Materials selection for and irradiation capabilities of MYRRHA

Joris Van den Bosch, LANL

H. Ait Abderrahim, SCK●CEN

P. Baeten, SCK●CEN

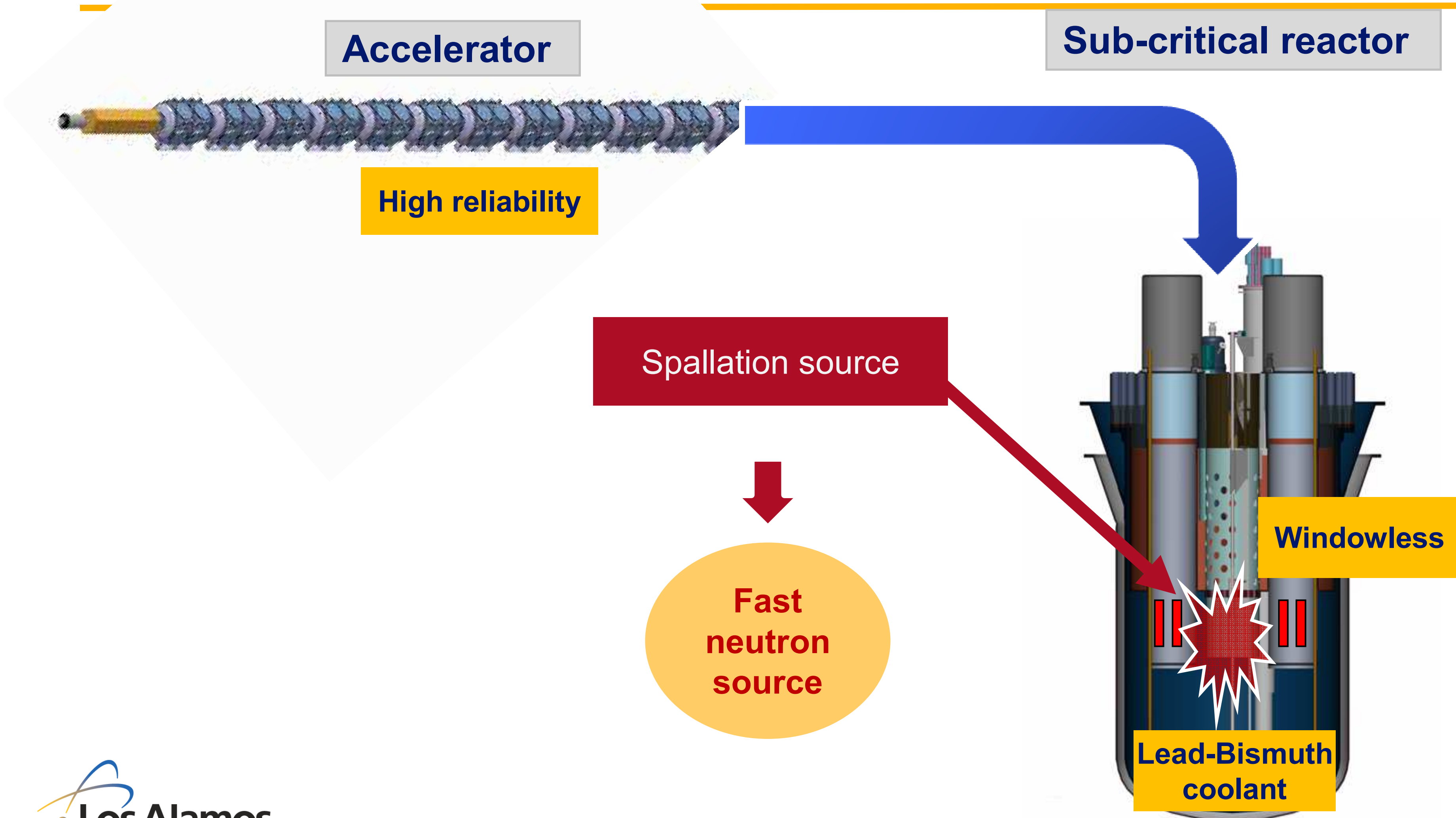
V. Sobolev, SCK●CEN

S. Gavrilov, SCK●CEN

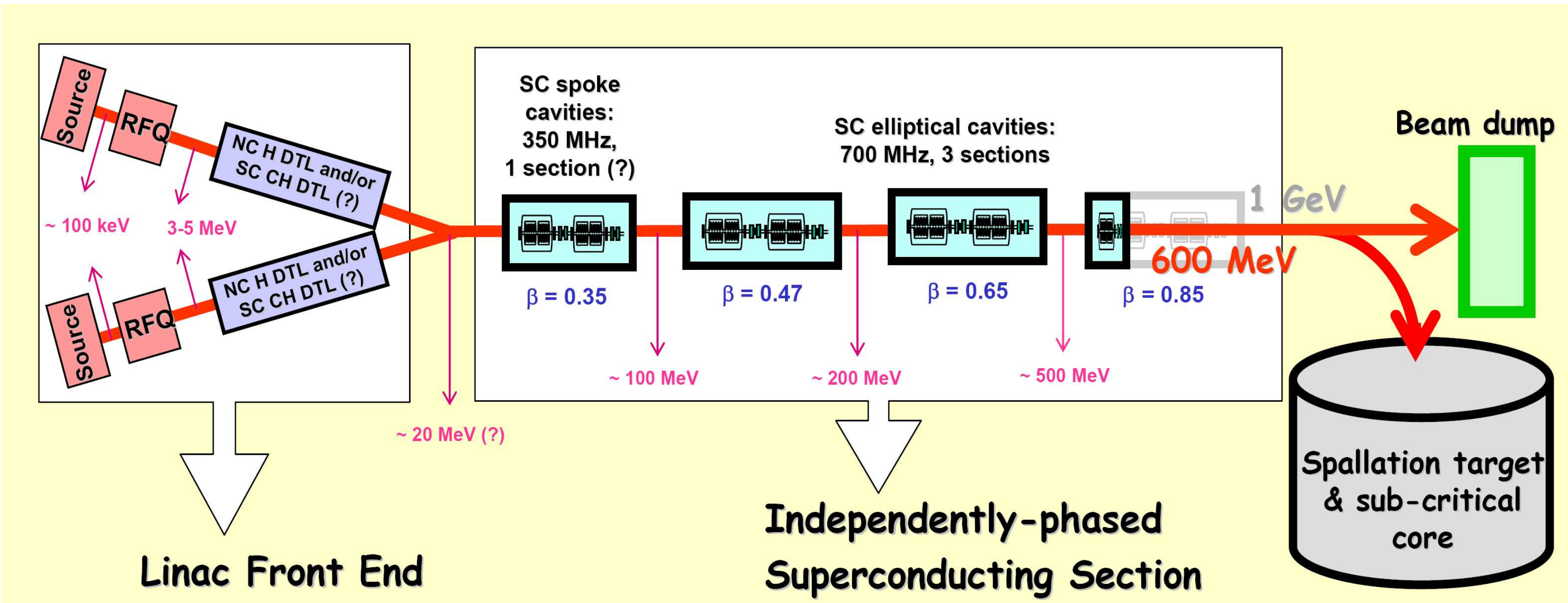
Outline

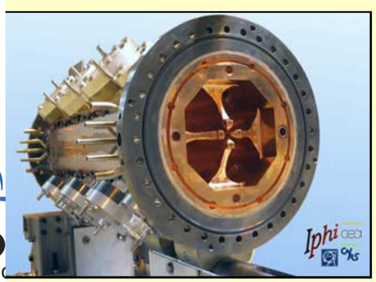
- MYRRHA design (brief)
- MYRRHA materials selection
- Material challenges towards MYRRHA
- MYRRHA material irradiation capabilities
- Summary

