MYRRHA – Draft 2
System Operation, Inspection & Maintenance

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On behalf of MYRRHA team and MYRRA support

http://www.sckcen.be/myrrha

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Summary

- Introduction
- Working Regime of MYRRHA
- Reactivity monitoring approach in MYRRHA
- I&C approach in MYRRHA
- ISI&R approach in MYRRHA
- Conclusions

Introduction

- MYRRHA is thought and designed as an experimental facility
- An experimental irradiation facility has a short operation cycle in order to allow loading and retrieval of irradiated devices on very regular and flexible manner
- an availability rate of 65% is targeted (3 MO +1 MSShD)*2 +3 MO + 3 MLShD)
- Advantages of such short cycle:
  - ➢ Preventive maint. On Accel. => improve Reliab.
  - ➢ Δk_{eff} small => afford I_p ct. during cycle => ease licensing

➢ ISI&R via RH & Robotics needed to achieve 65% avail.

Working Regime of MYRRHA (1)

- 3 MO +1 MSShD)*2 +3 MO + 3 MLShD:
  - 3 Months Operation:
    - ✓ Δk_{eff} small (-~1700 pcm) : can be compensated by core reshuffling, burnable absorber or combination
    - ✓ Allow good irradiation results for material damage (7 to 15 dpa/cycle), MA transmutation (>> than Chemical. Measurement), Fuel BU (10 GWd/t)
    - ✗ More challenging for short irradiations such as radioisotope production but feasible (need further design work)

Working Regime of MYRRHA (2)

- 3 MO +1 MSShD)*2 +3 MO + 3 MLShD:
  - 1 Month Short Shut Down :
    - ✓Partial Core reload (few fresh FA) and reshuffling
    - ✓Experimental devices handling
    - ✓Routine inspection
  - 3 Months Long Shut Down :
    - ✓larger Core reload and reshuffling
    - ✓Fuel transfer from the in-vessel storage
    - ✓Experimental devices handling
    - ✓Heavy maintenance such as Spallation Target extraction and parts replacement

Reference Core

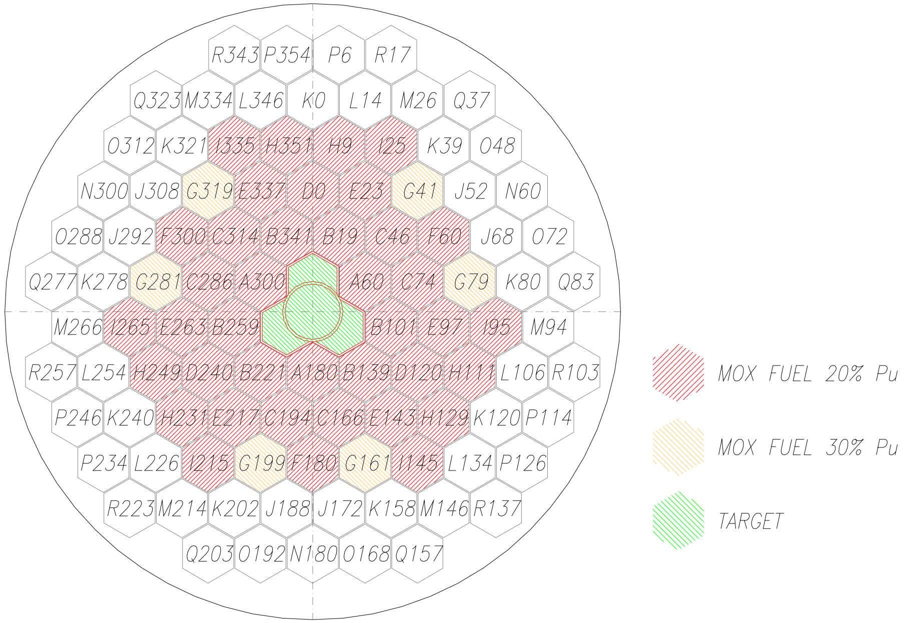
The reference core consists of 45 fuel assemblies:

- 39 assemblies with 30% MOX (positions A-F, H-I)
- 6 assemblies with 20% MOX (position G)

k_{eff}	0.94589
k_s	0.95236
ρ [pcm]	-5721
ρ_s [pcm]	-5002
P [MWth]	43

Targeted operating regime:

