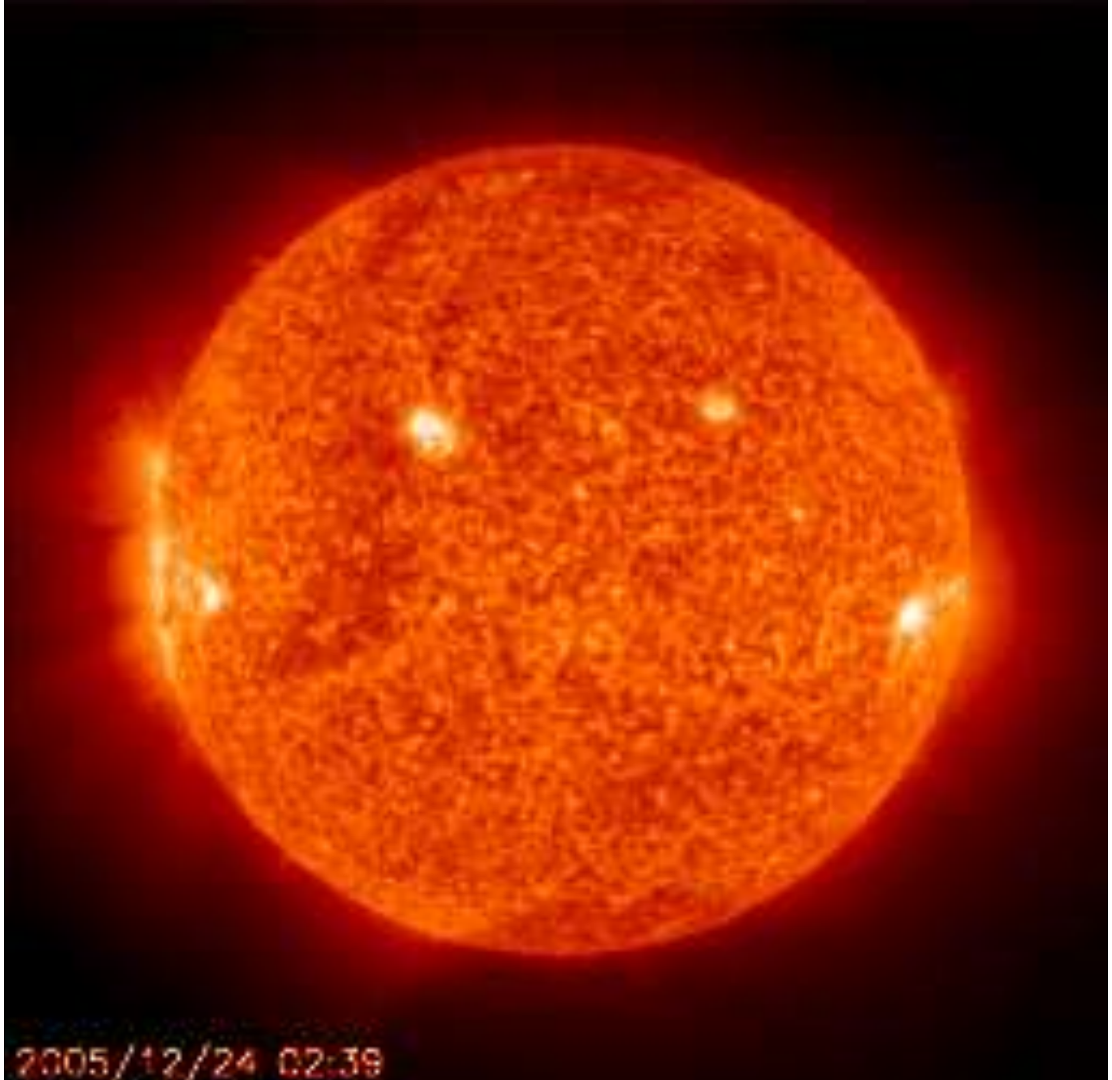
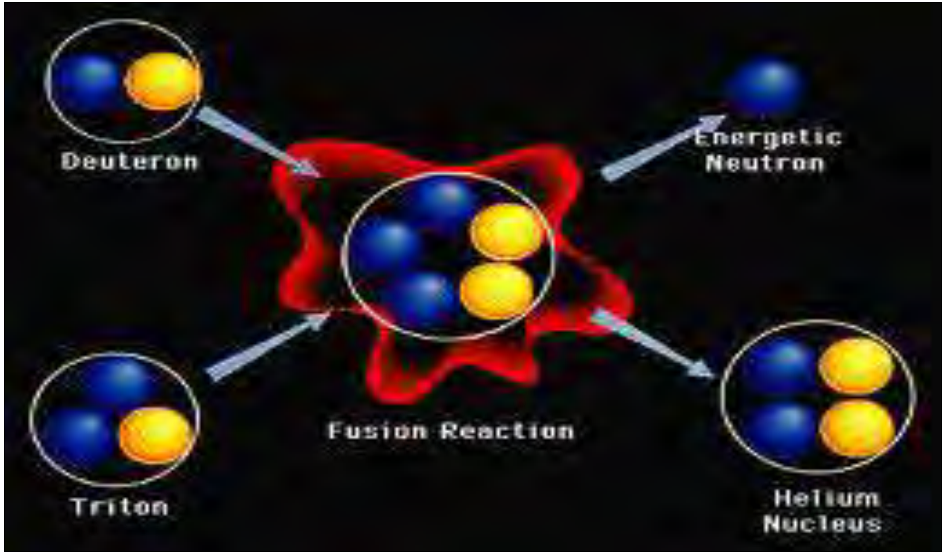
Potencijali fuzijskih elektrana

Tonči Tadić

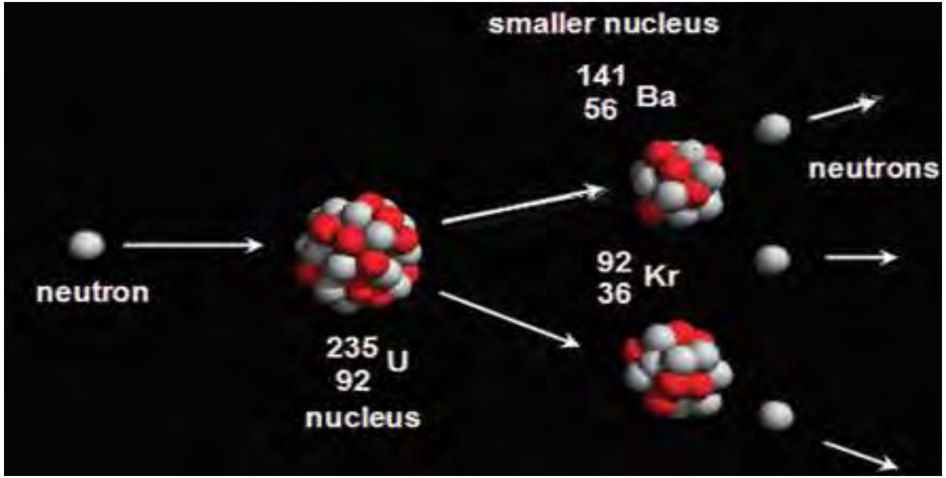
Institut Ruđer Bošković


2005/12/24 02:39

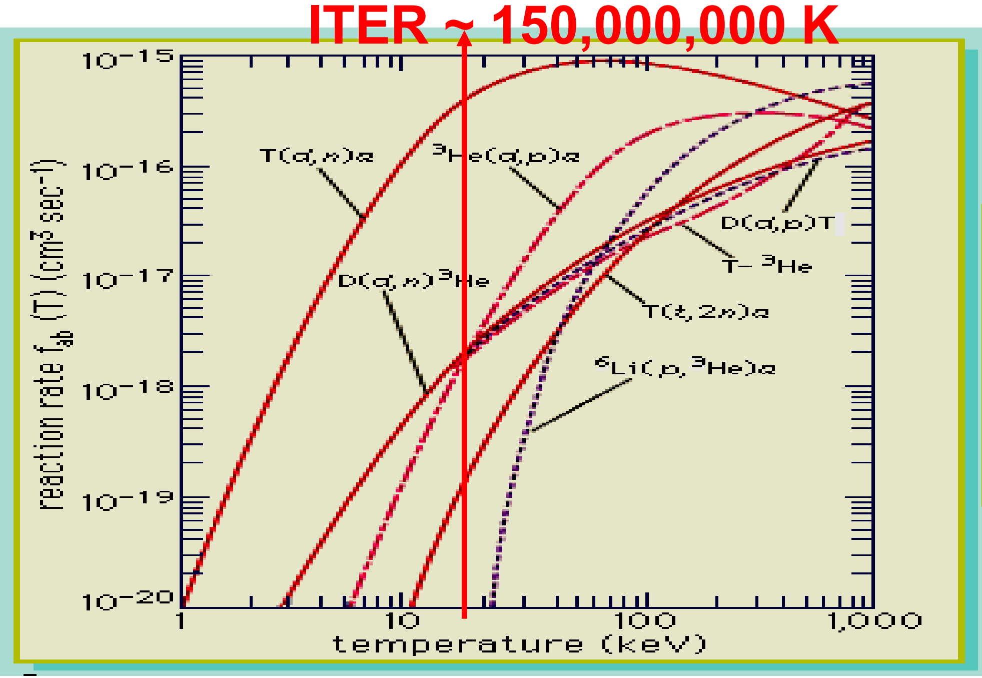
Fuzija = spajanje jezgri rezultira oslobađanjem energije
- Velika energija po jedinici mase



Fisija = razbijanje jezgre rezultira oslobađanjem energije

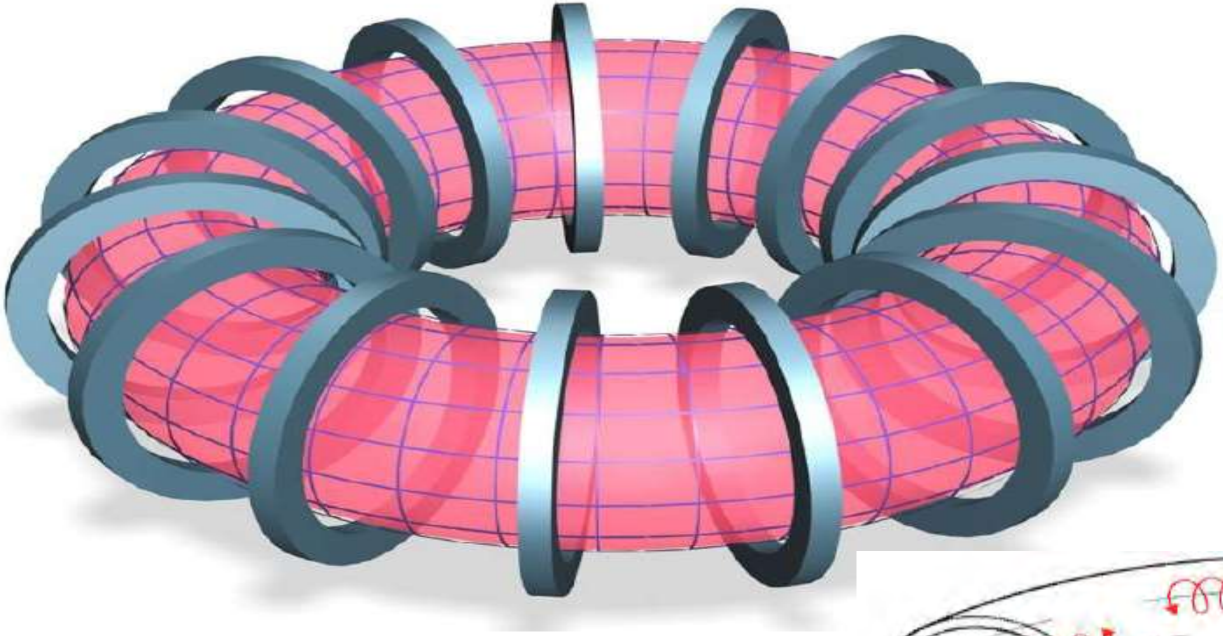


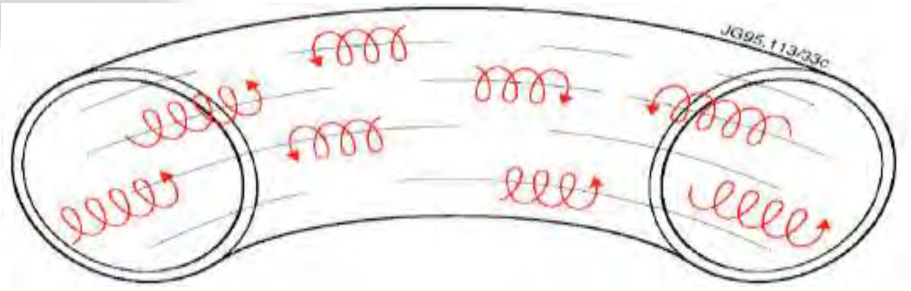
REACTION	ENERGY RELEASE	NOTES
$^{2}D_{1} + {}^{3}T_{1} \rightarrow {}^{4}He_{2} + n$	17.6 MeV (2.8×10^{-12} J)	Large cross section - $T_R > 10^8$ K
$^{1}H_{1} + {}^{1}H_{1} \rightarrow {}^{2}D_{1} + \beta^{+} + \nu$	0.42 MeV (6.7×10^{-14} J) + 1.02MeV from β^{+} + e	Small cross section - $T_R > 10^8$ K
$^{1}H_{1} + {}^{2}D_{1} \rightarrow {}^{3}He_{2} + \gamma$	5.49 MeV (8.7×10^{-13} J)	Medium cross section - $T_R > 10^8$ K
$^{2}D_{1} + {}^{2}D_{1} \rightarrow {}^{3}He_{2} + n$	3.32 MeV (5.3×10^{-13} J)	Small cross section - $T_R > 10^9$ K
$^{2}D_{1} + {}^{2}D_{1} \rightarrow {}^{1}H_{1} + T$	4.04 MeV (6.4×10^{-13} J)	Small cross section - $T_R > 10^9$ K



One keV is equivalent to a temperature of 11,000,000 K. The rate of reaction between deuterium and tritium is seen to be higher than all others and is very substantial, even at temperatures in the 5- to 10-keV range (see text).

TOKAMAK
TOroidalnaja KAmera s MAgnitnimi Katuškami



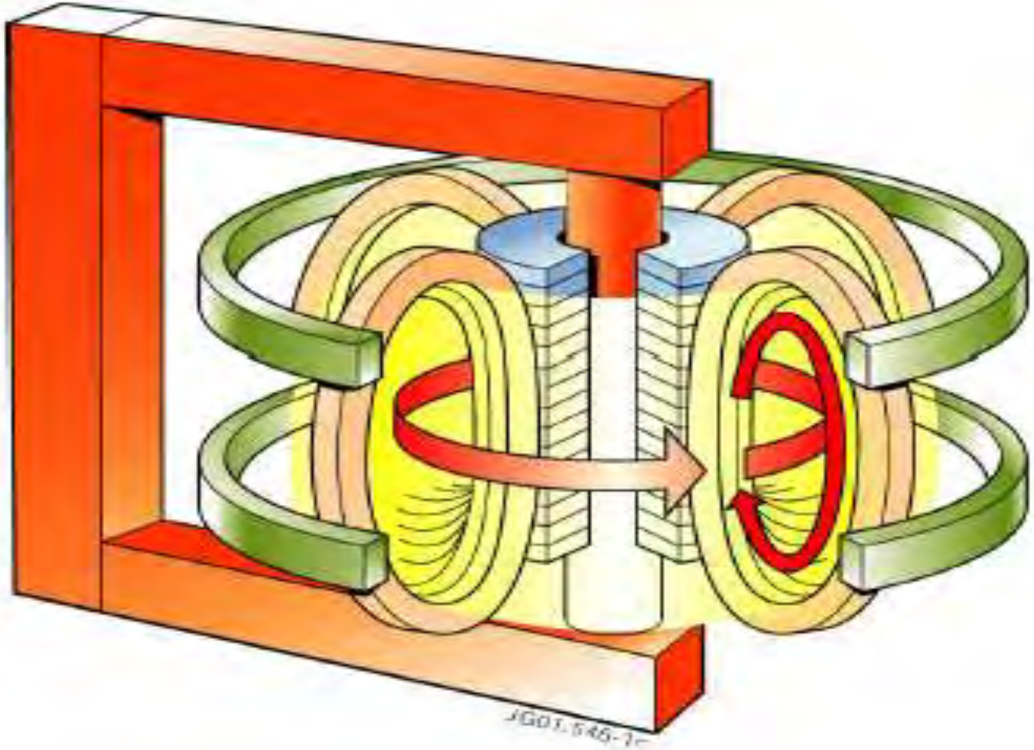


Pozitivni i negativni naboji u magnetskom polju kruže u suprotnom smjeru

Ako postoji neka vanjska sila, npr. sila teže / gravitacija, pozitivni i negativni naboji u magnetskom polju se razilaze

Ako magnetsko polje nije homogeno, pozitivni i negativni naboji se razilaze

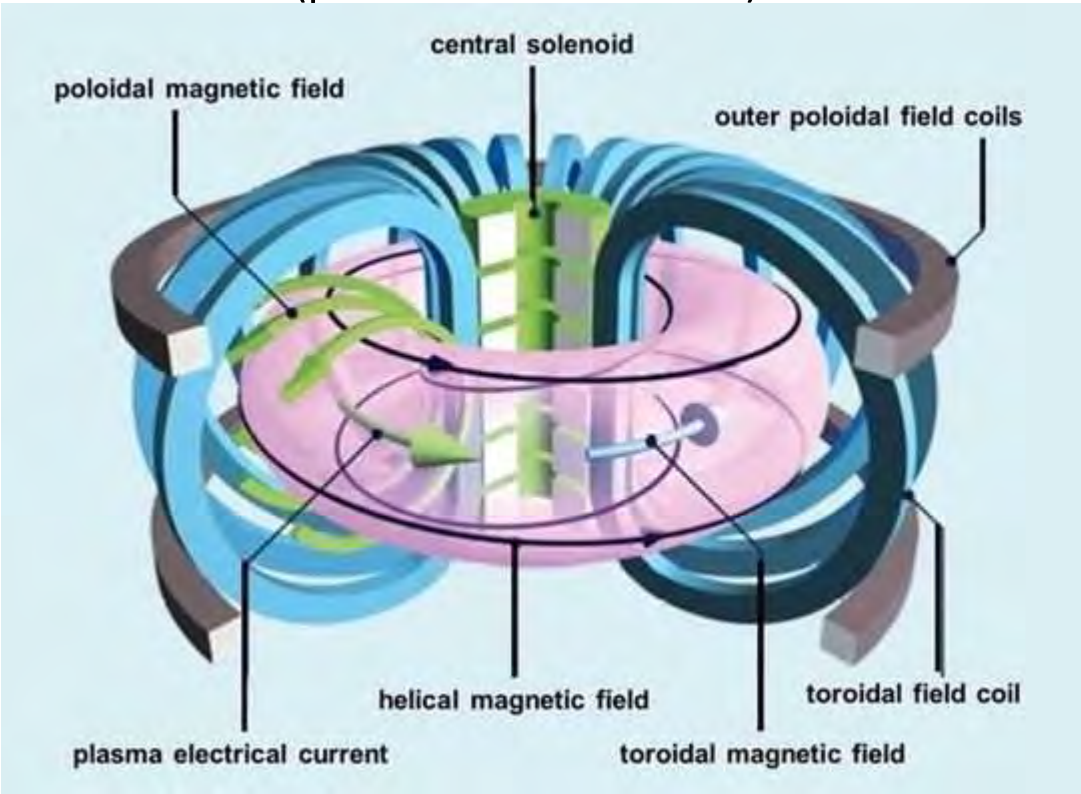
RJEŠENJE: UVESTI STRUJU U PLAZMU POMOĆU MAGNETSKE INDUKCIJE – SLIČNO PRIMARU I SEKUNDARU U TRANSFORMATORU



Centralni solenoid
(primar transformatora)

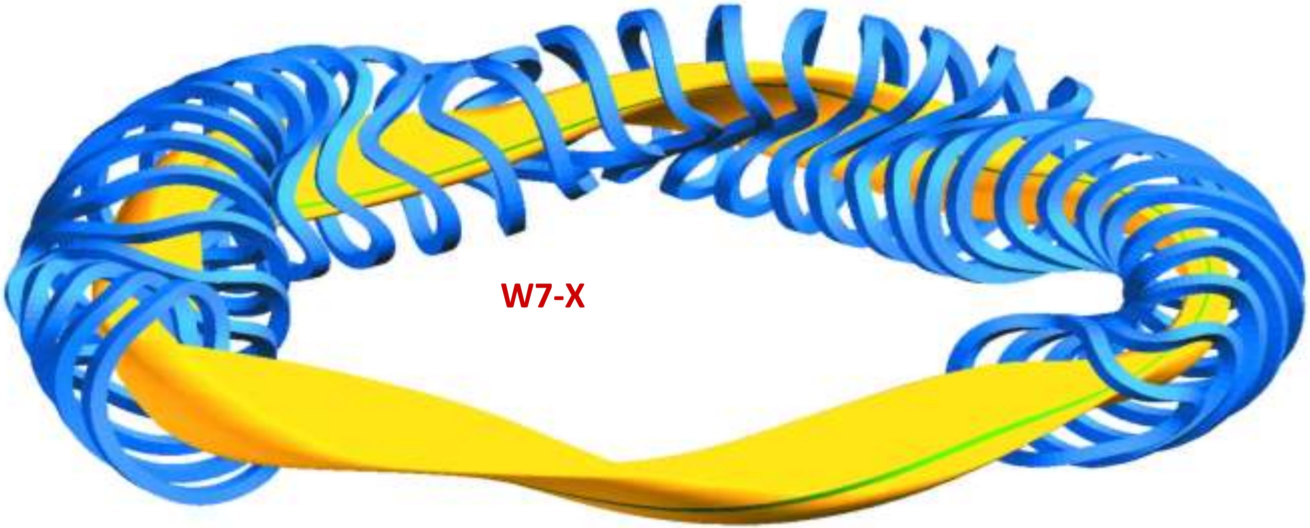
Poloidalno
magnetsko polje

Poloidalne
zavojnice



Inducirana struja
plazme (sekundar
transformatora)

Toroidalne
zavojnice

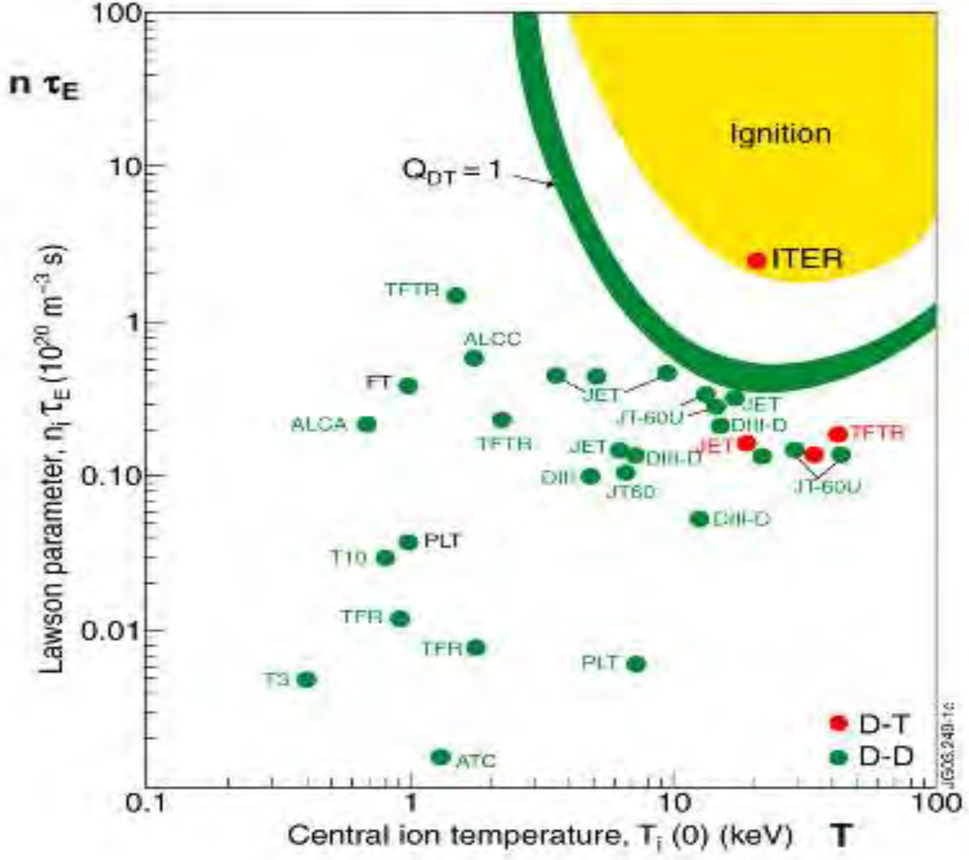


A long term alternative to the tokamak: Stellarators

Stellarator “Wendelstein” W7-X


Plasma

Lawson Criterium



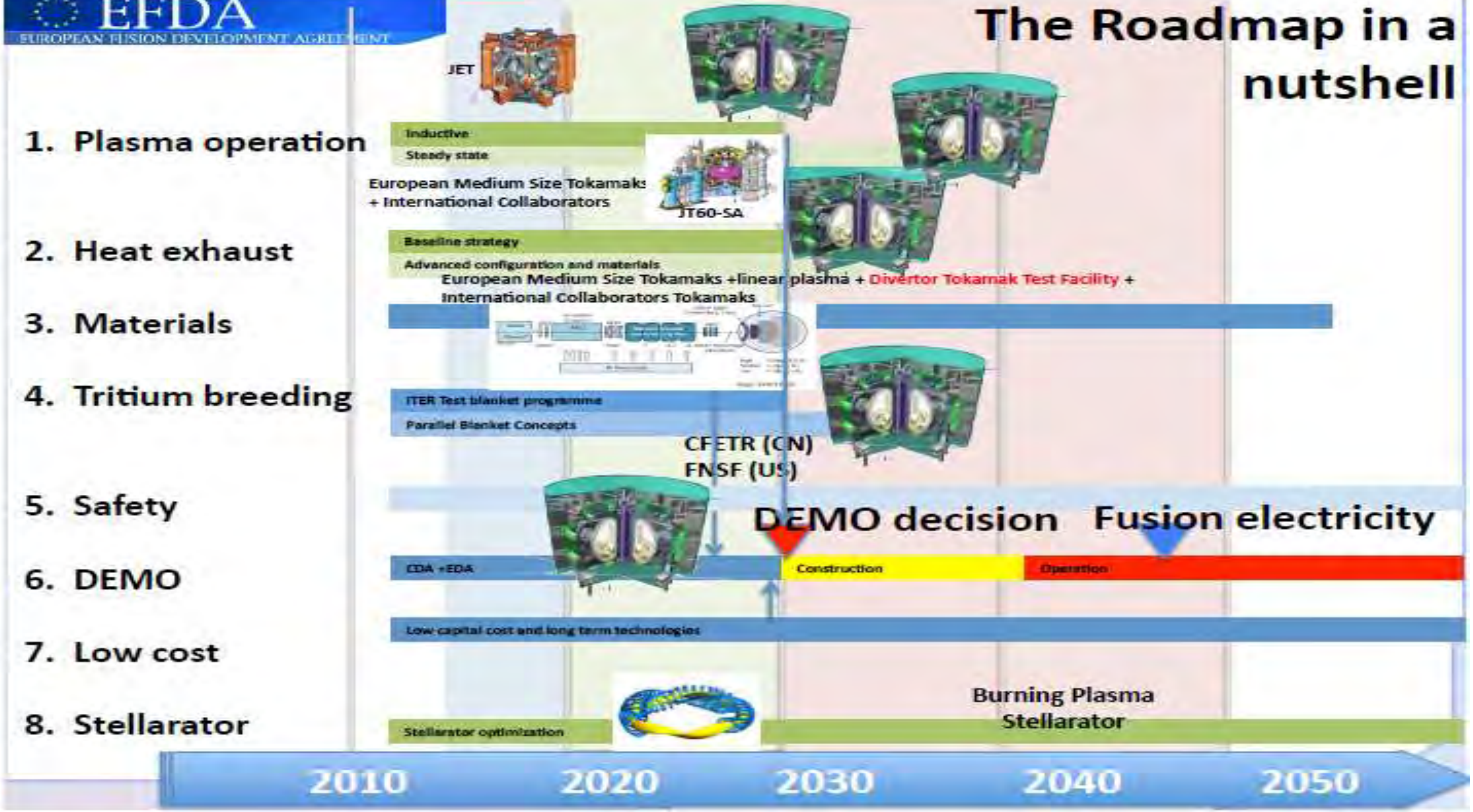
Triple product criterium to achieve ignition: the fusion of D+T