MYRRHA an innovative concept



MYRRHA components: Accelerator





Lay out

Inner vessel

Cover

Core structure

Spallation loop

Heat exchangers

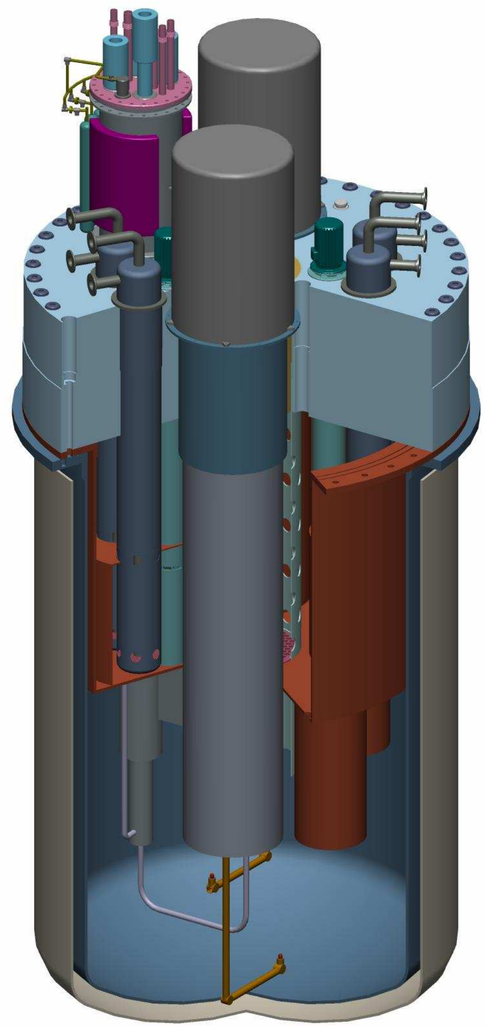
Pumps

Diaphragm

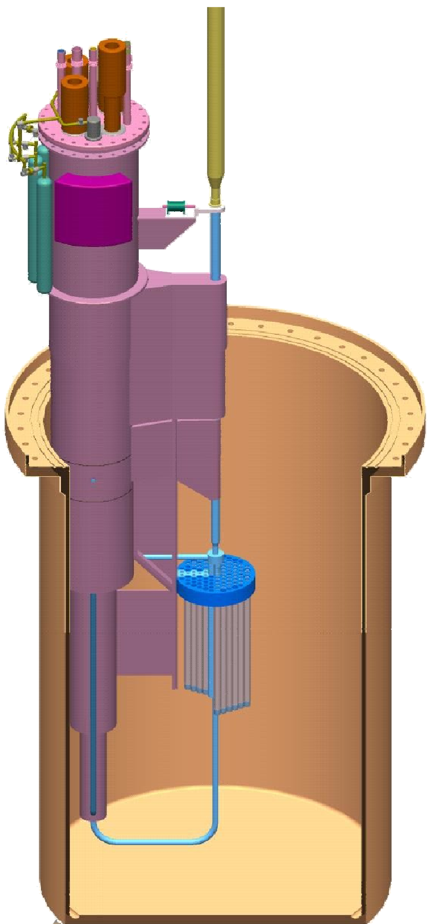
Fuel storage

Fuel manipulators

Guard vessel

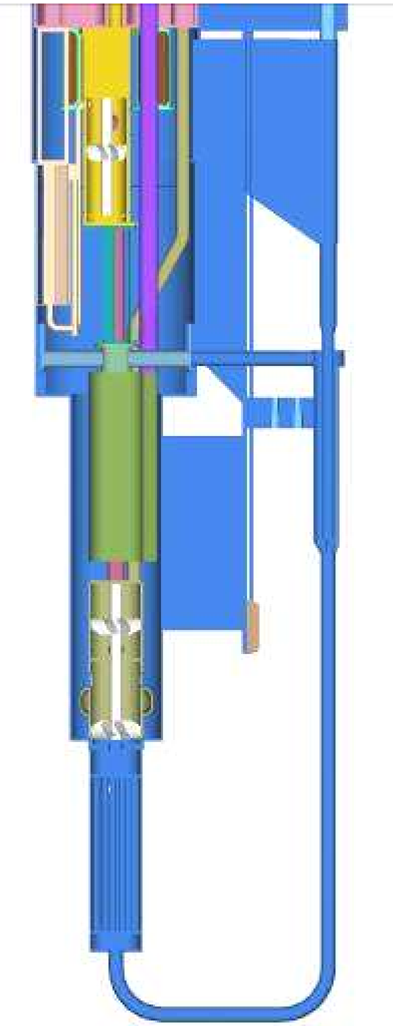


MYRRHA components: Spallation target



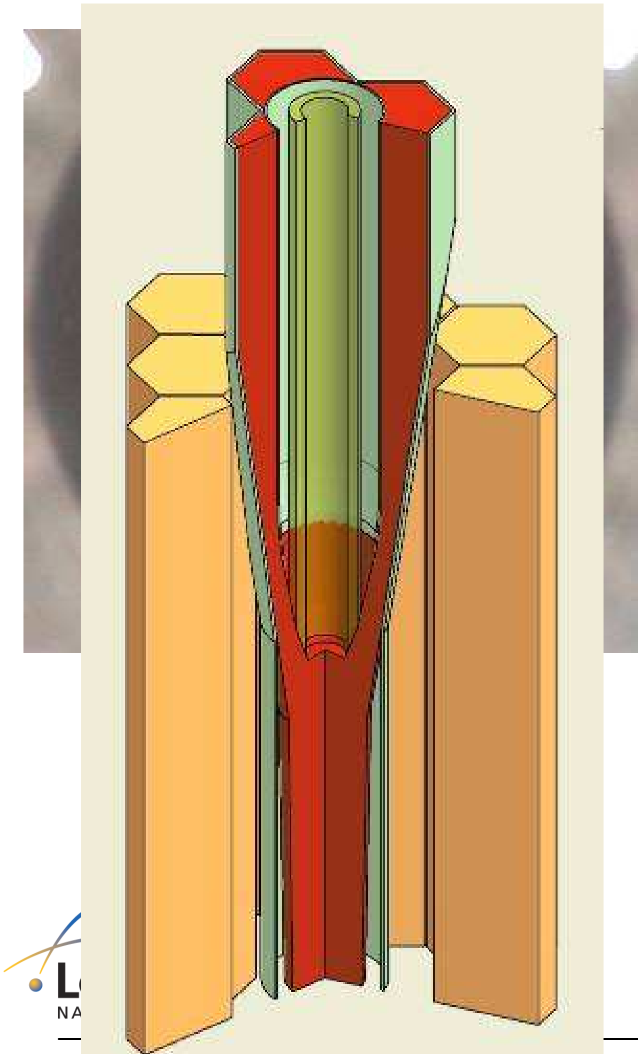
- Tasks
  - Produce 10^{17} neutrons/s to feed subcritical core @ k_{eff}=0.95
  - Accept megawatt proton beam
    - **600 MeV, 2.5-3 mA ⇒ ≈1-1.2 MW heat**
    - 300 mm penetration depth
    - Pb-Bi eutectic as target material
  - Fit into central hole in core
    - compact target
    - windowless (beam density)
    - Off-axis geometry
  - Match MYRRHA purpose as experimental irradiation machine
    - flexible remote handling
  - Survive (lifetime)

