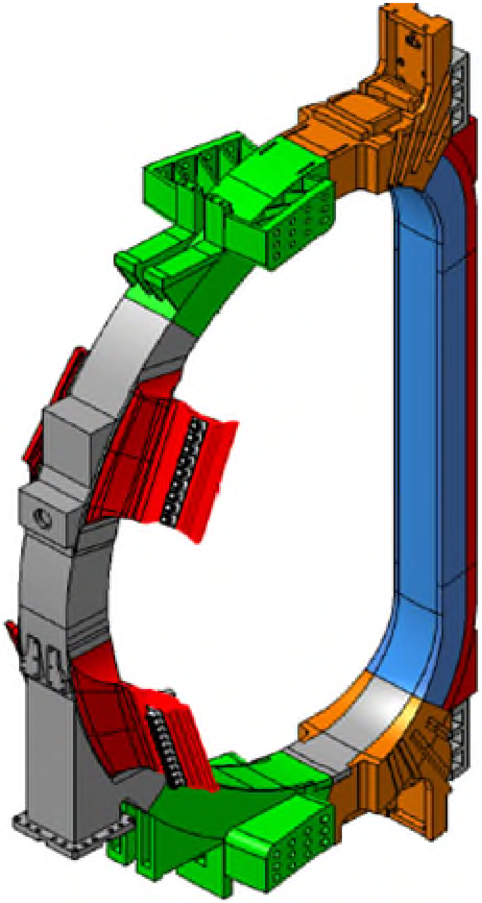
TF Coil – Mass Comparison



Mass of (1) TF Coil:

~360 t

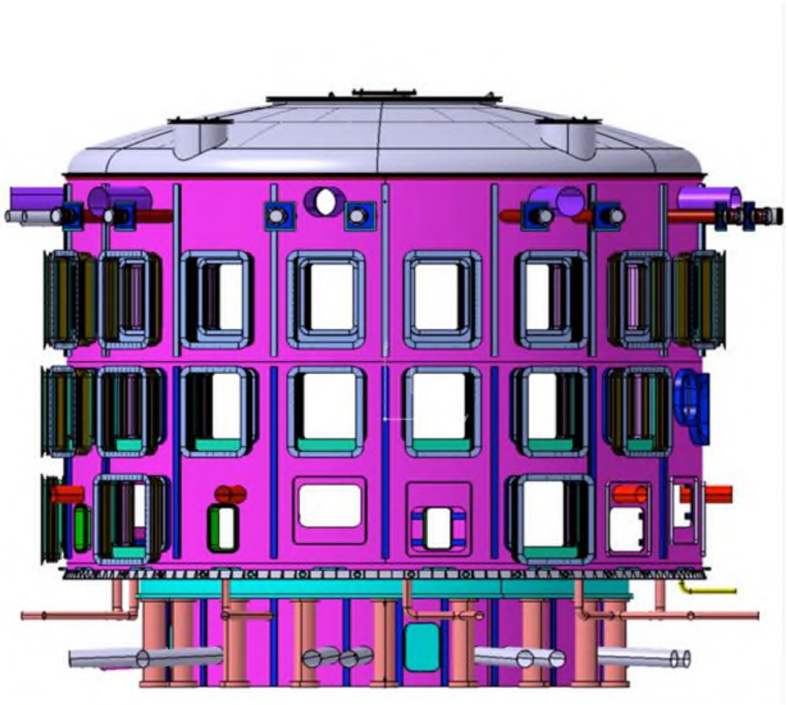
16 m Tall x 9 m Wide

D8 Caterpillar Bulldozer

~35 t


FUSION FOR ENERGY
BRINGING THE POWER OF THE SUN TO EARTH
iter
china eu india japan korea russia usa
ELYTT ENERGY
ASG SUPERCONDUCTORS
ENIM
dalkia GROUPE EDF
VEOLIA
FUSION FOR ENERGY
ELYTT ENERGY
ALSYOM
SEIV
Criotec IMPIANTI
sea alp engineering
CMU 32t
OUT

Cryostat Size Comparison



ITER Cryostat
~28 m Tall x
29 m Wide

Jefferson Memorial (Washington DC)
~29 m Tall (floor to top of dome)

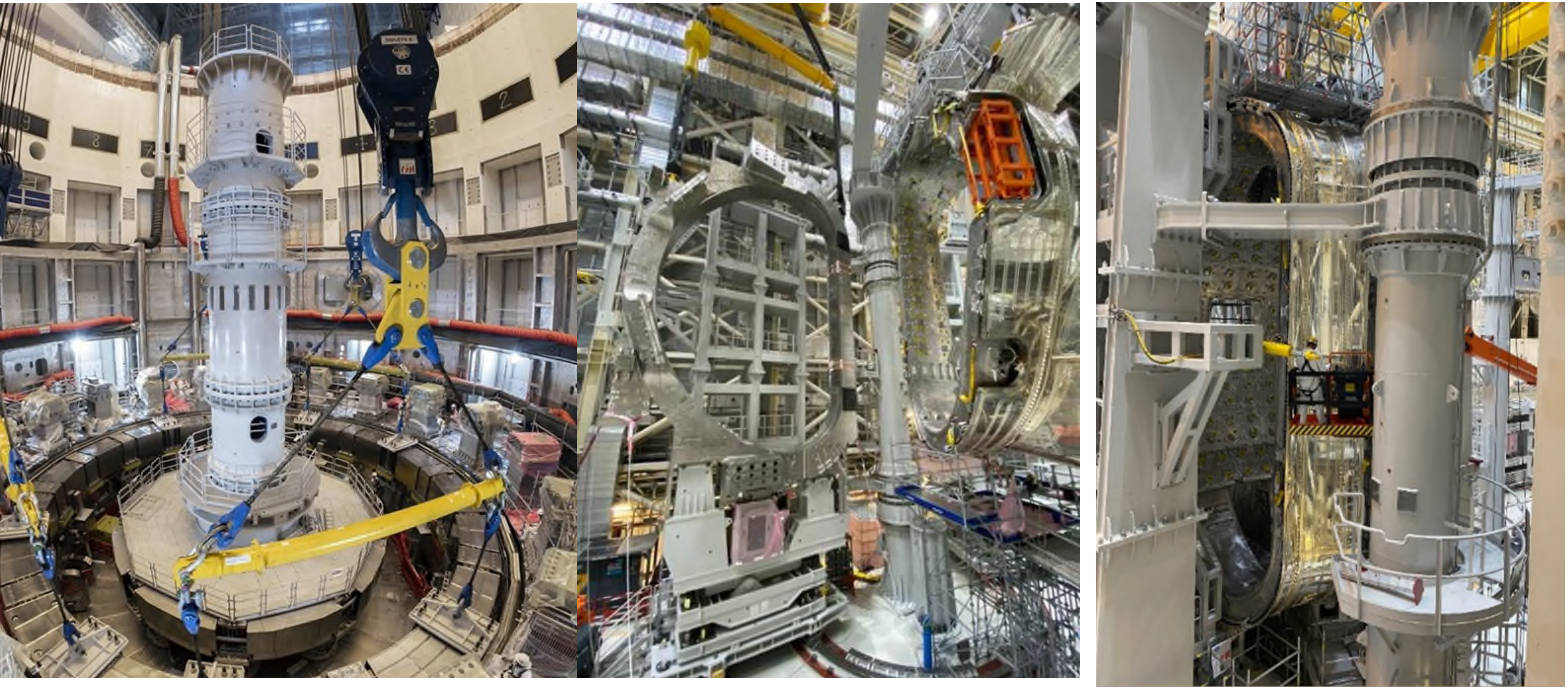
Parte superior Criostato

ITER site

Tokamak Complex

Resting on 493 seismic pads, the 440 000-ton Tokamak Complex comprises 7 levels (2 underground).

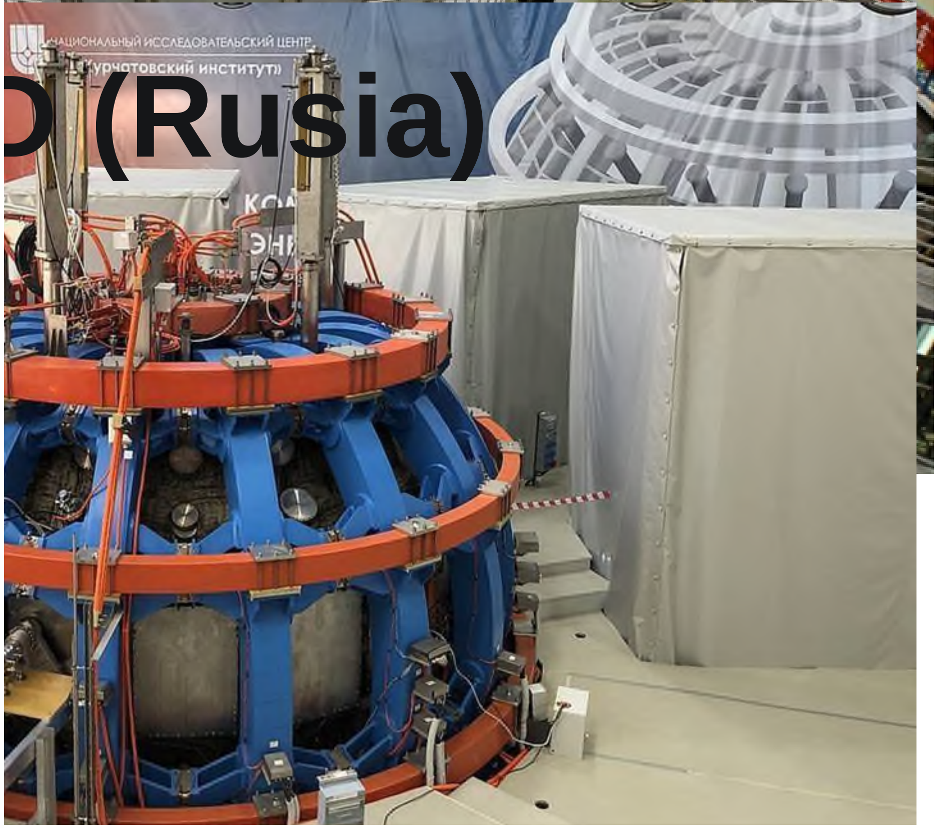
Impressive Progress with ITER Assembly



Nuevos Experimentos en marcha

JT60SA (Japón)

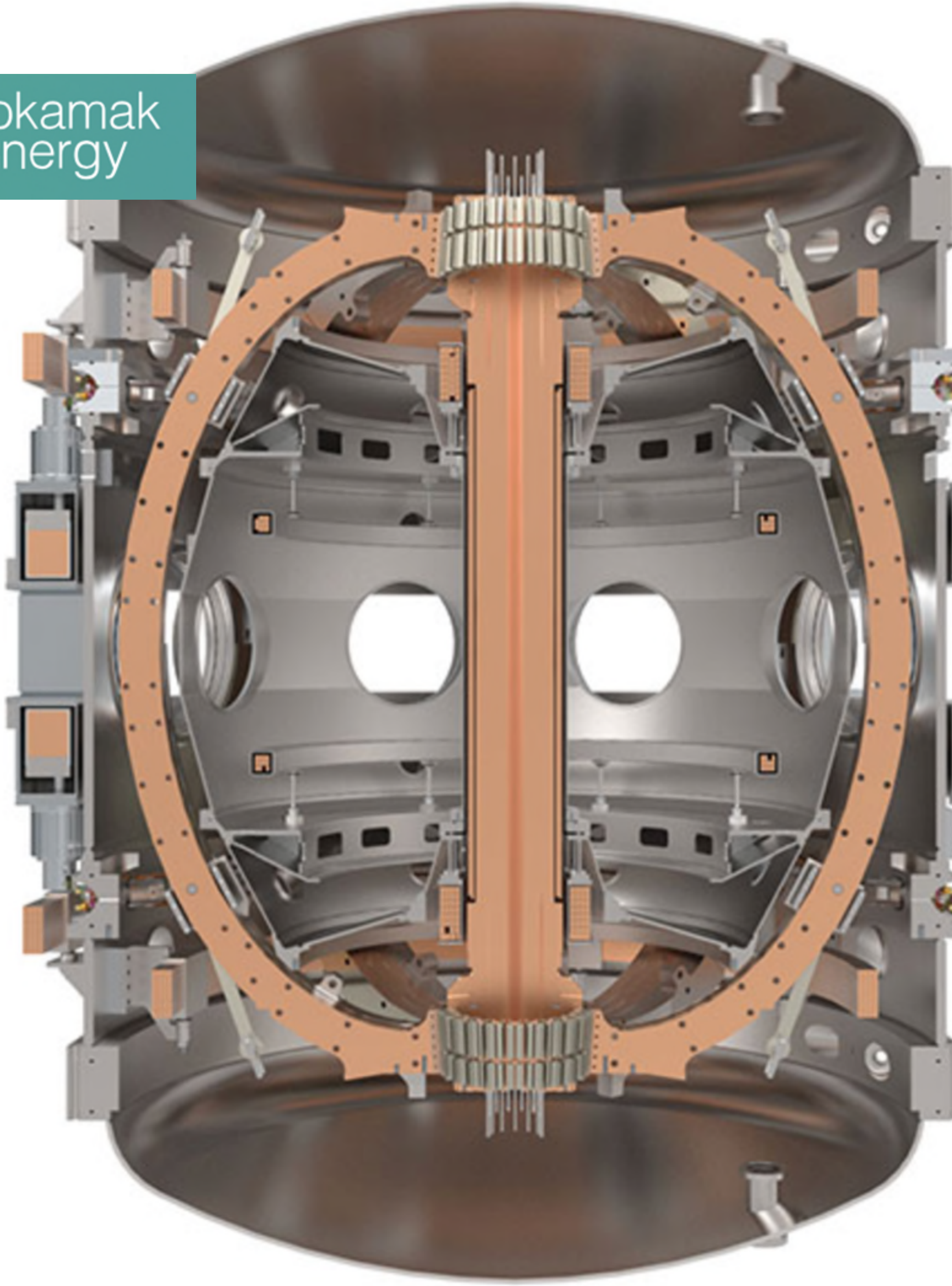
EAST (China)



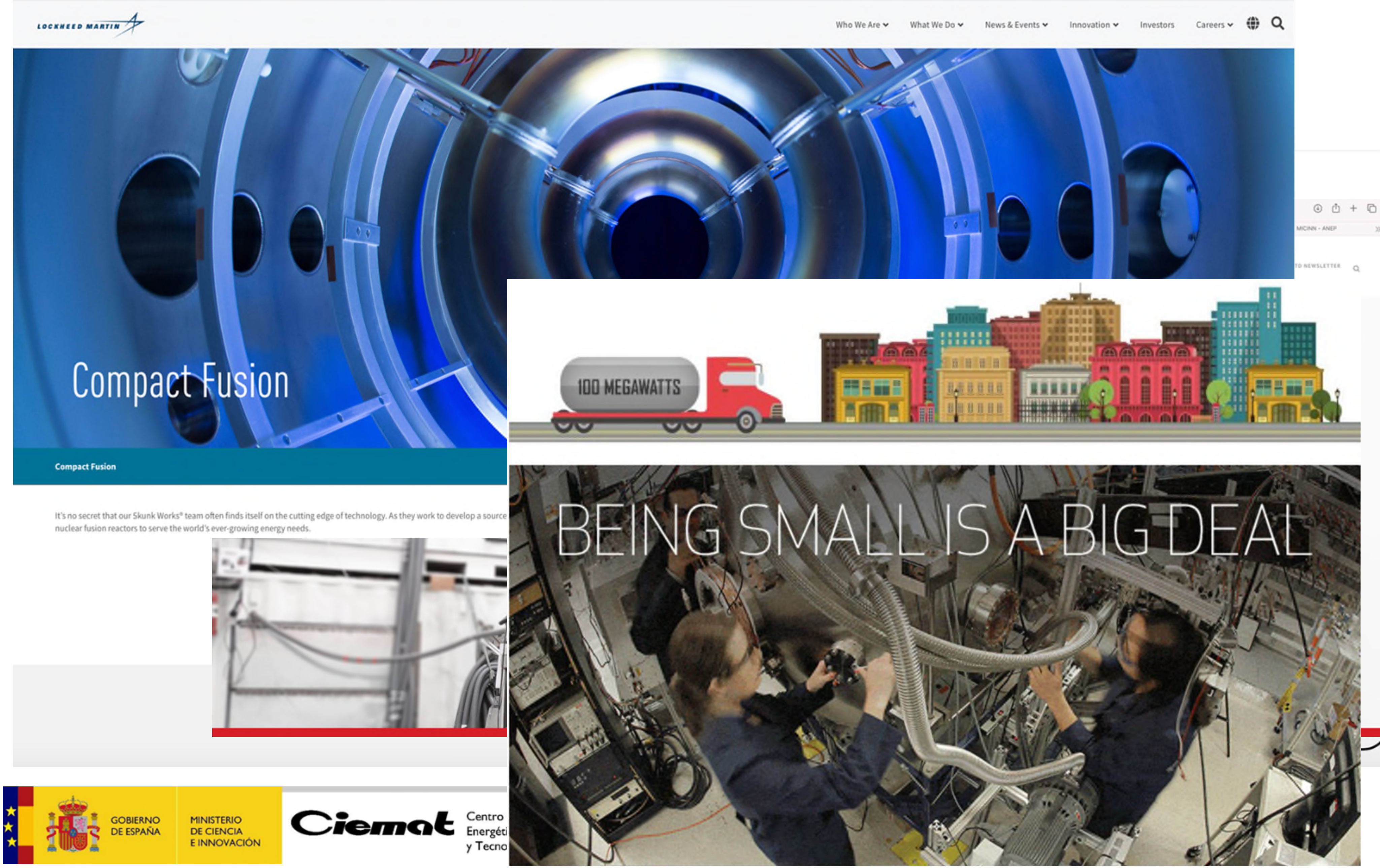
D (Rusia)