$$n_e T \tau_E \geq 10^{21} \text{keV s/m}^3$$

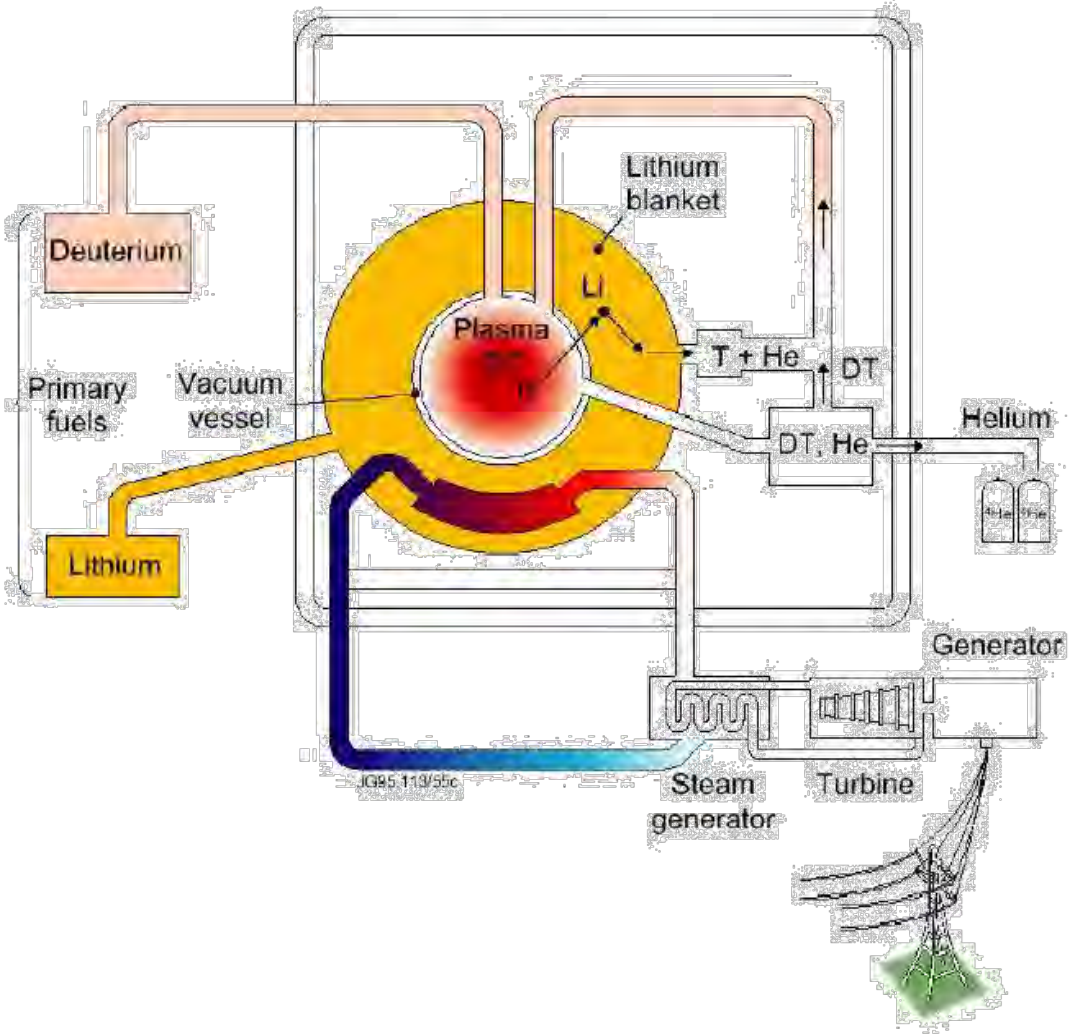
n_e – density
T – temperature
τ_E – confinement time

EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

The Roadmap in a nutshell



KONCEPT FUZIJSKE ELEKTRANE



Preliminary DEMO plant layout

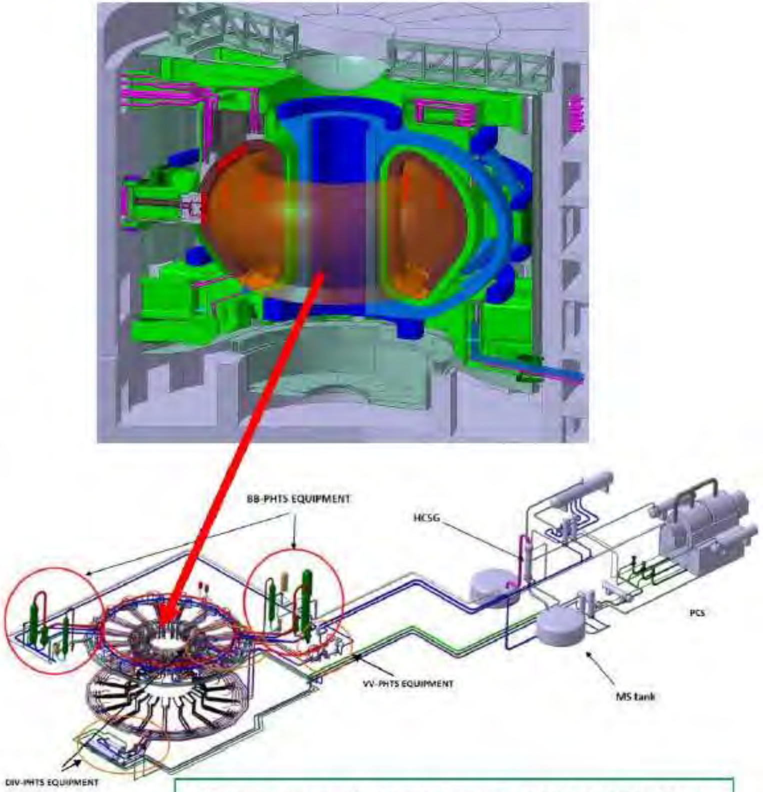
Courtesy: C. Gliss

DEMO Preconceptual design finished

- Preconceptual DEMO design activities from H2020 will soon be published in a special issue of Fusion Engineering and Design

  https://www.sciencedirect.com/journal/fusion-engineering-and-design/special-issue/10KZQ5JW058

- An extensive Gate Review process was organised to decide whether or not to go into the Conceptual Design Stage and, if so, what would be the starting point



G. Federici et al., Nucl. Fusion 59 (2019) 066013.

Fuzijski program EU

Za početnike

- EUROfusion = H2020 projekt
- Konzorcij 28 vodećih instituta + 156 Linked 3rd Parties
- Članice EU + CH + UK + UA
- Vodi fuzijska istraživanja
- Priprema dizajn ITER
- Priprema dizajn DEMO fuzijske elektrane
- Priprema dizajn neutronskog izvora za testiranje materijala za DEMO = DONES, u WPENS

- Fusion for Energy = agencija EU
- Na čelu Governing Board, po 2 člana iz članica EU + 2 EC
- Okuplja poslovni sektor
- Gradi ITER
- Vodi suradnju s Japanom
- Priprema gradnju DEMO fuzijske elektrane

EUROfusion 2022

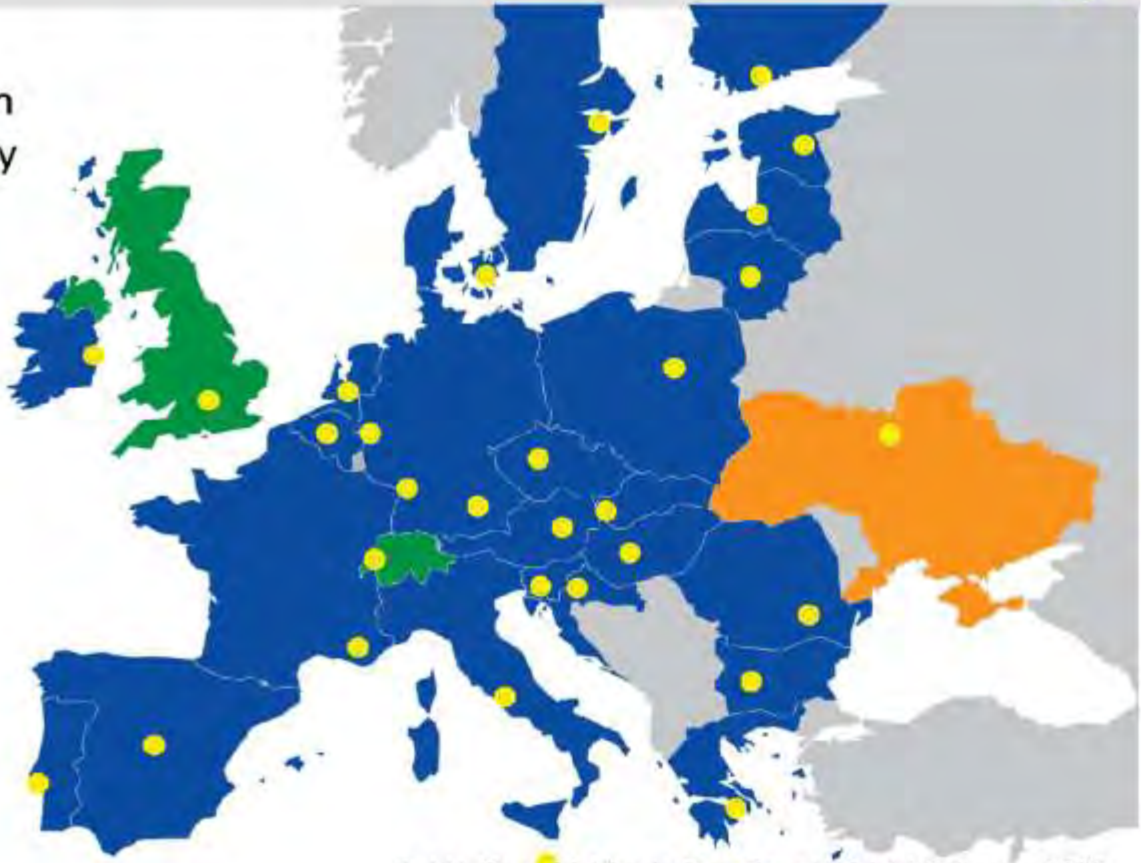
EUROfusion integrates R&D in fusion science and technology

28 Countries:

25 EU Member States

1 Associated Member

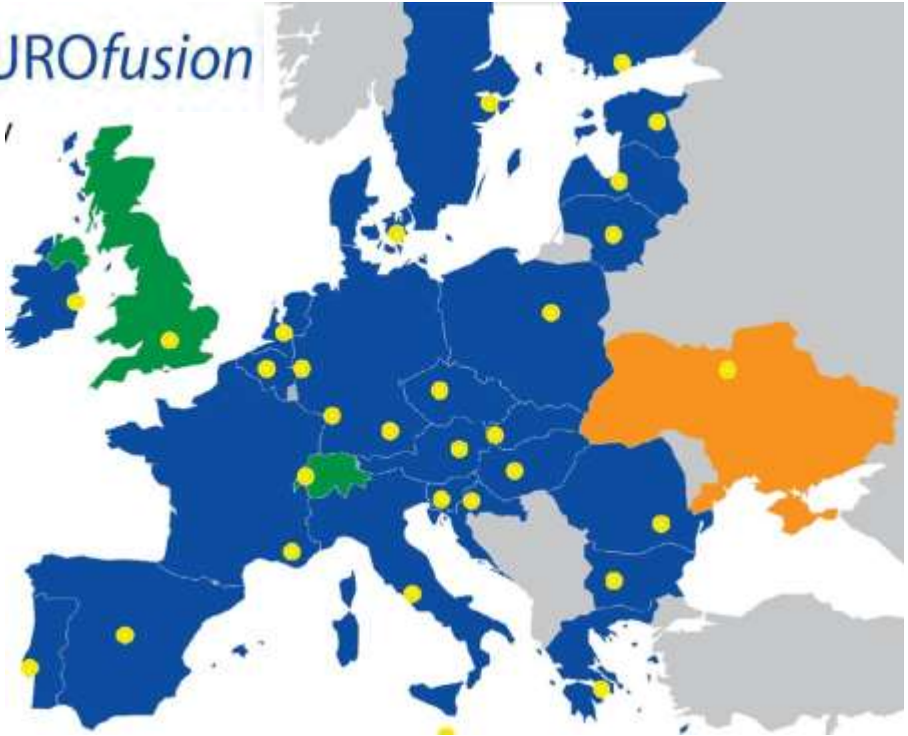
2 Associated Partners to IPP



Croatia actively participates in EUROfusion research

CROATIAN
FUSION
RESEARCH
UNIT

EUROfusion

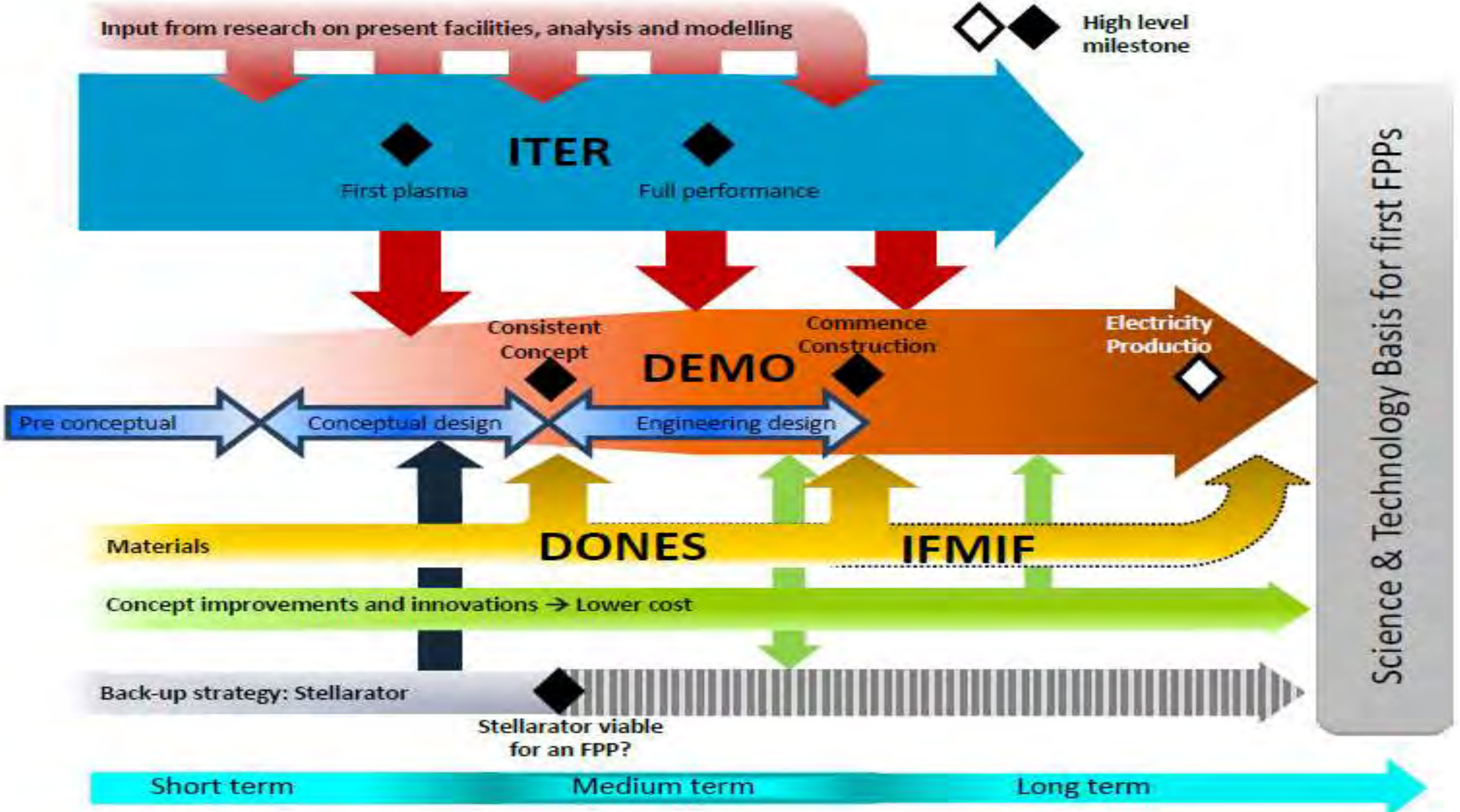


Industrial
Partners

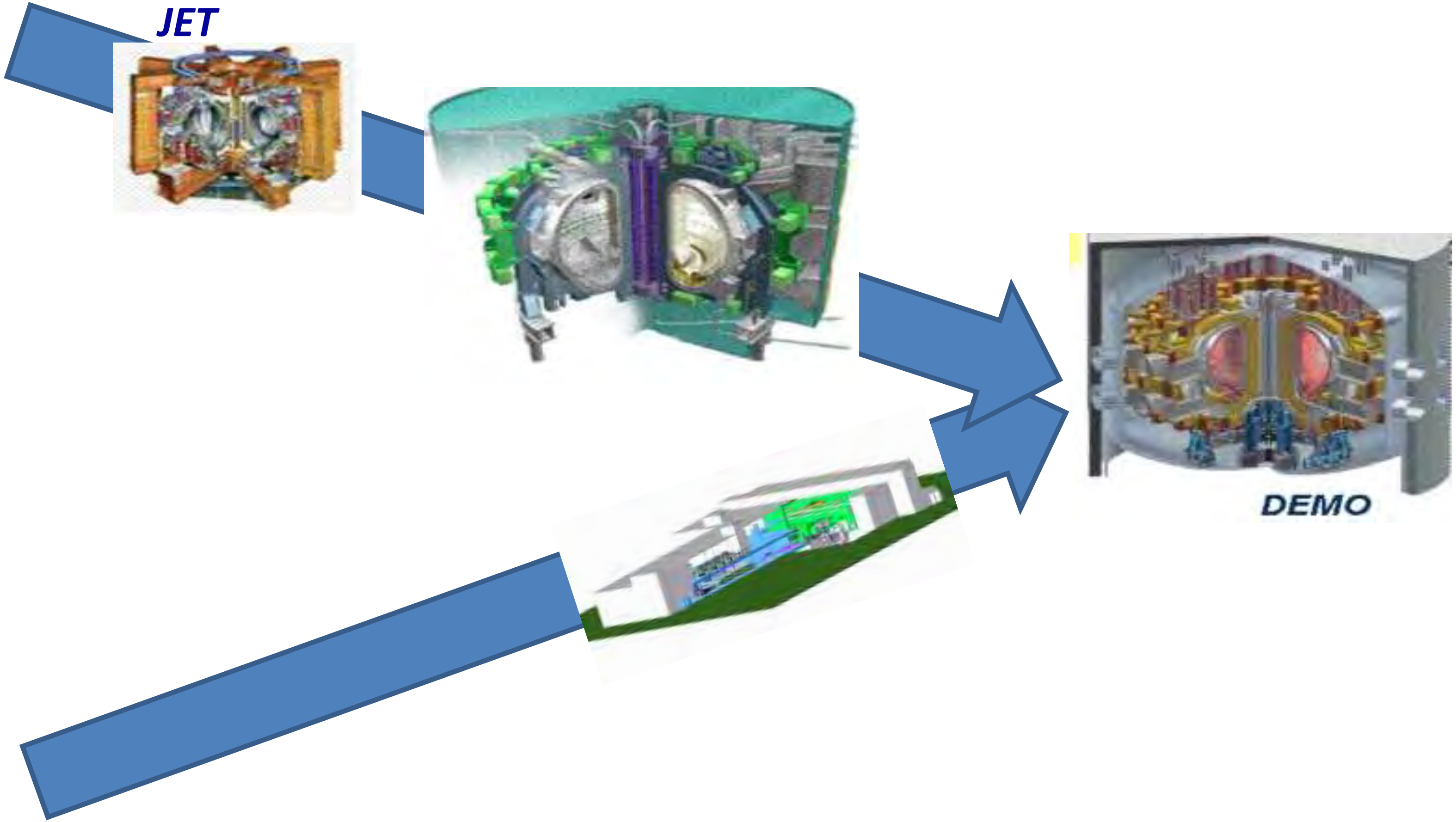
INETEC

APoS

EU Fusion Roadmap to Fusion Electricity (v2.0)



DONES je od jednake važnosti kao ITER za gradnju prve fuzijske elektrane DEMO



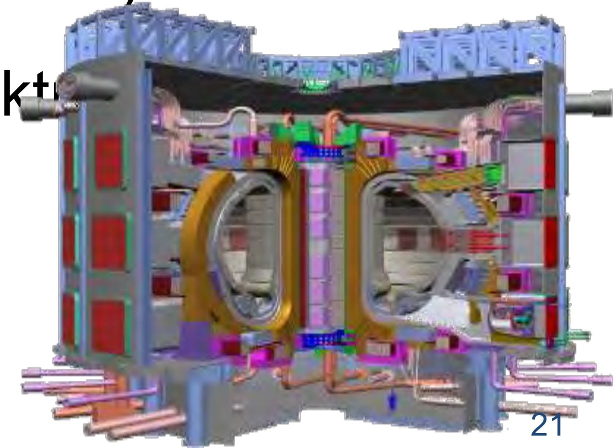
Ciljevi ITER-a

- Dokazati znanstvenu i tehnološku mogućnost dobivanja energije iz kontrolirane fuzije

  U tu svrhu treba:

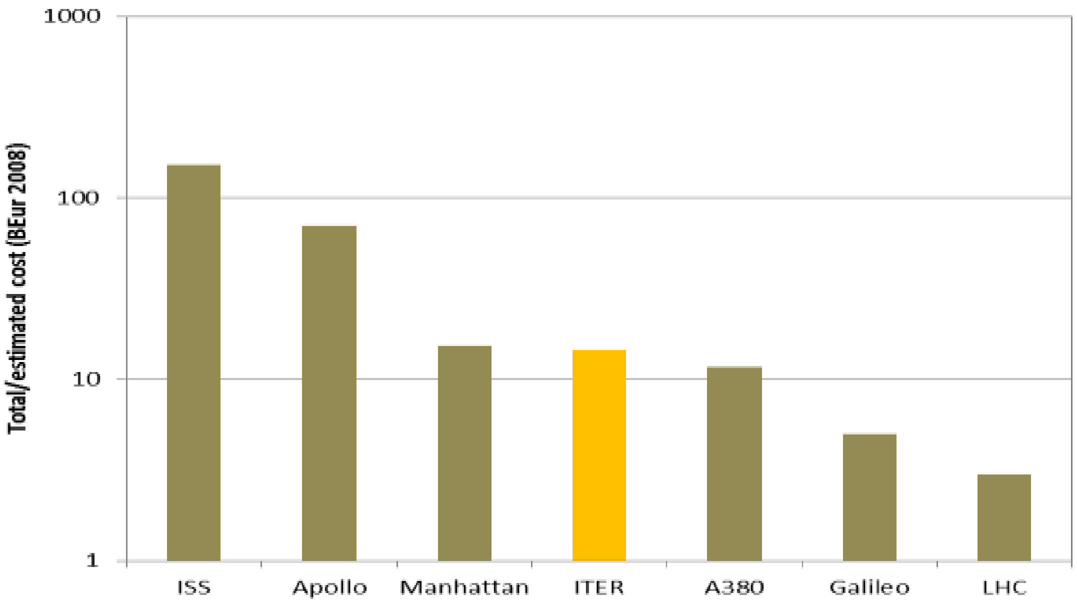
- Proučavati i optimizirati ponašanje vruće plazme
- Proizvesti 500 MW of fuzijske energije (Q>10)
- Testirati tehnologije nužne za fuzijsku elekt
- Raditi oko 20 godina

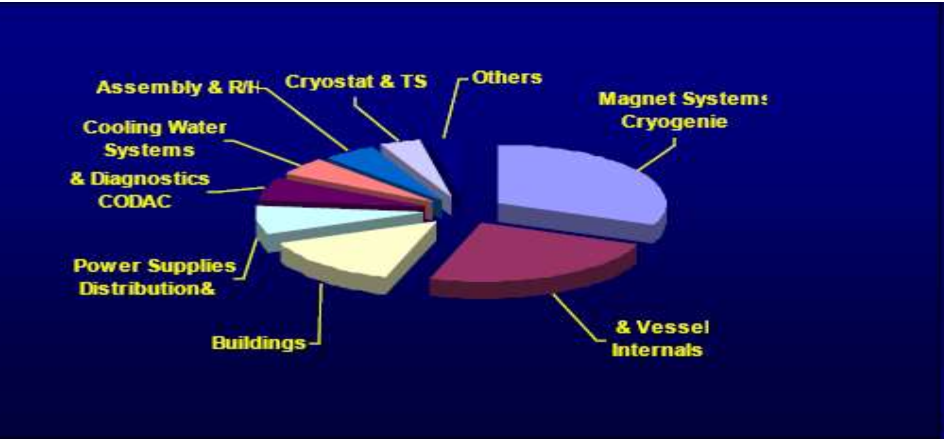
“ITER” na latinskom znači “put”

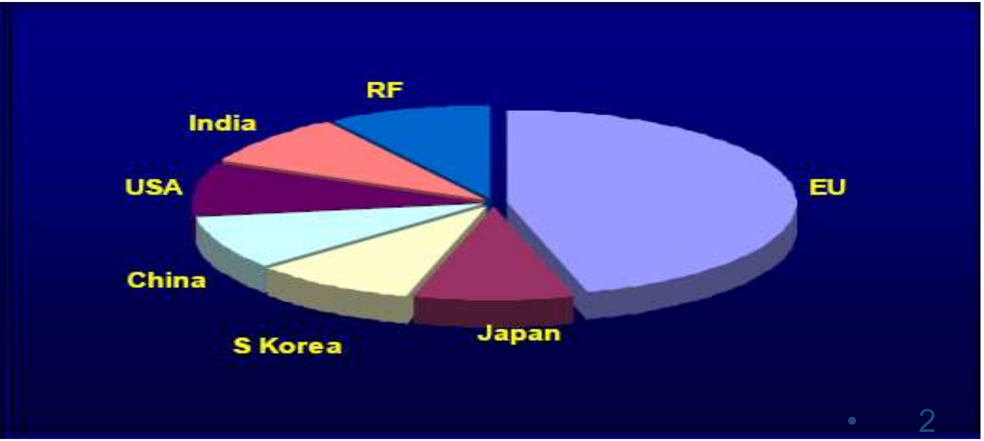


Tko gradi ITER ?