- 90 days of operation
- 30 days for maintenance, …
- 3 cycles a year



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Calculations

Burn up calculations were performed using:

- MCNPX 2.5.d2
- ORIGEN 2.2
- ℵ SPECTRUM 1.0a

Every assembly is divided into 5 segments – every segment has a different burn up library calculated by ℵ SPECTRUM

A cycle of 90 days is subdivided into intervals of 15 days – MCNPX calculates the total flux for depletion calculation in ORIGEN 2.2

JEF2.2 nuclear data is used in all calculations

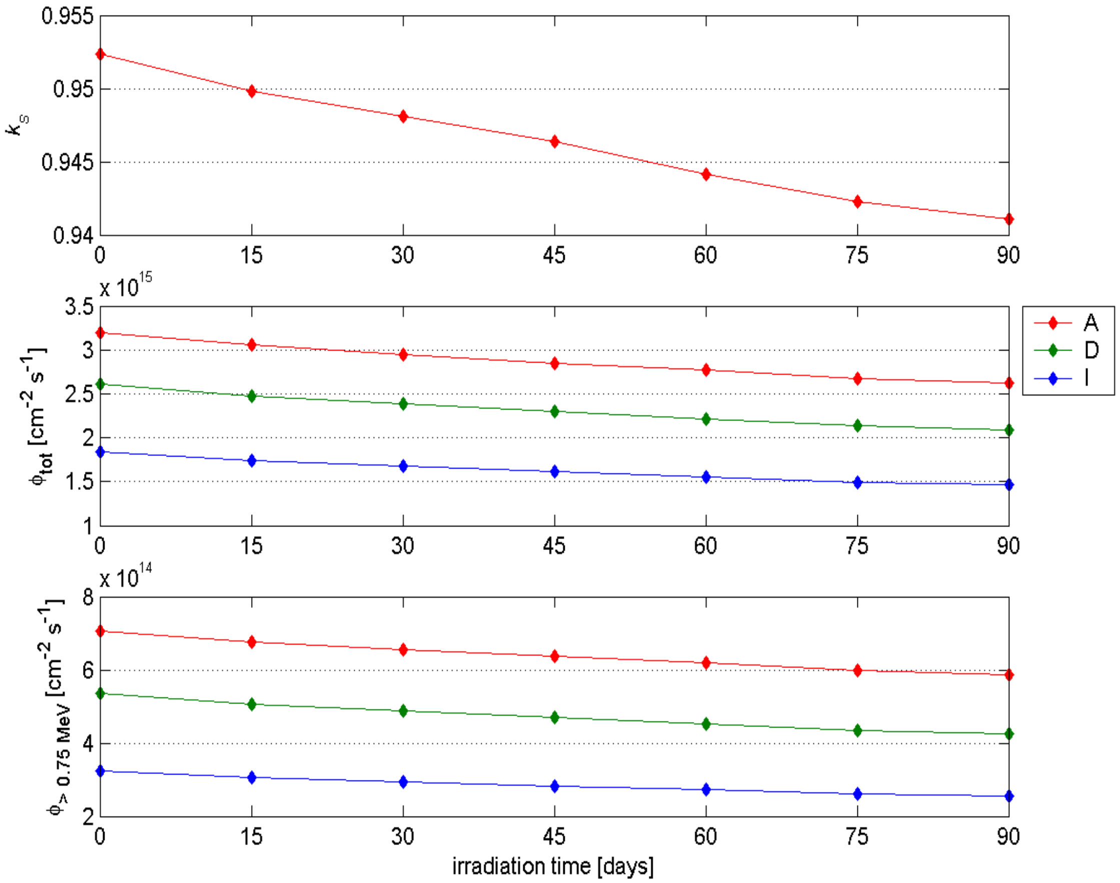
Burn up results

	BOC	EOC
k_s	0.95236	0.94105
k_{eff}	0.94589	0.93279
ρ_s [pcm]	-5002	-6265
ρ [pcm]	-5721	-7205
P [MWth]	43	34