Nuevas iniciativas privadas

tokamak energy



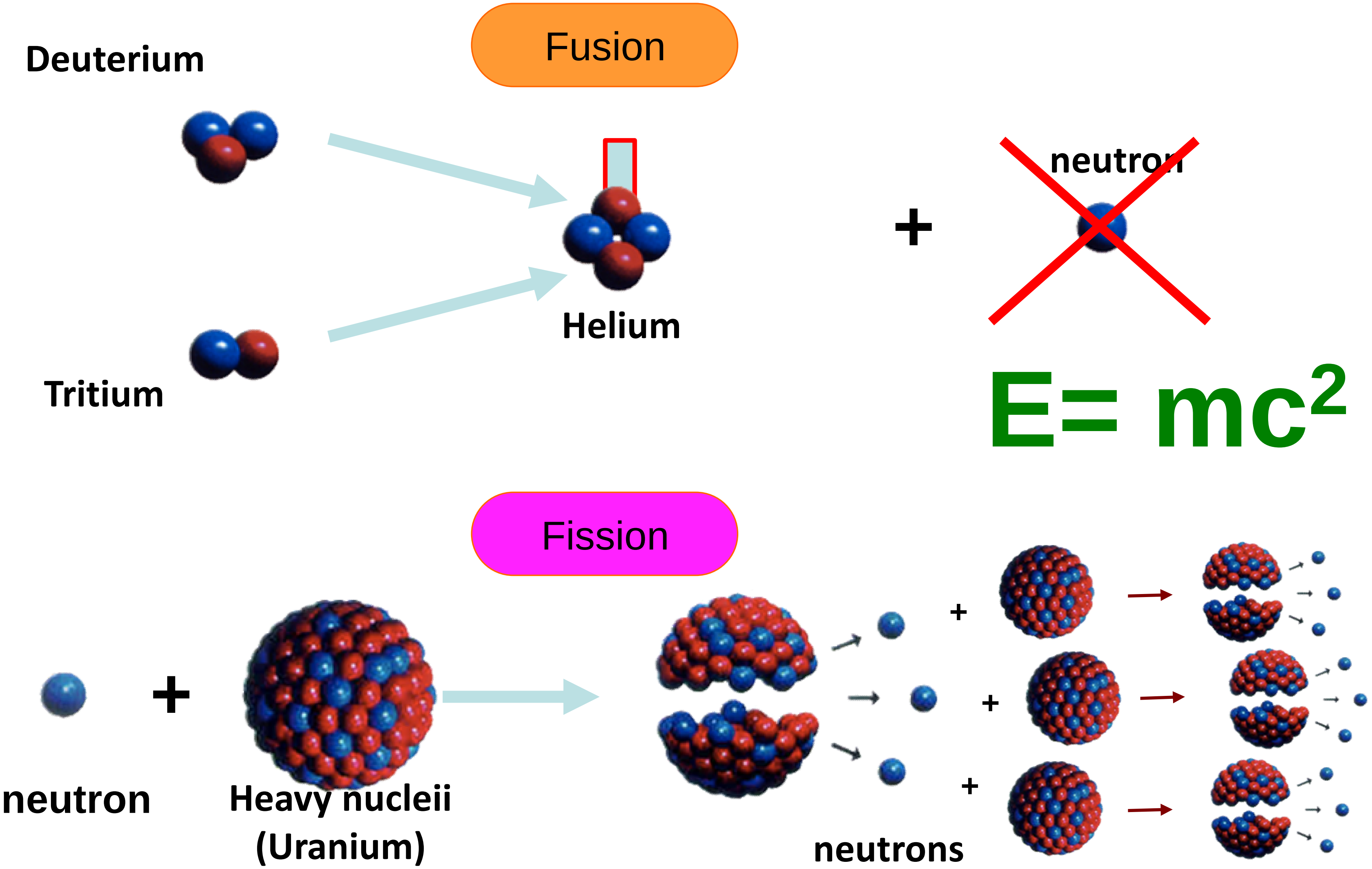
Nuevas iniciativas privadas



It's no secret that our Skunk Works® team often finds itself on the cutting edge of technology. As they work to develop a source
nuclear fusion reactors to serve the world's ever-growing energy needs.

Nuclear Fusion
Nuclear Safety
Issues

Physics



Fusion

Deuterium

Tritium

Helium

\+ ~~**neutron**~~

$$E = mc^2$$

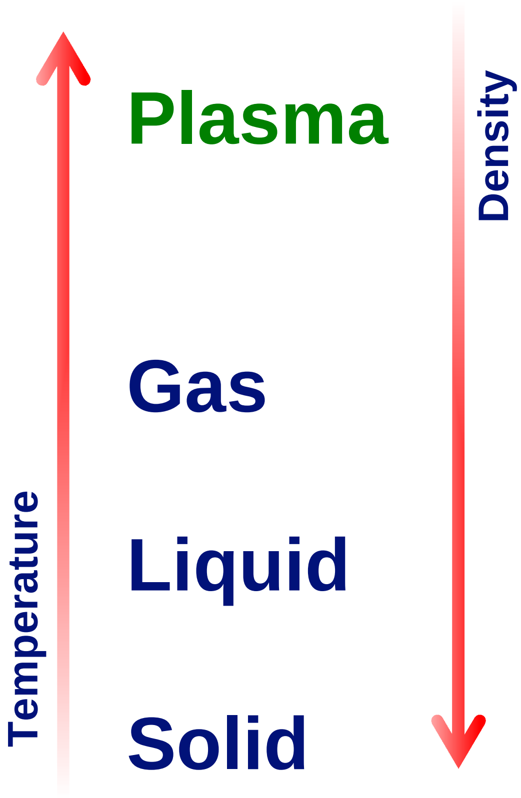
Fission

neutron + **Heavy nucleii (Uranium)**

neutrons

Plasma physics

Maxwell’s equations
Electromagnetic Physics



Plasma

Gas

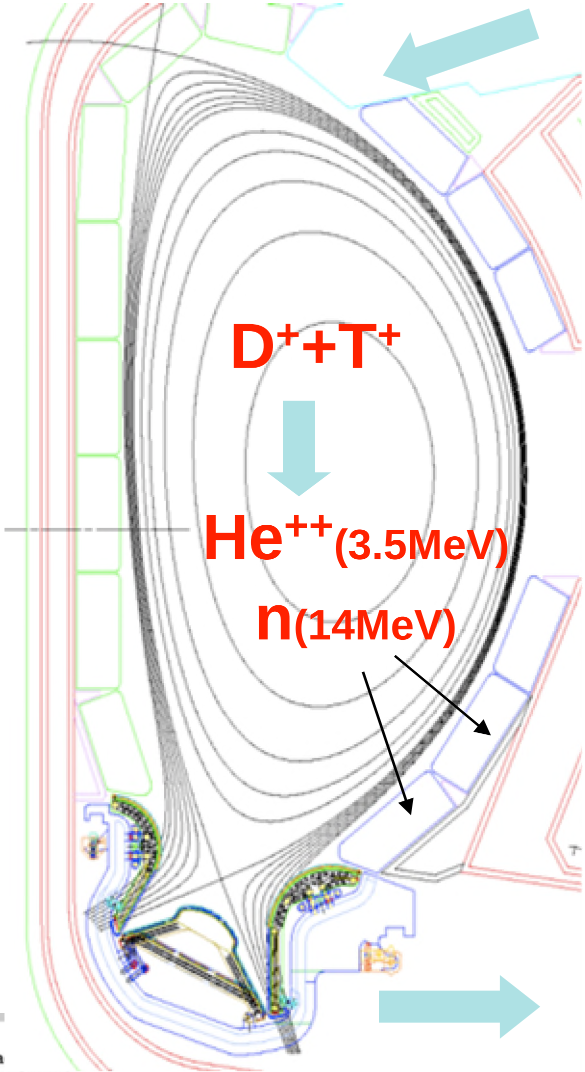
Liquid

Solid

Fusion in ITER Plasma

Donut Shape Plasma

V:	830m^3
R/a:	6.2m/2m
Vertical elongation:	1.85
Triangularity:	0.45
Density:	10^{20}m^{-3}
PeakTemperature:	17keV
Fusion Power:	500MW
Plasma Current :	15MA
Toroidal field:	5.3T



D_2,T_2 Fuel

$D^+ + T^+$

He^{++}(3.5MeV)

n(14MeV)

Blanket: neutron absorber

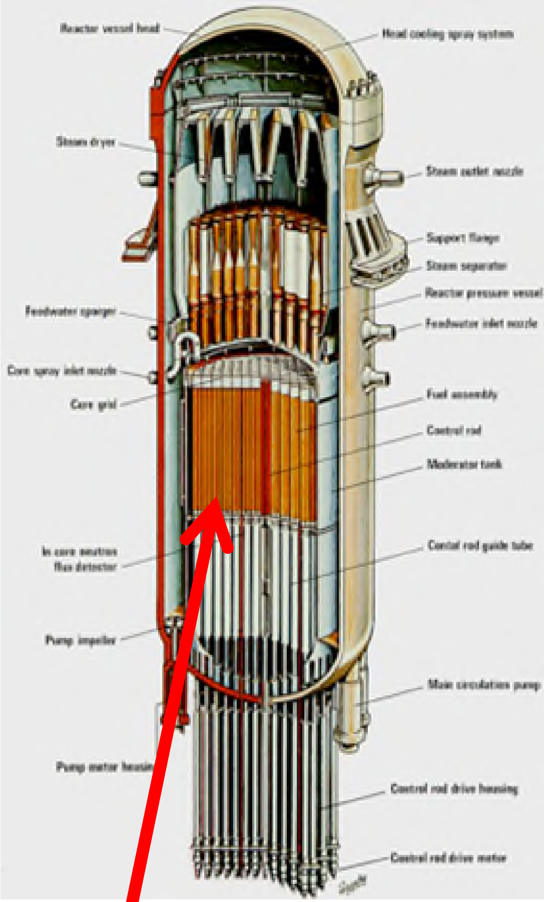
Power Plant
Li-->T
High temperature

Divertor: particle and heat exhaust

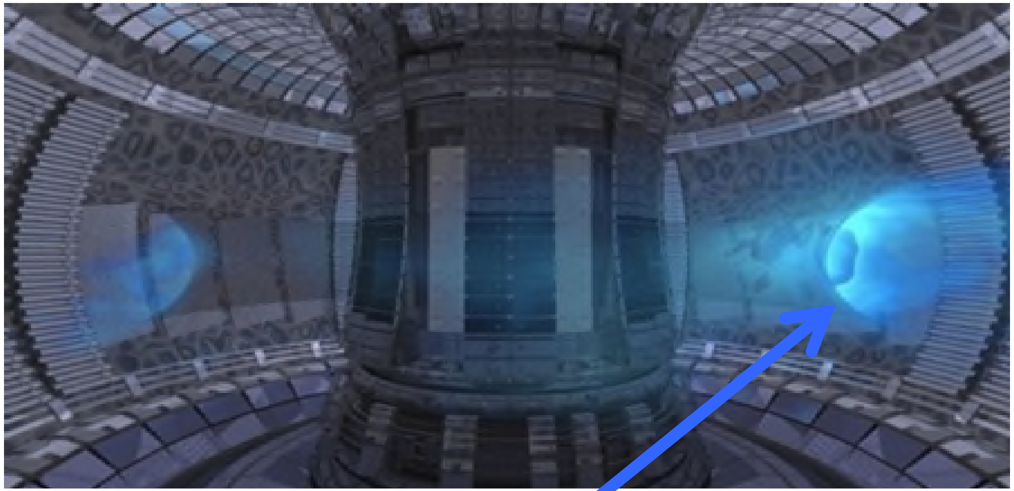
He, D_2,T_2, impurities

Fuel

Fission
Reactor Vessel



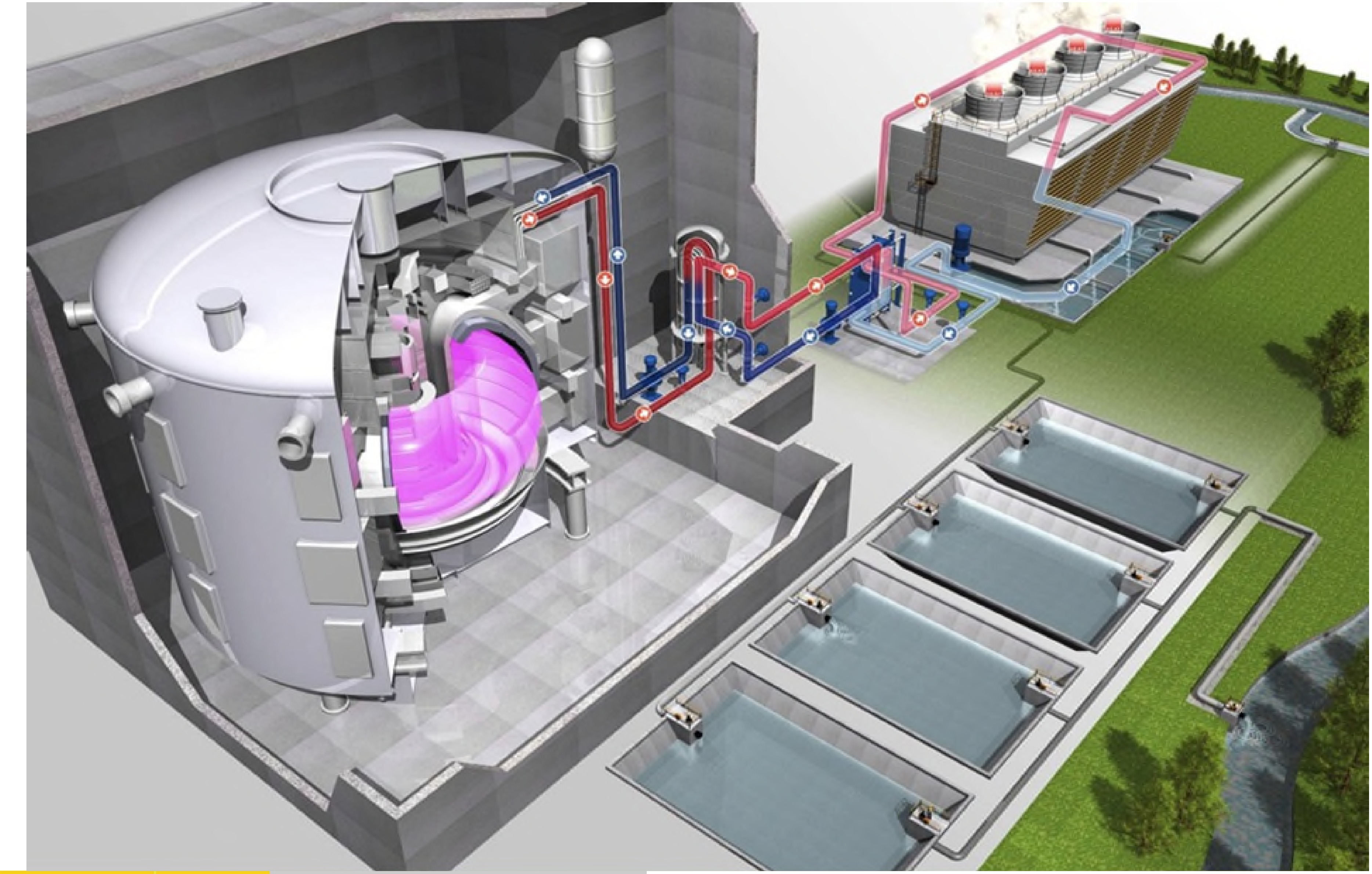
Fusion
Vacuum Vessel



≈ **Tons** of solid
Uranium isotopes

grams of gas Hydrogen isotopes

Schematic of ITER in-vessel component cooling system



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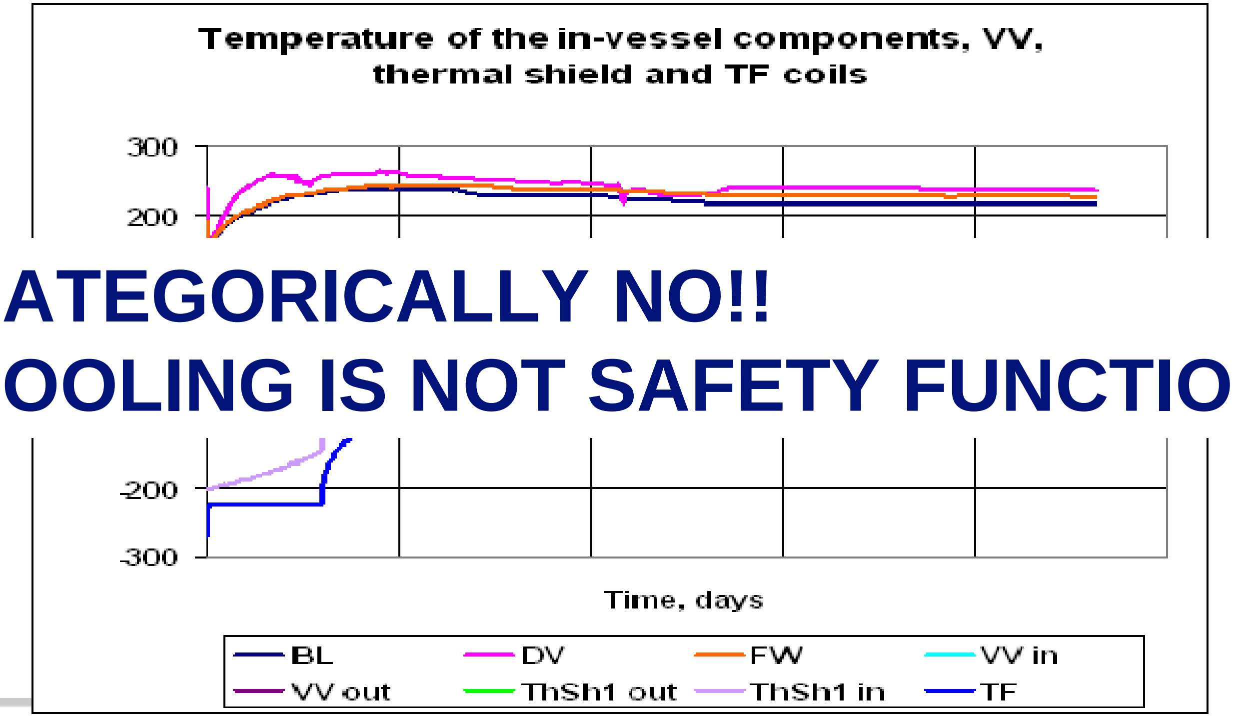
Can anything like Fukushima happen in ITER (Fusion) ?