- Ukupno 15 G EUR
- Oko 90% su materijalne donacije članica
- Donacije u 85 "paketa"
- EU finanira 45 % ITER-a kroz Fusion for Energy (F4E)



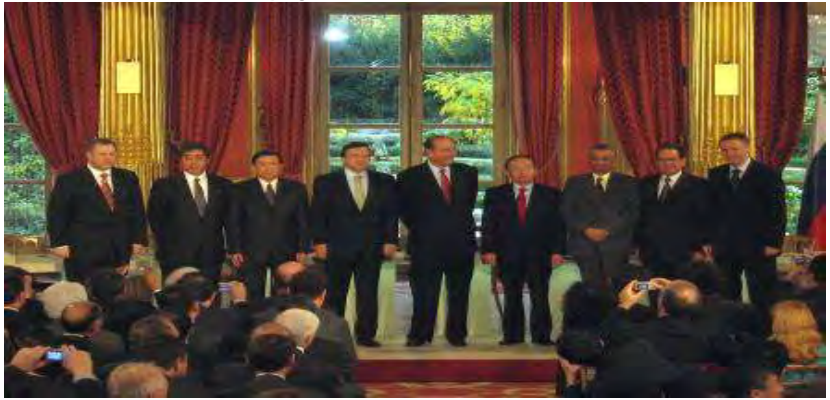




History of ITER

“For the benefit of mankind ”

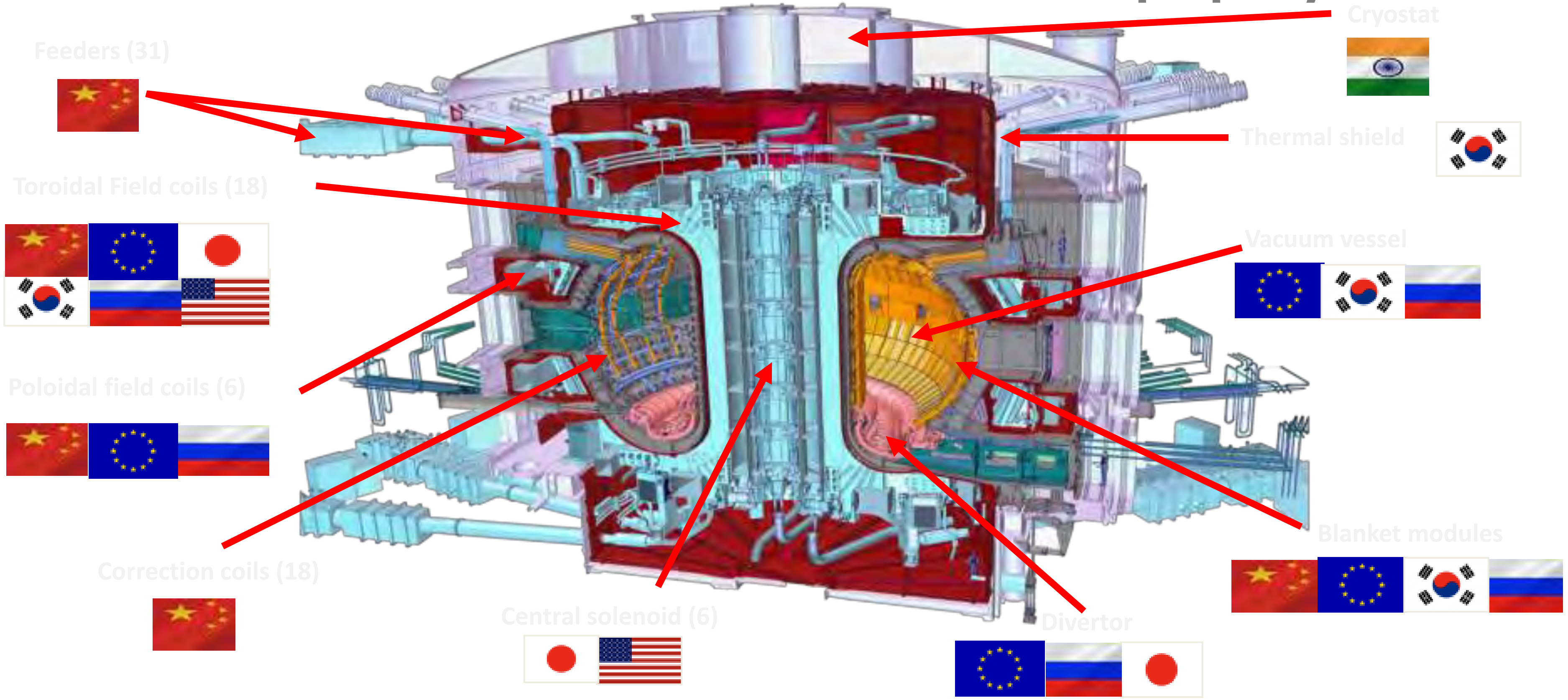
- **The idea for ITER originated from the Geneva Superpower Summit in 1985 where Gorbachev and Reagan proposed international effort to develop fusion energy…**
- …“*as an inexhaustible source of energy for the benefit of mankind*”.



November 21, 2006: China, Europe, India, Japan, Korea, the Russian Federation and the United States of America sign the ITER Agreement

Who manufactures what?

The ITER Members share all intellectual property



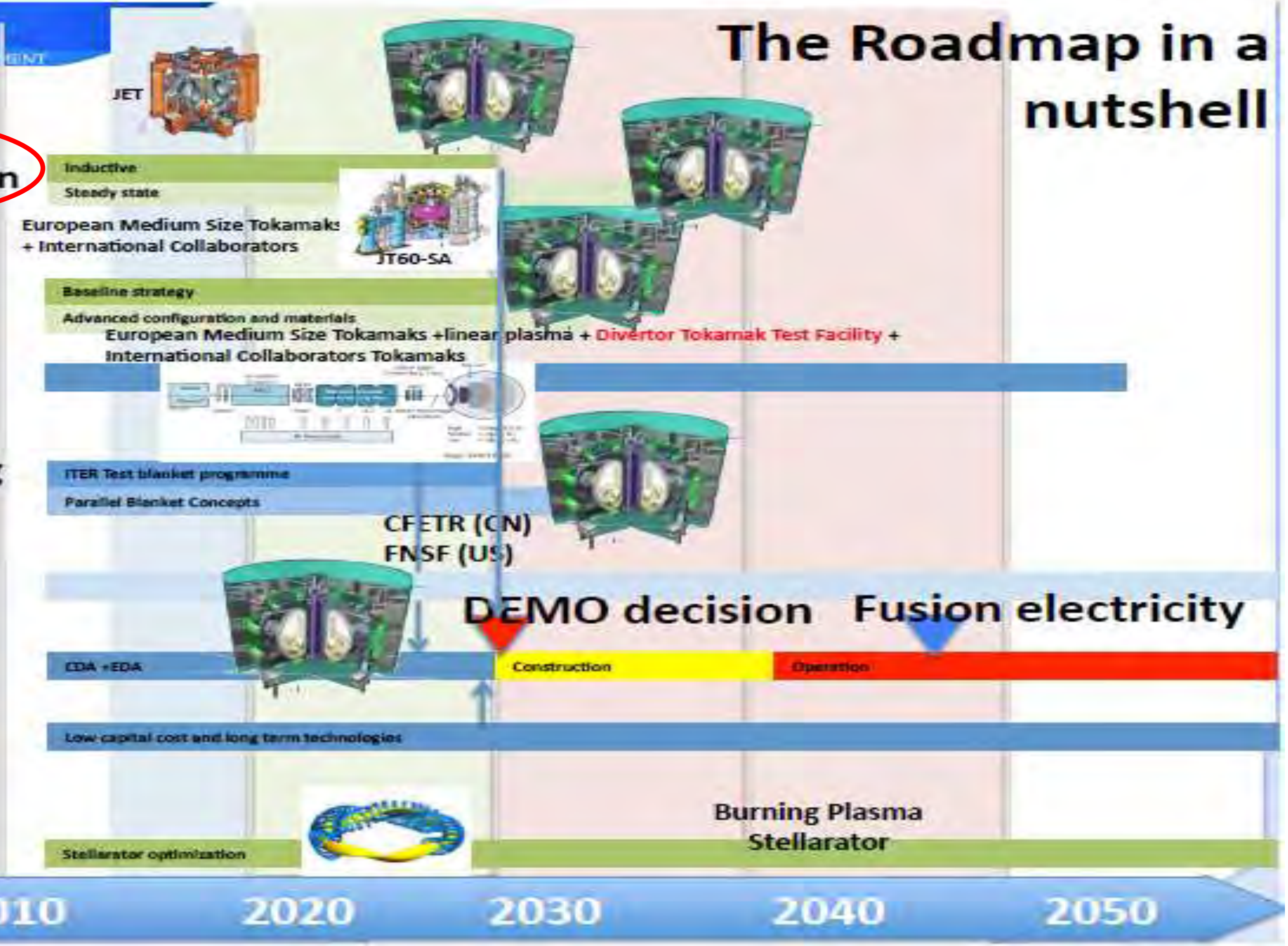
A staged approach to DT plasma

Extensive interactions among IO and DAs to finalize revised baseline schedule proposal

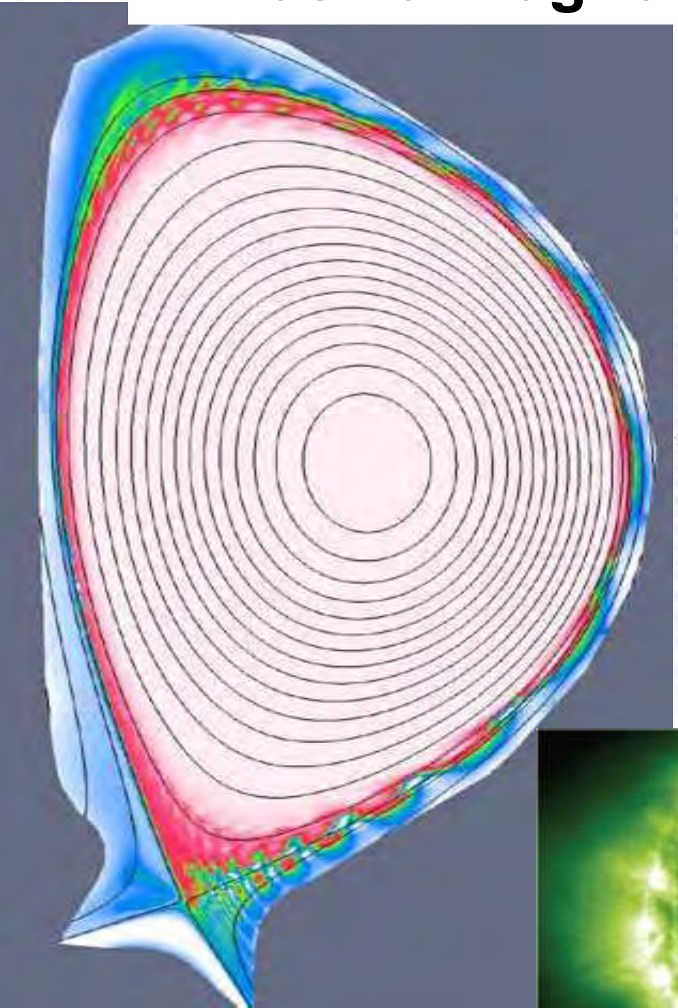
- ✓ Schedule and resource estimates through First Plasma (2025) consistent with Members' budget constraints
- ✓ Proposed use of 4-stage approach through Deuterium-Tritium (2035) consistent with Members' financial and technical constraints

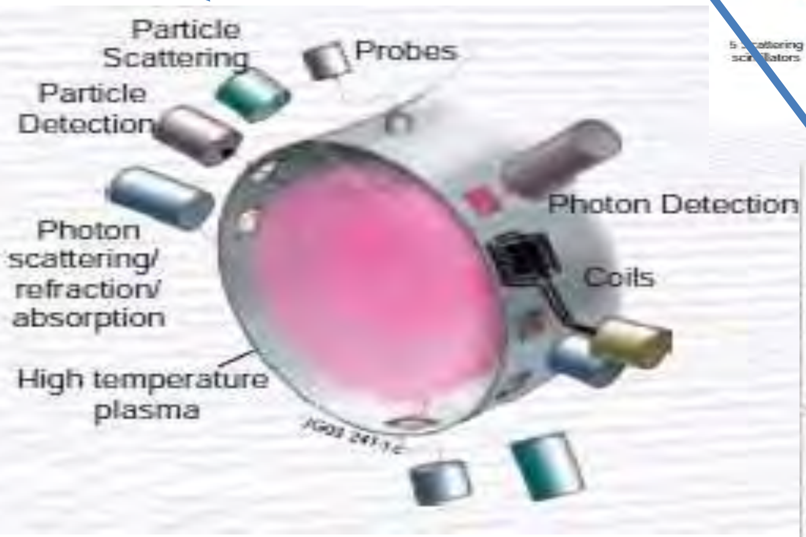
The Roadmap in a nutshell

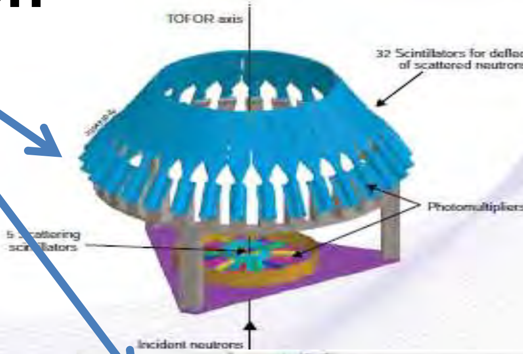
1. Plasma operation
2. Heat exhaust
3. Materials
4. Tritium breeding
5. Safety
6. DEMO
7. Low cost
8. Stellarator

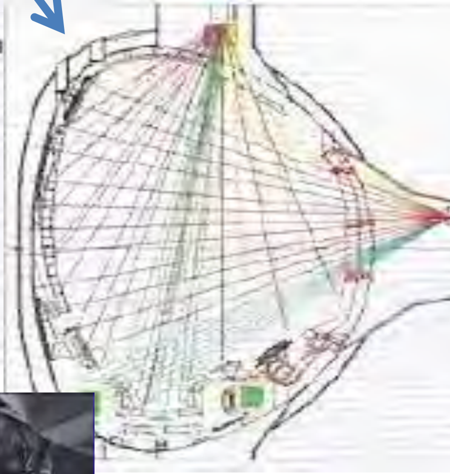


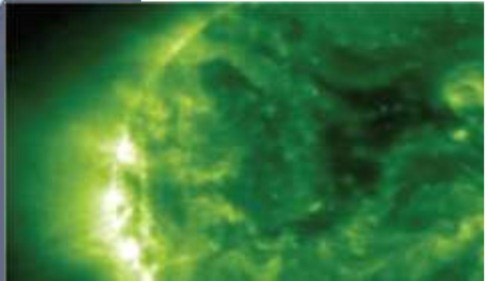
Plasma Diagnostics & Neutron detection



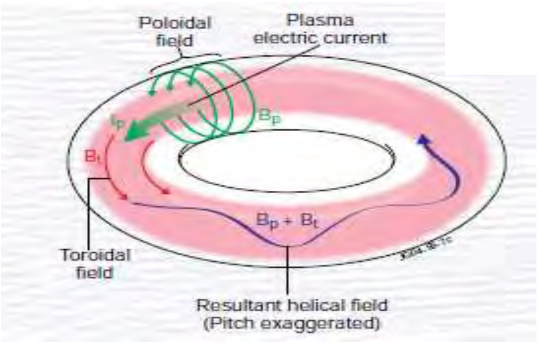




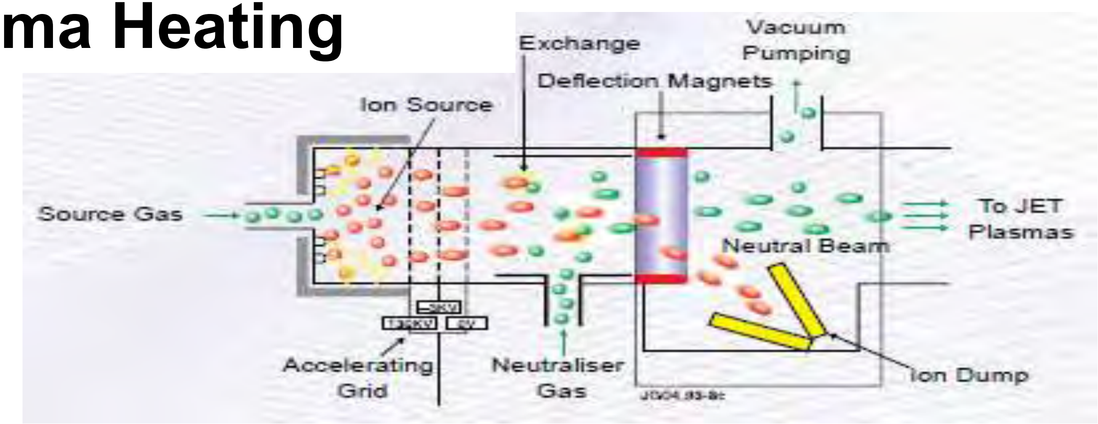




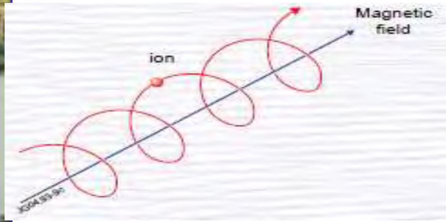
Plasma Heating



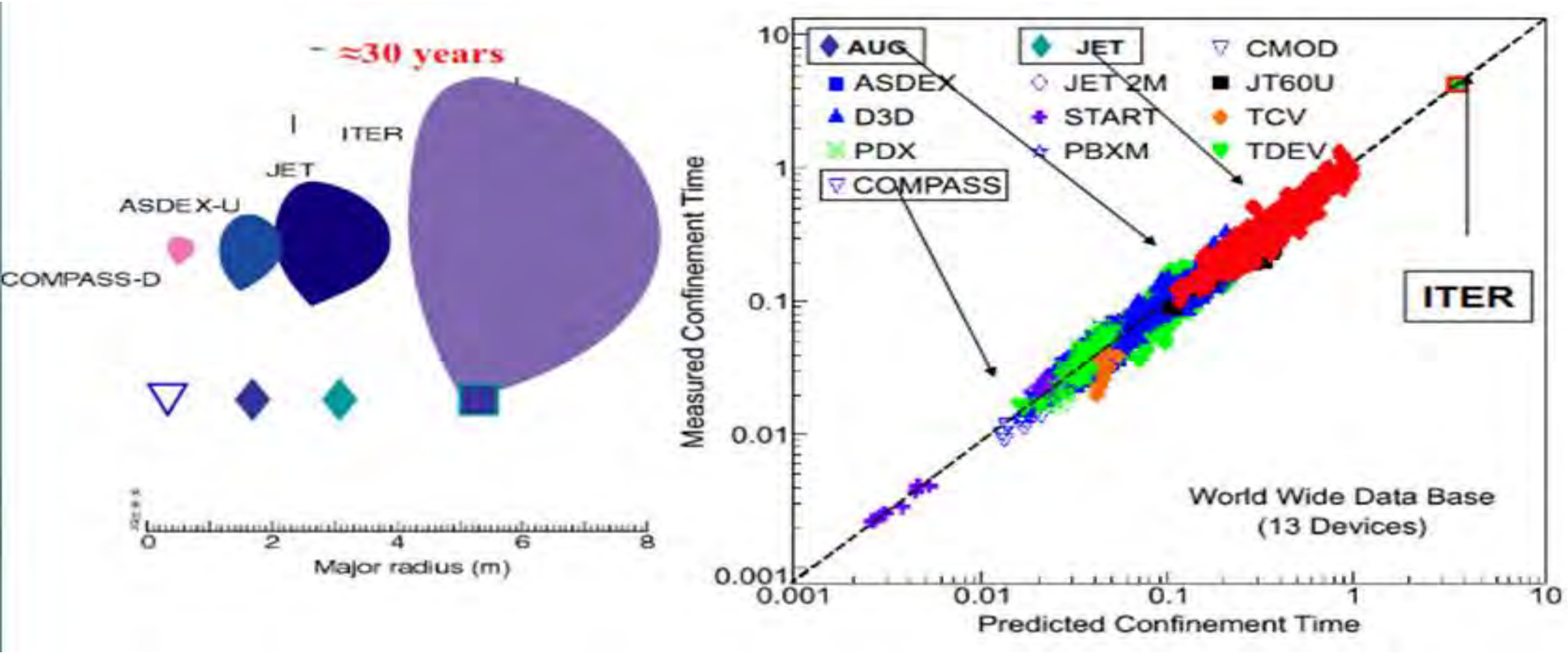
JET Ohmic heating = 5 MW



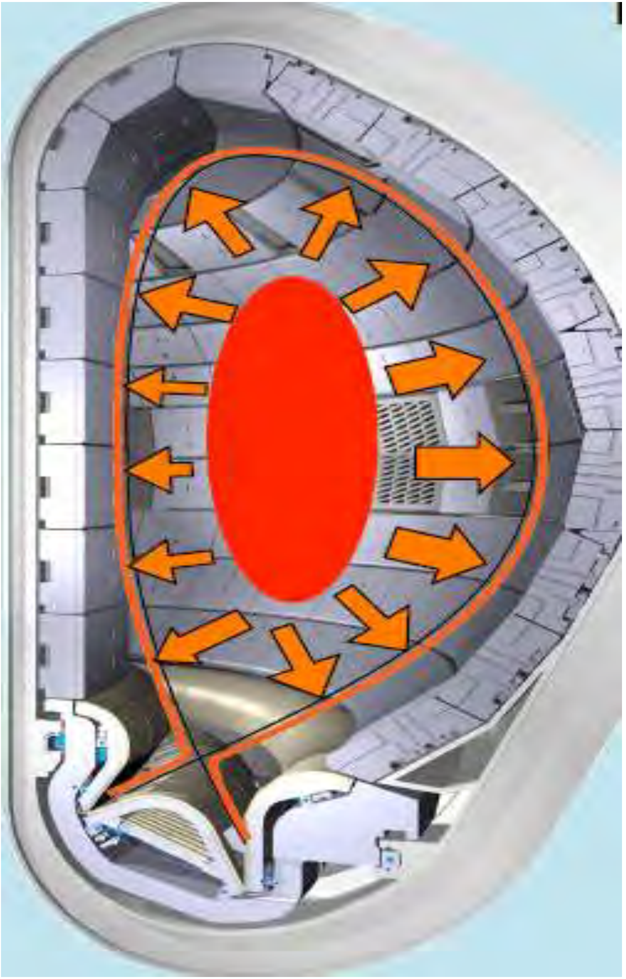
JET Neutral Beam Injection (NBI) = 23 MW



JET Ion Cyclotron Resonant Heating (ICRH) = 32 MW @ 23-57 MH



≈30 years
ITER
JET
ASDEX-U
COMPASS-D
0 2 4 6 8
Major radius (m)
AUG
JET
CMOD
ASDEX
JET 2M
JT60U
D3D
START
TCV
PDX
PBXM
TDEV
COMPASS
ITER
World Wide Data Base
(13 Devices)
Measured Confinement Time
Predicted Confinement Time
0.001 0.01 0.1 1 10



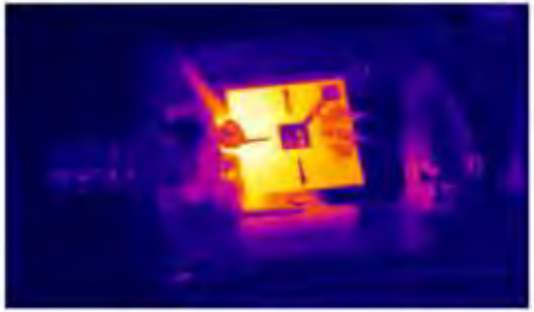
Zašto je važna veličina?