Spallation target loop configuration



- **LBE flow & cooling**
  - Forced convection (10-20 l/s)
  - $T_{max(LBE\ surface)}$=450°C; ΔT< 100 °C
  - Heat exchanger to main vessel coolant
- **Vacuum requirements**
  - Pressure above target <10^{-3}-10^{-4} mbar
  - Confinement of volatile spallation products
- **LBE conditioning**
  - Corrosion inhibition, -Filtering
- **Service by remote handling**
  - Entire spallation unit removable from main vessel after core unloading
  - Separate sub-unit with all active elements

Spallation target



- **Windowless target**
  - space considerations
  - beam density
- **Formation of target free surface**
  - Confluence of Vertical coaxial flow
  - Forced detachment
    - Decoupled inlet-outlet flow
    - Buffer during beam transients
  - Recirculation zone : in check
  - Feedback necessary (slow)
  - Proton beam distribution
    - Avoid recirculation zone heating

critical parameters of the MYRRHA components

Components	Material	Min. Temp. unlimited time (°C) [1]	Max. Temp. unlimited time (°C)	Max. Temp. lasting 1 week (°C)	Max. LBE velocity (m/s)	Max. Neutron damage (dpa/yr)	Max. Mech. stress (MPa)
Fuel Assemblies ▪**Clad** ▪**Structures**	**T91***	**200**	**450** **450**	**550** **550**	**1.6** **2.3**	**29** **29**	
Dummy Assemblies	**T91**	200	**350**	**550**	0.2		
Core Barrel	**316**	**200**	**350**	**550**	0.2	**1.54** [2]	**110**
Heat Exchanger	**T91**	**200**	**370**	**550**	**1.1**	0.032	**114**
Circulation Pumps	**To be defined MAXTHAL (Ti_3SiC_2)** [3]	200	**300**		**9**	0.06	**na**
Reactor Vessel	**316L**	**200**	**370**	**550**	0.1	0.6.10^{-4}	**60**
Diaphragm	**316L**	200	370	**550**	0.1	0.64	**~120(primary)** **~150(second)**
Core support plate	**T91**	200	400	**550**	**1.3**	**0.9**	170
Refuelling Equipment	**316L**	200	370	**550**	0.1		na
Purification System							
Target ▪**Structures** ▪**Pump**	**T91** **MAXTHAL / 316**	200	450	550	2.5 8		

Approach to MYRRHA fuel element qualification (0)

Fuel rod and sub-assembly pre-design

↓

Materials screening and selection

↓

Preparation of the database of the materials properties

↓

Search materials providers and the materials procurement

↓

Search manufacturers for components

↓

Fabrication (components, rods, SA)