- NO chain reaction to be stopped.
- NO fuel to melt:
  - Vacuum Vessel essentially empty
- Low after heat
  - NO from fuel.
  - Only in structures
  - Very large structures
  - Large cryogenic exchange surfaces



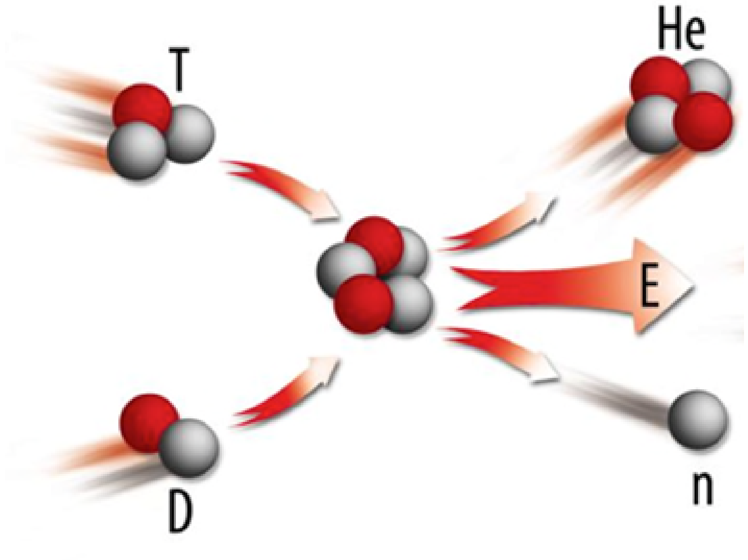
Temperature of the in-vessel components, VV, thermal shield and TF coils

CATEGORICALLY NO!!

COOLING IS NOT SAFETY FUNCTION

Is ITER a nuclear installation?

- The nuclear classification of ITER is due to:



- **Tritium inventory**

4 Kg **(nuclear fuel for ITER)**

- **Radioactive waste**

Very low (52%), low (39%) and medium activity/long life (9%)

41.688 Tons

(operation+dismantling)

The radioactive inventory classifies ITER in France as a

→ *BASIC NUCLEAR INSTALLATION*

ITER SAFETY FUNCTIONS

ITER has two safety functions:

- ➔ Confinement radioactive materials
- ➔ Limitation of radiation exposure

- There is no safety function associated to:
  - **Control of the fusion reactions.**
  - **Power dissipation (cooling systems)**

ITER General Safety Objectives

Normal Operation comprising events and plant conditions planned and required for ITER operation, including some faults or conditions which occur as result of ITER experimental nature

Incidents, or deviations from normal operation, comprising event sequences or plant conditions not planned but likely to occur one or more times during the life of the plant

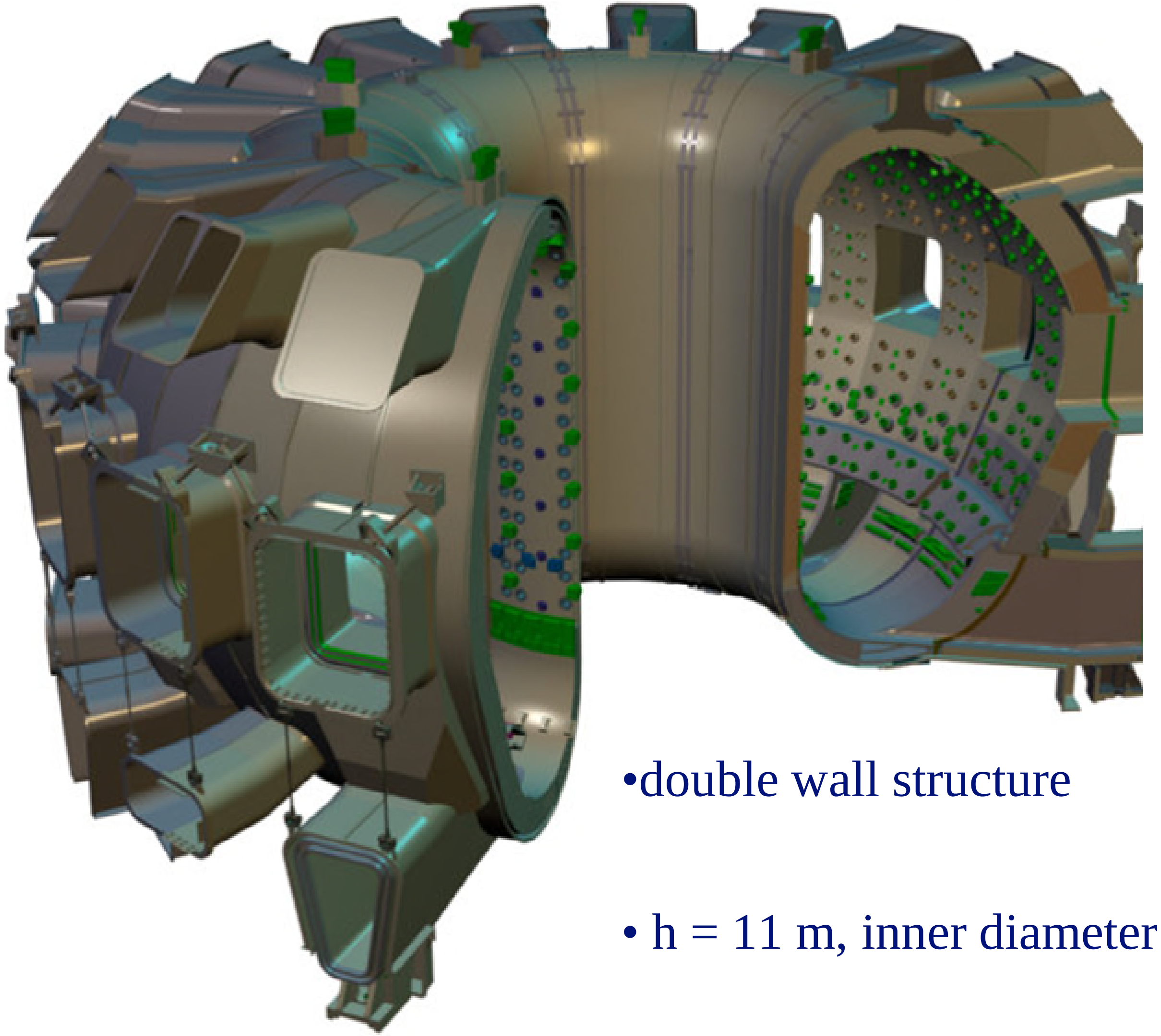
Accidents, comprising postulated event sequences or conditions not likely to occur during the life of the plant

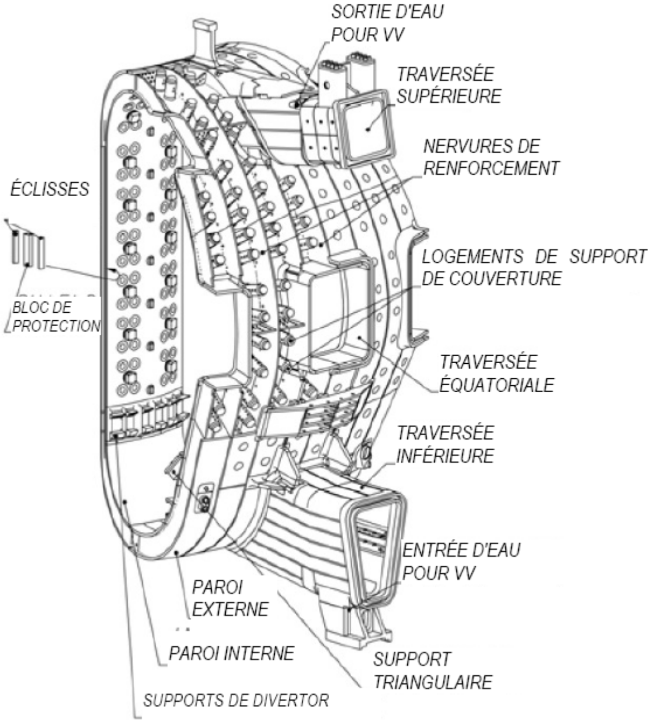
	Situations in design basis	
Normal situations	As low as reasonably achievable, and in any case less than: Maxin Avera	Releases less than the limits authorised for the installation
Incidental situations	As lov case	
Accidental situations	Take into account the constraints related to the management of the accident and post-accident situation	No immediate or deferred counter-measures (confinement, evacuation) **< 10 mSv** No restriction of consumption of animal or vegetable products
	Situations beyond design basis	
Hypothetical accidents	No cliff-edge effect; possible counter-measures limited in time and space	

Confinement of radioactive inventory

- Confinement is the most important safety function
  - Basic targets of confinement
  - Prevent spreading of radioactive material in normal operation
    - Keep radiological consequences
in off-normal conditions
within levels below the safety objectives
  - Confinement function is achieved by a coherent set of physical barriers and / or auxiliary techniques
    - First confinement system designed to prevent releases of radioactive materials into the accessible working areas
    - Second confinement system prevents releases to general public and the environment