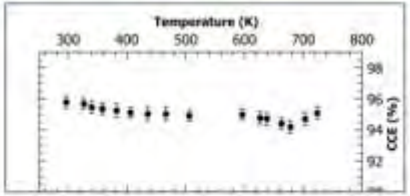
Veći tokamak = manji udio turbulencija

Veći tokamak = snaga grijanja se raspoređuje na veću površinu

Croatian fusion research highlights

Development of high-temperature radiation detectors for ITER & DEMO



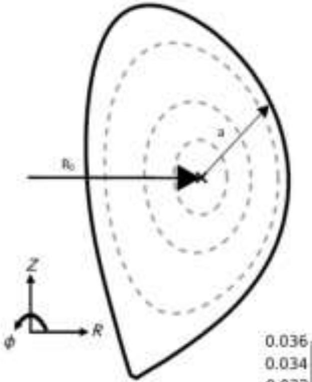


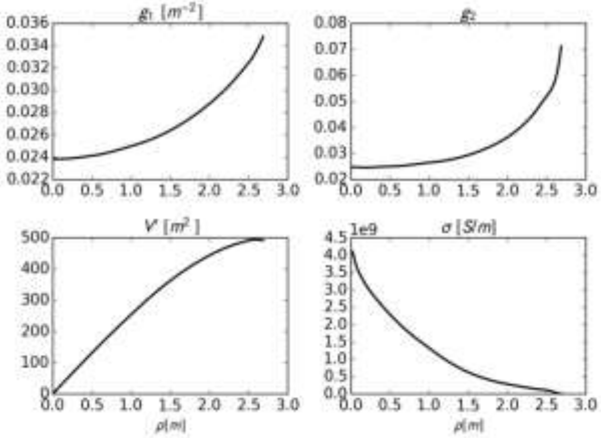
HIGHEST REPORTED TEMPERATURE FOR DIAMOND BASED SOLID-STATE RADIATION DETECTOR

725 K
450 °C

Modelling of magnetic fields for ITER

By FESB

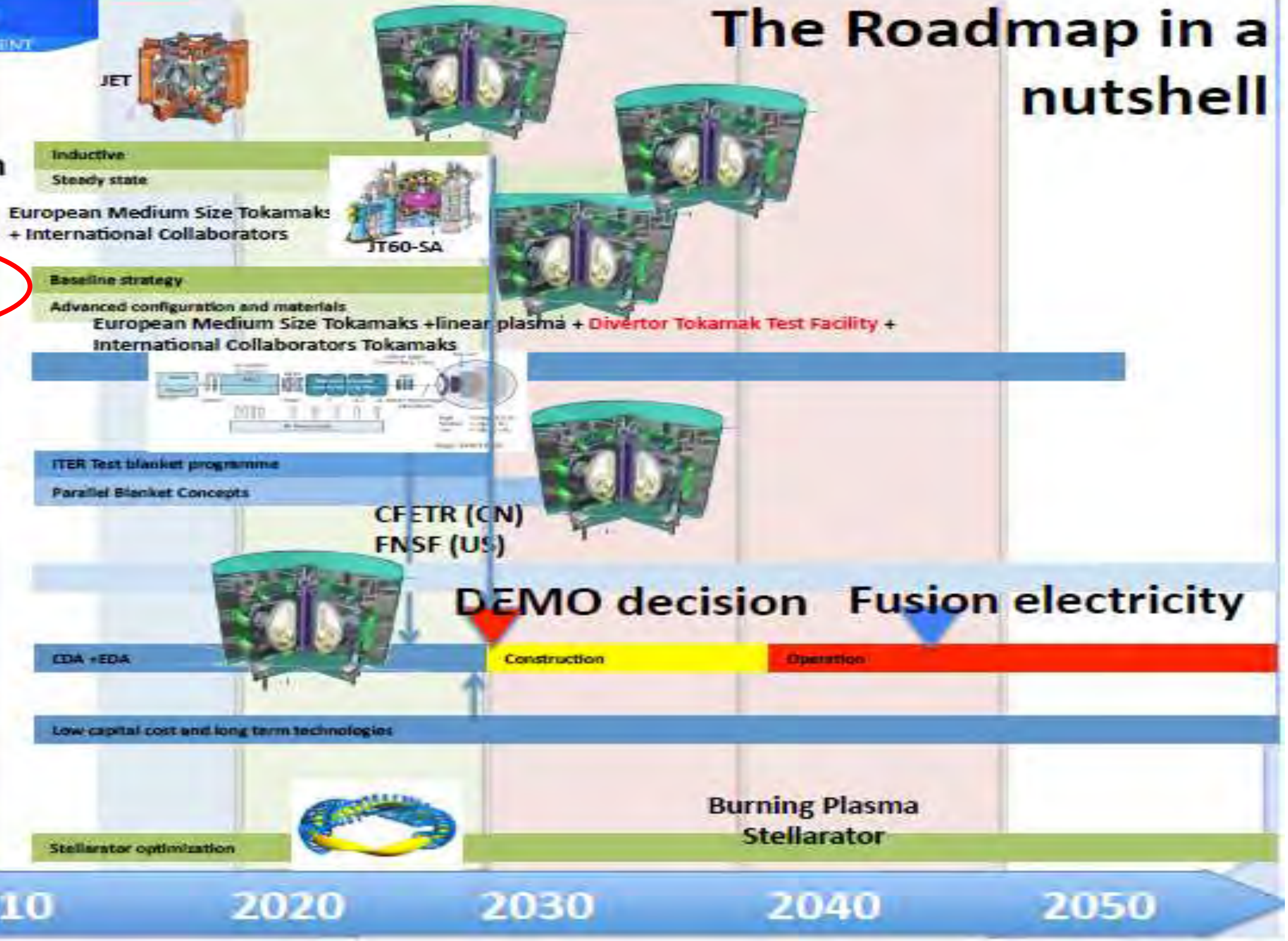




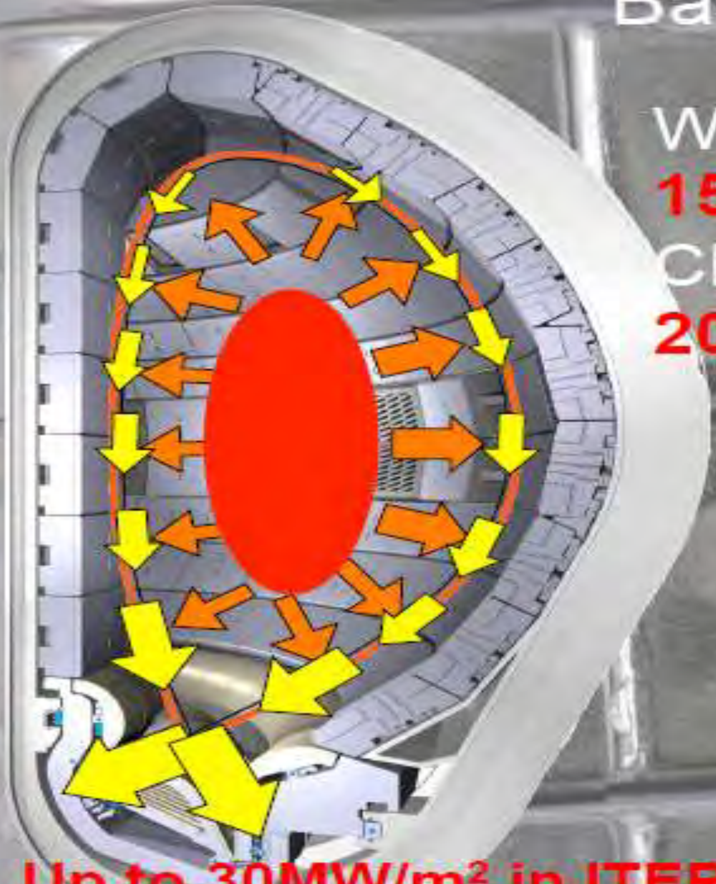
EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT

The Roadmap in a nutshell

1. Plasma operation
2. Heat exhaust
3. Materials
4. Tritium breeding
5. Safety
6. DEMO
7. Low cost
8. Stellarator



Mission 2: Heat and particle exhaust
Baseline strategy

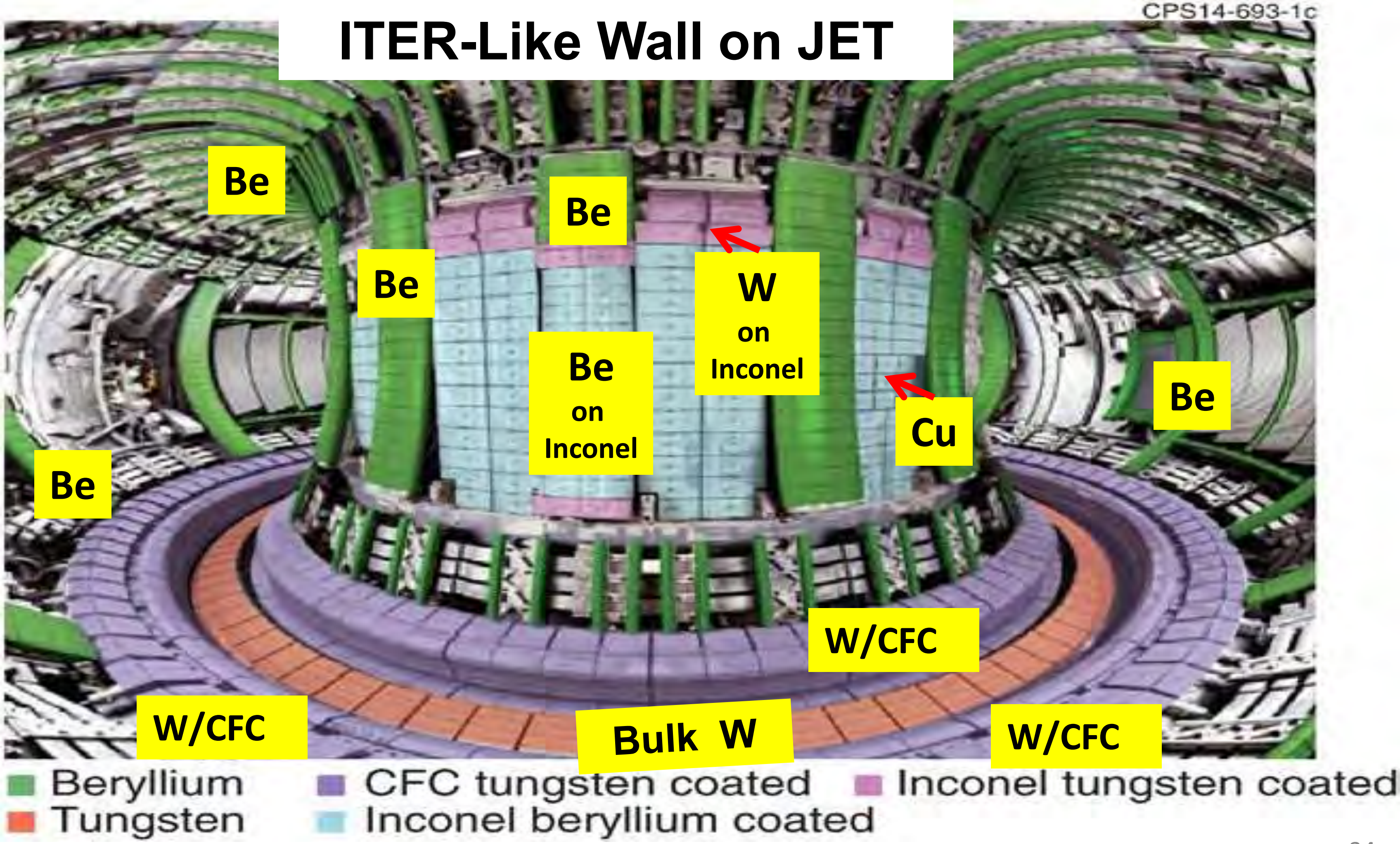


W macrobrush:
15 MW/m² x 1000 cycles

CFC monoblock
20 MW/m² x 2000 cycles

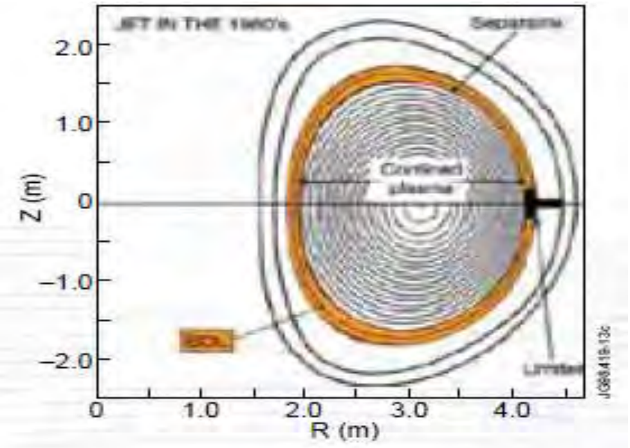
Up to 30MW/m² in ITER
(60MW/m² in a reactor ~ heat flux on the surface of the Sun!)

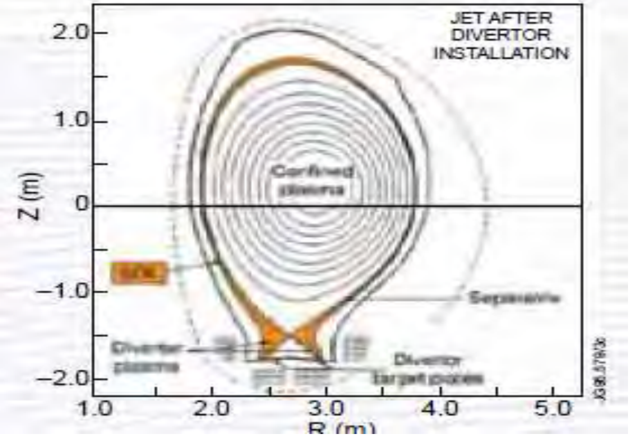
ITER-Like Wall on JET

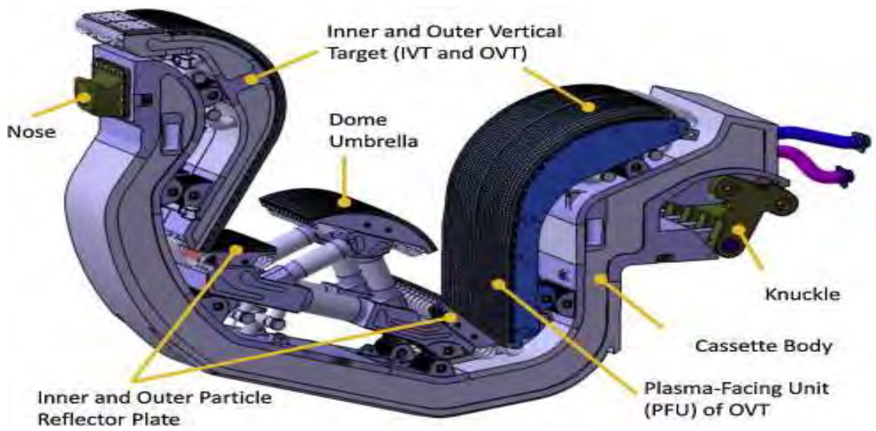


J.C. Flanagan et al., Plasma Phys. Control. Fusion 57 (2015) 014037

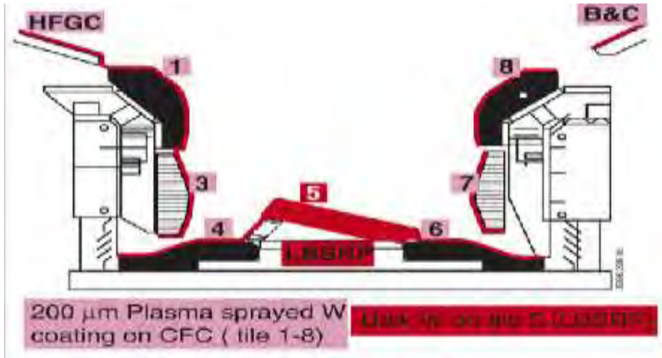
Plasma Edge & Scrape Off Layer (SOL) & Divertor Concept







Divertor at ITER (W plates)



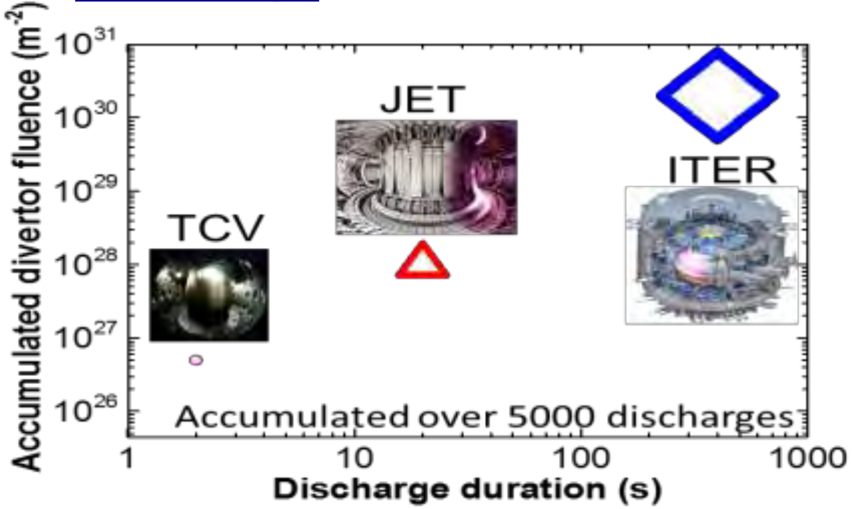
ITER-Like-Wall (ILW) Divertor at JET, made of W and W–coated CFC

Dust production at ITER

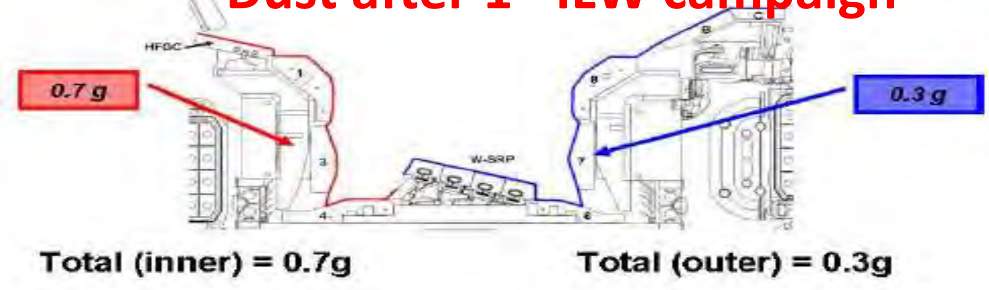
- <u>43% of material entering the divertor is converted to dust</u>

J. Likonen et al, J. Nucl. Mater. 463 (2015)

- <u>But only 1g of dust collected after 1st ILW ILW campaign (only 15μm deposits)!!</u>



Dust after 1st ILW campaign



K. Heinola et al, Phys. Scr. T159 (2014)

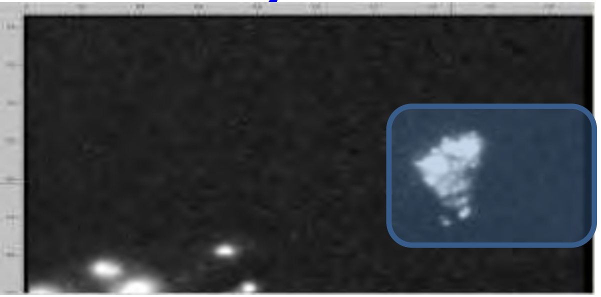
However, much larger divertor fluence is expected in ITER: much thicker co-deposits (~200nm/shot)

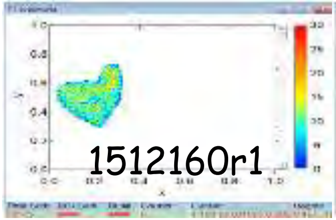
~50kg of Be dust in ITER operations

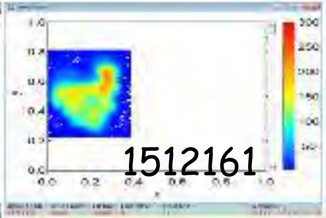
Dust analysis

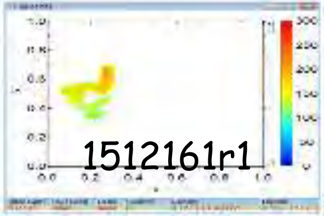
1512160-62

W-M



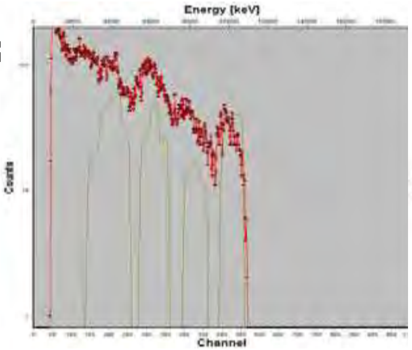




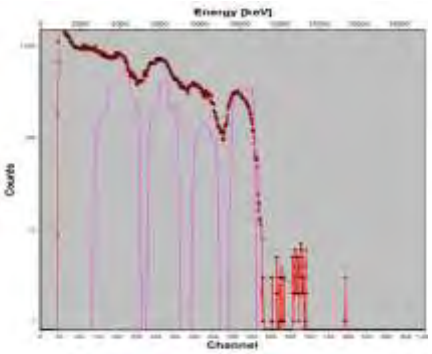


Be and D: semi/quantitative analys
By SIMNRA in atomic ratios:

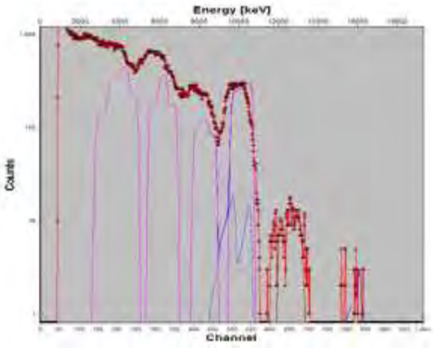
60r1 Be
61r1 Be:D = 0.9994:0.0006
62r1 Be:D = 0.987:0.013 maybe some N?



1512160r1



1512161r1



1512162r1

In PIXE dominating elements are W, Ni, Cr, Fe, Mo.

PIXE Gupix semi-quantitative analysis: iterative matrix solution with normalization to 100 %

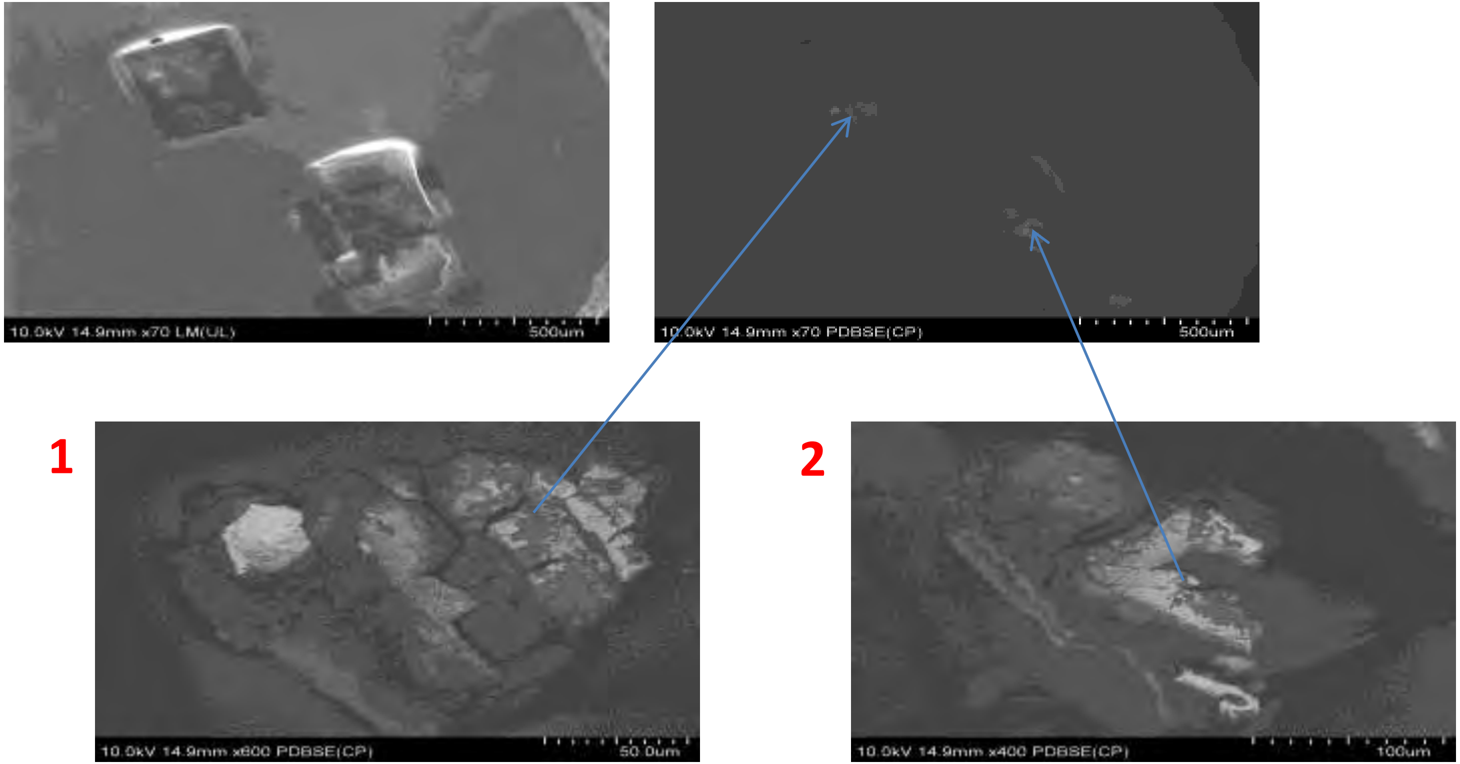
Results in weight %.

1512160r1: Na 7.4 w%?, Al 3.9 w%, Si 1.5 w%?, P 1.5 w%, S 1.7 w%, Cl 2.4 w%, Ca 0.45 w%?, Ti 0.18 w%?,
Cr 9.3 w%, Fe 6.6 w%, Ni 24.8 w%, Cu 3.6 w%, W(La) 26.6 w%, Mo L 9.4 w%.

1512161r1: Na 5.4 w%?, Al 4.2 w%, Si 1.1 w%?, P 2.4 w%, S 2.0 w%, Cl 2.4 w%, Ca 0.48 w%?, Ti 0.25 w%?,
Cr 9.3 w%, Fe 6.1 w%, Ni 26.3 w%, Cu 3.4 w%, W(La) 32.5 w%, Mo L 6.4 w%.