Reactivity loss:

$$\Delta\rho_s = -1263 \text{ pcm}$$

$$\Delta\rho = -1484 \text{ pcm}$$



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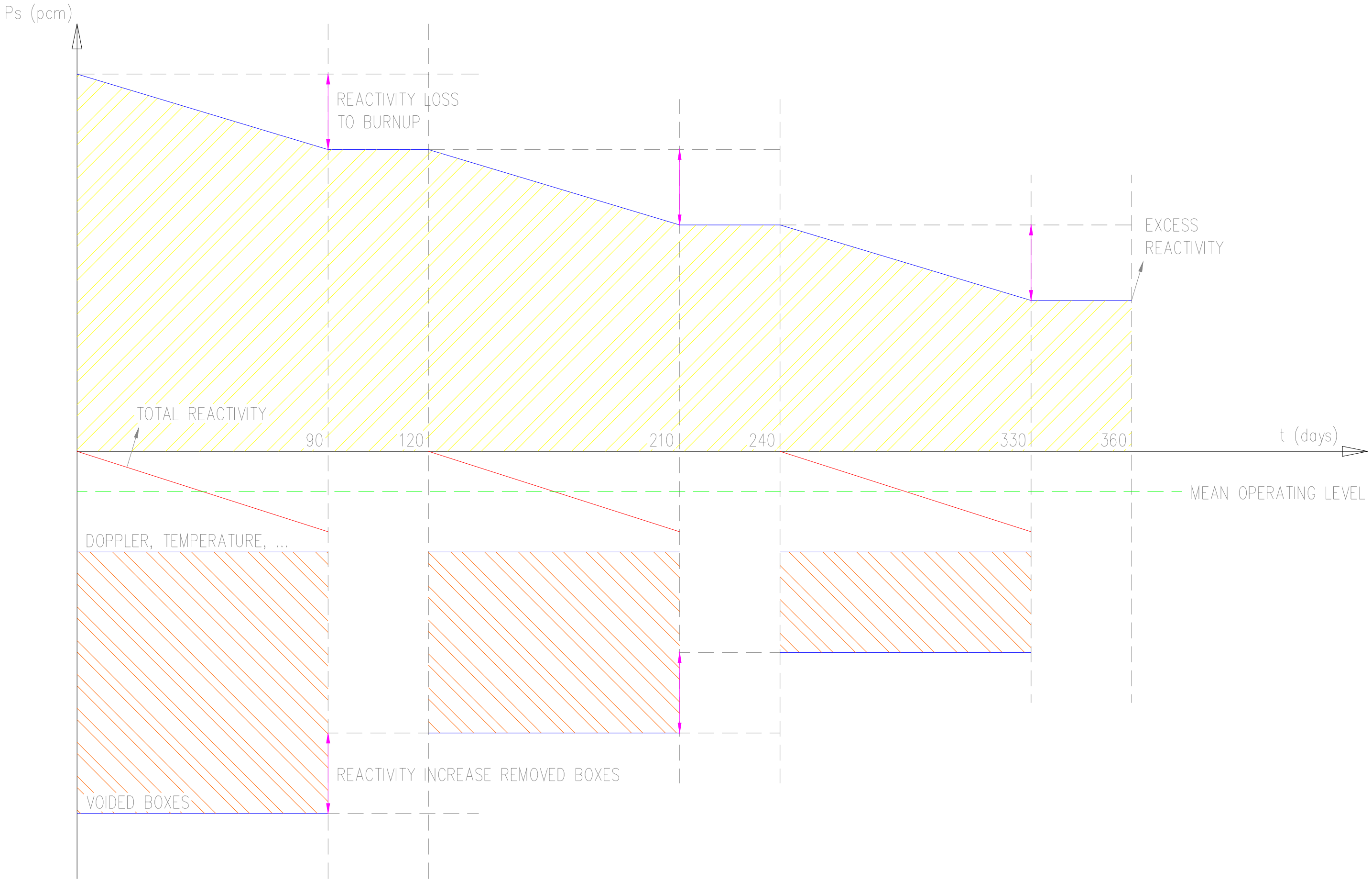
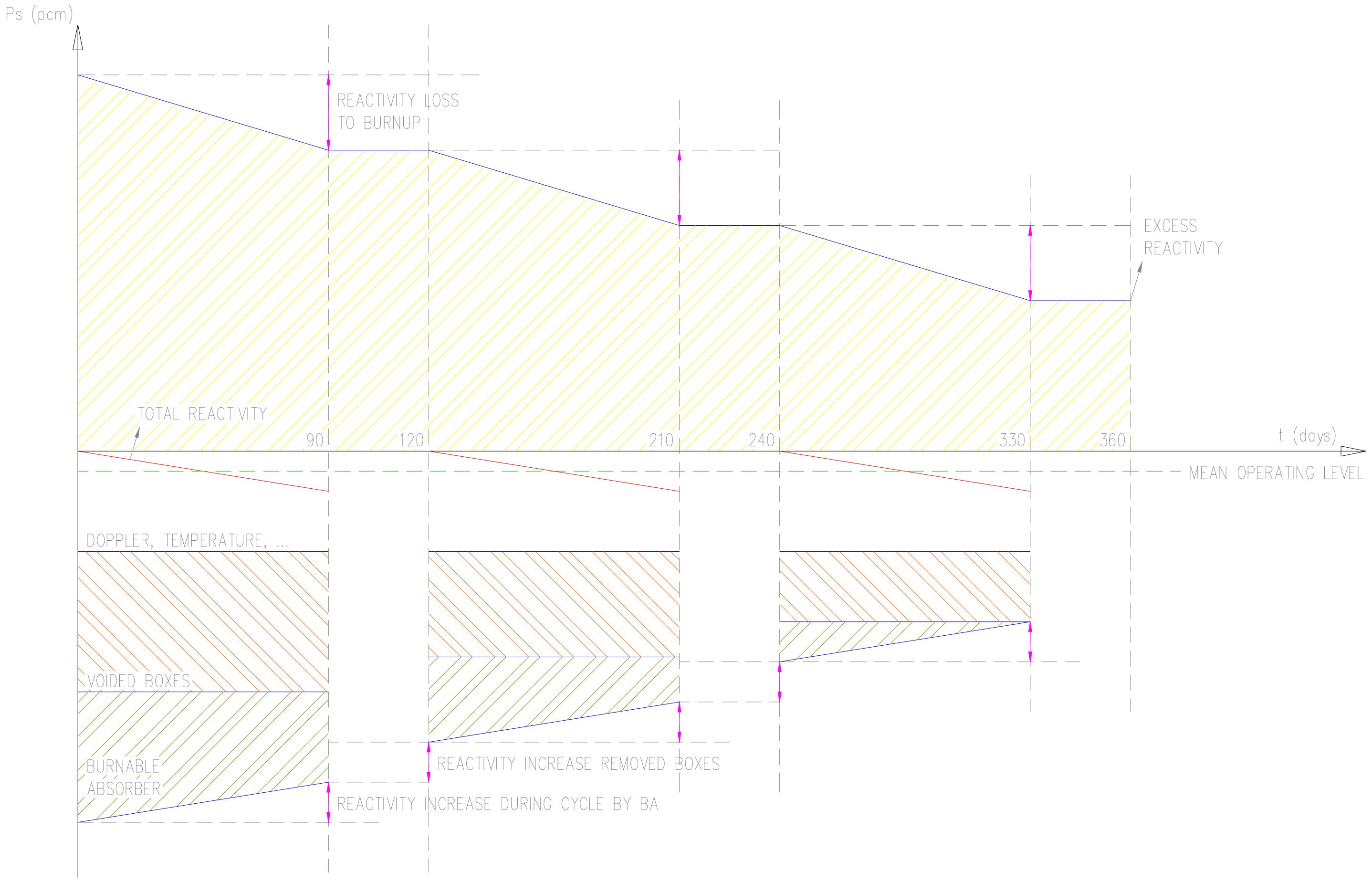
Reactivity Compensation Using Voided Boxes