Vacuum Vessel and associated components

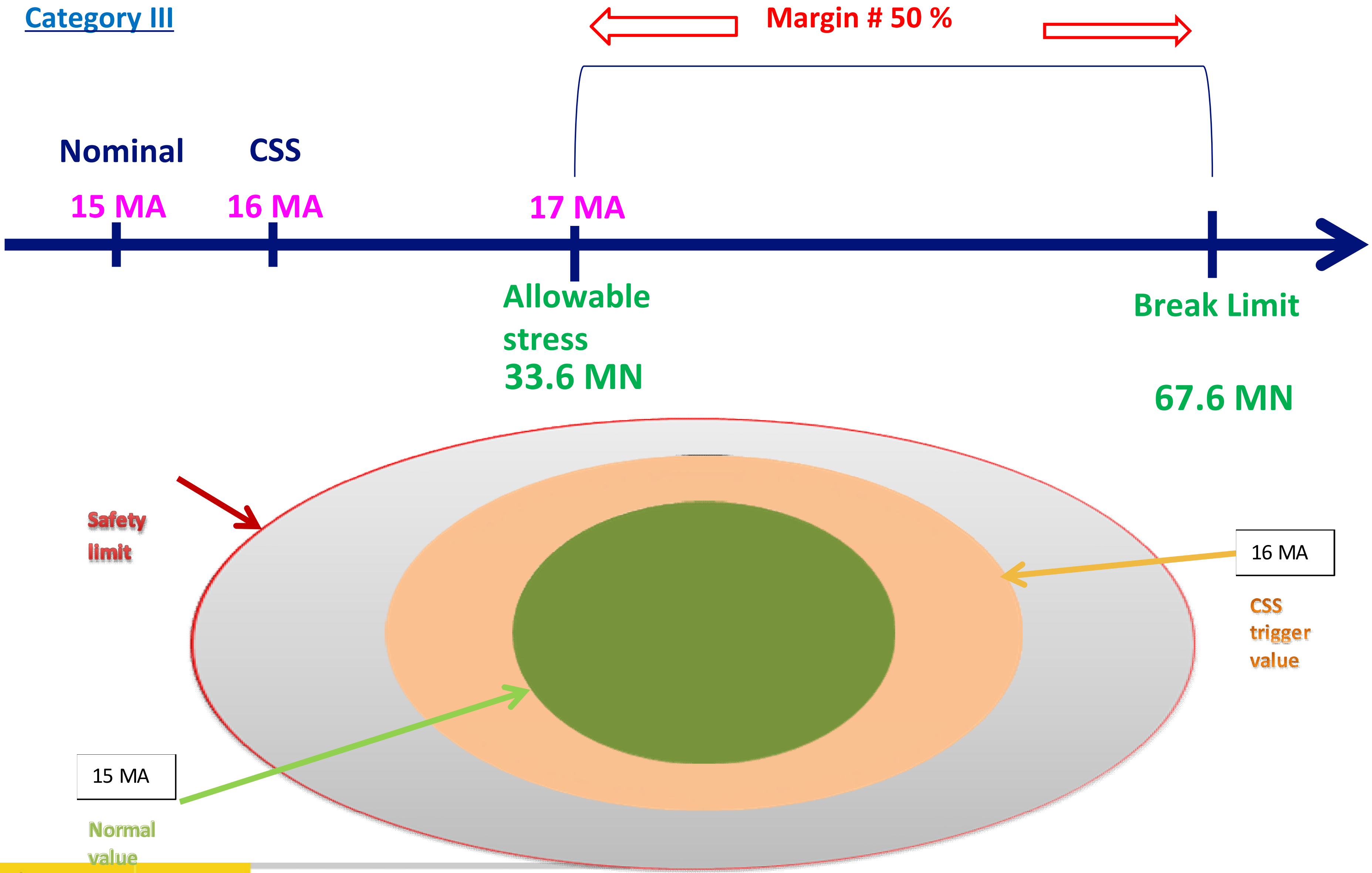




- double wall structure
- h = 11 m, inner diameter 6 m
- mass 5000 tonnes

PLASMA AND SAFETY ITER – DESIGN OF VV V.S ELECTROMAGNETIC LOADS

Category III


Margin # 50 %

Nominal

CSS

15 MA

16 MA

17 MA

Allowable stress

33.6 MN

Break Limit

67.6 MN

Safety limit

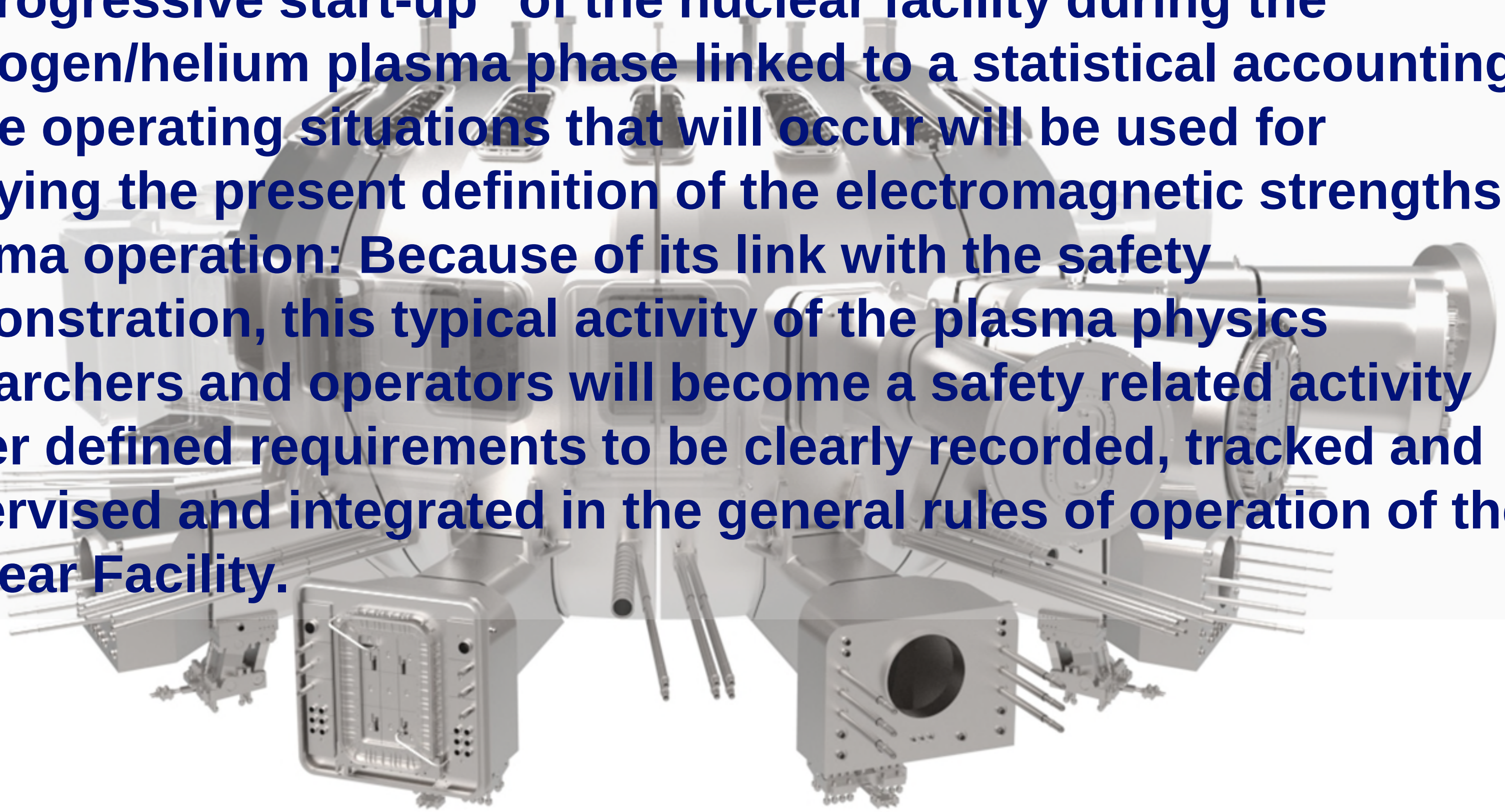
16 MA

CSS trigger value

15 MA

Normal value

Vacuum Vessel



- A “progressive start-up” of the nuclear facility during the hydrogen/helium plasma phase linked to a statistical accounting of the operating situations that will occur will be used for verifying the present definition of the electromagnetic strengths.
- Plasma operation: Because of its link with the safety demonstration, this typical activity of the plasma physics researchers and operators will become a safety related activity under defined requirements to be clearly recorded, tracked and supervised and integrated in the general rules of operation of the Nuclear Facility.

The VV and its function as first barrier, submitted to e-m forces is the main feature of fusion based on a tokamak

Safety Analysis

Internal Risks

- **Internal fire**,
- **Internal explosion**,
- Thermal deviations
- **Plasma transients**,
- Internal inundation,
- Missile effects,
- Whipping pipe,
- Mechanical risks,
- risques chimiques
- Magnetic and electromagnetic perturbations

External Risks

- Seismic,
- Extreme climatic conditions, like hot weather, extreme cold, rain, snow, wind and lightening,
- External inundation,
- External fire ,
- Plane crash,
- Accidents associated to the industrial environment and transport routes, mainly external explosions,
- Accidents in a nearby installation at the site of CEA Cadarache.

Site characteristics

Taking into account the full characteristics of the site

- **Meteorological conditions** : similar to those of Cadarache
- **Hydrological Parameters** : works designed for a hundred-year flood with margin
- **Hydrogeological Parameters**
  Many studies on piezometric aquifers (Cretaceous Miocene / Pliocene) year flood level centennial with confidence interval 95%: 305 m NGF, platform level: 315 m NGF => no risk of external inundation,
- **Geological Parameters** : Many studies on the characterization of the site (Cretaceous and Miocene), no specific tectonic detected
- **Seismic parameters** : consideration of the SMS to the rock (5.8) and a low frequencies paleoseismic plus margin (7)
- **Point zero chemical and radiological** : no anomalies detected

What are the effects of an earthquake followed by flooding?

Basic assumption of unlikely event:

- seismic event followed by
- failure of Serre-Ponçon Dam

Response to seismic event

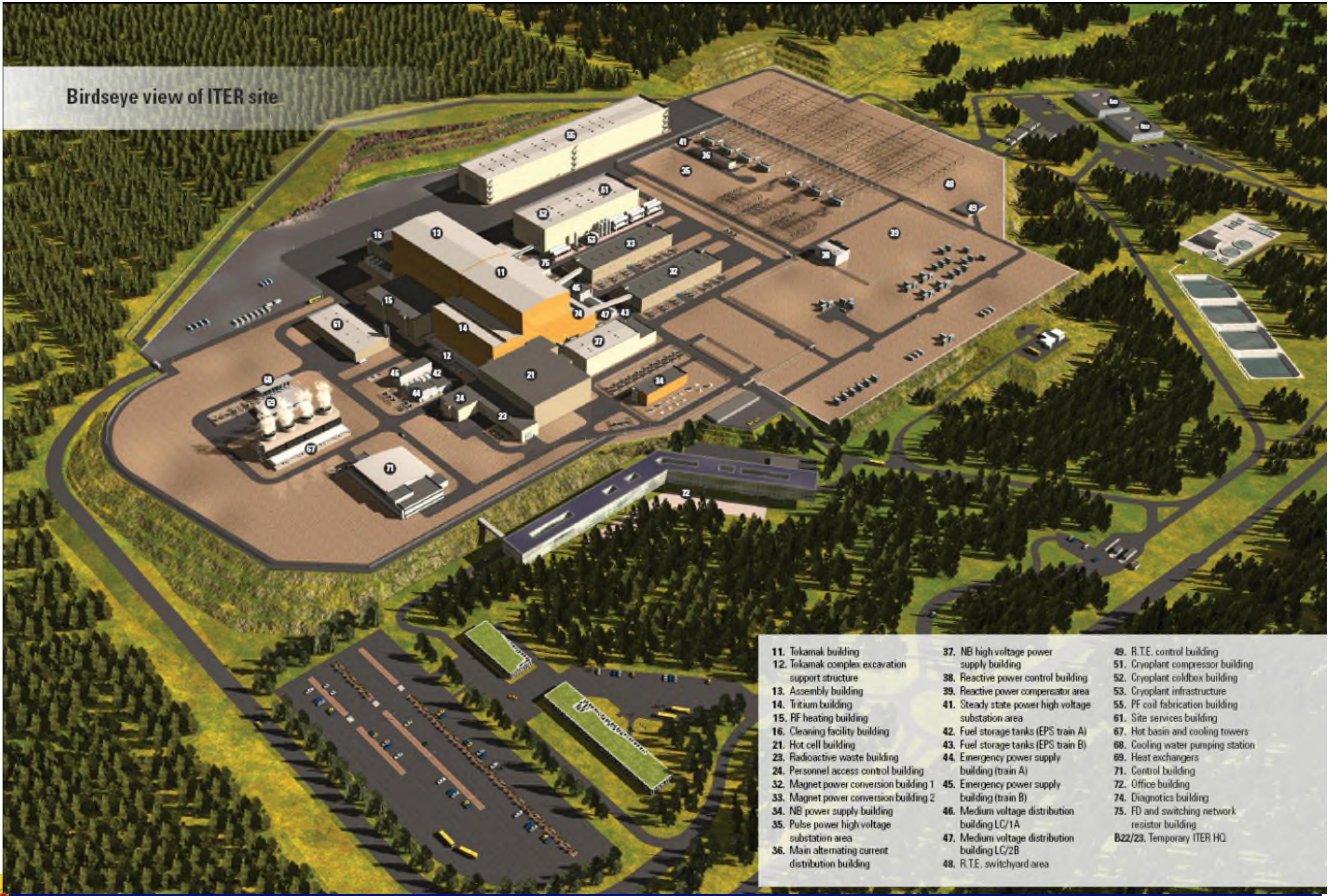
- safe state
- plasma shut down
- inventory placed in safe storage
- plant systems isolated
- inventory placed in safe storage
- all within minutes of initiating event
- residual heat removal by natural convection

Centenial flood of Durance - failure of the Serre-Ponçon dam

- maximum flood level: 265 meter above sea level
- first raft of nuclear buildings: 298 m ASL
- exceptional rain flood level: 305 m ASL
- nuclear building constructed on a second raft at 315 m ASL

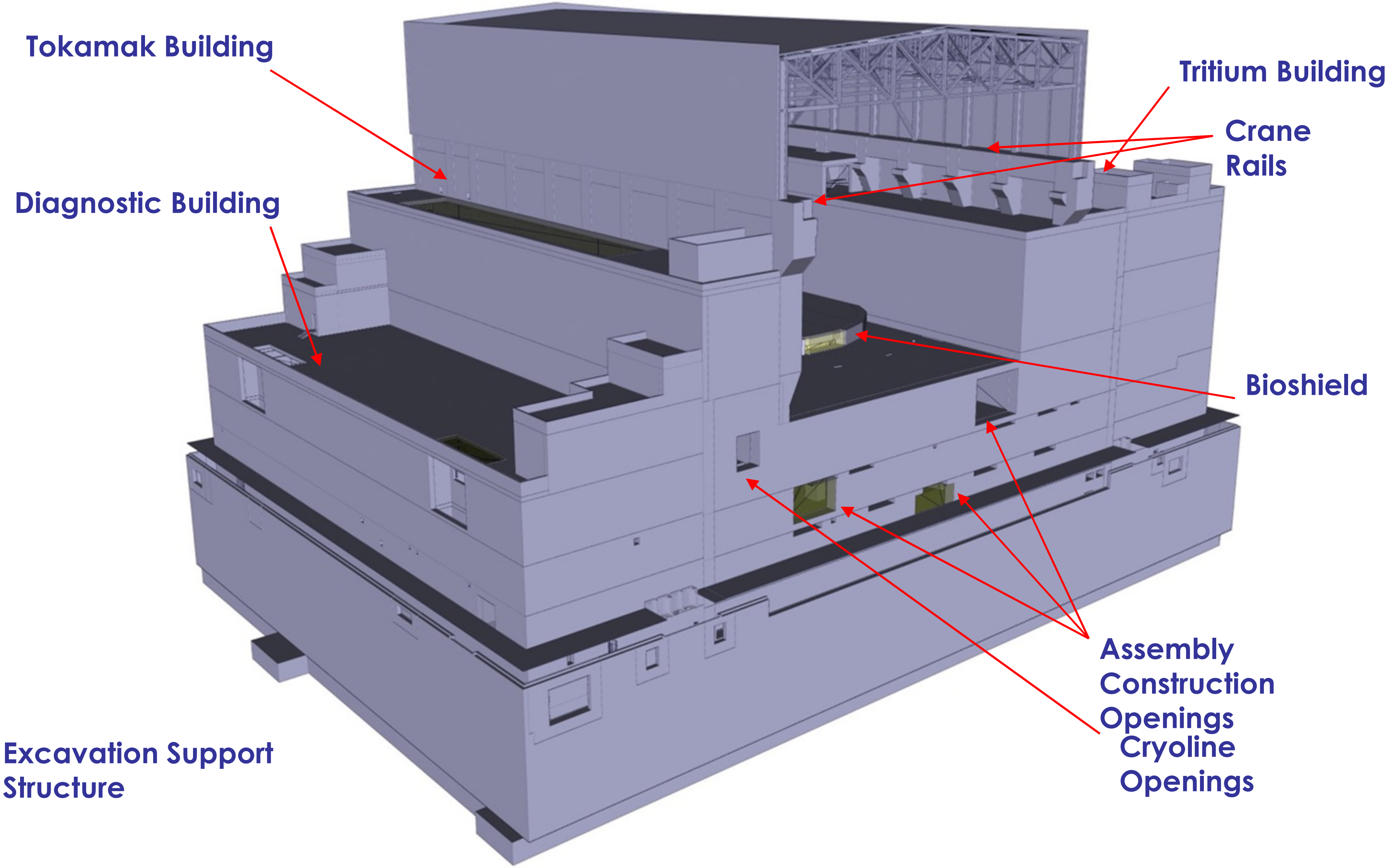
Earthquake followed by exceptional flooding is neither probable nor problematic.

Birdseye view of ITER site



11. Tokamak building
12. Tokamak complex excavation support structure
13. Assembly building
14. Tritium building
15. RF heating building
16. Cleaning facility building
21. Hot cell building
23. Radioactive waste building
24. Personnel access control building
32. Magnet power conversion building 1
33. Magnet power conversion building 2
34. NB power supply building
35. Pulse power high voltage substation area
36. Main alternating current distribution building
37. NB high voltage power supply building
38. Reactive power control building
39. Reactive power compensator area
41. Steady state power high voltage substation area
42. Fuel storage tanks (EPS train A)
43. Fuel storage tanks (EPS train B)
44. Emergency power supply building (train A)
45. Emergency power supply building (train B)
46. Medium voltage distribution building LC/1A
47. Medium voltage distribution building LC/2B
48. R.T.E. switchyard area
49. R.T.E. control building
51. Cryoplant compressor building
52. Cryoplant coldbox building
53. Cryoplant infrastructure
55. PF coil fabrication building
61. Site services building
67. Hot basin and cooling towers
68. Cooling water pumping station
69. Heat exchangers
71. Control building
72. Office building
74. Diagnotics building
75. FD and switching network resistor building
B22/23. Temporary ITER HQ

Overall Tokamak Complex Dimensions: 118m x 81m x 74m



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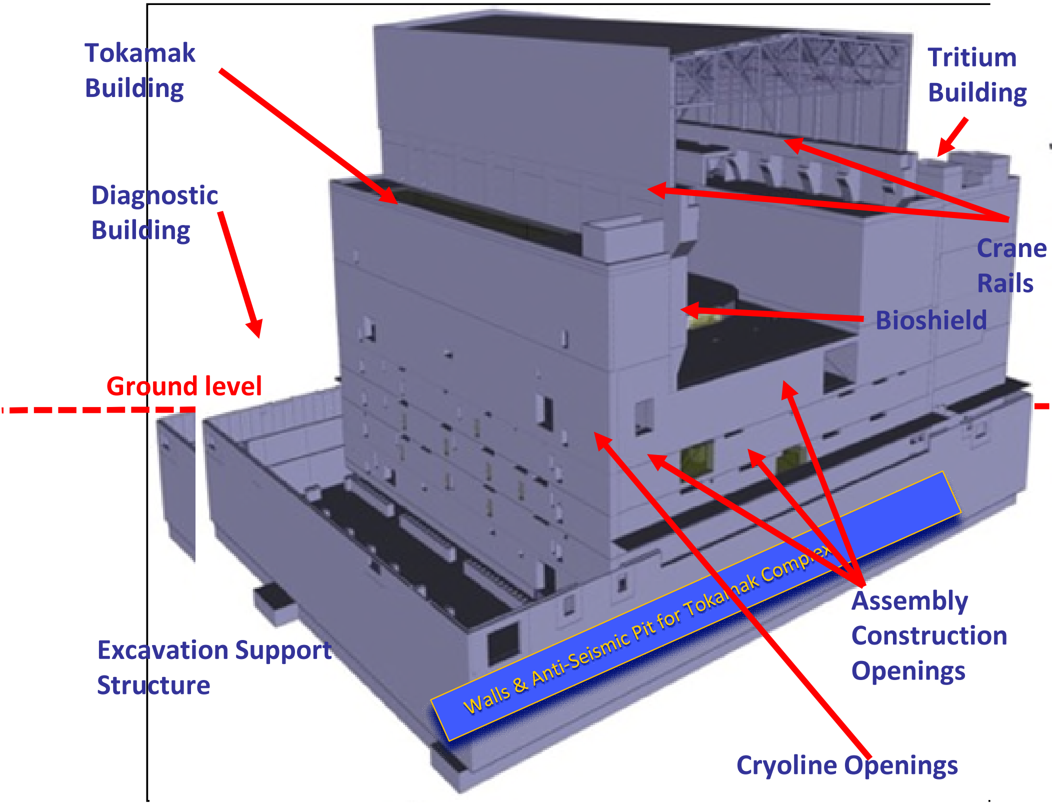
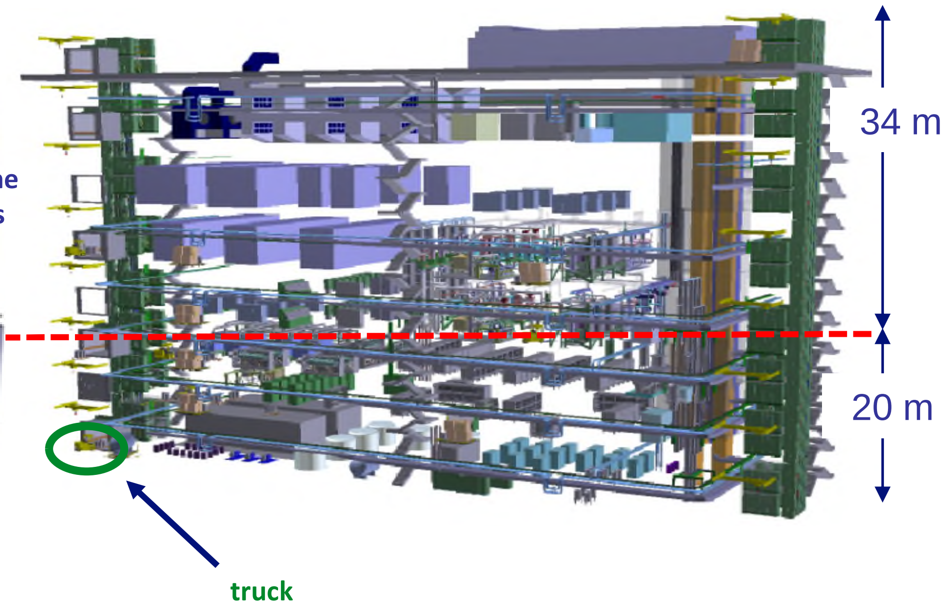
Robustness of the 2nd confinement