1512162r1: **Si 4.2 w%, S 5.3 w%, Cl 6.7 w%, K 0.26 w%, Ca 0.37 w%, Ti 0.33 w%,**
Cr 12.8 w%, Fe 7.9 w%, Ni 26.1 w%, Cu 5.7 w%, W(La) 20.4 w%

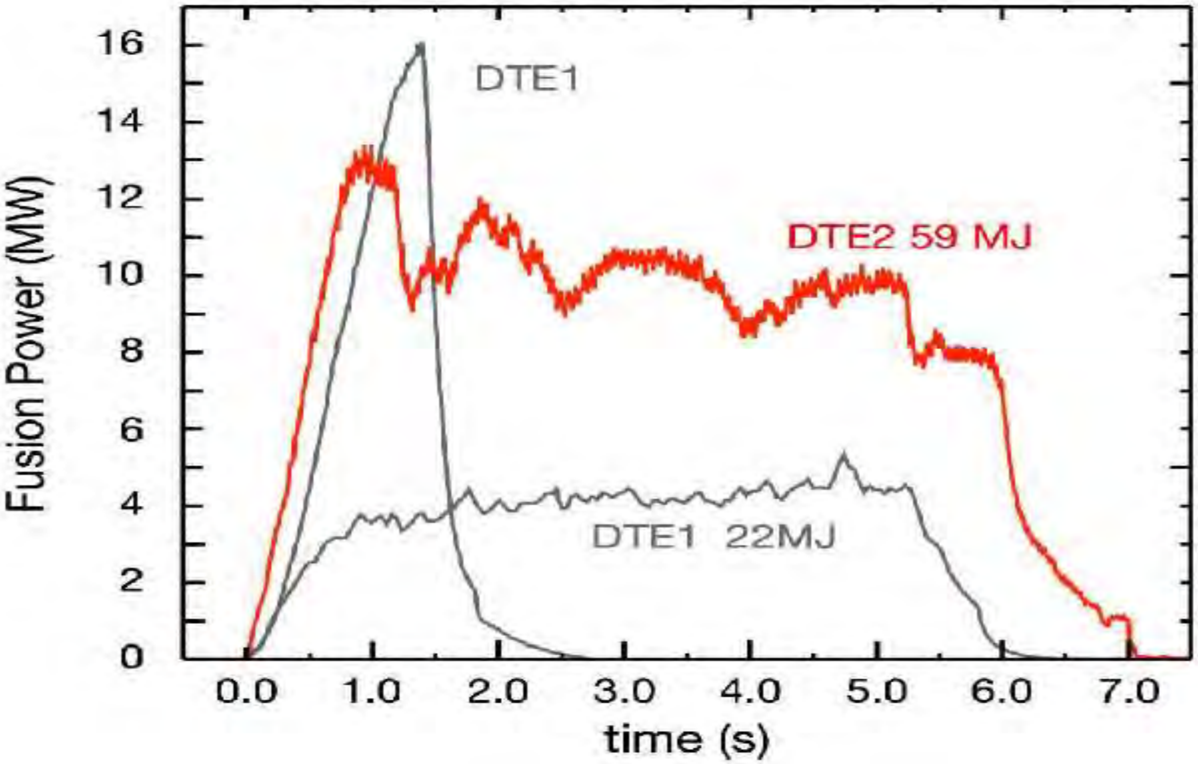
SEM/EDX studies of composition and internal structure of dust particles analysed by micro-NRA/PIXE



More information in: E. Fortuna-Zalesna et al., "Studies of dust from JET with the ITER-Like Wall: Composition and internal structure", Nuclear Materials and Energy (2017), In Press

RBI / CRU Greeting card for St.Valentine's day, as appeared at EUROfusion and ITER website:

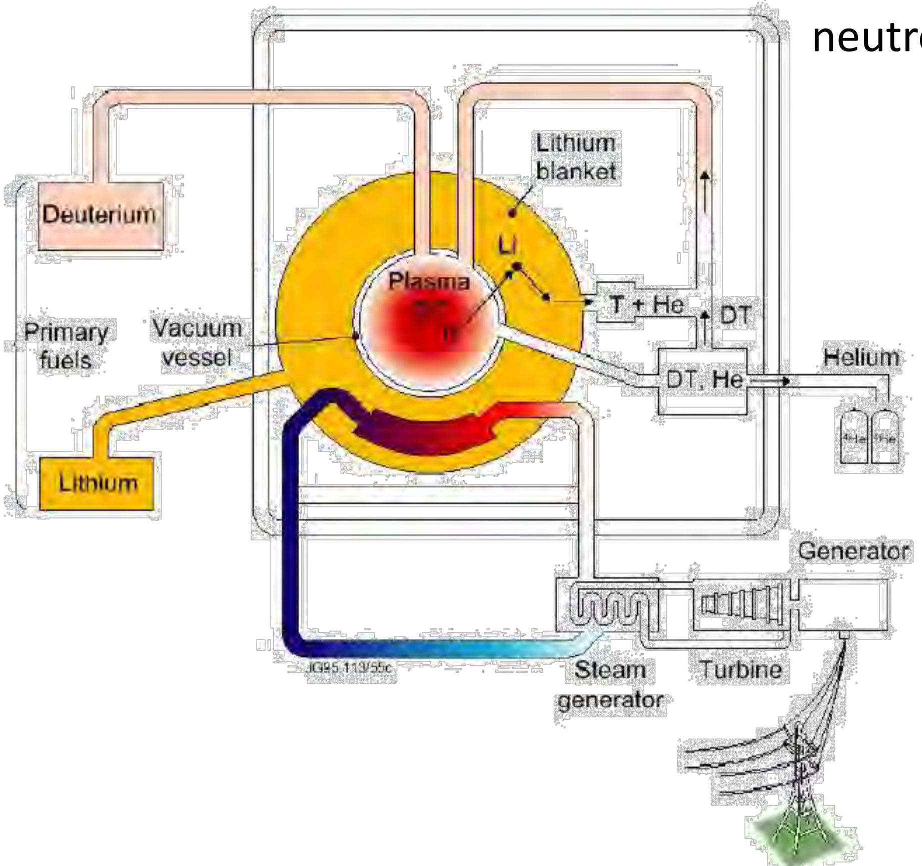
Heart-shaped dust particle, size 120 by 100 μm,
made mainly of W, Ni, Cr, Mo and Fe, with traces of Be, Al, Cu and Na;
He3 microbeam mapping of W M line



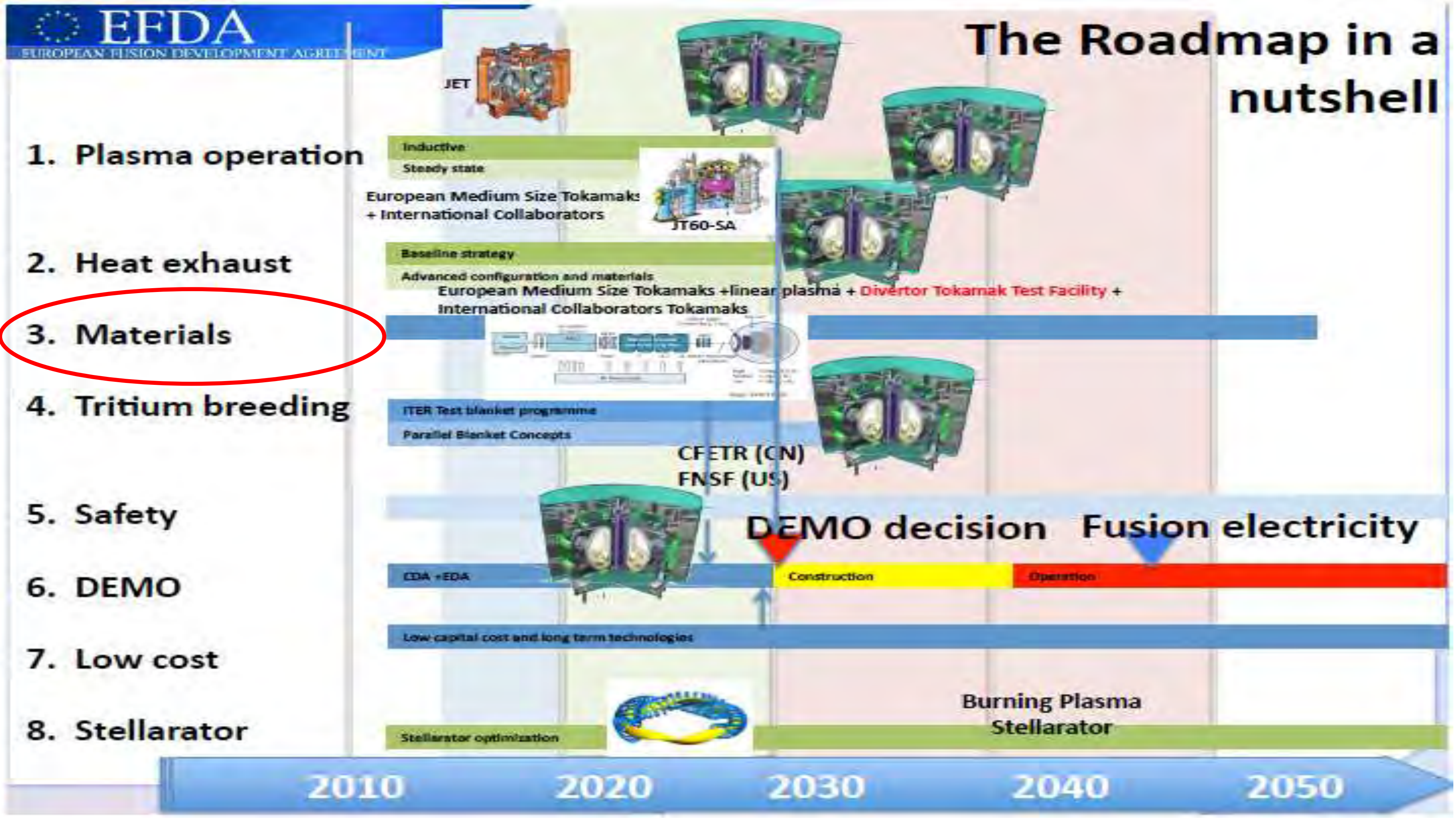
DTE1
DTE2 59 MJ
DTE1 22MJ
Fusion Power (MW)
time (s)
0
2
4
6
8
10
12
14
16
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0

Čemu služi DONES ?

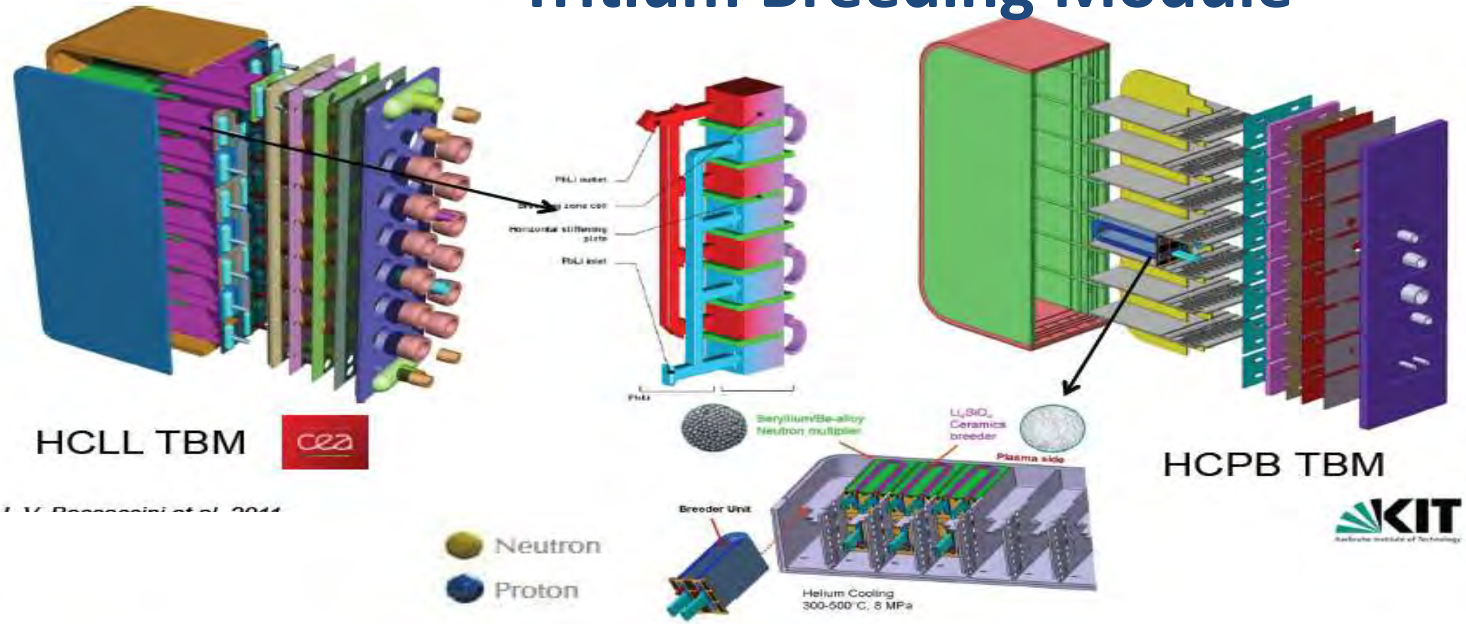
Fuzijski reaktor u elektrani DEMO će proizvoditi intenzivni tok neutrona energije 14.1 MeV. Potrebni su materijali otporni na zračenje neutrona intenzivno kao na površini Sunca.

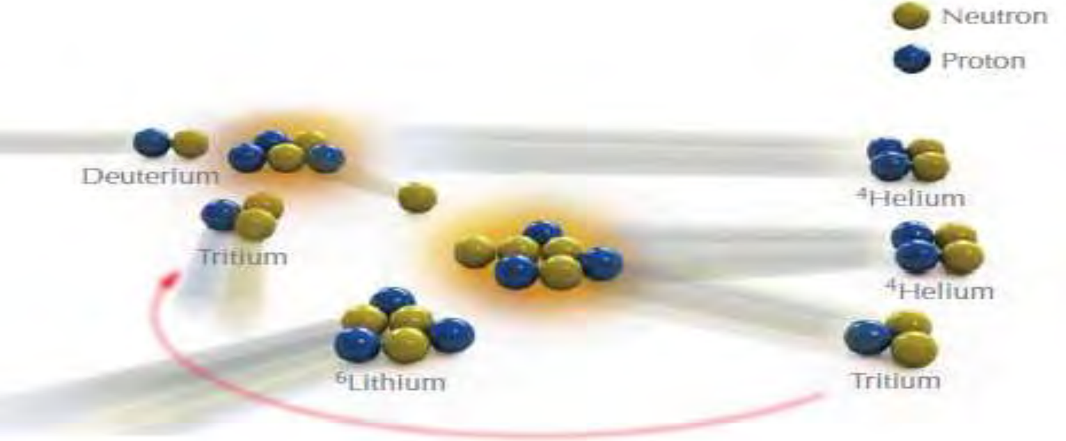


Potreban je posebni uređaj za Testiranje otpornosti materijala na intenzivno zračenje fuzijskih neutrona

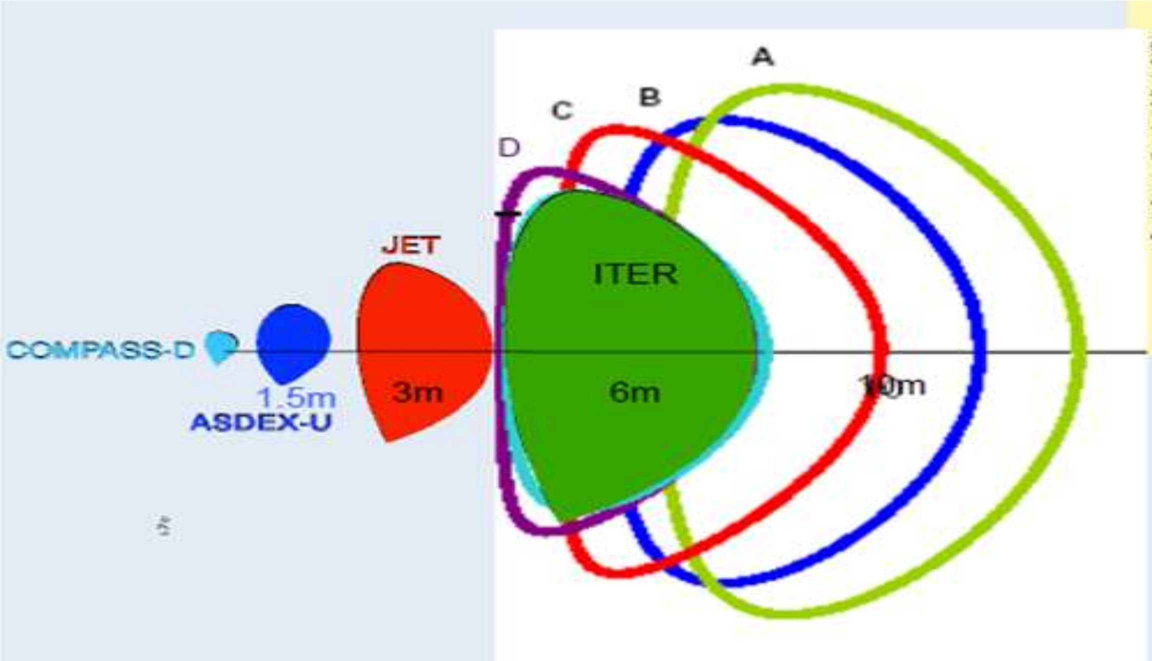

EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT
The Roadmap in a nutshell
1. Plasma operation
2. Heat exhaust
3. Materials
4. Tritium breeding
5. Safety
6. DEMO
7. Low cost
8. Stellarator
JET
Inductive
Steady state
European Medium Size Tokamaks
+ International Collaborators
JT60-SA
Baseline strategy
Advanced configuration and materials
European Medium Size Tokamaks +linear plasma + Divertor Tokamak Test Facility +
International Collaborators Tokamaks
ITER Test blanket programme
Parallel Blanket Concepts
CFETR (CN)
FNSF (US)
DEMO decision
Fusion electricity
CDA +EDA
Construction
Operation
Low capital cost and long term technologies
Burning Plasma
Stellarator
Stellarator optimization
2010
2020
2030
2040
2050

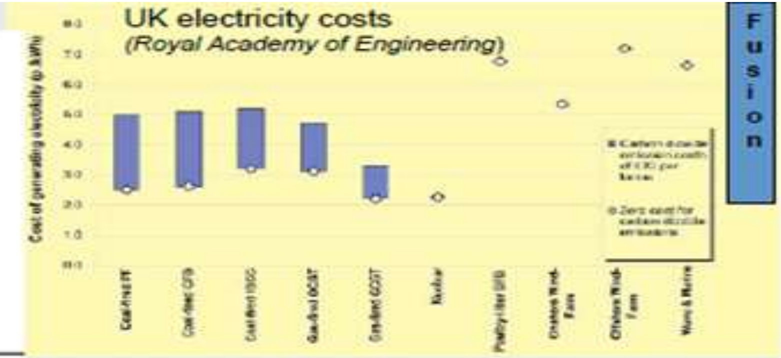
Tritium Breeding Module





Dizajn fuzijske elektrane DEMO

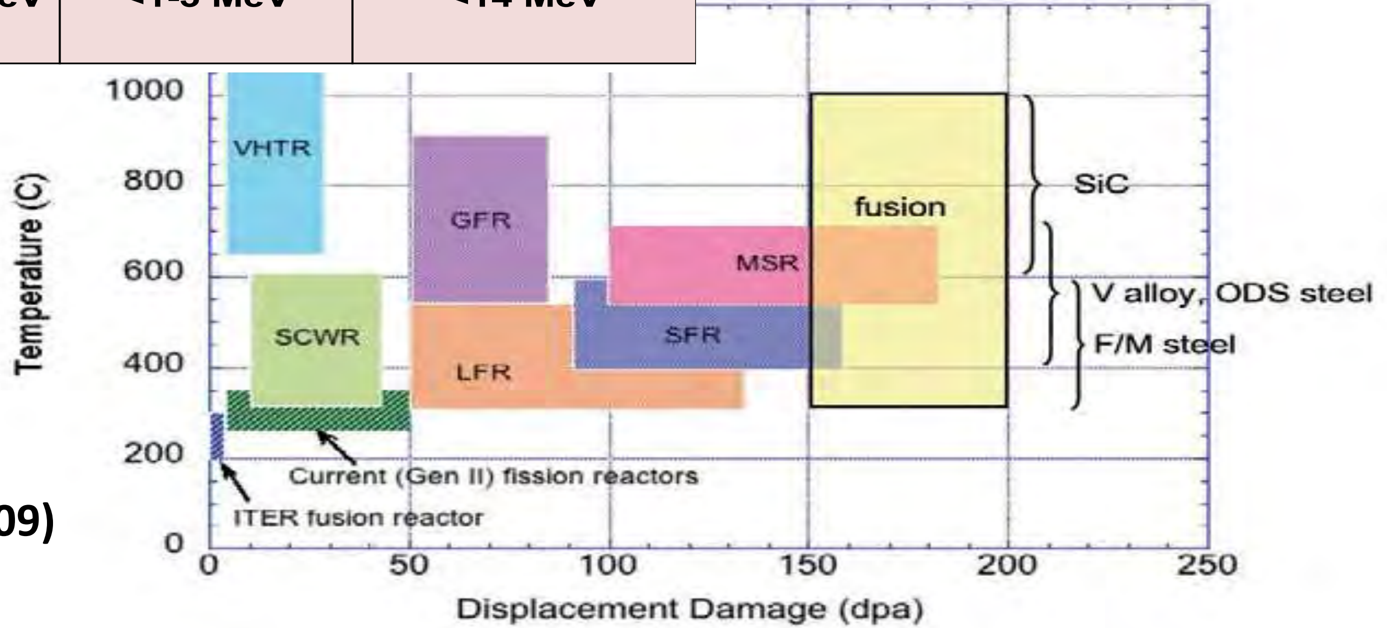




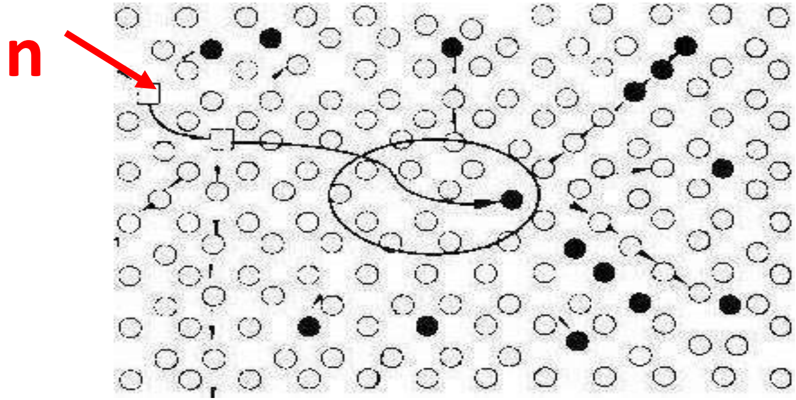
Cost of electricity from fusion expected to be competitive with other sources (IEA Levelised Cost Approach)

	Fission (Gen. I)	Fission (Gen. IV)	Fusion (DEMO/PROTO)
Structural alloy T_{max}	<300˚C	500-1000˚C	550-1000˚C
Max dose for core internal structures	**~1 dpa**	**~30-150 dpa**	**~150 dpa**
Max transmutation helium concentration	**~0.1 appm**	**~3-10 appm**	**~1500 appm (~10000 appm for SiC)**
Particle Energy E_{max}	**<1-2 MeV**	**<1-3 MeV**	**<14 MeV**

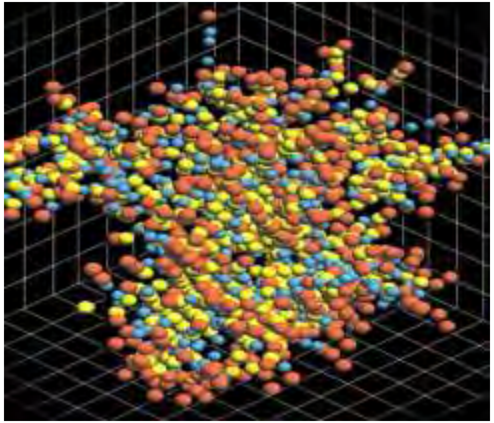
A. Moeslang and J. Reiser
EFPW- December 2014

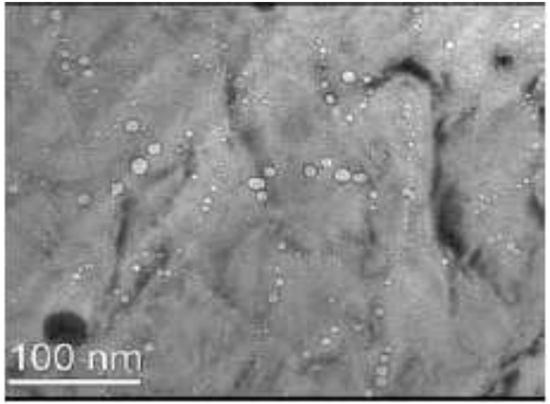


S.J. Zinkle & J.T. Busby, Materials Today 12 (2009) 12



Damage induced in materials by neutron irradiation





Ion beams' simulation of neutron damage:

a) **Collision cascade resulting from neutron knock-off collision with nuclei is simulated by self-ion irradiation;**

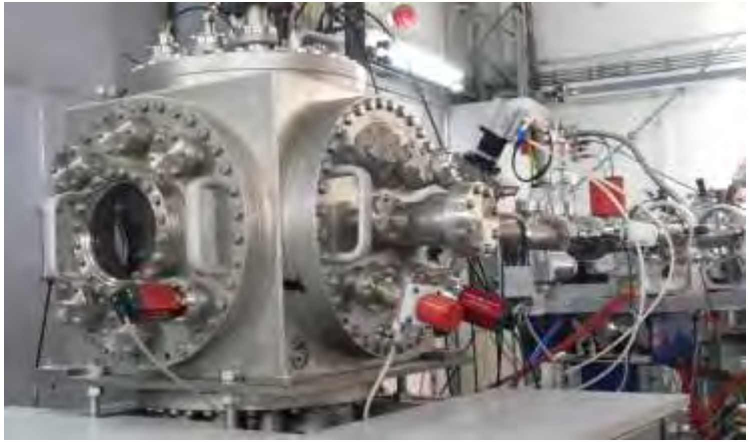
b) **Accumulation of H i He due to transmutation reactions (n,α) i (n, p) is simulated by proton or He ion beam;**

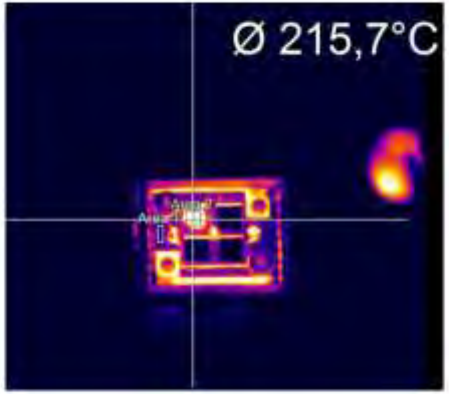
PROS: Fast defects' production & Non-radioactive sample