↓

Pre-qualification of components

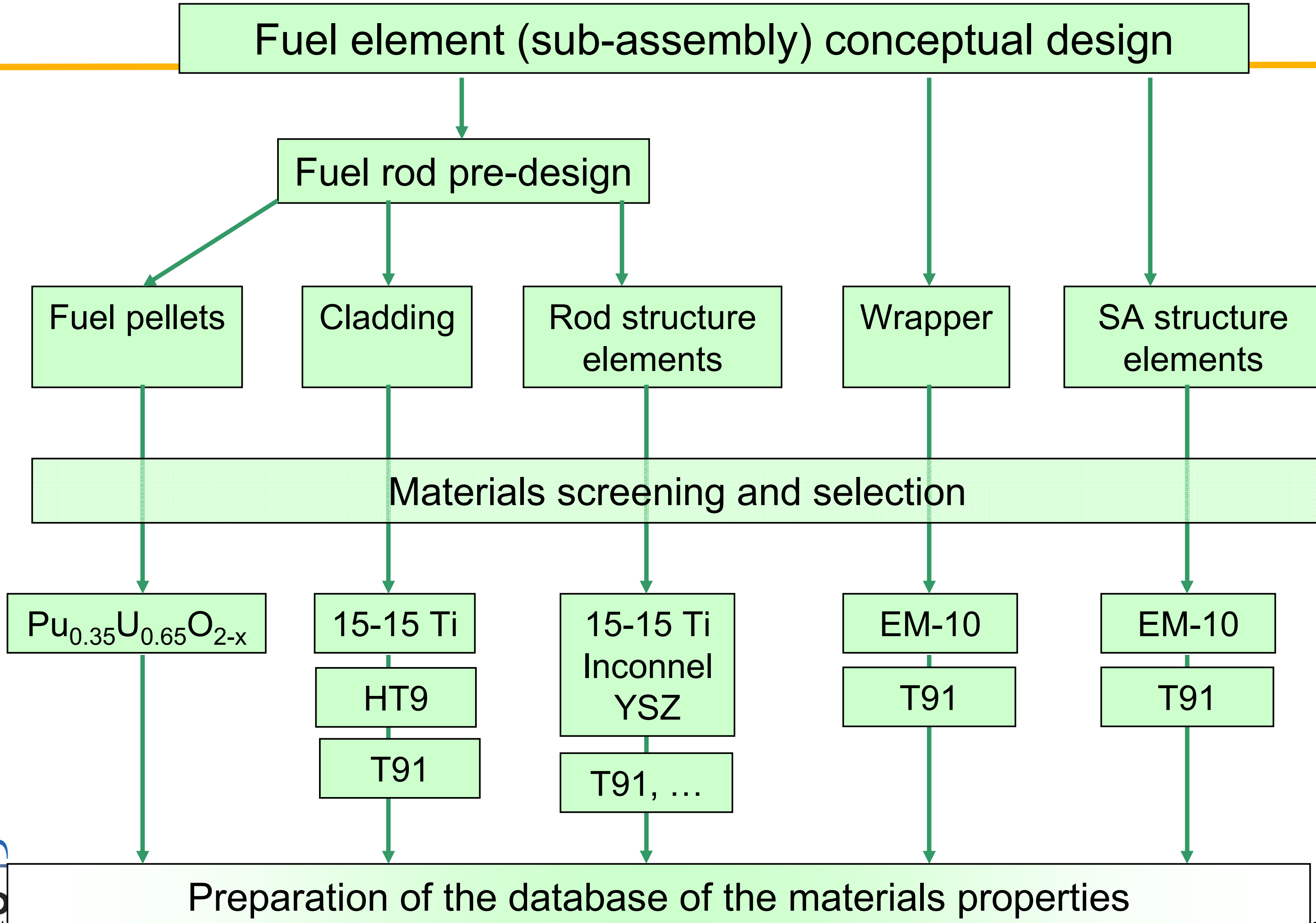
↓

Qualification…

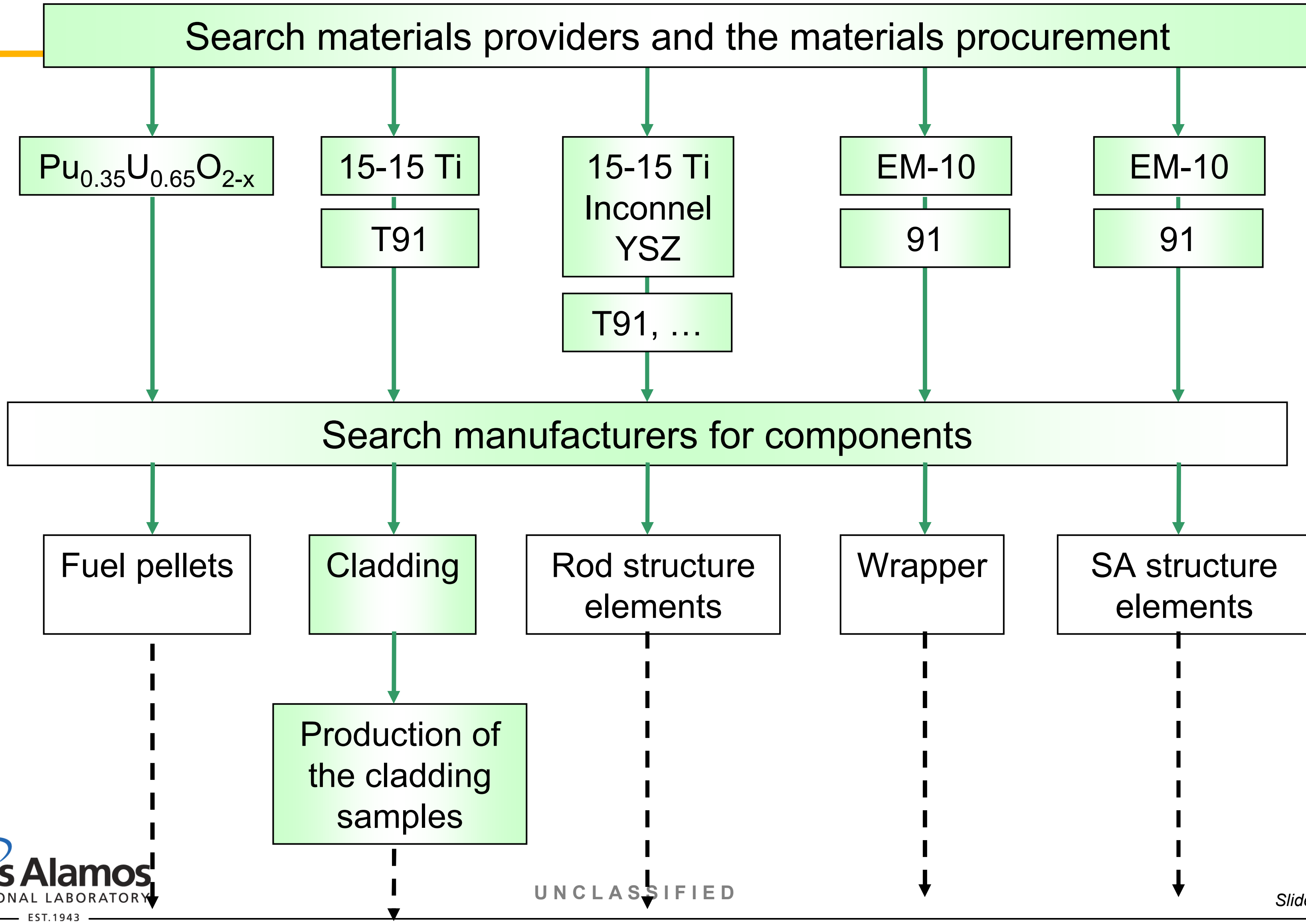
↓

Licensing for the production of SA

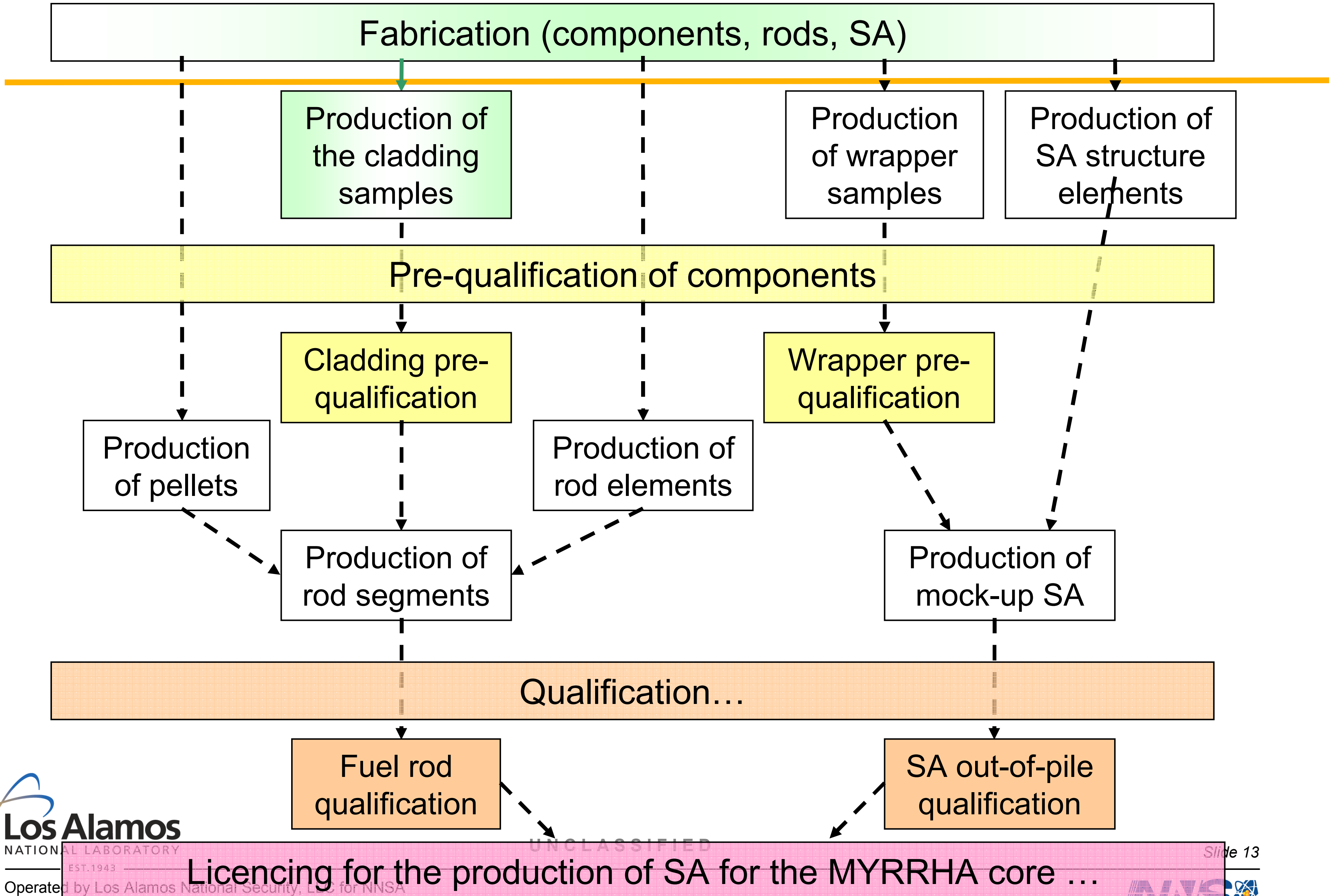
Approach to MYRRHA fuel element qualification (I)



Approach to MYRRHA fuel element qualification (II)



Approach to MYRRHA fuel element qualification (III)



“Ways” for clad qualification

- **15-15 Ti short track**
  - Visibility of this track should be explored
  - To obtain database of 15-15Ti properties (CEA?)
    - Literature very limited
  - To define list of damaging effects at cladding/coolant boundary
  - To define experimental matrix
- **15-15 Ti long track**
  - To define list of **all** possible damaging effects
  - To define experimental matrix
- **T91 long track**
- **Fabrication**

Scheme of experiments for fuel pin re-qualification

Out-of-pile

- Corrosion tests
  - stagnant
  - flow
- Mechanical tests
- Pressurized tubes
- Fuel pins tests