Reactivity Compensation Using Voided Boxes and Burnable Absorber

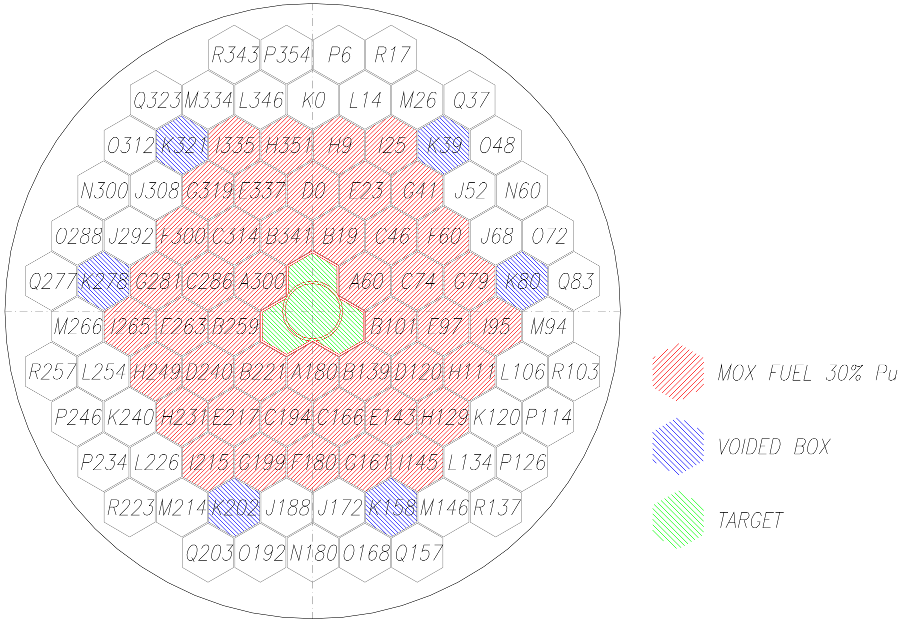


Modified Core

To demonstrate the previous concepts, we performed burn up calculations on a modified core:

- Replaced 20% MOX by 30 % MOX: $\Delta\rho_s = +1783$ pcm
- Added 6 voided box assemblies: $\Delta\rho_s = -1421$ pcm

	Reference core	Full 30% MOX core	Adding voided boxes
k_{eff}	0.94589	0.96614	0.94969
k_s	0.95236	0.96881	0.95565
ρ [pcm]	-5721	3505	-5298
ρ_s [pcm]	-5002	-3219	-4640
P [MWth]	43	69	46



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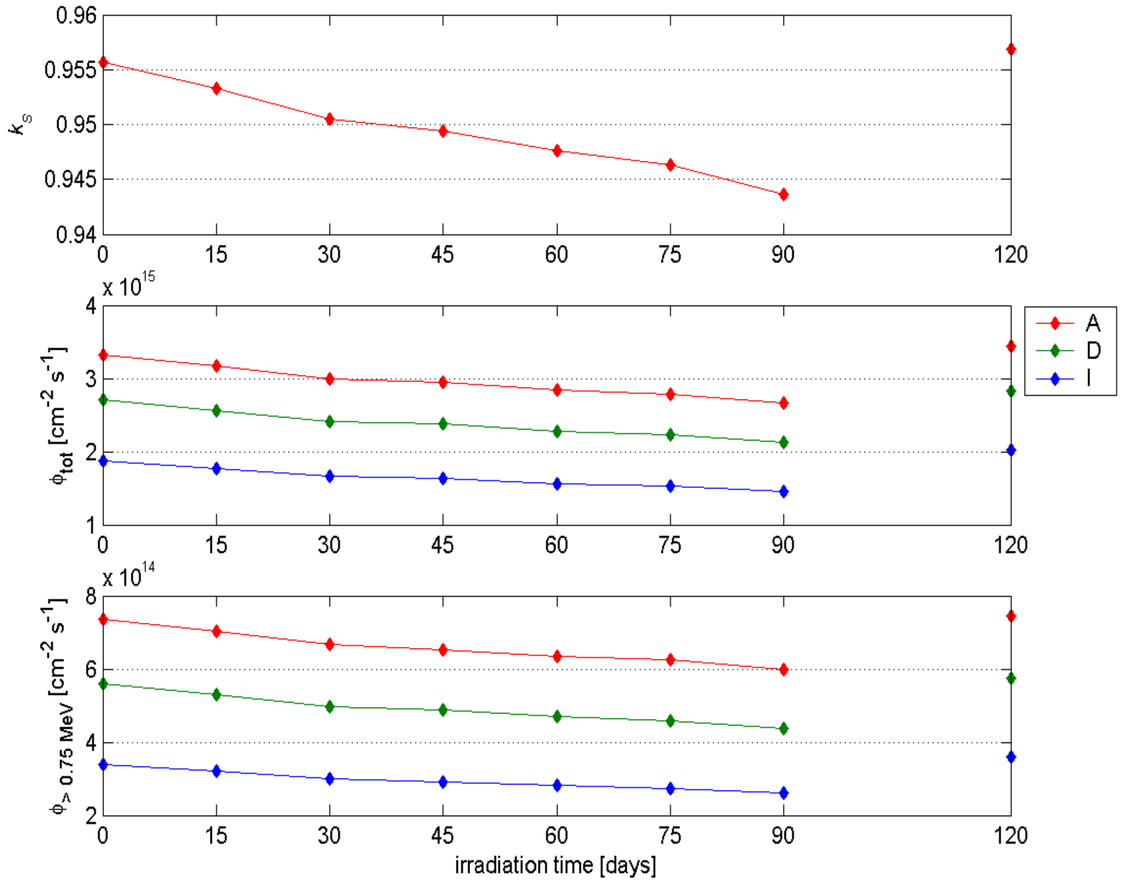
Burn up results