CONS: Low ion range

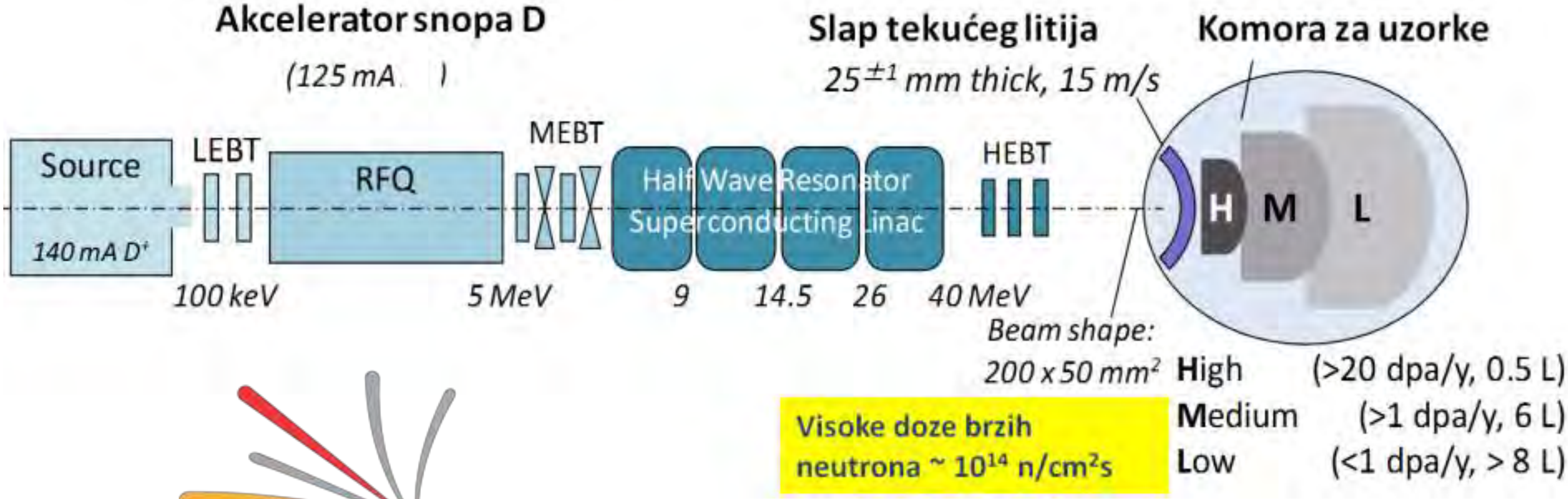
Croatian fusion research highlights

Irradiation of fusion materials by one or two ion beams at dual-beam facility DiFU and dual-microbeam facility





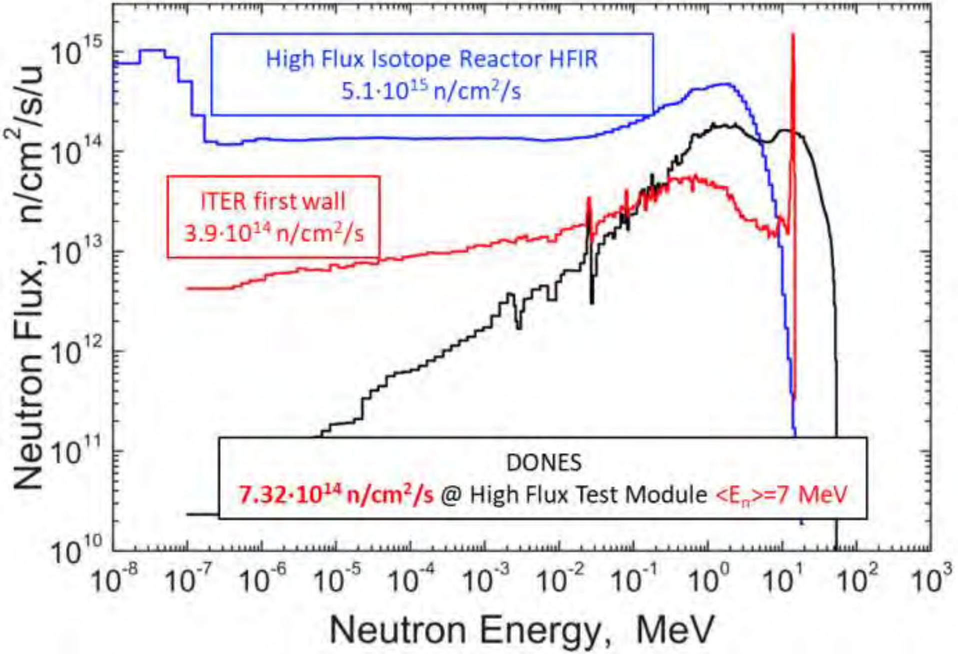
Osnovni sustavi uređaja DONES = DEMO Oriented Neutron Source

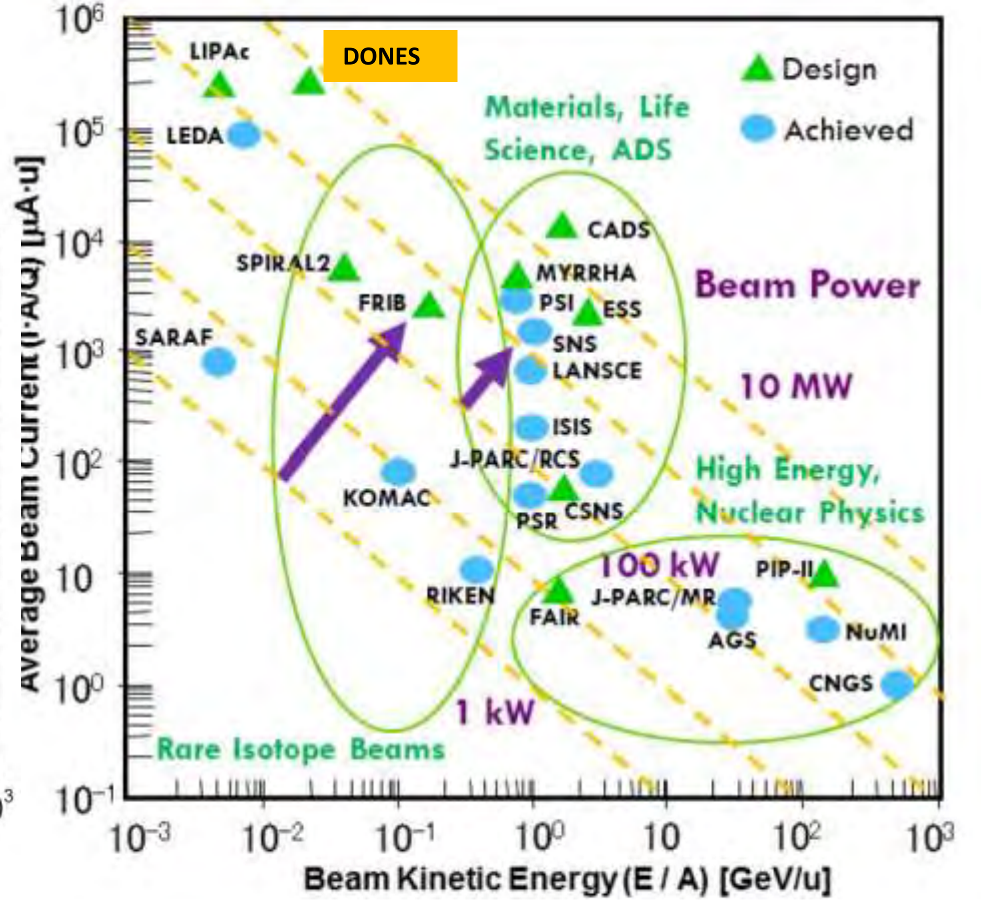


DONES

High technology development in many different areas, including:

- Liquid metals management (lithium)
- Robotics and remote handling
- Control systems, Sensors and diagnostics
- Criogenics
- Materials
- ….





DONES Program naslanja se na seriju pripremnih projekata

DONES Preparatory Phase

DONES Program

DONES Consolidation Project

Validation Phase (IFMIF/EVEDA):	IFMIF/EVEDA in BA >>>>>>> LiPAC	(2007. -)
Design and Engineering Phase	WPENS in EUROfusion	(2014. -)
Site Selection Phase	MoU HR-ES	(2014. – 2018.)
Preparatory Phase	DONES-PreP ::::: ESFRI	(2019.-2021.)
Site preparation	DONES-PRIME :::::	(2021. -)
Construction, Installation, Testing and Systems Commissioning Phase		(2022.-2030.)
Plant Integrated Commissioning		(2030.-2031.)
Operation Phase		(2032.-2052.)
Decommissioning Phase		(2052.-2095.)

DONES Program Mission

To develop a data base of fusion-like neutron irradiation effects in materials materials

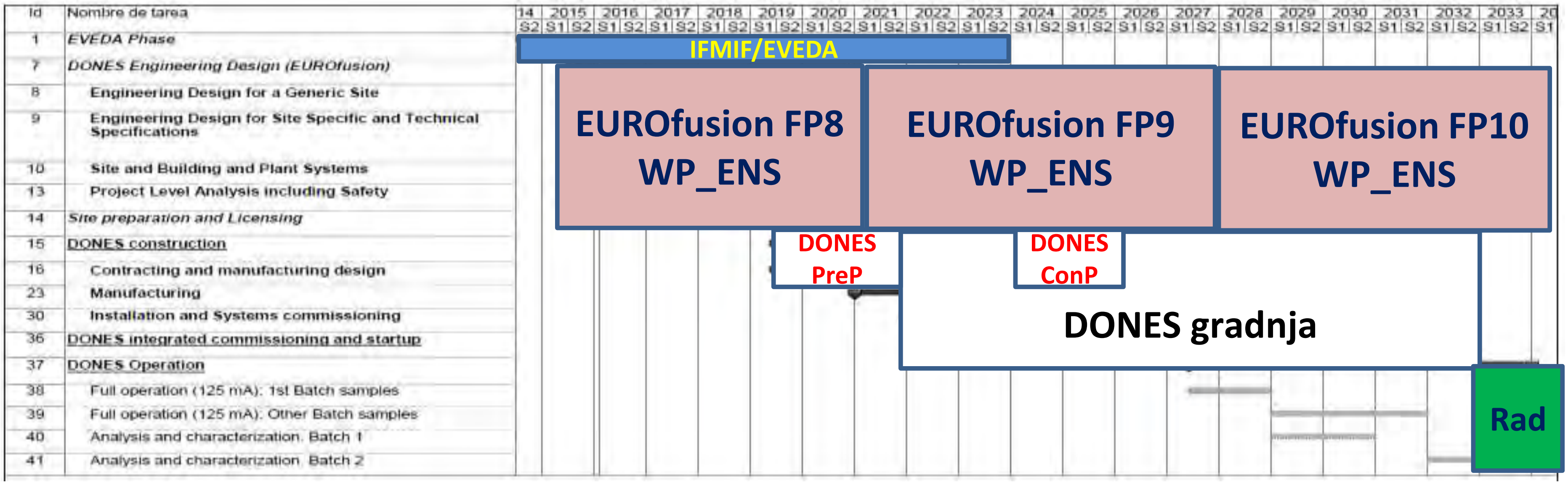
DONES Program Objectives

- To provide a neutron source producing high energy neutrons at sufficient intensity and irradiation volume.
- Generate materials irradiation test data for DEMO
- Generate data base for benchmarking with computational material science
- To develop a Complementary Experiments workprogram

The DONES Facility

The fusion relevant neutron source and that will allow to fulfill the objectives of the Program.

Vremenski okvir i cijena DONES-a



Ozračavanja uzoraka prvih 20 godina: od 2032. do 2052.

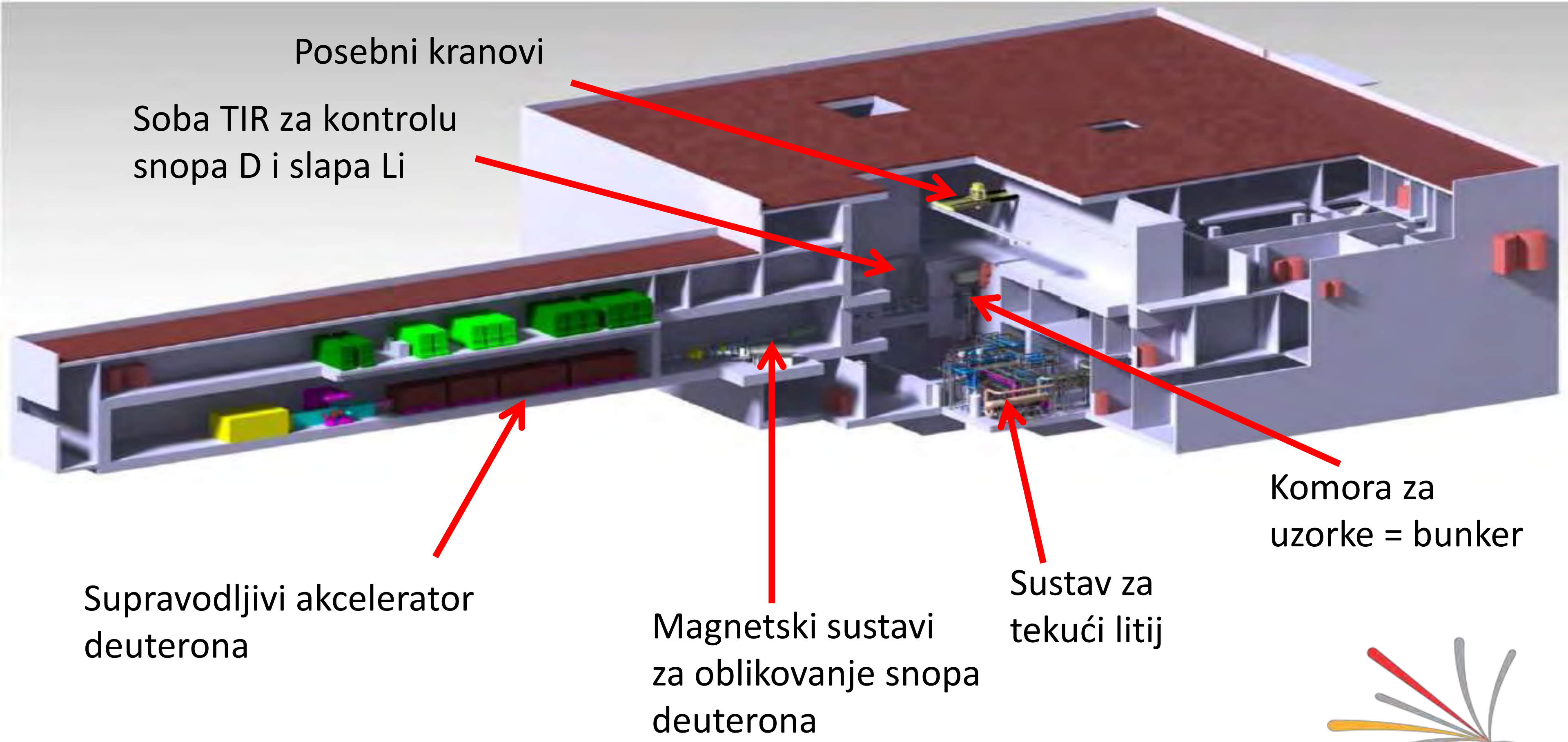
- Nakon 20 g.: kraj rada ili dogradnja drugog akceleratora i nastavak rada
- Španjolski doprinos = 50%; Hrvatski doprinos 5% ; EU doprinos (kroz agenciju F4E) = 20%

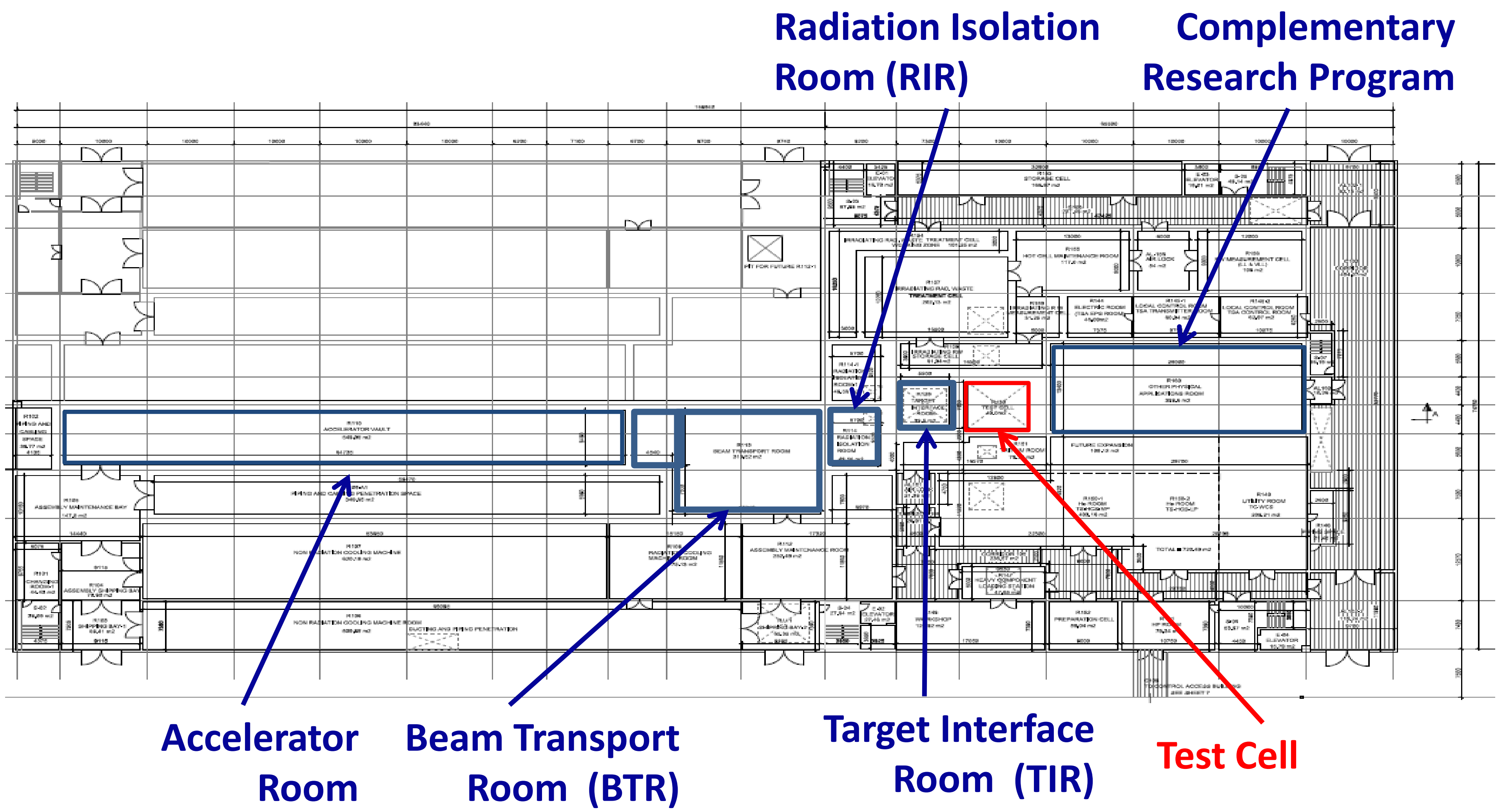
IFMIF-DONES Facility

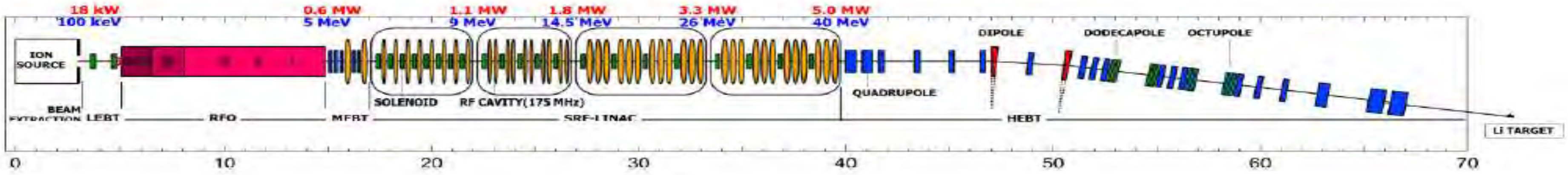
The site is located at Escúzar - 18 km southwest from Granada city- Spain

Spanish - Croatian site selected by EU

Osnovni sustavi DONES-a

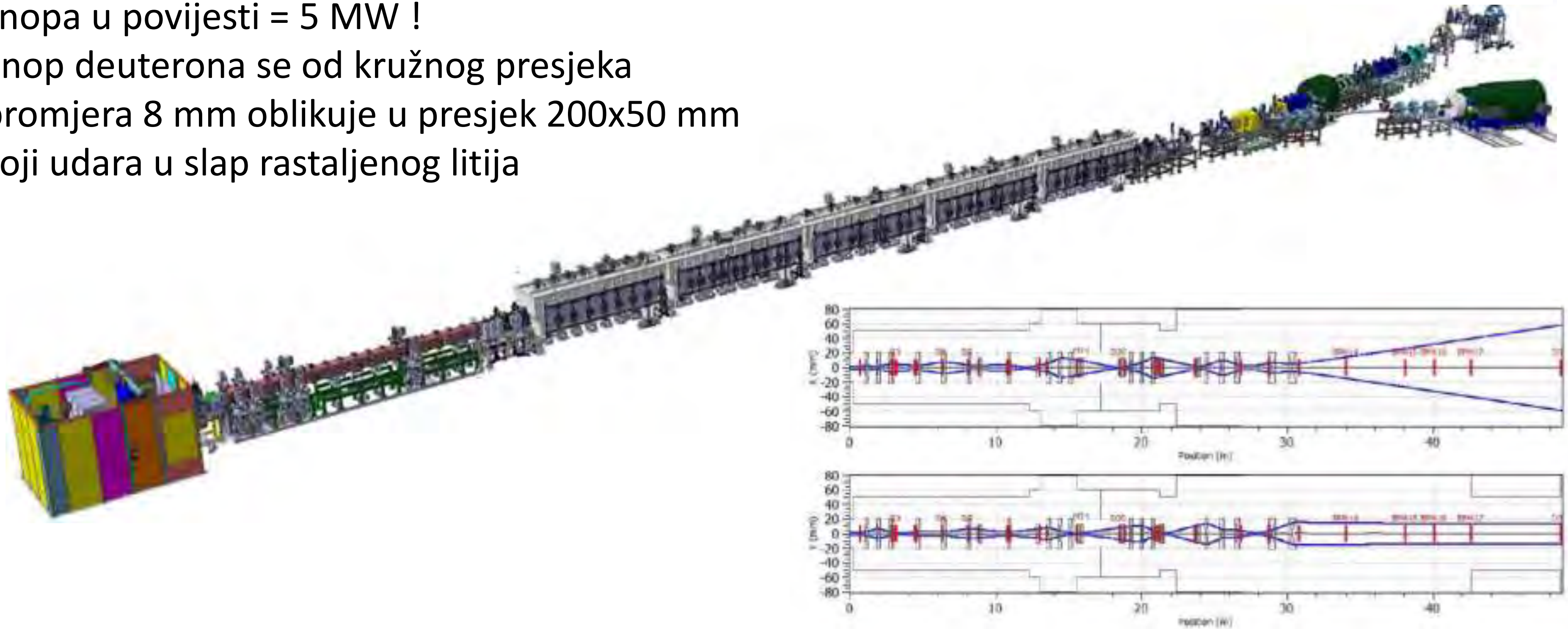



Radiation Isolation Room (RIR)
Complementary Research Program
Accelerator Room
Beam Transport Room (BTR)
Target Interface Room (TIR)
Test Cell

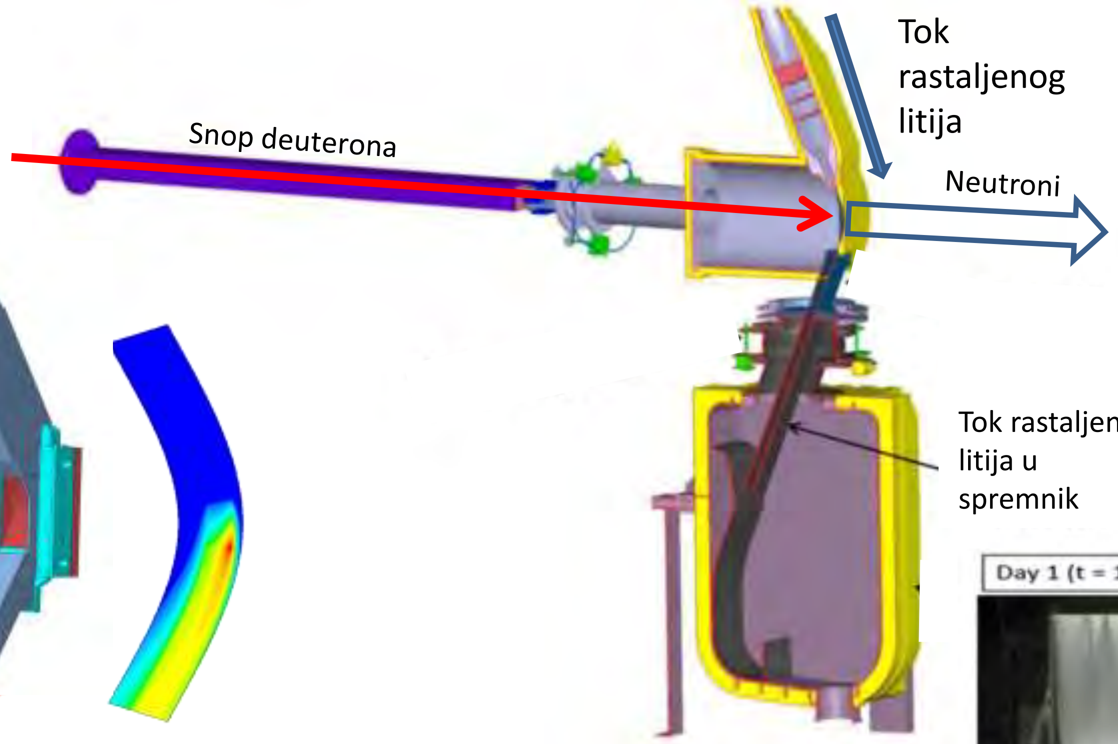


Akcelerator DONES-a imati će najveću snagu snopa u povijesti = 5 MW !