In-pile

- Corrosion tests
  - stagnant
  - flow
- Mechanical tests
- Pressurized tubes
- Fuel pins tests

ASTIR & LEXUR II **MYRMAT**

Preliminary time schedule

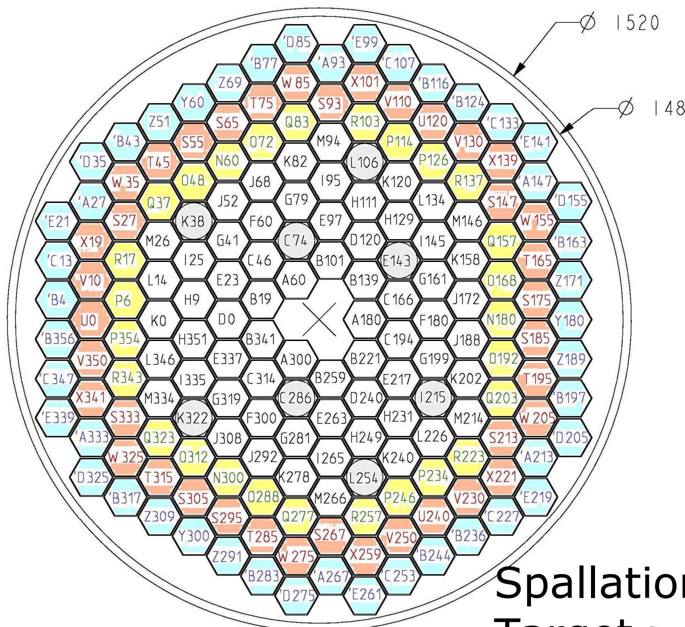
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
I. FUEL ELEMENT DESIGN	Pre-design done											
II. MATERIALS SELECTION	Done											
III. DATABASE of properties	Under way											
IV. MATERIALS PROCUREMENT	??? Only samples for studies											
V. FABRICATION:												
1) Cladding samples												
1a. Short samples	Done, but with different diameters											
1b. Full-scale	???											
2) Fuel pellets	???											
3) Structure elements	???											
4) Fuel rods	???											
4a: segments for prequalification	???											
4b: full-scale fuel rods	???											
VI. PREQUALIFICATION (components):												
1) Cladding	Partially done in IP EUROTRANS											
LEXUR II												
GETMAT												
MYRMAT												
2) Wrapper (out of pile)	Under way											
IP EUROTRANS												
GETMAT												
3) Fuel pin (segments irradiation)*						??? - availability of MTR						
VII. LICENSING (for fuel fabrication)												
VIII. FABRICATION of FUEL (2												
IX. FIRST CORE LOADING												

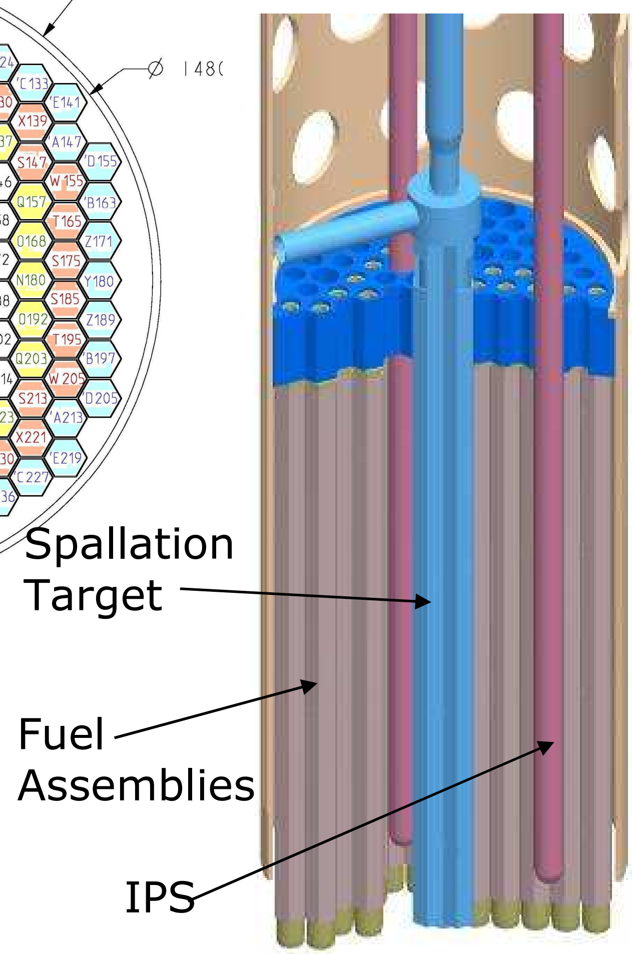
???