- In any case it has been demonstrated that the safety challenge in case of a full failure of the Vacuum Vessel is very limited taking into account the robustness of
  - ✓ the second confinement system comprising the concrete external walls of the buildings
  - ✓ the associated filtering and detritiating systems



Tokamak Complex Dimensions: 118m x 81m x 74m



Tritium Building

The second confinement system is essential for a fusion nuclear facility

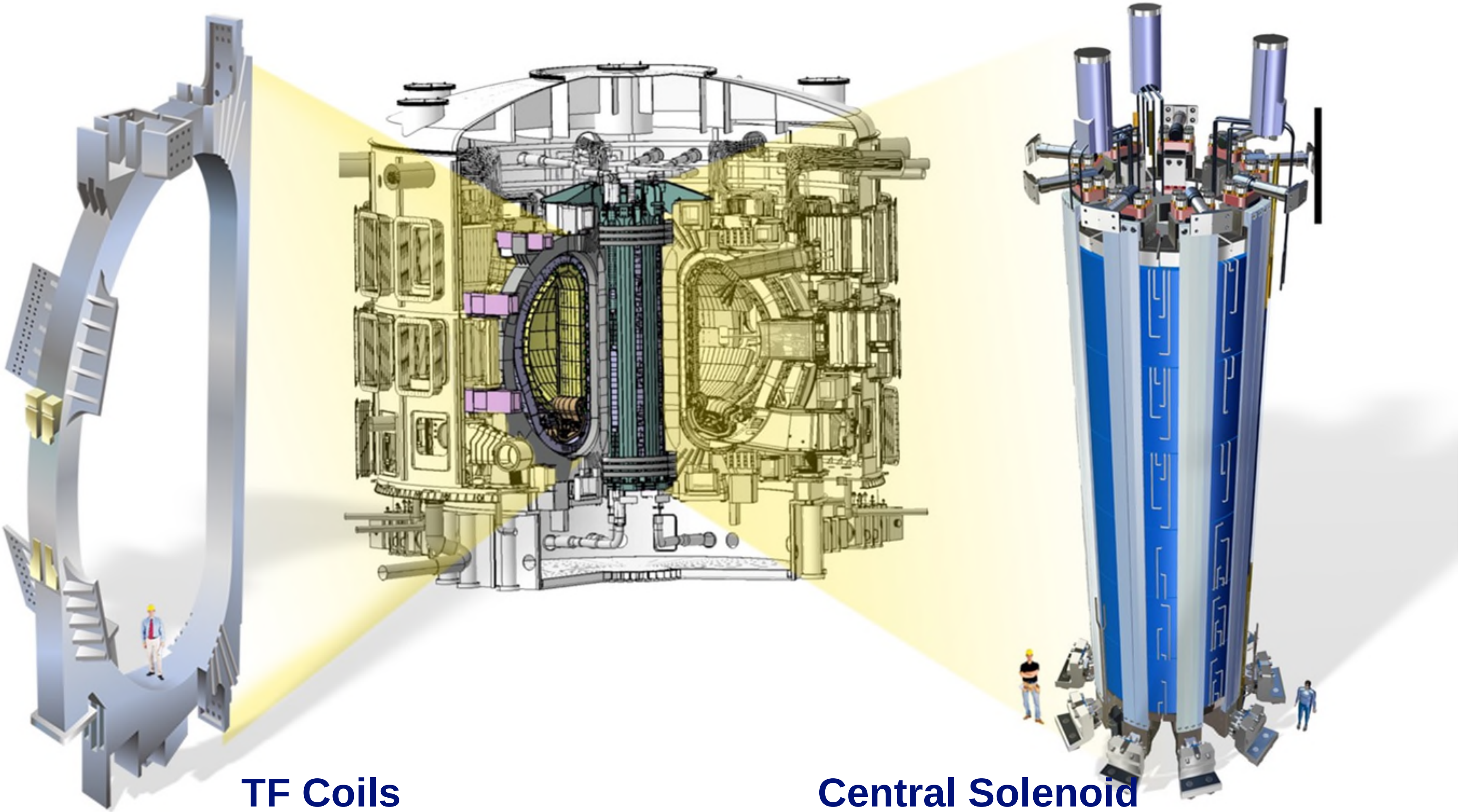
Design Basis Accidents

V1	In-vessel FW pipe leakage
X6	Heat exchanger leakage
X1	Loss of divertor heat sink
X2	Pump trip in divertor HTS
T1	Tritium process line leakage
L1	Loss of off-site power for 32 hours
	blackout for 1 h in Hot cell
V2	Multiple FW pipe break
	Multiple FW pipe break + 10 DV pipes break
V3	Loss of vacuum through one VV/cryostat penetration line (500 MW)
	Loss of vacuum through one VV/cryostat penetration line (700 MW)
X3	Pump seizure in divertor
X7	Heat exchanger tube rupture
X4	Large VV coolant pipe break (ACP mass is reduced 100 times: it is lower than in FW/BLK loop by factor 100)
	baking

X5	Large DV ex-vessel coolant pipe break
	baking (controlled releases means through the stack and releases shall be multiplied by filtering factor)
X8	Coolant pipe break inside Port Cell (normal operation)
	baking, valves close
E1	Stuck divertor cassette and failure of cask
T2	Failure of transport hydride bed
T3	Isotope separation system failure
T4	Failure of fueling line
T5	Leak of tritiated water from WDS
M1	Toroidal field coil short
M2	[illegible] confinement barrier
C1	Cryostat air ingress
C2	Cryostat water ingress
C3	Cryostat helium ingress
H1	Loss of confinement in hot cell

Magnets Safety

Magnets - Unprecedented Size and Performance



TF Coils
11.8 Tesla, 41 GJ
400 MN centering force

Central Solenoid
13 Tesla, 7 GJ
20 kV, 1.2 T/s

WHAT COULD BE THE SAFETY ISSUES AND DESIGN IMPLICATIONS?

- Is there an impact on the 1 st confinement barrier credited in ITER safety analysis?

the first confinement is the vacuum vessel and contains 1 ton of activated dusts and 1 kg of tritium

- Is there an impact on the last confinement barrier credited in ITER safety analysis through the anchorage of the coils to the civil work?

On major part of the last confinement barrier is the basemate where anchorage ensured the support of the magnets systems, the VV and the cryostat

IS THERE AN IMPACT ON THE FIRST CONFINEMENT BARRIER?

✓ A postulated event (DBA) is a full terminal short of a **TF coil** (TF coil short):

two ground faults in the coil busbar circuit : one on side of the TF coil, while undergoing a fast discharge, plus the failure of the monitoring systems to detect these faults.

- Substantial local plastic deformation can be expected to occur in the TF case (in the shorted coil and the adjacent coils) and intercoil structures.

- There may be a loss of cryostat vacuum due to thermal shield damage.

➔ However, gross structural failure is not predicted. There is no impact of magnets on the vacuum vessel and no radiological consequences are predicted

IS THERE AN IMPACT ON THE FIRST CONFINEMENT BARRIER?

✓ A postulated event (DBA) is a full terminal short of a TF coil (TF coil short):

two ground faults in the coil busbar circuit : one on side of the TF coil, while undergoing a fast discharge, plus the failure of the monitoring systems to detect these faults.

- Substantial local plastic deformation can be expected to occur in the TF case (in the shorted coil and the adjacent coils) and intercoil structures.

- There may be a loss of cryostat vacuum due to thermal shield damage.

➔ However, gross structural failure is not predicted. There is no impact of magnets on the vacuum vessel and no radiological consequences are predicted

IS THERE AN IMPACT ON THE FIRST CONFINEMENT BARRIER?

✓ Another postulated event is an arc inside a **PF/CS coil** (Arc near confinement barrier).

- The arc develops as a result of a failure (or inability) to discharge the coil when a quench occurs.
- The quench will propagate slowly and local conductor melting followed by the development of arcs, is likely.
- The melted material produced by the coil internal arcs may not be contained by the thin coil casing and would probably be spread over components in the cryostat in the vicinity of the shorted coil. It is possible that external arc energy associated with the coil short is sufficient to melt the conductor of the superconducting busbars

→cause local melting around the cryostat feed-throughs.

→However, no radiological consequences are predicted.

THINK ON THE NON-IMAGINABLE ACCIDENT TO CHECK OUR MARGIN?

✓ FUKUSHIMA event pushes us to check for this non plausible accident what could the remaining safety margin

✓ A BDBA scenario is postulated and it is not derived from any identified mechanism by which a magnet failure could initiate

Damage to vacuum vessel and cryostat resulting in large holes

large holes, 1 m^2 created simultaneously in VV and cryostat

➔ **Radiological consequences very limited (0.14 mSv, 2.5 km)**

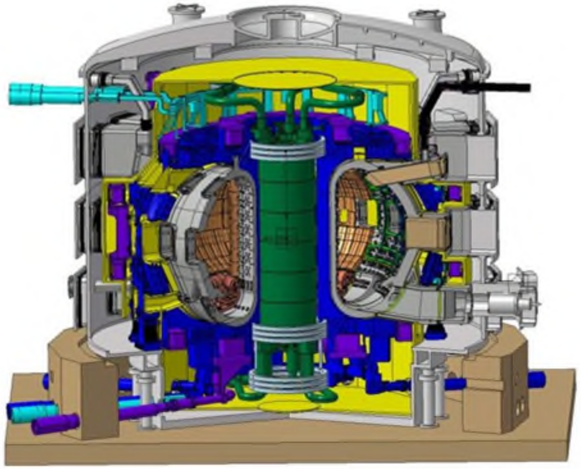
➔ **No countermeasure for the public**

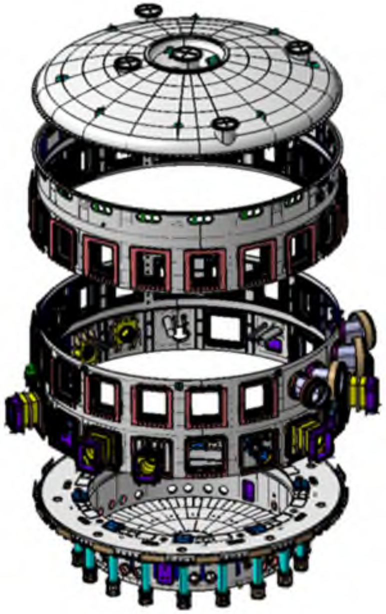
Minimizing the potential for damage

- The potential for a magnet fault to lead to damage to confinement has been minimized by their design.
- Magnet systems incorporate multiple monitoring and protection systems in the design.
- Two of these detection and protection systems are designated Safety Important Class (SIC) as they provide the following safety functions:
  - **TF coil quench detection**
  - **Fast discharge of TF coil stored energy**

IS THERE AN IMPACT ON THE LAST CONFINEMENT BARRIER CREDITED IN ITER SAFETY ANALYSIS THROUGH THE ANCHORAGE OF THE COILS TO THE CIVIL WORK?

- The two main tokamak components (VV and magnetic coils) rest on the cryostat pedestal ring. The pedestal ring is supported by the building basemat.
- The magnets gravity support system consists of columns made up of flexible compression plates resting on the pedestal ring and resisting vertical and toroidal movements.
- Each PF coils are connected directly to the TF magnet assembly.
- The VV thermal shield is attached to the TF coil system.
- The in-vessel systems (blanket modules, divertor) are directly supported by the vessel.
- The cryostat is supported by the basemat.
- The tokamak building is supported by the basemat.





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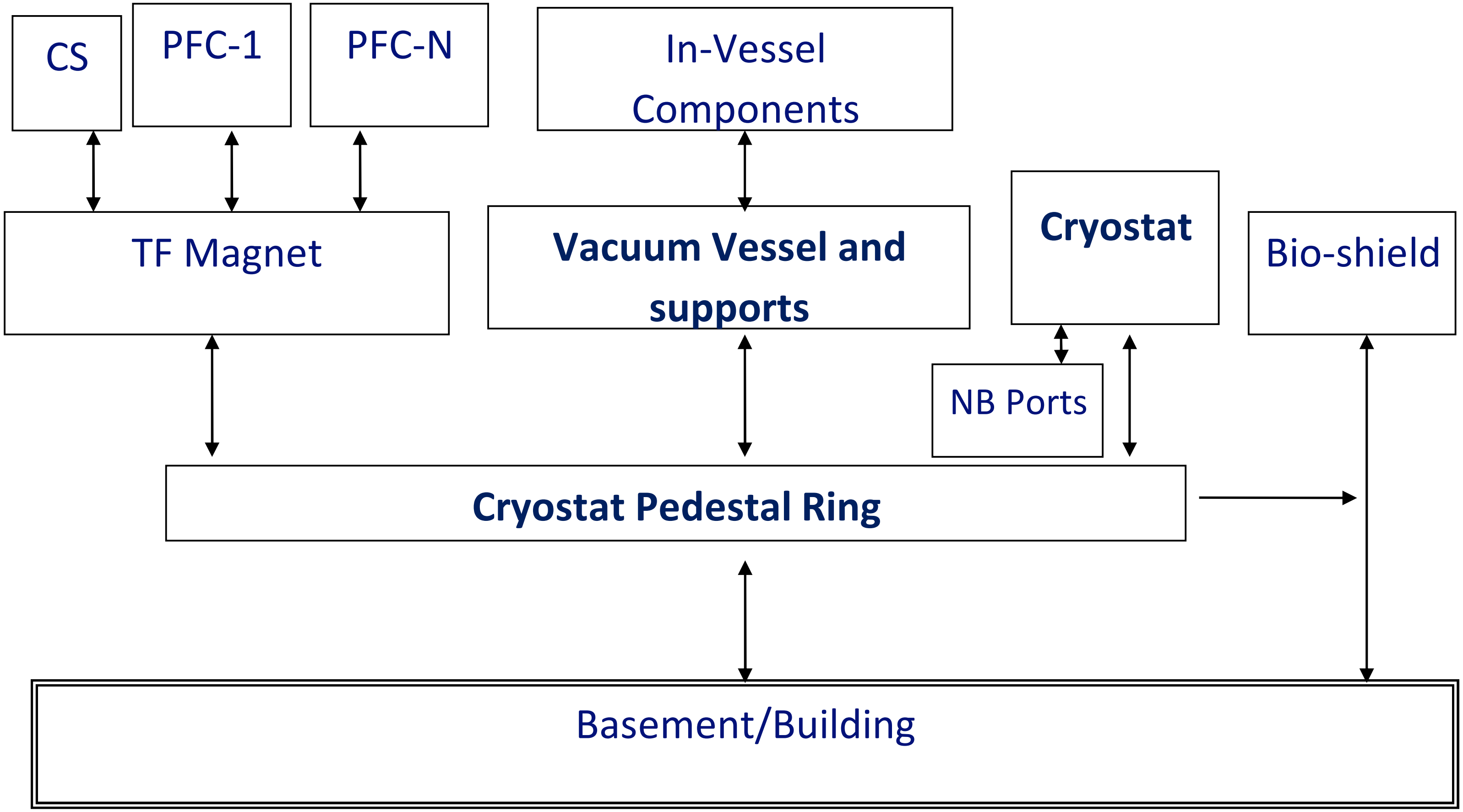
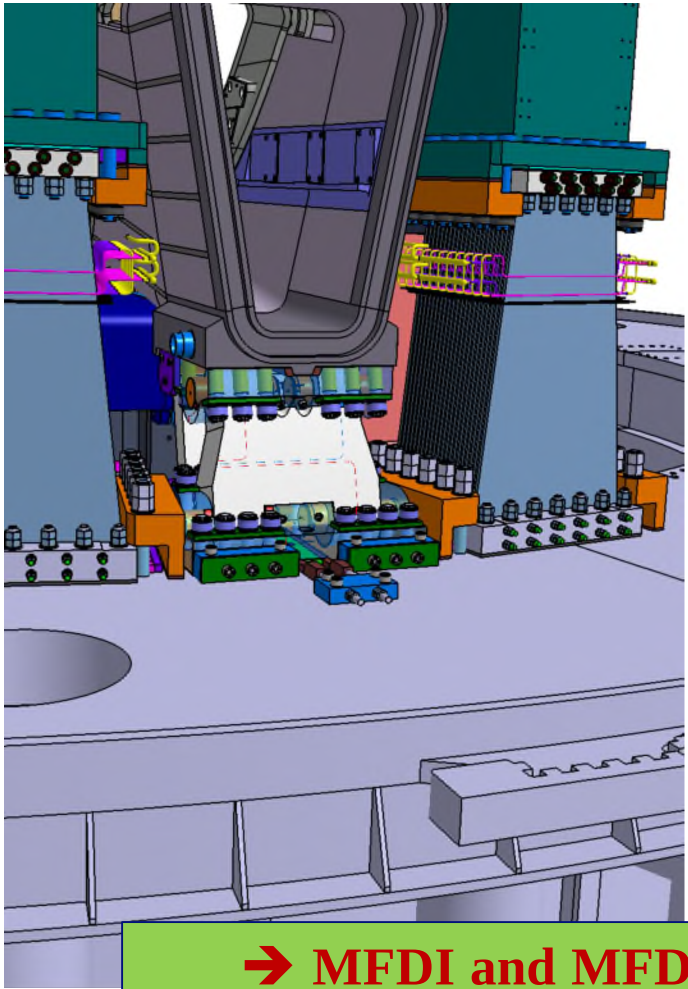
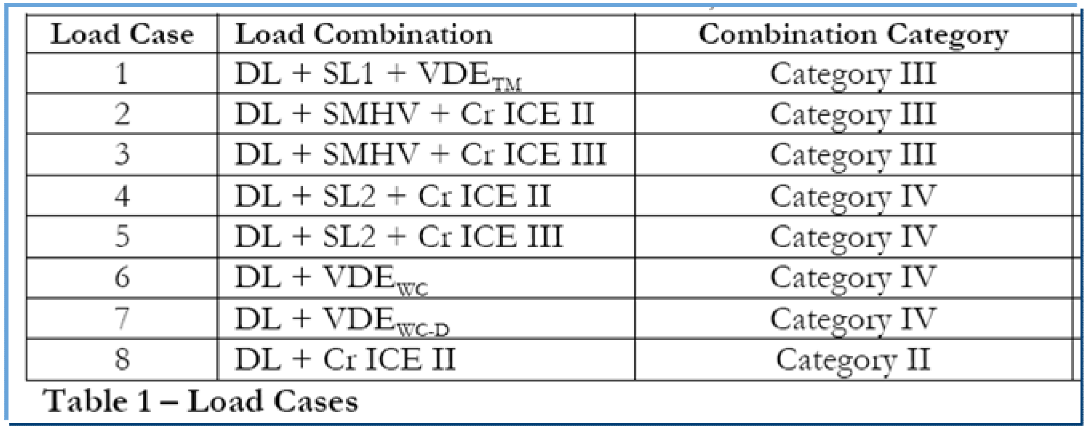
The support hierarchy is schematically shown