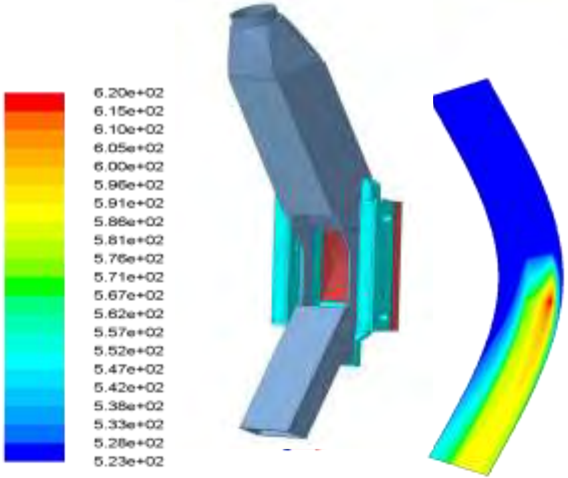
Snop deuterona se od kružnog presjeka promjera 8 mm oblikuje u presjek 200x50 mm koji udara u slap rastaljenog litija

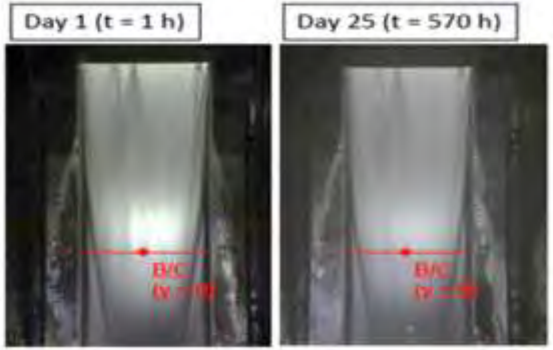


Snop deuterona udara u slap rastaljenog litija i proizvodi neutrone koji udaraju u uzorke

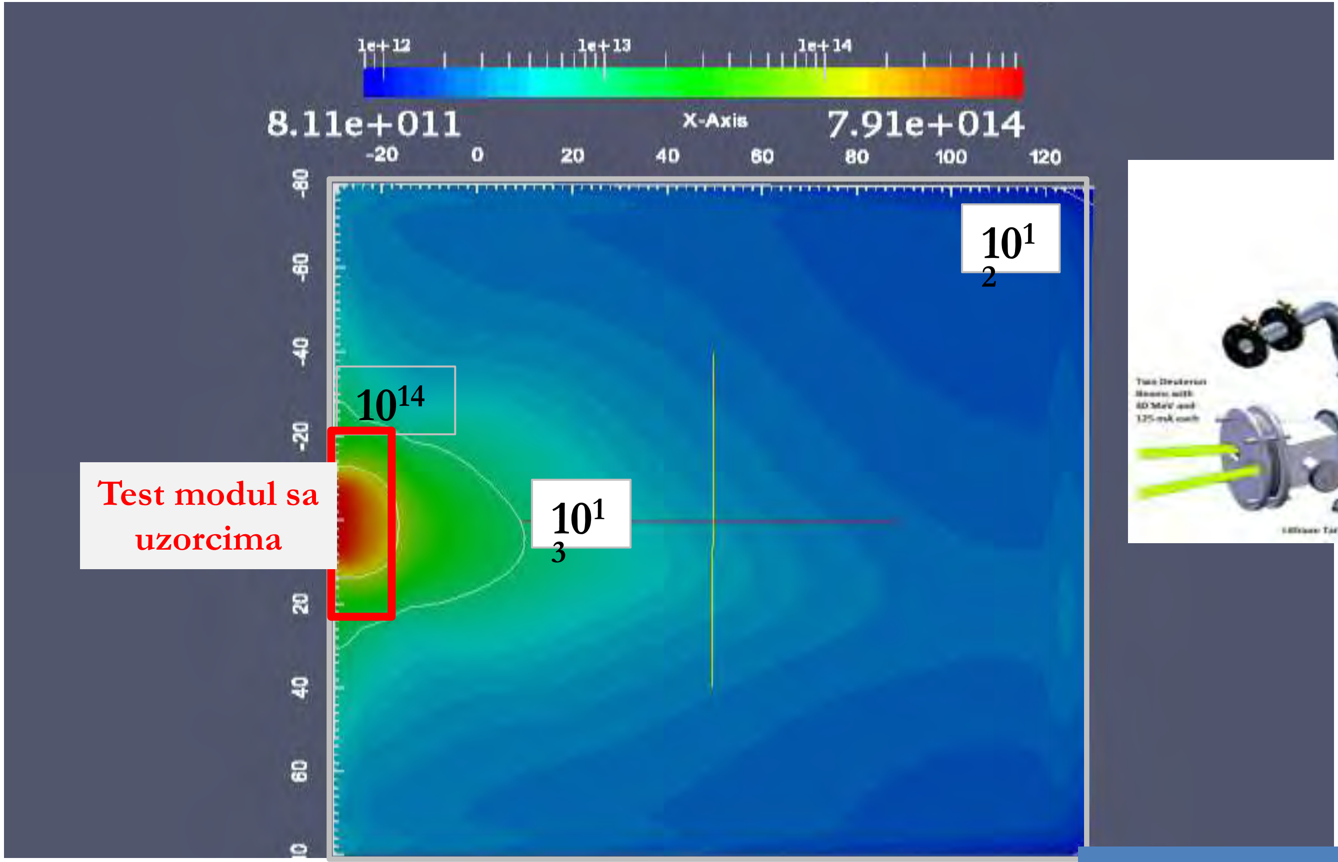


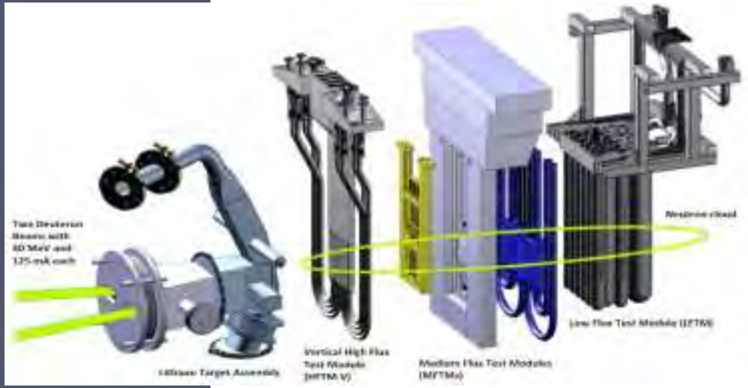
Litij teče na 300 ^{0}C,
brzinom 15 m/s,
slap litija je debljine
2 cm, a širine 20 cm





Tok neutrona na raznim dijelovima komore za uzorke (n /cm^2 s), jedan akcelerator

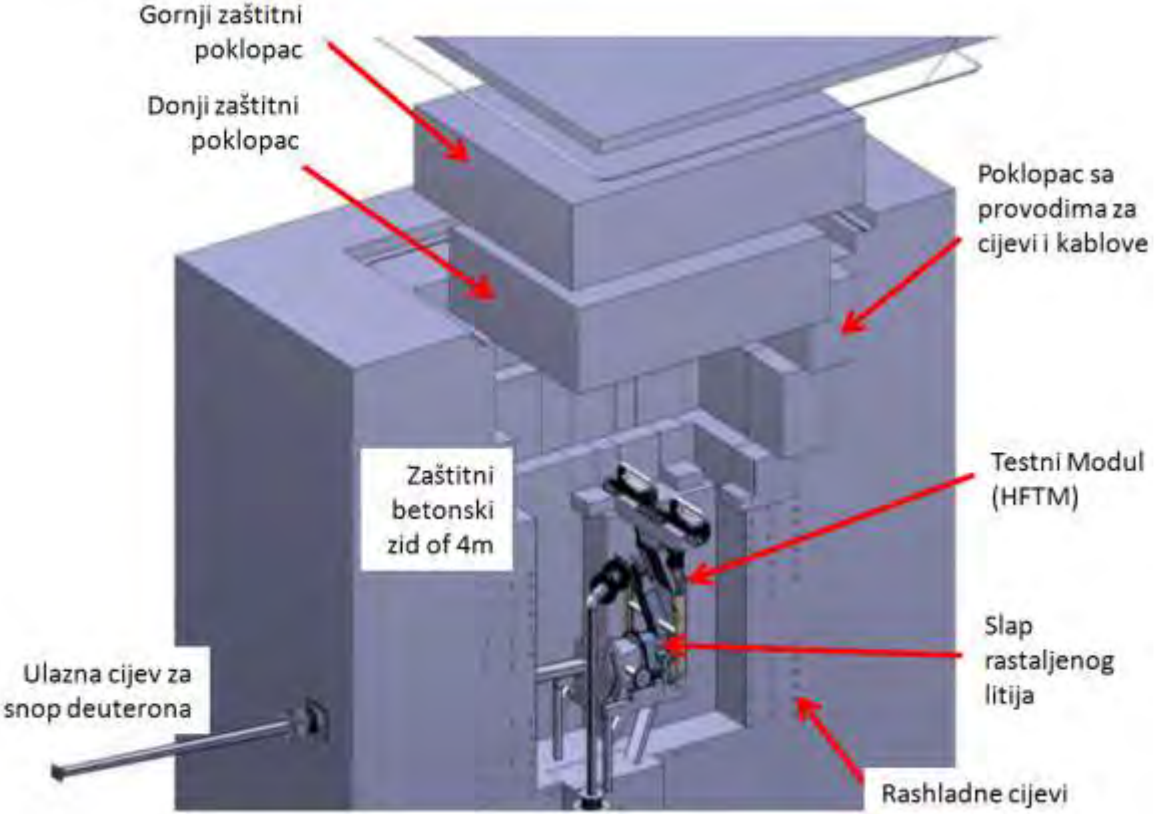




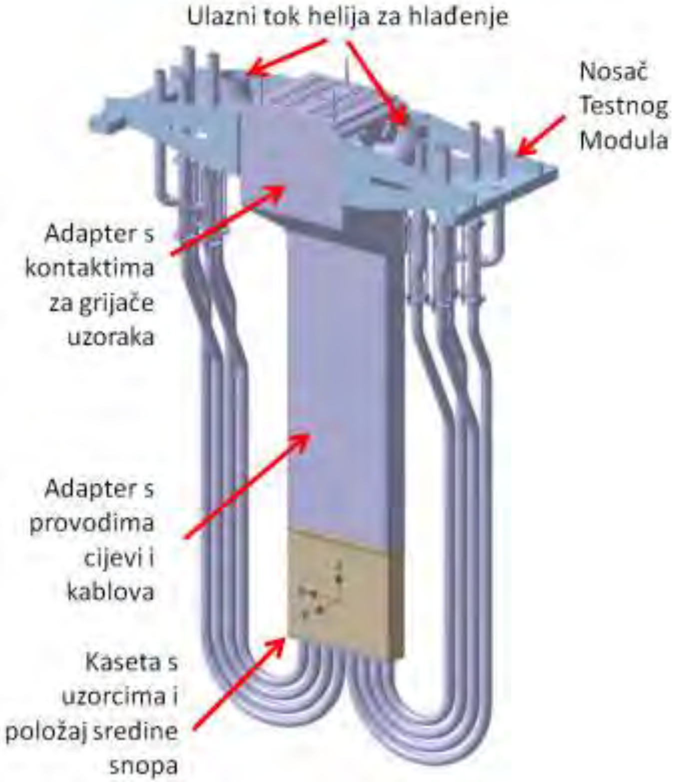
Prijedlog za složeniji Test Cell

F. Mota et al. (2015)

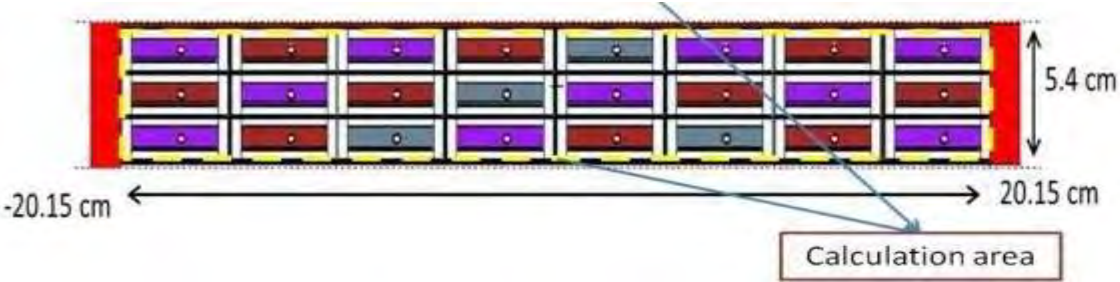
Komora za testiranje (Test Cell) na DONES-u je betonski bunker sa 4 m debelim stijenkama.



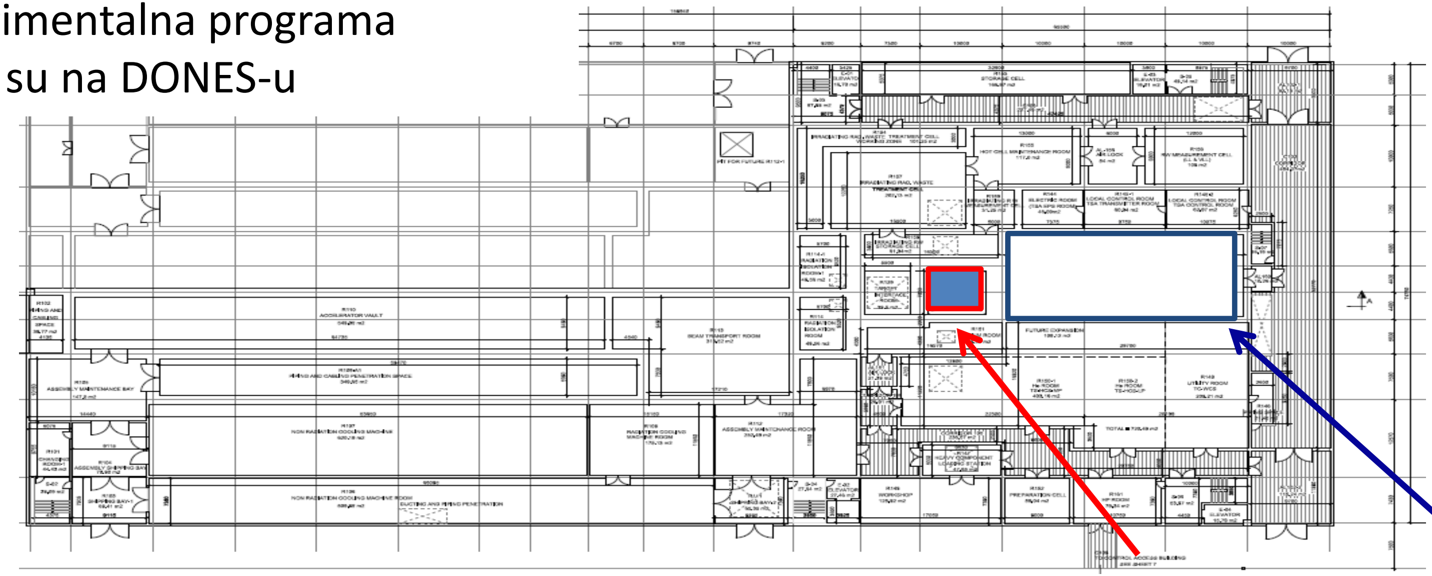
Uzorci u Testnom modulu (HFTM)



Uzorci su smješteni u modul širine 20 cm, koliko je širok snop iona (20 cm x 5 cm)



Tri eksperimentalna programa planirana su na DONES-u



Komora za testiranje EP.1 & 2

Prostorija za Komplementarna istraživanja EP.3

EP.1 = Fuzijski materijali – regulira EUROfusion/Euratom

EP.2 = Druga fuzijska istraživanja – raspolaže zemlja-partner

EP.3 = Komplementarna istraživanja izvan fuzije – raspolaže zemlja-partner

Hrvatski doprinos 5% vrijednosti DONES-a = znači 5% eksperimentalnih kapaciteta za EP.2 i EP.3

DONES

Hrvatsko – španjolska suradnja
Ključni datumi:

2016 -17 Za domaćinstvo IFMIF-DONES-a natjecale su se Hrvatska i Španjolska.

2017 "Gentlemen Agreement" IRB – CIEMAT pretvorio je ovo natjecanje u partnerstvo;
F4E je zaključio: obje lokacije su OK, španjolska je bolja.

2018 Hrvatska i Španjolska 20.6. potpisale MOu i dogovorile lokaciju i suradnju IFMIF-DONES
IFMIF-DONES je zajedničkim djelovanjem postao ESFRI projekt.

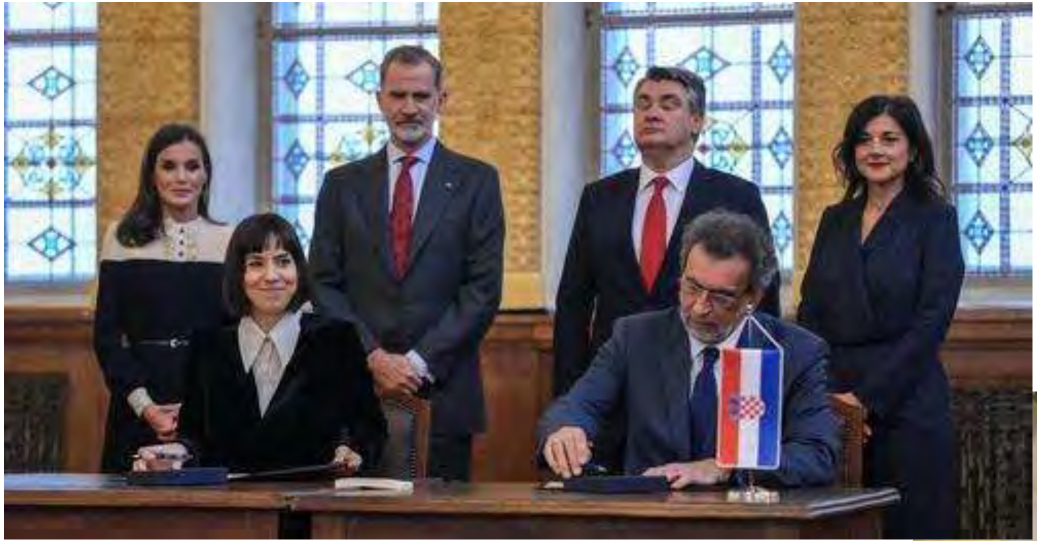
2019 - 21 DONES PreP projekt: Španjolska i Hrvatska s drugim europskim partnerima pripremile su pravnu i organizacijsku podlogu za IFMIF-DONES.

2022 Španjolska i Hrvatska potpisale su u ožujku zajedničku deklaraciju o promicanju suradnje u IFMIF-DONES kroz namjenski MoU; HR-ES MoU potpisan 17.11.
Osnivaju se konzorciji IFMIF-DONES España i DONES.HR.

2023 16.3. Osnovan Upravni odbor DONES Programa (DONES SC)

Potpisivanje HR-ES Ministarskog MoU o suradnji na DONES-u, Madrid, 20. 6. 2018.

HR i ES delegacije u F4E GB, voditelji projekta DONES, Barcelona, 4. 12. 2017.



Potpisivanje HR-ES Ministarskog MoU o pokretanju projekta DONES-a, Zagreb, 17.11. 2022.

DONES

Osnivanje DONES Steering Committee,
Granada, 16. 3. 2023.;
Predsjednik DONES SC je Staša Skenžić iz RH
HR i ES imaju 55% vrijednosti projekta


DONES

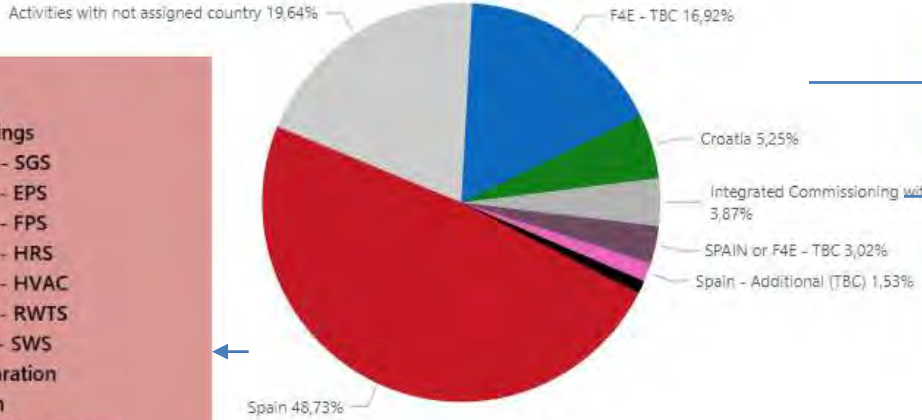

AYUNTAMIENTO DE ESCUZAR
EL PROYECTO DEL ACELERADOR
DE PARTICULAS
IFMIF
DONES

Agreed (or close to agreement) Packages

RH-06 - Robotic arm + crane - Beam Dump
RH-07 - Crane in the BTR
RH-08 - Decontamination Station for AS
RH-09 - Inspection and Testing Machine
RH-10 - Lift Frame for PCPs
RH-11 - RH Control System + Control Room
RH-12 - Viewing Systems Beam Dump and BTR
RH-13 - Crane Li Loop
RH-14 - Mast Arm and Robotic Arm - TIR
RH-15 - Multipurpose System for the HFTM
RH-16 - Other RH equipment not yet fdefined
LS-12 - DONES Steel Eurofer (STUMM+Target System+HFTM)

AS-04 - SRF LINAC (exc. Cavities and couplers)
AS-07a - RF Power Plant (MEBT+Cryomodules) Excluding RF 1 Cryo
AS-10 - Accelerator System Ancilliaries - Water - WPCL
AS-11 - Accelerator System Ancilliaries - Gas - GDS
AS-12 - Accelerator System Ancilliaries - Cryoplant
AS-13 - Accelerator System Ancilliaries - Electric - EPD
AS-14 - Accelerator System Ancilliaries - Integration - LICS, ancilliaries transport
AS-15 - Accelerator System Ancilliaries - Vacuum - HV Pumps
AS-16 - Accelerator System Ancilliaries - Vacuum - Primary Pumps
AS-17 - Accelerator System Ancilliaries - Vacuum - Vacuum Valves
AS-18 - Accelerator System Ancilliaries - Vacuum - Gauges

In discussion - Close to Agreement



RH-01 - HROC
RH-02 - Access Cell Mast Crane
LS-02 - Heat Removal System (Secondary and Tertiary Loop)
LS-05 - Oil Recovery Subsystem
AS-09 - TIR Components

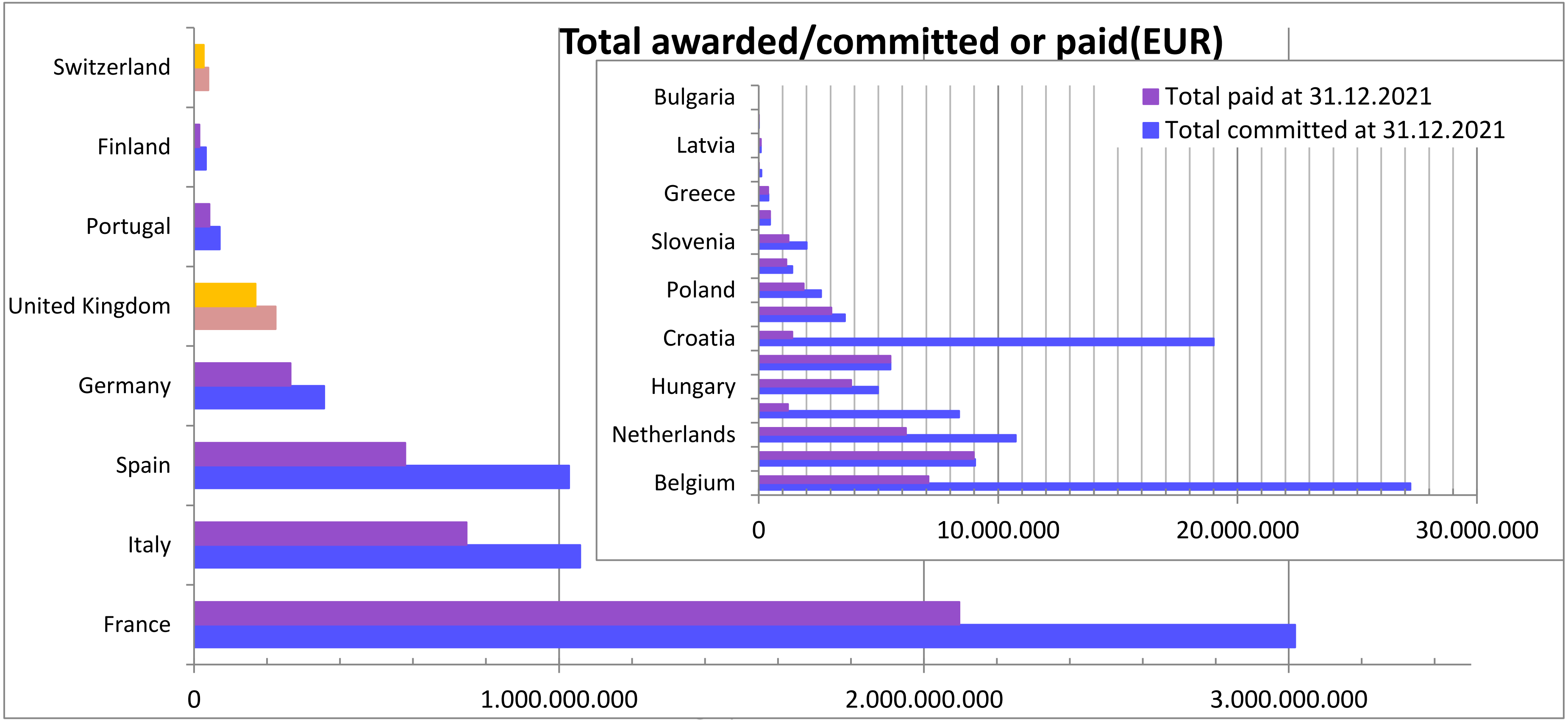
In discussion - Close to Agreement

AS-06 - HEBT & Beam Dump (excl TIR)
AS-07b - RF Power Plant (MEBT+Cryomodules) - RF 1 Cryo ONLY

TS-01 - Test Cell - (Liner + TLIC + TCCP + gas tightening components)
TS-02 - Test Cell - (TSP, PCPs, Biological Shielding walls + other components)
AS-03 - MEBT