Core loading in the MYRRHA actual planning

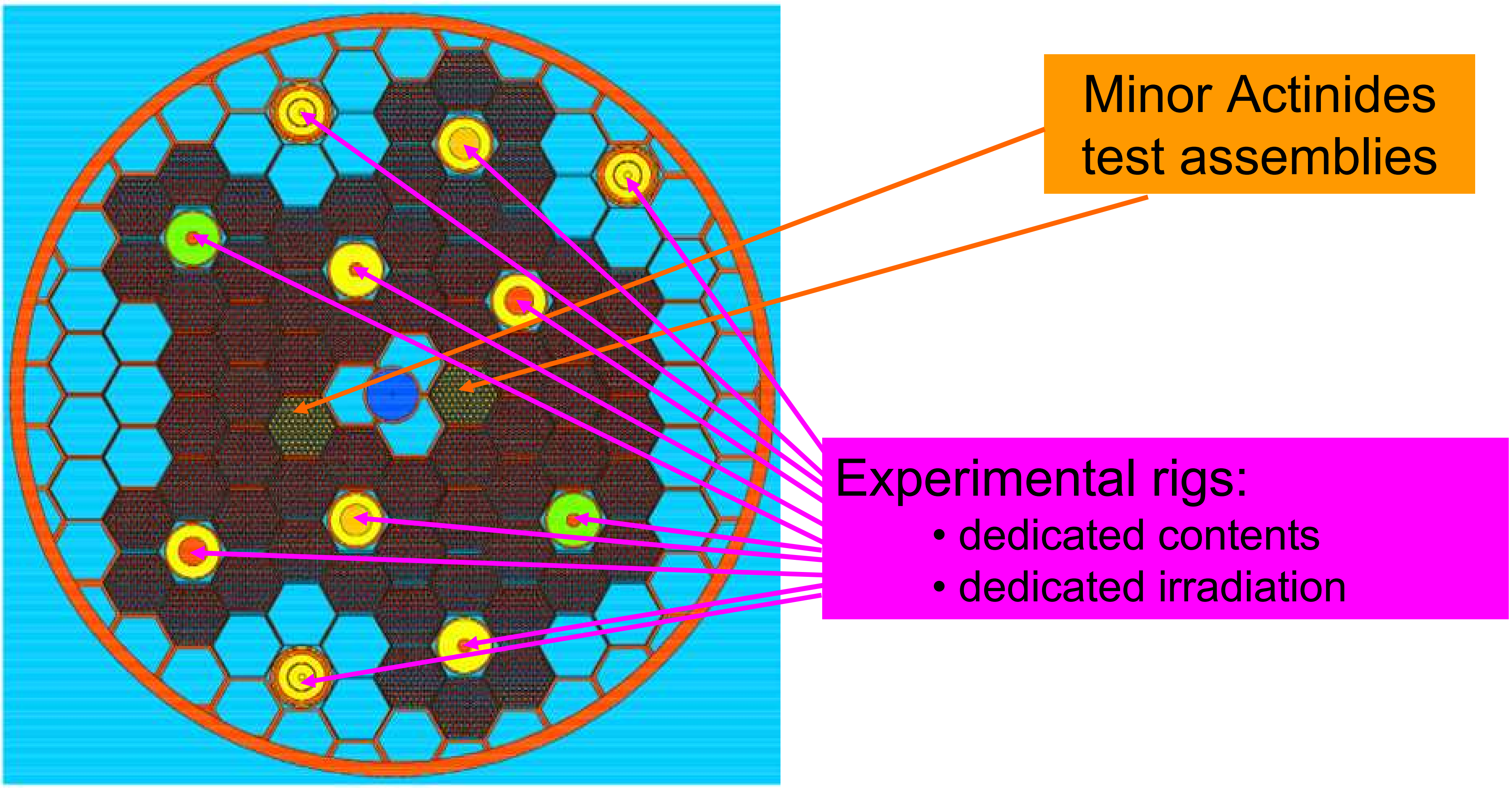
MYRRHA components: Subcritical Core

- $k_{eff} \approx 0.95$
- **183 hexagonal macro-cells**
- **Target-block hole :**
  3 FA removed
- **72 positions for fuel assemblies**
  (8 IPS positions included)
  - ≈30 % MOX fuel
- **27 positions for fuel assies or dummy assies (filled with LBE) (yellow)**
- **84 additional cells for core reconfiguration**