- A fast discharge of the PF and CS coils (MFDI) is defined as a category I event
- A fast discharge of all coils (MFDII) is defined as a category II event



Load Case	Load Combination	Combination Category
1	DL + SL1 + VDE_{TM}	Category III
2	DL + SMHV + Cr ICE II	Category III
3	DL + SMHV + Cr ICE III	Category III
4	DL + SL2 + Cr ICE II	Category IV
5	DL + SL2 + Cr ICE III	Category IV
6	DL + VDE_{WC}	Category IV
7	DL + $\text{VDE}_{WC\text{-}D}$	Category IV
8	DL + Cr ICE II	Category II

Table 1 – Load Cases

➔ MFDI and MFDII are not designing loads for the anchorage on basemat

➔ No impact on civil work

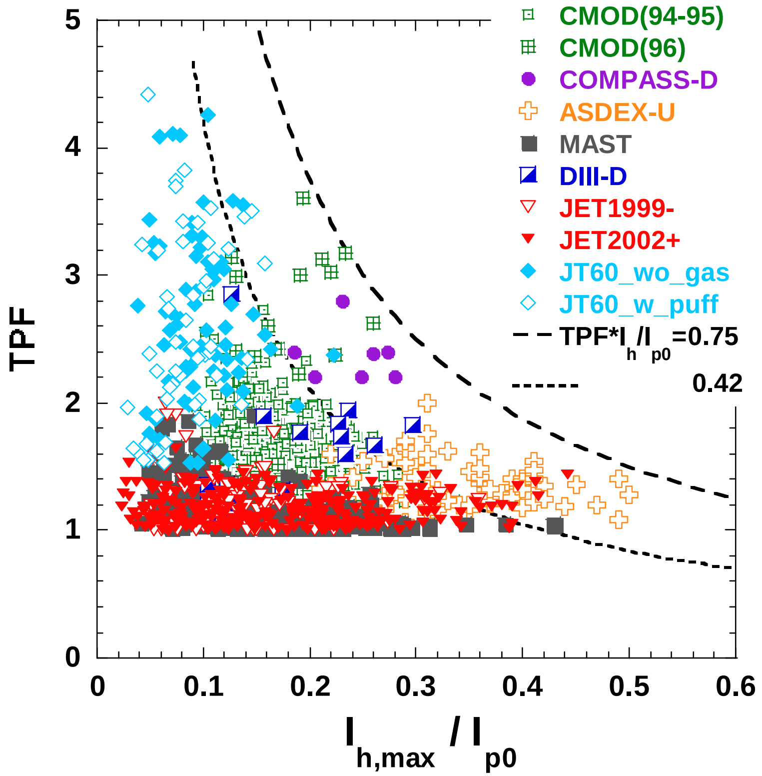
CONCLUSIONS

- The coils are not SIC (not credited in safety analysis)
- The Instrumentation of the coils is SIC (TF quench detection)
- The fast discharge units are SIC
- TF coils : gross structural failure is not predicted. There is no impact of magnets on the vacuum vessel and no radiological consequences are predicted
- PF/CS coils : cause local melting around the cryostat feed-throughs. However, no radiological consequences are predicted
- MFDI and MFDII are not designing loads for the anchorage on basemate, no impact on civil work

Disruption related safety issues

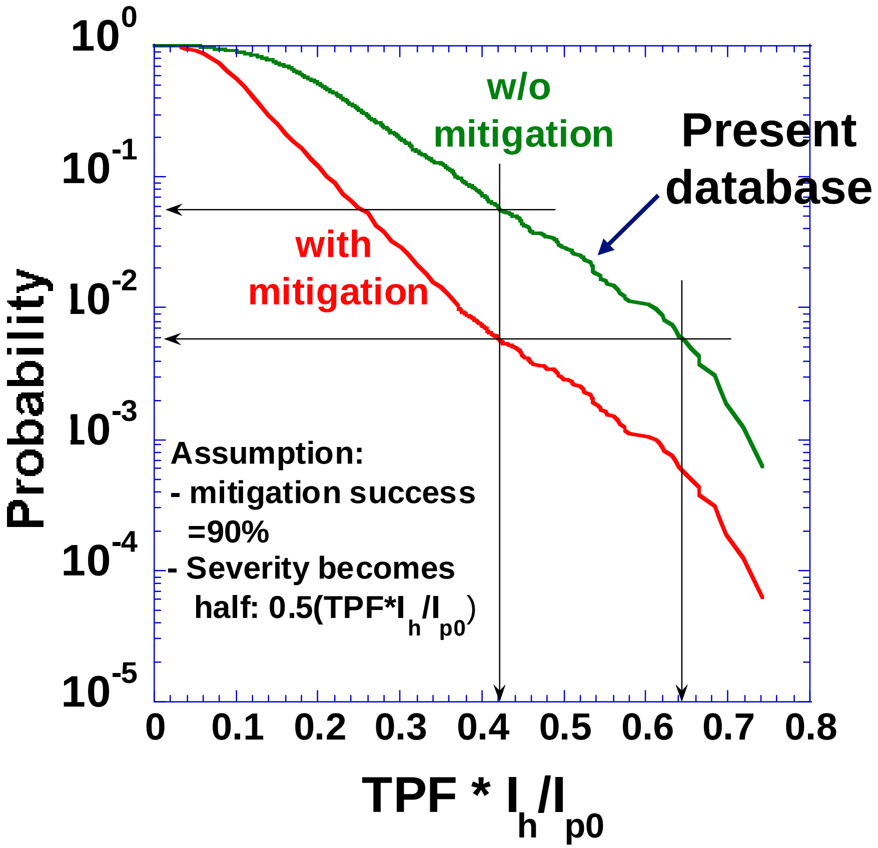
1. Vertical force due to halo current
2. Heat load
3. Runaway electrons
4. Rotation of asymmetric halo and plasma current

1. Vertical force due to halo current



- Severity of vertical force
  $f_h \equiv TPF \times I_{halo}/I_P$
- From database of halo current, upper boundary is $f_h \approx 0.75$, no VDEs beyond 0.75
- Actual design is performed with lower value of f_h (presently 0.42) assuming that event with $0.42 < f_h < 0.75$ will occur only rarely (classified as Cat. III event)
- When Cat. III event occurs, detailed time consuming inspection is necessary
  ==> operation efficiency is degraded
  ==> such event should be 1-2 during device lifetime

- When based on present database, number of Cat.III events is expected to be $300 \times 0.065 \approx 20$ during life



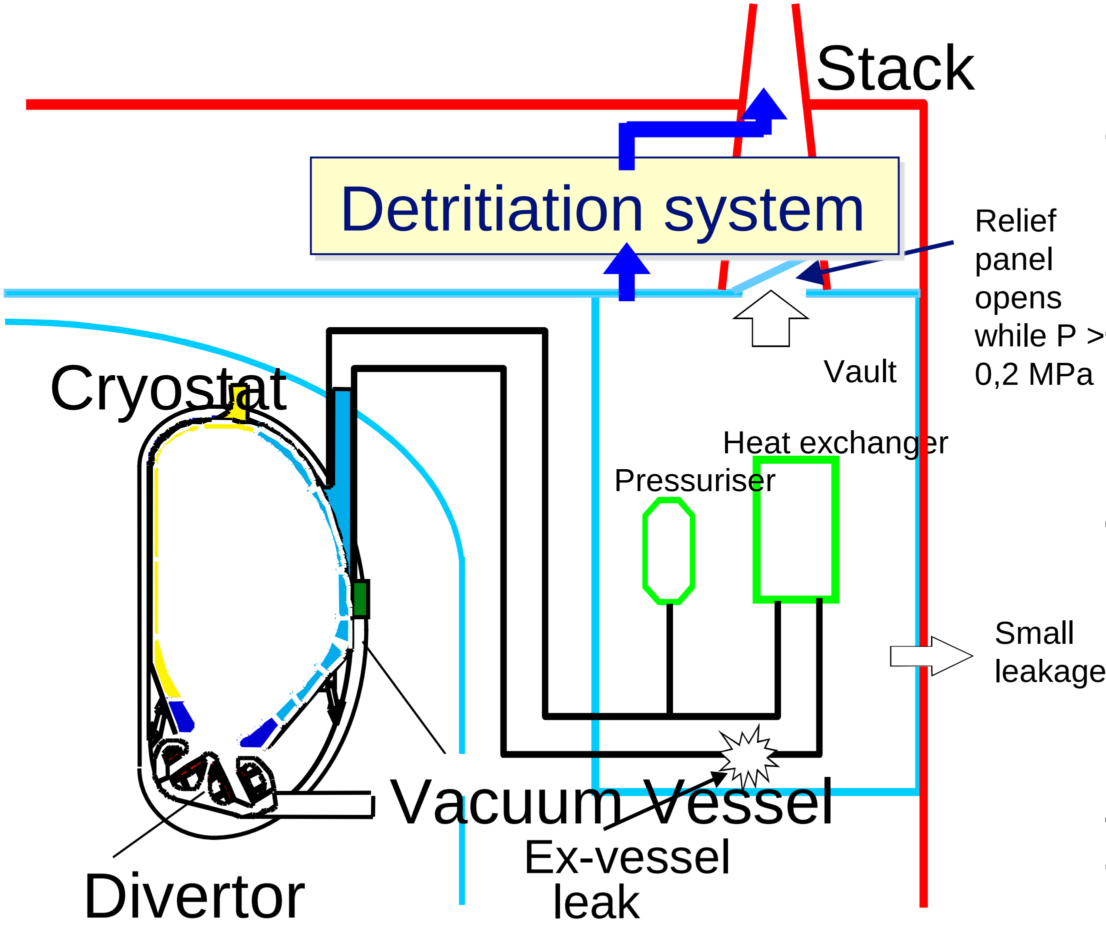
- With mitigation performance;
  - Reduction of EM load: 1/2
  - Success rate: 90 %

  number of Cat.III events is expected to be $300 \times 0.006 \approx 2$ during life

- If without mitigation much higher value of $f_h \approx 0.64$ needs to be specified to reduce Cat.III events to ≈ 2 during life

Accident study

Design basis accident generating the most significant doses to the closest people



Guillotine rupture of the largest pipe of the divertor cooling system during its phase of drying

- ✓ **Releases come from the pressurization of the chamber containing a portion of the cooling loops and from the opening the discharge valve for a few seconds**

The accident "envelope" leads to 18 µSv to the most nearby person (Chateau de Cadarache), taking into account inhalation and ingestion of contaminated.

The dose is mainly due to the discharge through the chimney of activated corrosion products (over 90% of dose)

Beyond Design Basis Accidents

Loss of vacuum through one vacuum vessel penetration line plus 2 hours blackout and in-vessel FW coolant leak

Multiple failure of first wall cooling loops inside vacuum vessel together with failure of both windows in an RF heating line (“wet bypass”)

Multiple failure of the first wall cooling loops inside vacuum vessel together with a failure of Fusion Power Termination System

FW Ex-Vessel Loss of Coolant with Failure of Fusion Power Termination System

Hydrogen and dust explosion in the vacuum vessel

Damage to VV and cryostat resulting in large holes of 1 m2

Large VV ex-vessel coolant pipe break plus loss of flow in all intact PHTS loops

Cryostat water and helium ingress (2600 kg of He)

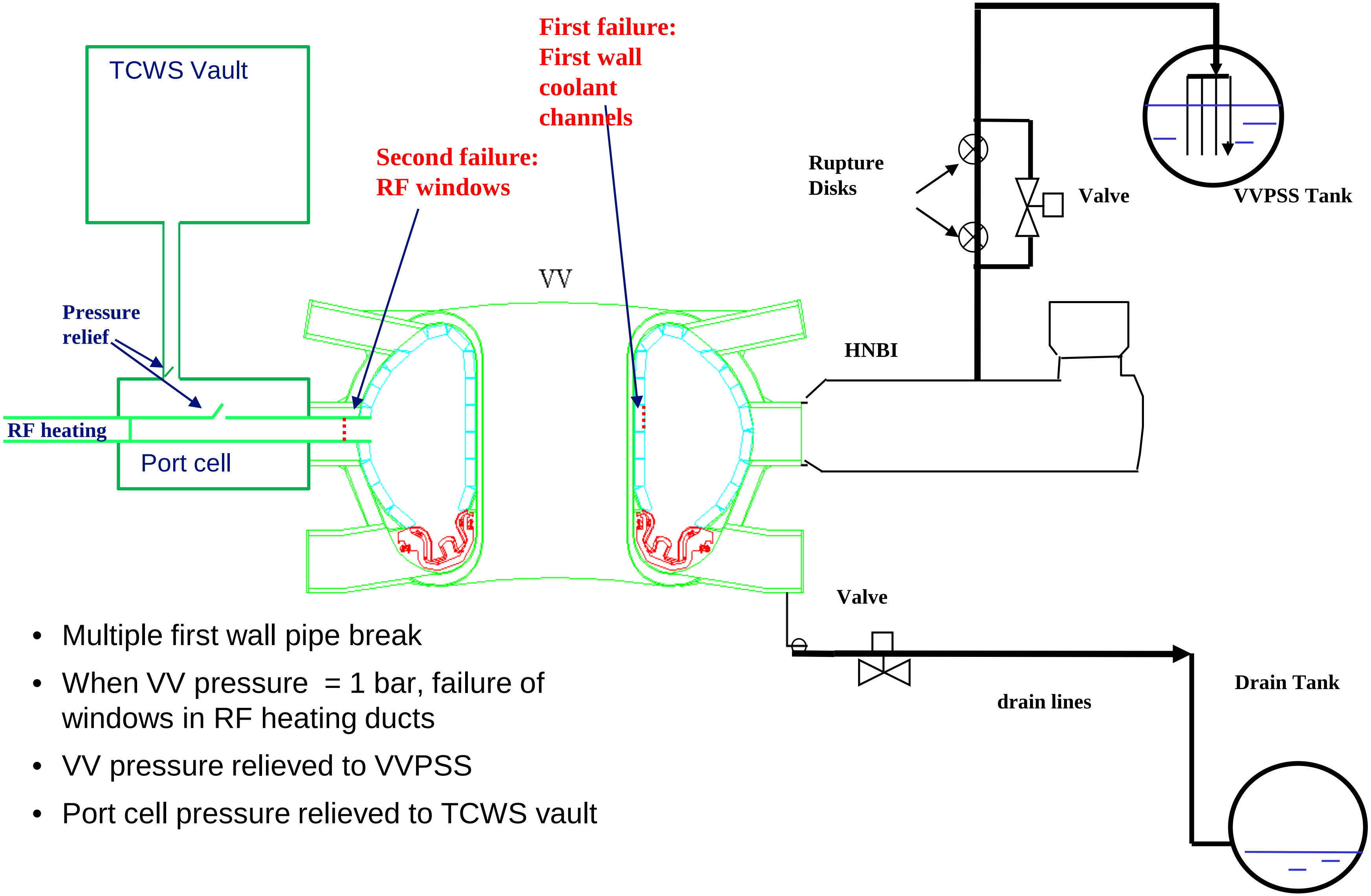
Confinement Failures in the Tritium Plant