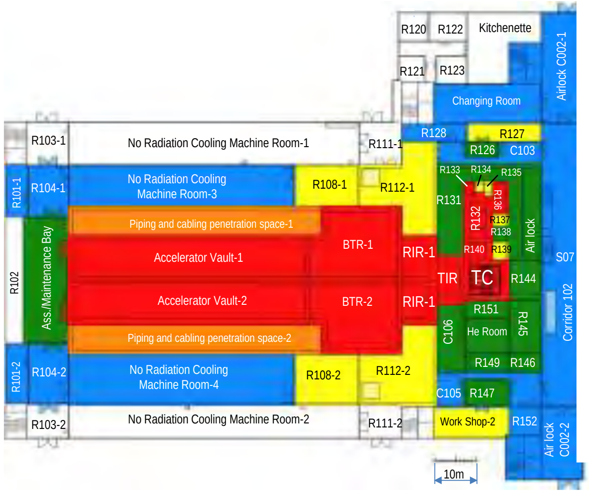
BP-01 - Seismic Pit
BP-02 - Main Building
BP-03 - Auxiliary Buildings
BP-04 - Plant Systems - SGS
BP-05 - Plant Systems - EPS
BP-06 - Plant Systems - FPS
BP-07 - Plant Systems - HRS
BP-08 - Plant Systems - HVAC
BP-09 - Plant Systems - RWTS
BP-10 - Plant Systems - SWS
BP-11 - Site Final Preparation
CS-01 - CODAC System
CS-02 - Machine Protection System
CS-03 - Safety (Control) System

TOTAL DISTRIBUTION OF CONTRACTS



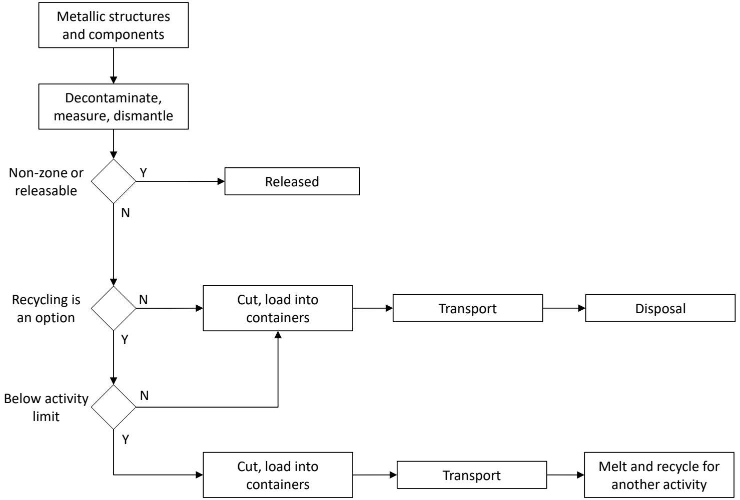
Croatian fusion research highlights @ IFMIF-DONES

Radiation monitoring and personnel dosimetry at DONES



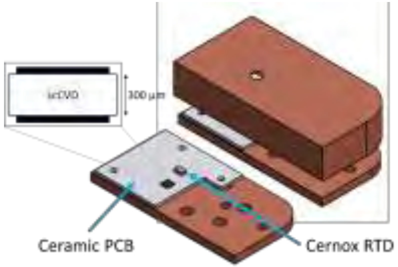
DONES decommissioning strategy

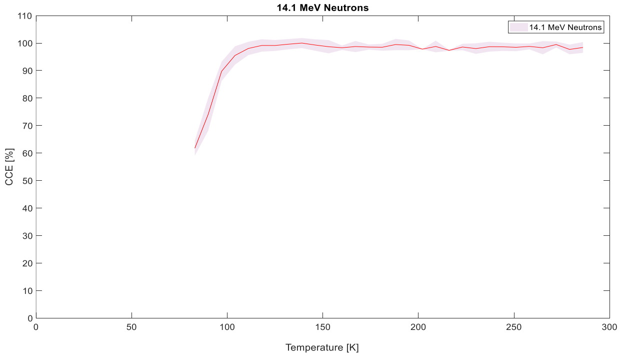
RBI in partnership with APOSS



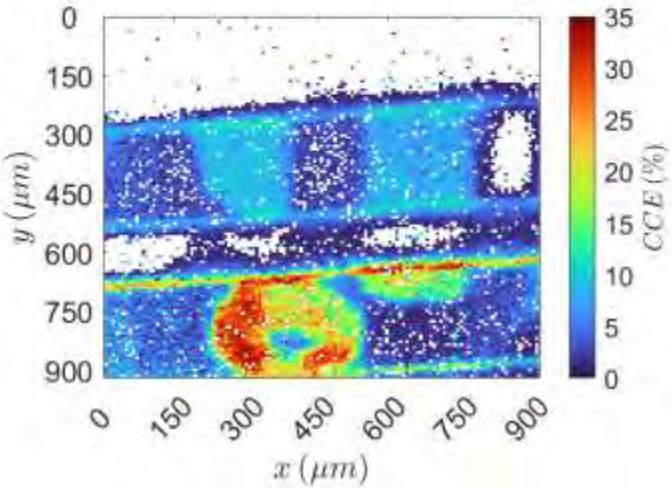
Croatian fusion research highlights @ IFMIF-DONES

Development of Micro-Loss Monitors – neutron detectors for DONES accelerator



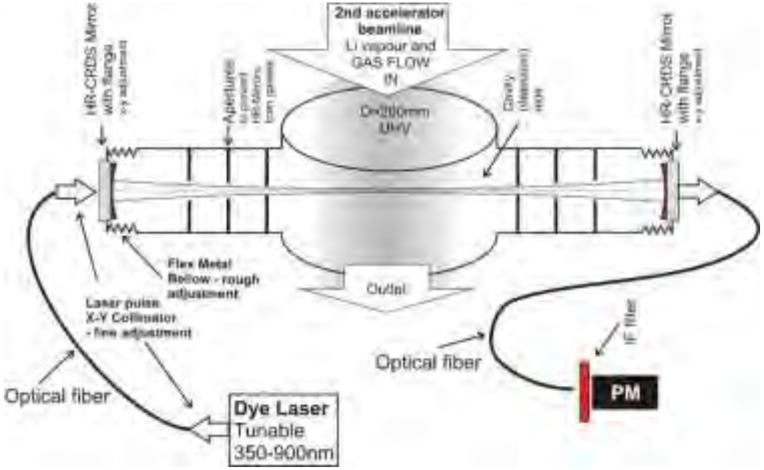


Assessmentof neutron induced damage in electronics at DONES

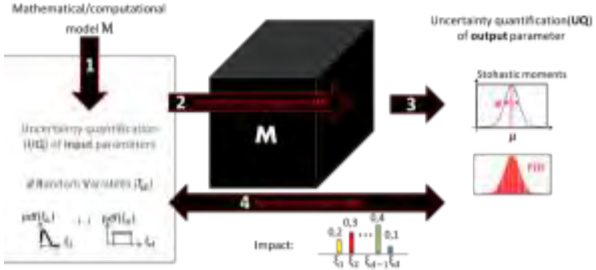


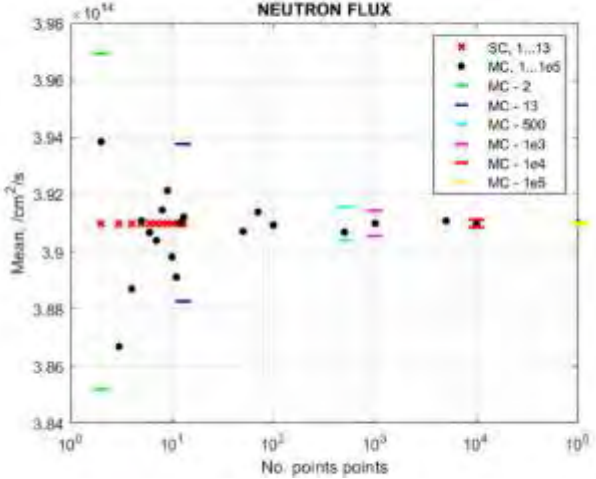
Croatian fusion research highlights @ IFMIF-DONES

Cavity Ring-Down Spectroscopy laser systems for lithium evaporation monitoring by IF

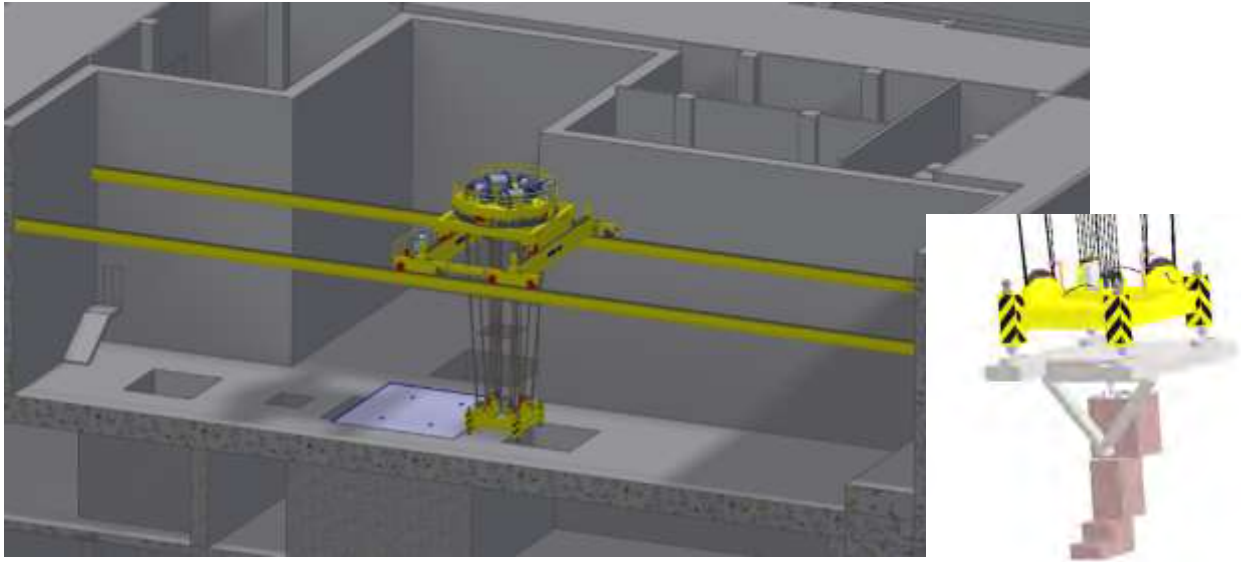


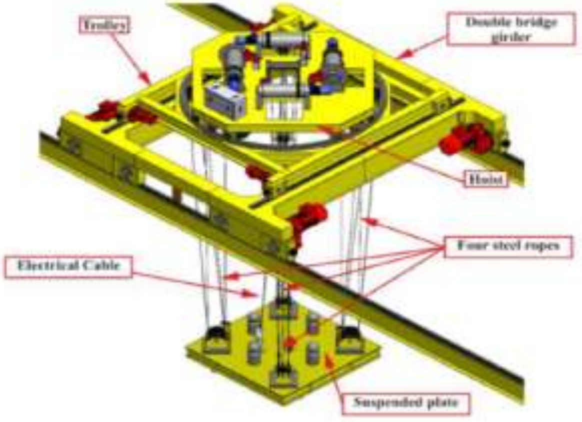
Assessment of error propagation in tuning of DONES accelerator by FESB

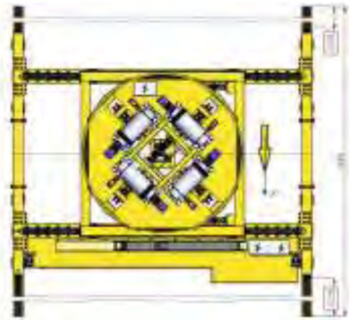


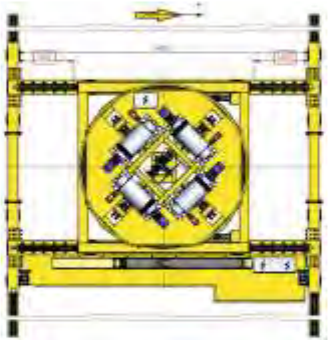


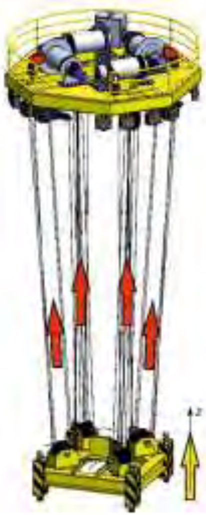
Heavy Rope Crane – HROC – za rukovanje poklopcima i teškim teretima



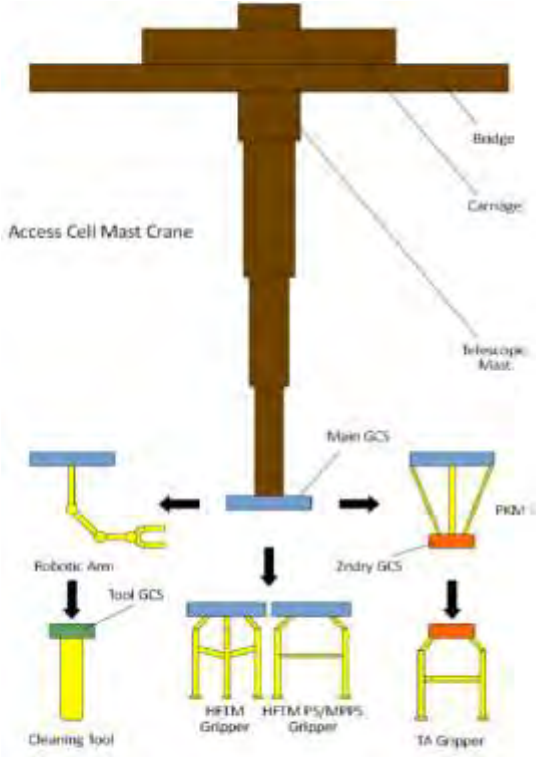


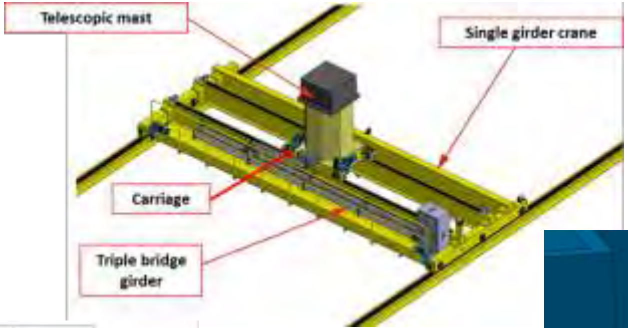


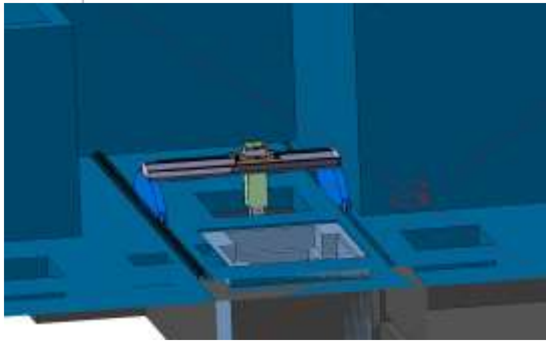




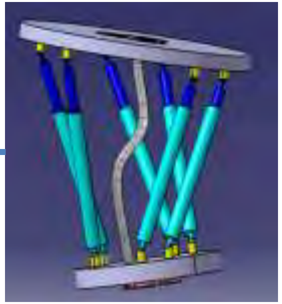
Access Cell Mast Crane – ACMC – za rukovanje uzorcima i opremom







Robotska ruka

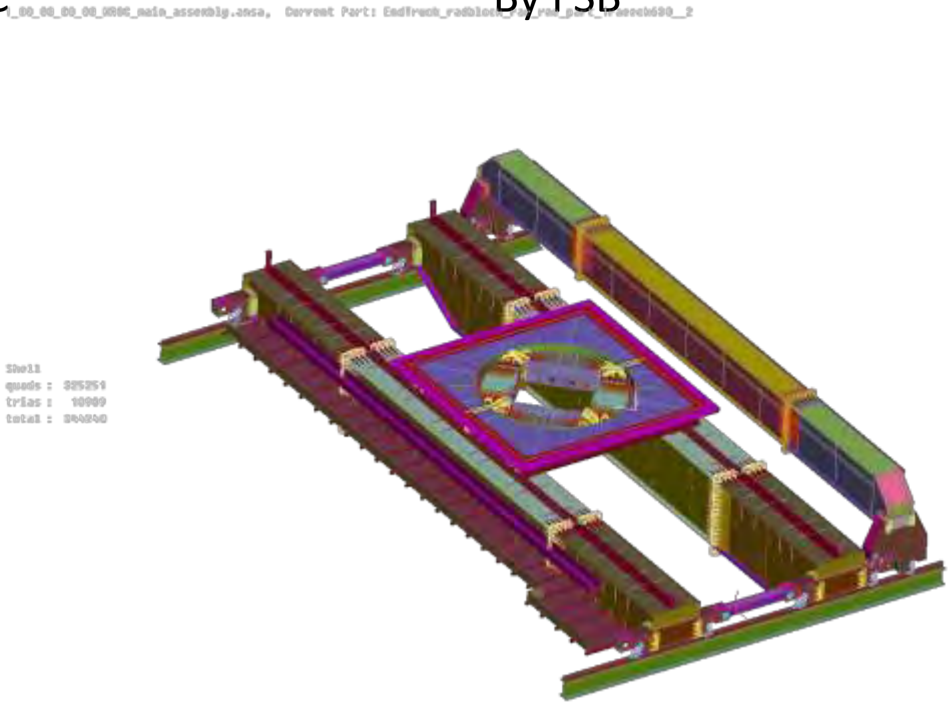


Paralelni Kinetički Manipulator (PKM)

Croatian fusion research highlights @ IFMIF-DONES

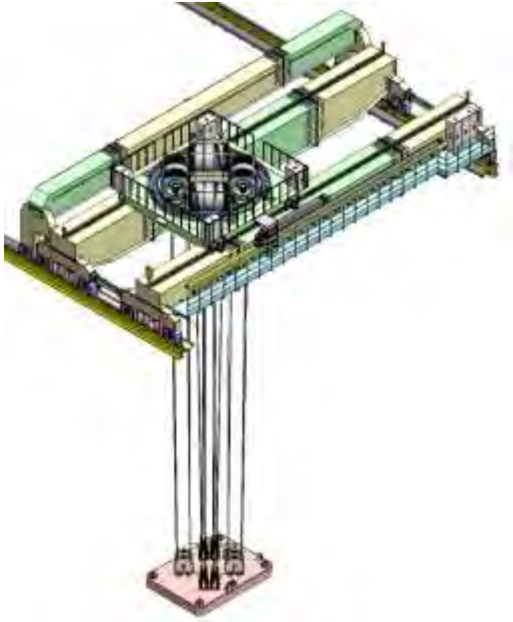
Remote Handling integration
RBI & FSB in partnership with INETEC

Seismic assessment for cranes
By FSB



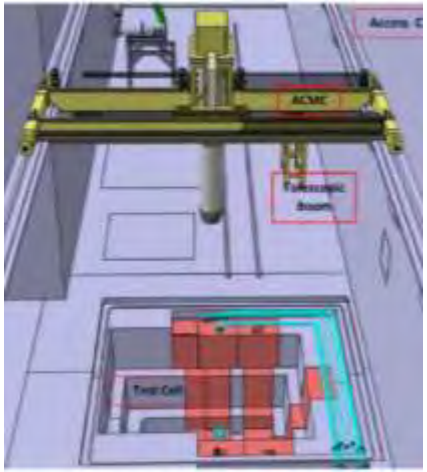
Key Remote Handling Systems

DONES.HR
FUSION IS THE FUTURE



Heavy Rope Crane (HROC) for precise positioning of 100+ tons concrete lids at Test Cell of DONES

Designed by RBI, FSB & INETEC



Access Cell Mast Crane (ACMC) for sample manipulation

Designed by RBI, FSB & INETEC

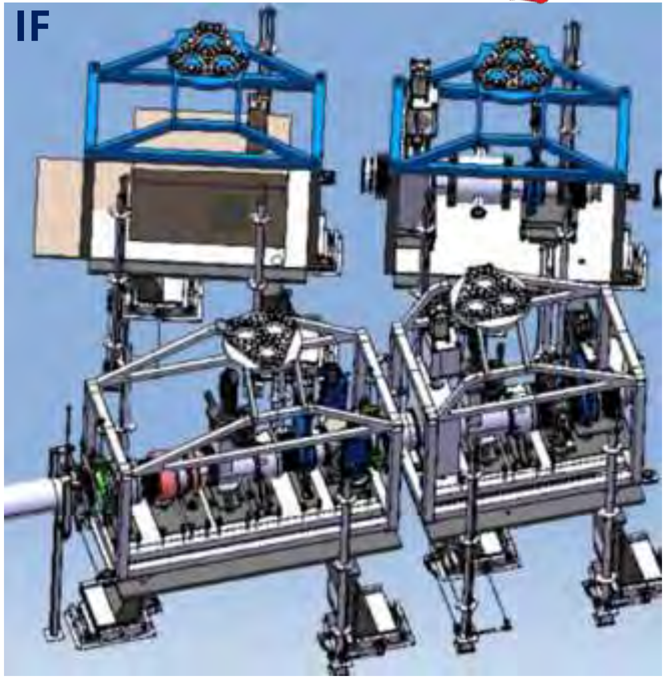
Croatian Contribution

Target Interface Room

DONES.HR
FUSION IS THE FUTURE

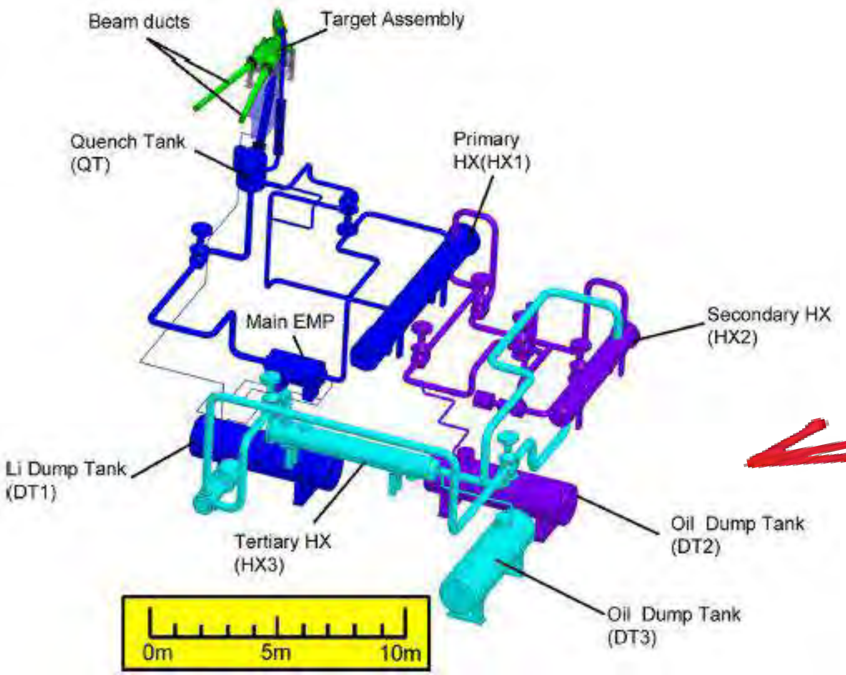
The key TIR section of the IFMIF-DONES accelerator consists of four modules, with all sorts of sensor systems to diagnose the incredibly powerful ion beam of 5 MW and laser systems for characterization of “waterfall” of molten lithium.

CRDS Laser system for lithium evaporation monitoring **Designed by IF**



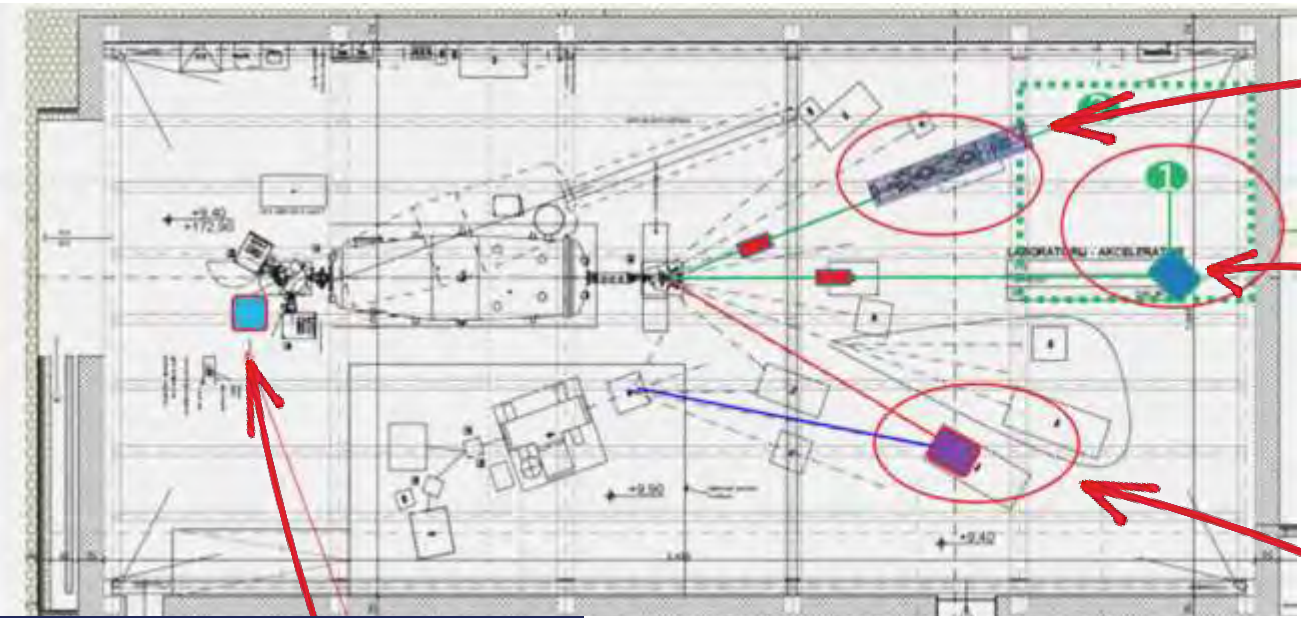
Croatian Contribution

Heat Exchangers for molten lithium loop



Oil-Oil and Oil-Water
10 MW Heat Exchangers with
related diagnostics and Oil Dumps

Croatian Contribution



Setup for DONES Accelerator System Ion Beam Diagnostics Testing

Setup for DONES Accelerator System Radiation Detectors Testing

DiFU dual-beam facility for ion beam irradiaton and pre-selection of fusion materials

Multi-cusp High-power ion source

Croatian Contribution

After O-ZIP Project - new RBI accelerator center will host the DONES Support Facilities

DONES.HR
FUSION IS THE FUTURE

And other Support Facilities required by our Spanish partners

IFMIF-DONES ENABLES FUSION POWER

For the first fusion power plant to work, a series of complex research and testing of technologies and materials will be conducted.

Here, a <u>collaboration between academia and industry will be crucial.</u>

IFMIF DONES GRANADA — THE KEY TO THE FUTURE

DONES.HR

IFMIF-DONES ESPAÑA