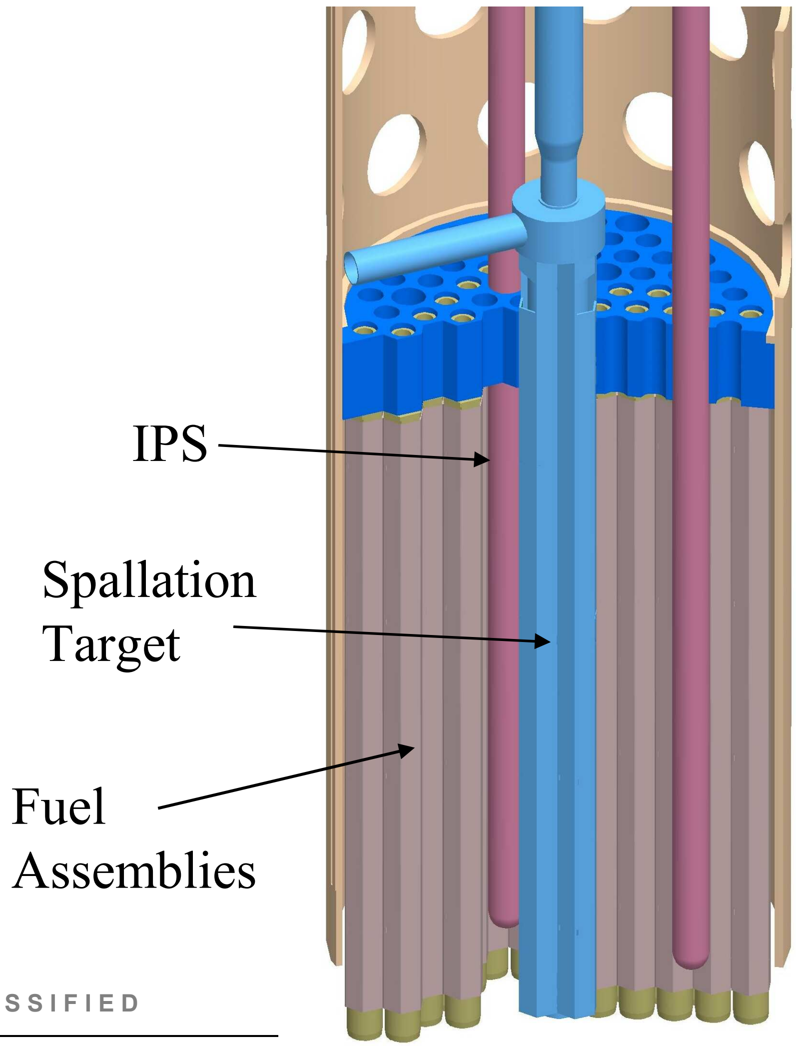


MYRRHA: a Flexible Experimental Facility

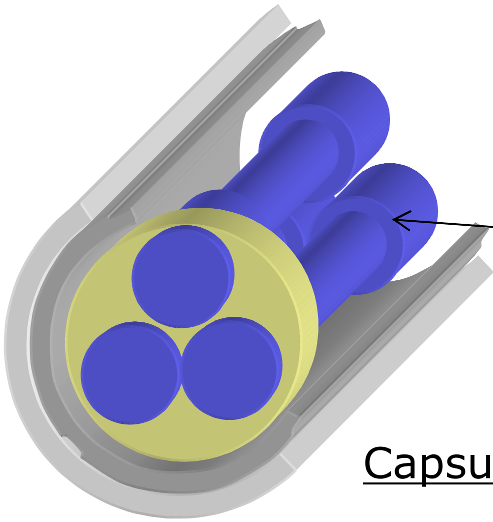


Material Irradiation in MYRRHA

- **IPS Location in the core**

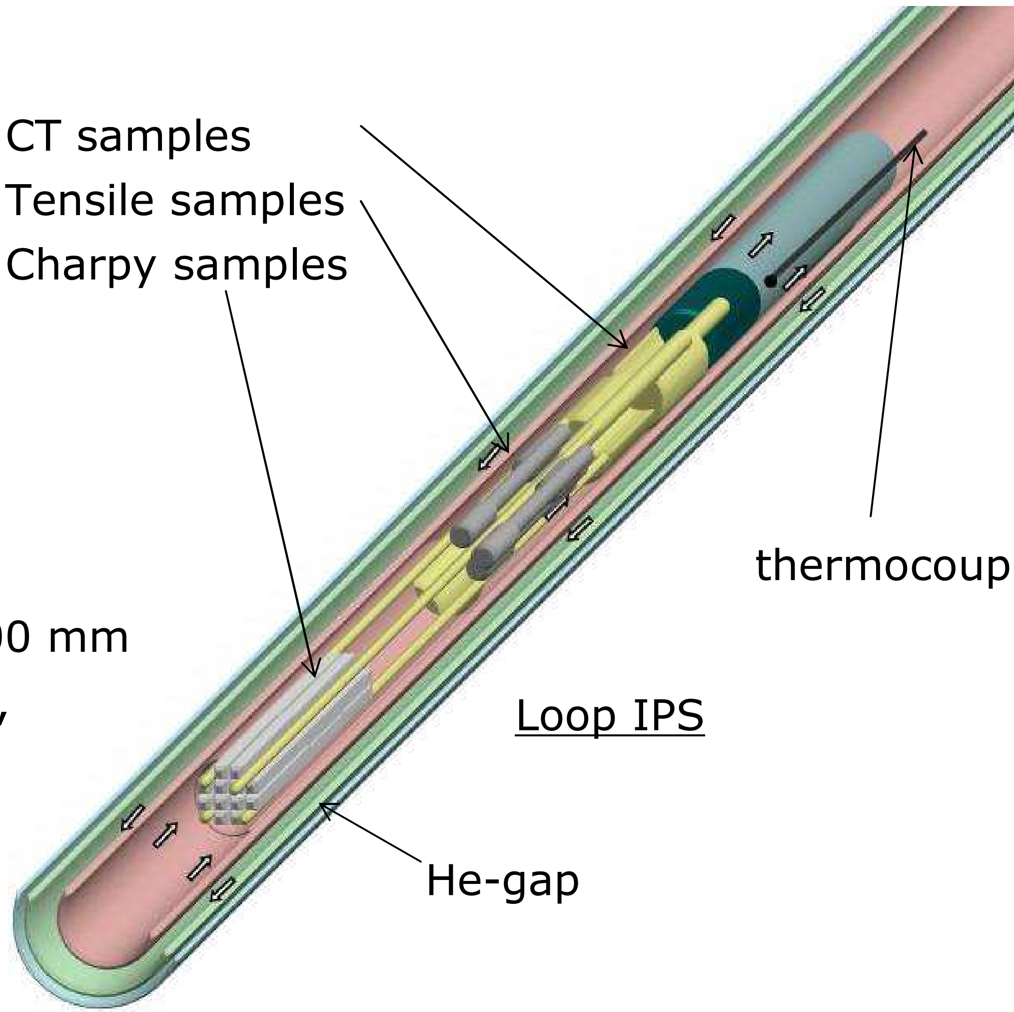


IPS Material Testing Typical Layout



Capsule IPS

CT samples
Tensile samples
Charpy samples



thermocouple

Loop IPS

He-gap

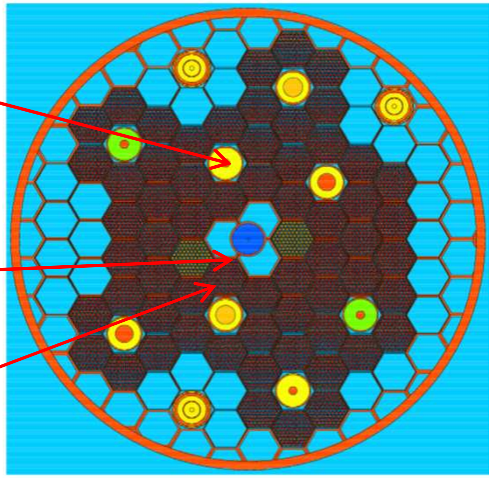
IPS outside diameter 80 mm

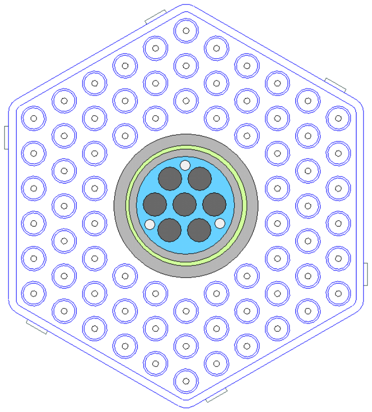
Length for irradiation test 600 mm

Instrumentation : dosimeter, thermocouple,…

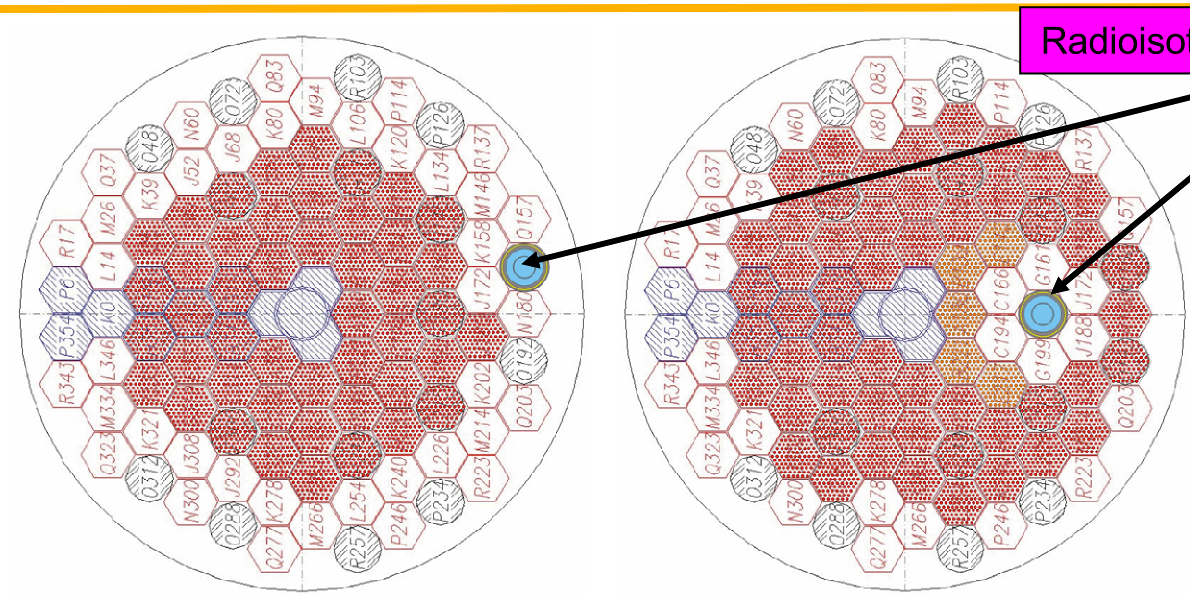
Irradiations of materialsin XT-ADS

- In IPS closest to spallation target
  - dpa: 18 dpa/EFPY
  - appmHe/dpa: 0.30 – 0.40
- Close to target module for fusion materials
  - dpa: about 31 dpa/EFPY (360 EFPDs)
  - appmHe/dpa: 6.4
- In hottest fuel assembly
  - dedicated irradiation fuel assembly, but no “loop-type”, limited volume
  - results in hottest pin clad:
    - dpa : about 30 dpa/EFPY
    - appmHe /dpa: about 3.8





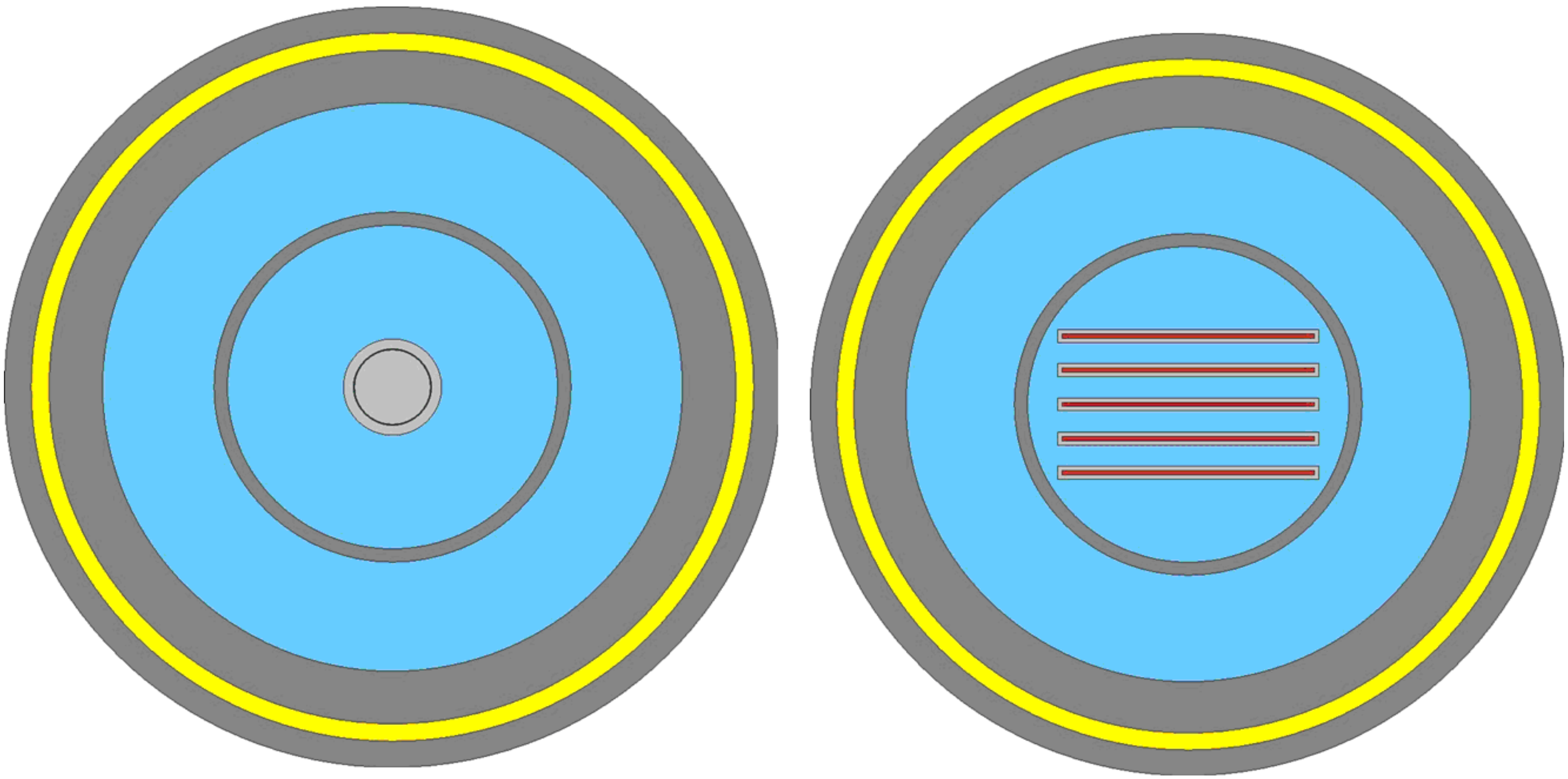
MYRRHA Core configuration with Radioisotopes production device