Fire in the T-plant

Hydrogen Deflagration and Detonation in the Tritium Plant

Fire in the waste processing area plus propagation to buffer storage room in the hot cell

“Wet By-pass Scenario”



- Multiple first wall pipe break
- When VV pressure = 1 bar, failure of windows in RF heating ducts
- VV pressure relieved to VVPSS
- Port cell pressure relieved to TCWS vault

SAFETY ISSUES

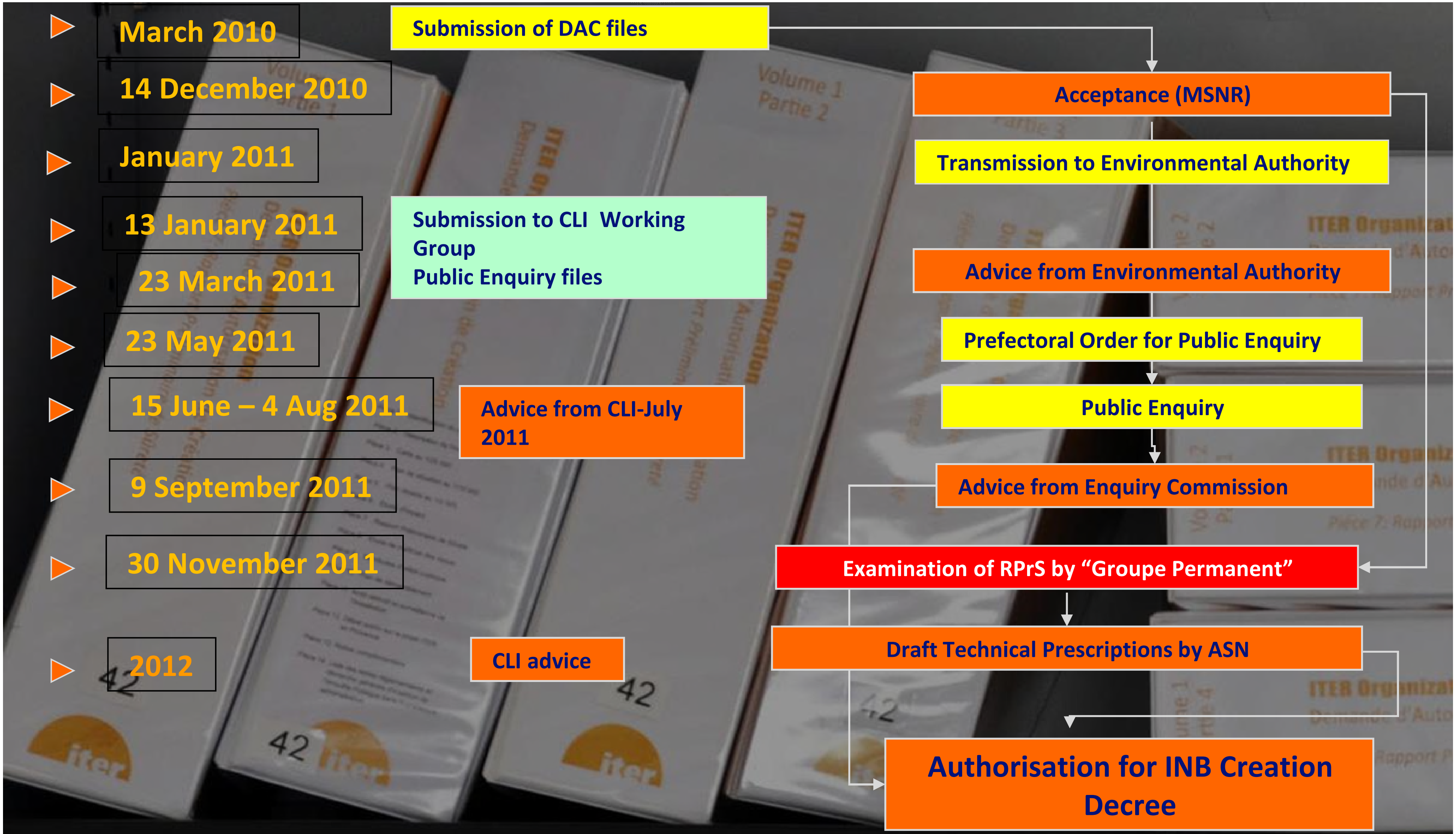
- ANNUAL DOSE IN NORMAL CONDITIONS < 10 µSv at 200
  Long term < 3µSv

- MAXIMUM DOSE IN DESIGN BASIS ACCIDENT < 100 µSv at 200 m
  Long term < 17.6 µSv

- DUST EXPLOSION IN VACUUM VESSEL 332 µSv at 200 m
  BEYOND DESIGN ACCIDENT Long term < 200 µSv

- OTHER BEYOND BASIS ACCIDENTS ALSO SHOW LOW IMPACT AND NO “CLIFF EDGE” EFFECT:
  - ✓ Fire in tritium plant following failure of fire protection provisions: Maximum public dose 1.1 mSv (short term, 200m).
    Long term: 200 µSv
  - ✓ Worst event (“wet bypass”): max dose 4 mSv (short term, 200m),
    Long term: 130 µSv

Licensing milestones



- March 2010
- 14 December 2010
- January 2011
- 13 January 2011
- 23 March 2011
- 23 May 2011
- 15 June – 4 Aug 2011
- 9 September 2011
- 30 November 2011
- 2012

Submission of DAC files

Acceptance (MSNR)

Transmission to Environmental Authority

Submission to CLI Working Group
Public Enquiry files

Advice from Environmental Authority

Prefectoral Order for Public Enquiry

Advice from CLI-July 2011

Public Enquiry

Advice from Enquiry Commission

Examination of RPrS by “Groupe Permanent”

CLI advice

Draft Technical Prescriptions by ASN

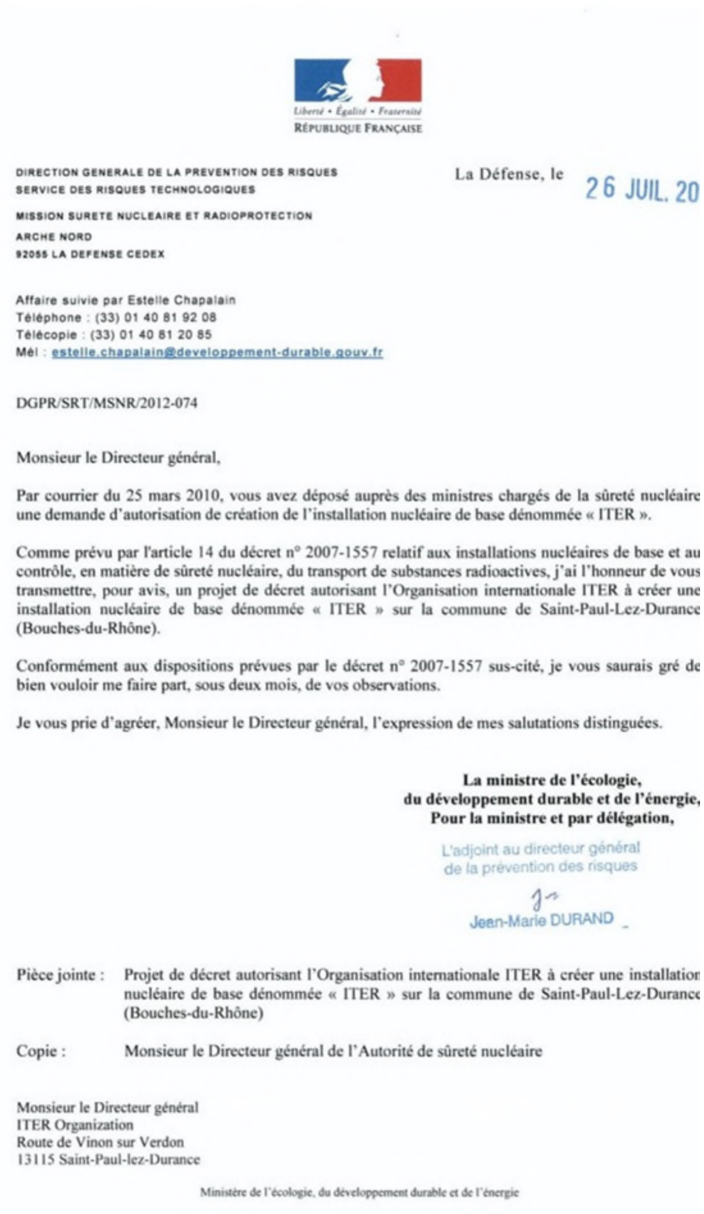
Authorisation for INB Creation Decree

The 26th of July 2012, after the start of ITER Council, the Minister sent the letter informing:

- Authorizing the process for creation decree of INB ITER sending the draft.
- Listing the recommendations to be satisfied in due time.

What are the implications ?

- Full nuclear operator : application of Quality order of 1984 will be strictly imposed by ASN.
- Binding contract between IO and ASN: SQS duty to support the DG to check that any modification to the RPrS must be tracked, justified and can be refused if the safety impact is significant (DR, NCR).



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DIRECTION GENERALE DE LA PREVENTION DES RISQUES
SERVICE DES RISQUES TECHNOLOGIQUES
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ARCHE NORD
92055 LA DEFENSE CEDEX

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Mél : estelle.chapalain@developpement-durable.gouv.fr

La Défense, le 26 JUIL. 20

DGPR/SRT/MSNR/2012-074

Monsieur le Directeur général,

Par courrier du 25 mars 2010, vous avez déposé auprès des ministres chargés de la sûreté nucléaire une demande d'autorisation de création de l'installation nucléaire de base dénommée « ITER ».

Comme prévu par l'article 14 du décret n° 2007-1557 relatif aux installations nucléaires de base et au contrôle, en matière de sûreté nucléaire, du transport de substances radioactives, j'ai l'honneur de vous transmettre, pour avis, un projet de décret autorisant l'Organisation internationale ITER à créer une installation nucléaire de base dénommée « ITER » sur la commune de Saint-Paul-Lez-Durance (Bouches-du-Rhône).

Conformément aux dispositions prévues par le décret n° 2007-1557 sus-cité, je vous saurais gré de bien vouloir me faire part, sous deux mois, de vos observations.

Je vous prie d'agréer, Monsieur le Directeur général, l'expression de mes salutations distinguées.

La ministre de l'écologie,
du développement durable et de l'énergie,
Pour la ministre et par délégation,

L'adjoint au directeur général
de la prévention des risques

Jean-Marie DURAND

Pièce jointe : Projet de décret autorisant l'Organisation internationale ITER à créer une installation nucléaire de base dénommée « ITER » sur la commune de Saint-Paul-Lez-Durance (Bouches-du-Rhône)

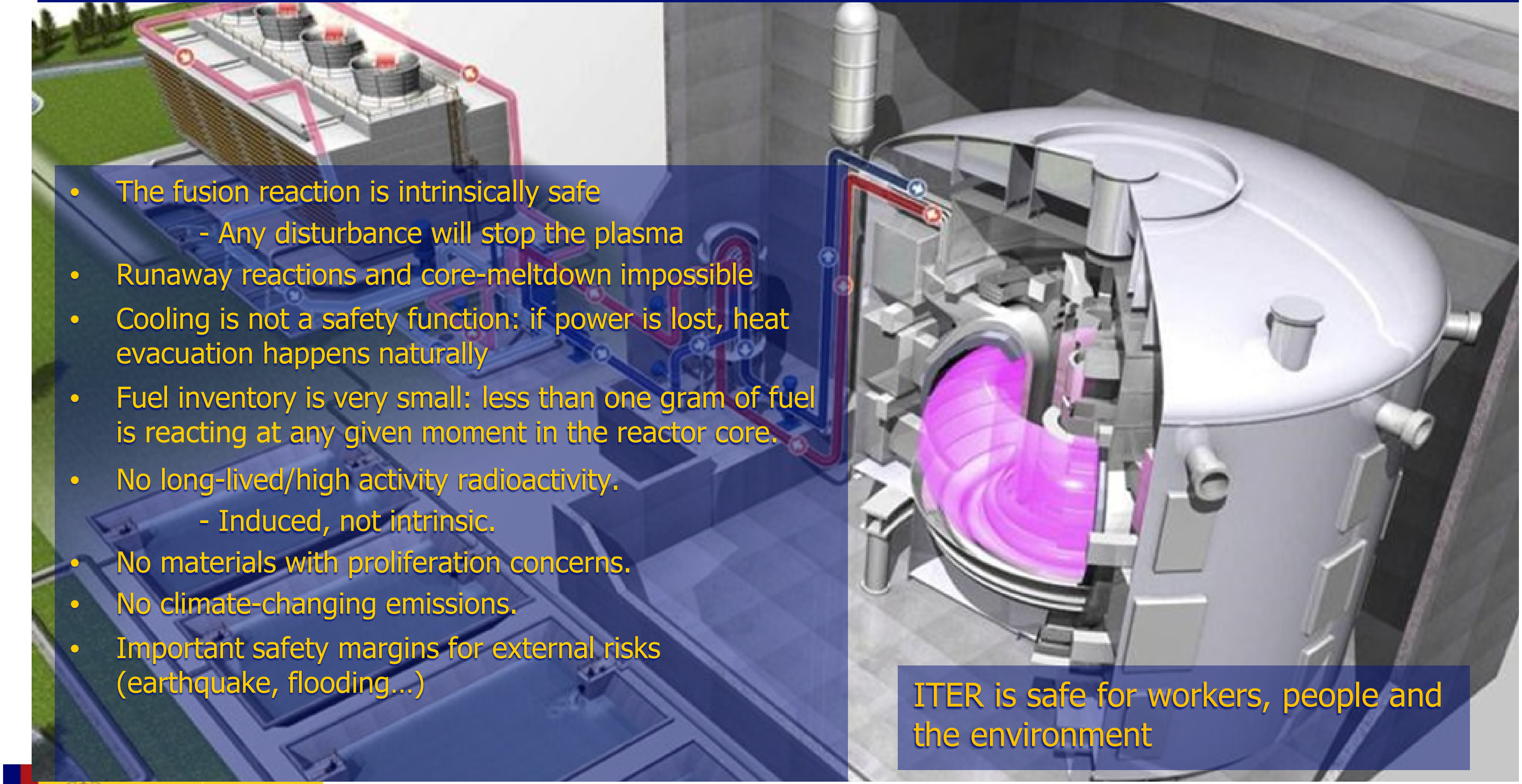
Copie : Monsieur le Directeur général de l'Autorité de sûreté nucléaire

Monsieur le Directeur général
ITER Organization
Route de Vinon sur Verdon
13115 Saint-Paul-lez-Durance

Ministère de l'écologie, du développement durable et de l'énergie

How safe is ITER?

A Fukushima-like accident is impossible in ITER



- The fusion reaction is intrinsically safe
  - Any disturbance will stop the plasma
- Runaway reactions and core-meltdown impossible
- Cooling is not a safety function: if power is lost, heat evacuation happens naturally
- Fuel inventory is very small: less than one gram of fuel is reacting at any given moment in the reactor core.
- No long-lived/high activity radioactivity.
  - Induced, not intrinsic.
- No materials with proliferation concerns.
- No climate-changing emissions.
- Important safety margins for external risks (earthquake, flooding…)

ITER is safe for workers, people and the environment

GOBIERNO DE ESPAÑA

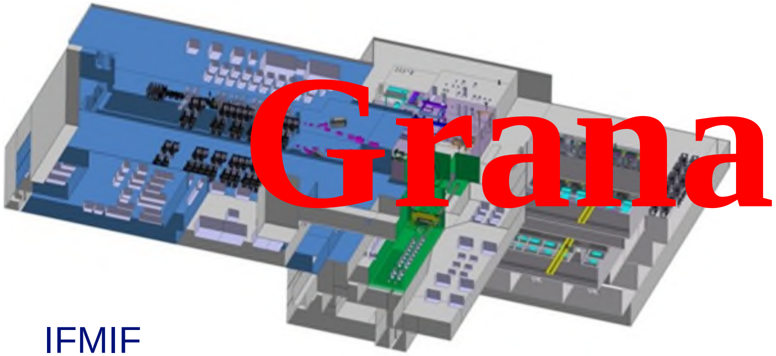
MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

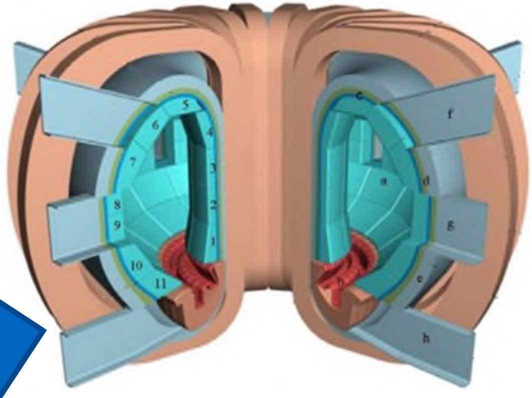
EUROPEAN ROADMAP TO NUCLEAR FUSION ENERGY

CIEMAT



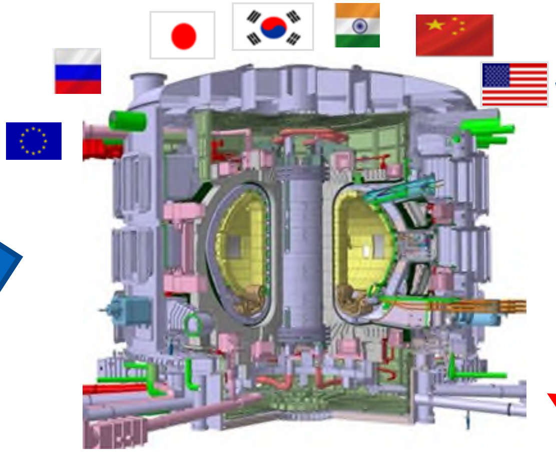
Granada?