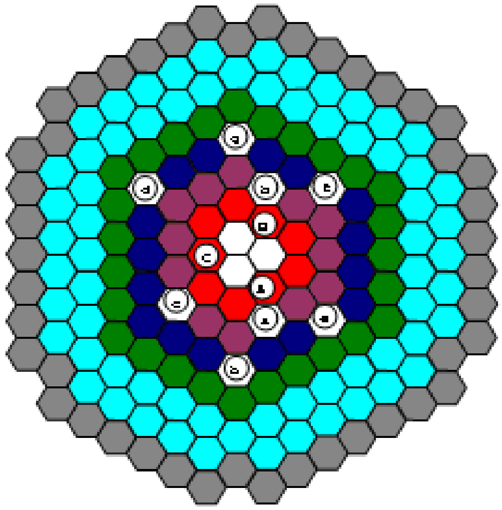
Radioisotope	Φ_{tot} (n/cm^2s)	Activity (Ci/g)
IPS-loop loaded in inner channel		
^{99}Mo	$2.2\ 10^{15}$	$1.2\ 10^{3}$
^{192}Ir	$2.3\ 10^{15}$	$1.8\ 10^{3}$
IPS- loop loaded in outer channel		
^{99}Mo	$1.4\ 10^{15}$	$0.9\ 10^{3}$
^{192}Ir	$1.5\ 10^{15}$	$1.8\ 10^{3}$

T_{irr} = 9 EFPDs for Mo
7 EFPDs for Ir

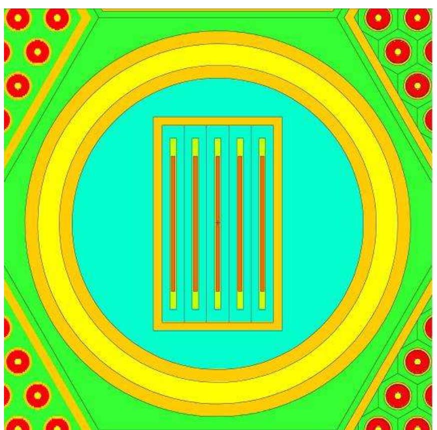
Radioisotope production for
targets: Ir^{nat} capsule (left); ^{235}U-plates (right)



^{99}Mo Production

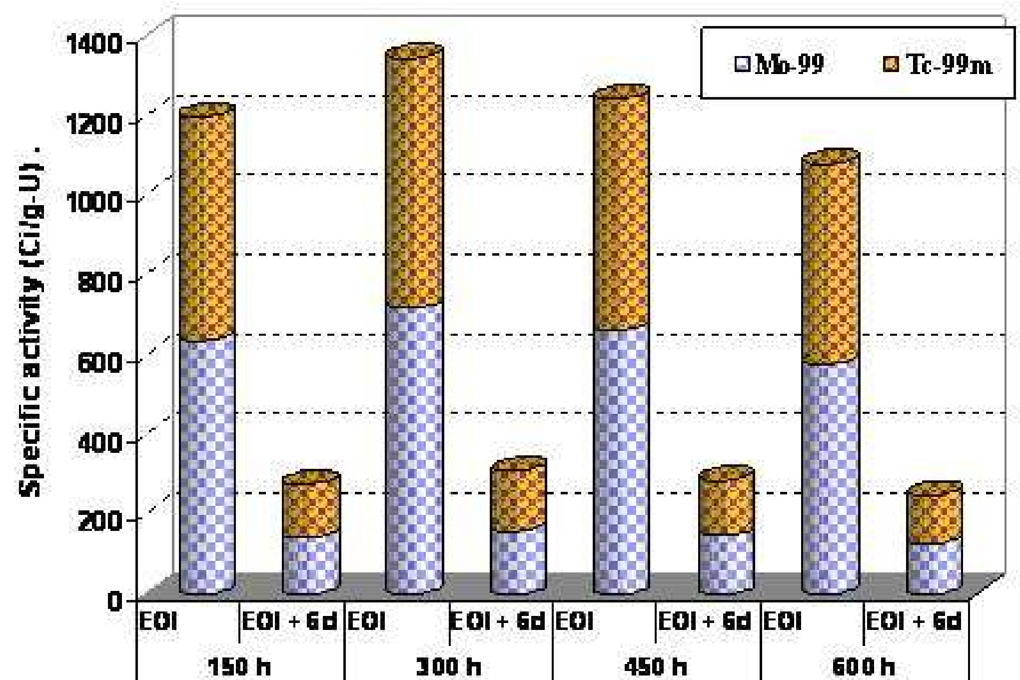


Core configuration with IPS position



Irradiation IPS with 5 HEU targets

Production performance in C74 channel



	150 h EOI	150 h EOI + 6d	300 h EOI	300 h EOI + 6d	450 h EOI	450 h EOI + 6d	600 h EOI	600 h EOI + 6d
Tc-99m	559	136	628	152	581	141	505	122
Mo-99	638	141	717	158	663	146	576	127

Irradiation cycle length

Summary

- **Design not final (CDT within European Framework Program 7)**
- **First choice material selection is final;**
- **Strong effort needed towards licensing;**
  - Cladding is most critical component at this point;
  - Mechanical properties under irradiation while in contact with LBE are critical.
- **MYRRHA is to be:**
  - A flexible neutron irradiation testing facility as successor of the SCK•CEN MTR BR2 (100 MW)
  - An attractive fast spectrum testing facility in Europe for Gen.IV and Fusion
  - A full step ADS demo facility and P&T testing facility
  - A technological prototype as test bench for LFR Gen.IV
  - An attractive tool for education and training of young scientists and engineers

One picture is better than a thousand words, we are in 2017~2020