IFMIF
2 D+ beams, 40 MeV, 125 mA on a Li target



DEMO ≥ 500 MW_{el}

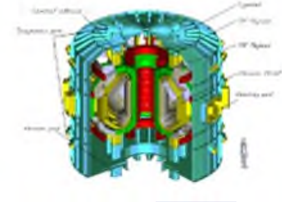
1 – 2 horas



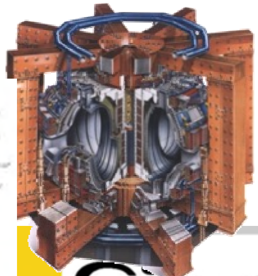
ITER – 500 MW_{th}

300– 500 secs

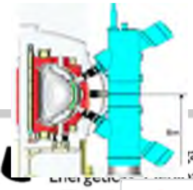
CIEMAT



K-STAR



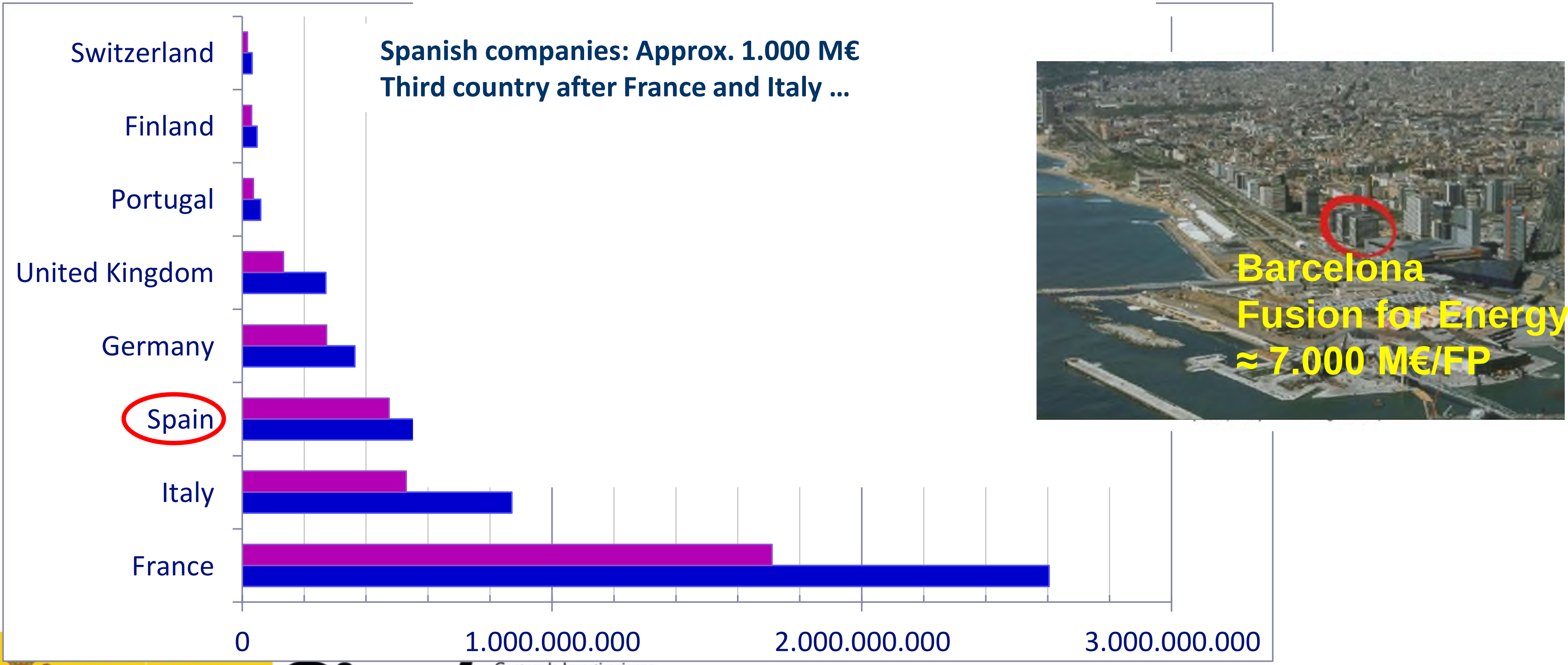
JET



JT-SU

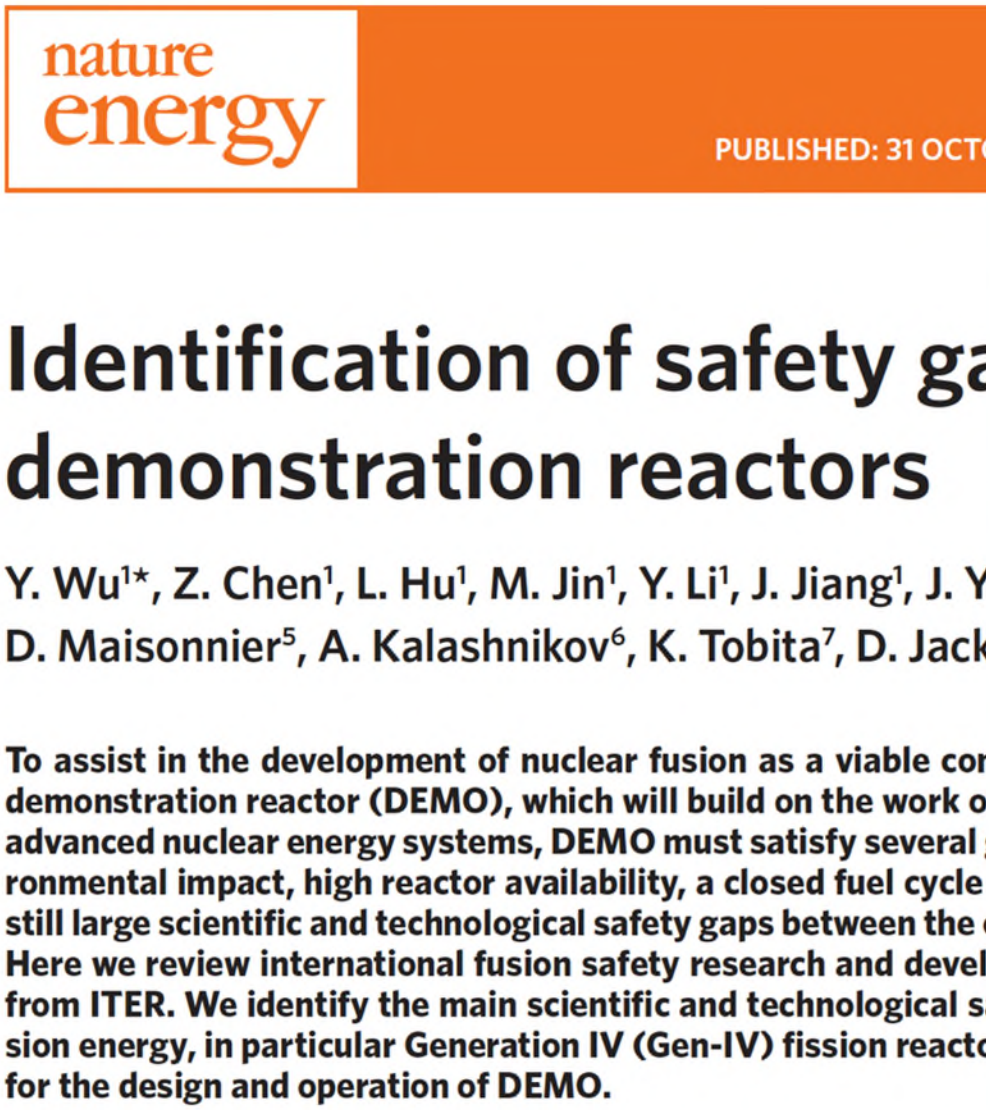
Scientific and technical returns

- 15 Univ/Centers of R+D y 5 companies participated in “Eurofusion- H2020”, coordinated by CIEMAT
- TJ-II (45% financed by UE), 60% was built by spanish companies
- The Agency “European Fusion for Energy” is in Spain (working budget 45 M€/year, 350 personas, Barcelona)
- Industrial european contracts for ITER at F4E:



Spanish companies: Approx. 1.000 M€
Third country after France and Italy …

Barcelona
Fusion for Energy
≈ 7.000 M€/FP



nature energy

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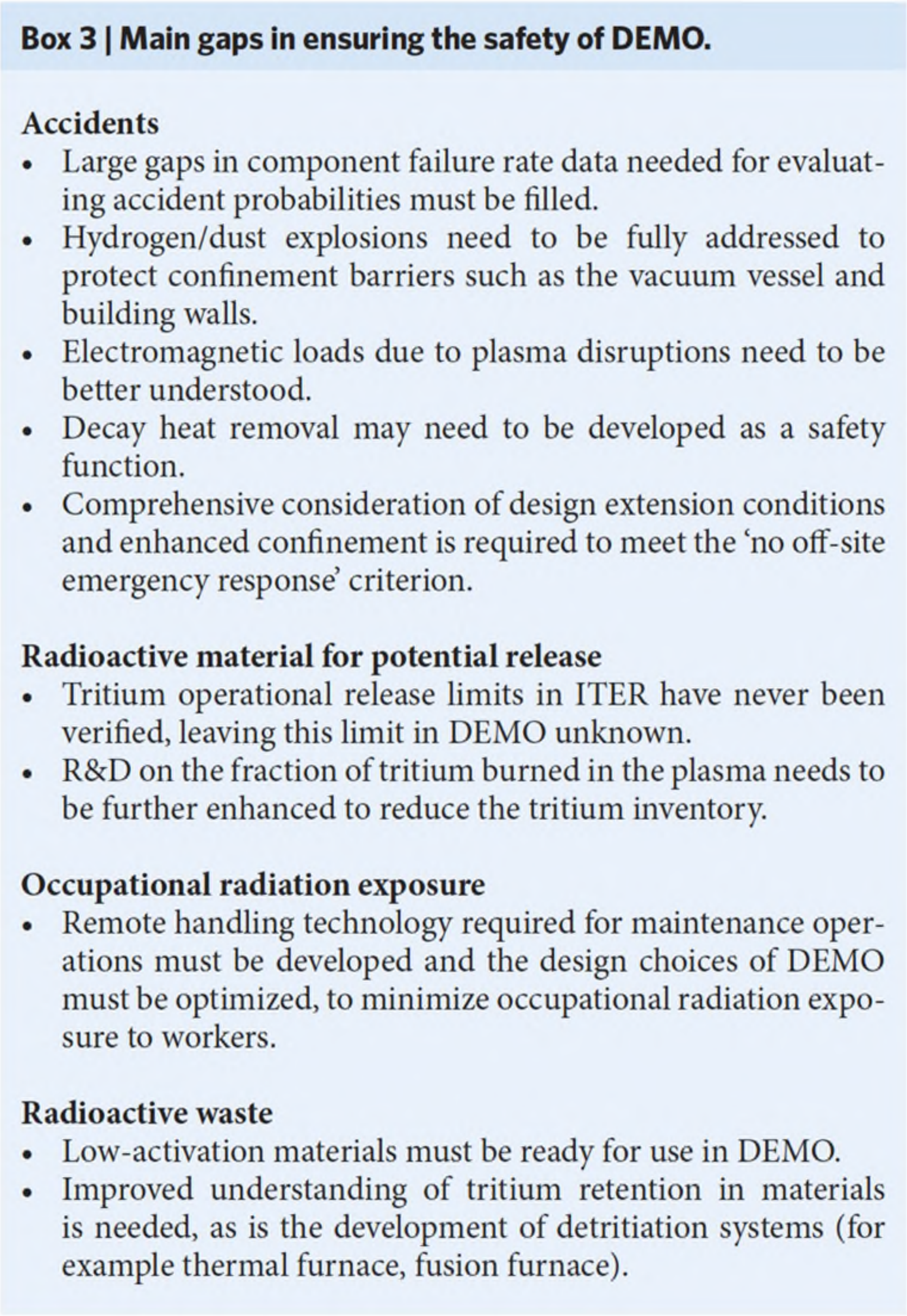
Identification of safety ga demonstration reactors

Y. Wu[1]*, Z. Chen[1], L. Hu[1], M. Jin[1], Y. Li[1], J. Jiang[1], J. Y
D. Maisonnier[5], A. Kalashnikov[6], K. Tobita[7], D. Jack

To assist in the development of nuclear fusion as a viable co
demonstration reactor (DEMO), which will build on the work o
advanced nuclear energy systems, DEMO must satisfy several
ronmental impact, high reactor availability, a closed fuel cycle
still large scientific and technological safety gaps between the
Here we review international fusion safety research and devel
from ITER. We identify the main scientific and technological s
sion energy, in particular Generation IV (Gen-IV) fission react
for the design and operation of DEMO.



Box 3 | Main gaps in ensuring the safety of DEMO.

Accidents

- Large gaps in component failure rate data needed for evaluating accident probabilities must be filled.
- Hydrogen/dust explosions need to be fully addressed to protect confinement barriers such as the vacuum vessel and building walls.
- Electromagnetic loads due to plasma disruptions need to be better understood.
- Decay heat removal may need to be developed as a safety function.
- Comprehensive consideration of design extension conditions and enhanced confinement is required to meet the 'no off-site emergency response' criterion.

Radioactive material for potential release

- Tritium operational release limits in ITER have never been verified, leaving this limit in DEMO unknown.
- R&D on the fraction of tritium burned in the plasma needs to be further enhanced to reduce the tritium inventory.

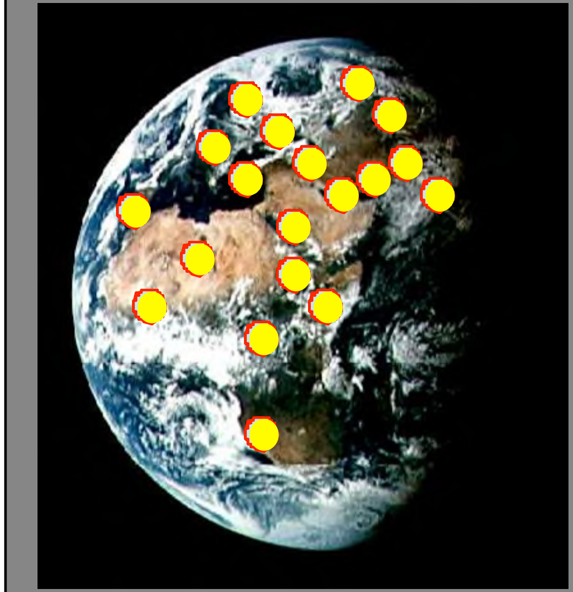
Occupational radiation exposure

- Remote handling technology required for maintenance operations must be developed and the design choices of DEMO must be optimized, to minimize occupational radiation exposure to workers.

Radioactive waste

- Low-activation materials must be ready for use in DEMO.
- Improved understanding of tritium retention in materials is needed, as is the development of detritiation systems (for example thermal furnace, fusion furnace).

Ultimos comentarios



- No hay una solución sencilla, ni probablemente única al problema energético de la Humanidad. Intensificar la investigación en Energía es una necesidad.
- Viabilidad científica de la fusión ha sido demostrada (16 MW en JET).
- El Laboratorio mundial ITER, la demostración tecnológica, se está instalando en Europa (Cadarache). Barcelona acoge la Agencia Europea del proyecto.
- La investigación en Fusion Nuclear esta en un momento muy positivo tanto con las iniciativas publicas como las privadas

Fusión nuclear es una realidad y puede ser la fuente de energía inagotable, barata y medioambientalmente aceptable del Futuro si resolvemos todos sus retos (incluidos los nucleares)