	BOC1	EOC1	BOC2
k_s	0.95565	0.94367	0.95682
k_{eff}	0.94969	0.93611	0.95118
ρ_s [pcm]	-4640	-5969	-4513
ρ [pcm]	-5298	-6825	-5133
P [MWth]	46	35	48

Reactivity loss cycle 1:

$$\Delta\rho_s = -1329 \text{ pcm}$$

$$\Delta\rho = -1527 \text{ pcm}$$



Conclusions For BU swing Mgt

During a cycle of 90 days, the power and flux in MYRRHA drop by 20% on average

The first burn up results demonstrate that:

- the proposed operational cycles are realistic
- in the case studied, no new fuel assemblies are needed in the second cyle to obtain the same operational level of the first cycle

Further study:

- introducing BA into the core – combined with voided box assemblies
- burn up calculations of multiple cycles

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Reactivity Monitoring Techniques

- “Reference” method in critical reactors
  - Rod-drop → MSA/MSM
- Continuous monitoring techniques
  - Current-to-flux indicator
  - Harmonic source oscillation
- Pulsed Neutron Source methods
  - Fitting method
    - 1, 2, 3 exponentials
    - Kp-method
  - Area method
- “Source Jerk” type techniques
  - Standard Source Jerk technique
  - Source Modulation method
  - ADS Source Jerk technique (Beam trips)
- Noise Techniques
  - Rossi-alpha
  - Feynman-alpha
  - APSD, CPSD
  - Cf source driven method
- Reactivity monitoring philosophy in ADS

Reactivity values obtained with different experimental techniques in MUSE

	Rod drop + MSA	Rod drop +MSM	PNS fitting			Kp method	PNS Area		Source Jerk	Source mod.	Rossi-α (Area)
			1 exp	*2 exp*	*3 exp*		*SCK*	*CIEMAT*			
SC0	-1.9	-1,86	-1,93	-1.92		-2,2	-2,00	-1.96	-1,92	-2,18	-2.04
SC2 - 1006 cells	-9.1	-8,7			-8.7		-8,9	-8.5			-8.8
SC2 - 1004 cells	-9.7	-9,1				-9,7				-9,7	
SC3	-14.1	-13,6		-15.6	-11,7	-14,1	-13,7	-12,3	-14.6		-13,4

Current-to-flux reactivity indicator (1)

- Subcritical multiplication

$$\varphi = c\frac{I}{1-k_{eff}} = c\frac{I\,(1-\rho_{PI})}{-\rho_{PI}} \Rightarrow \rho_{PI} = -\frac{c\dfrac{I}{\varphi}}{1-\dfrac{cI}{\varphi}} \approx -c\frac{I}{\varphi}$$

- Characteristics
  - On-line measurement
  - Current- and flux measurement
    - Well-known technology
    - Very good relative accuracy < 1% ?
    - Simplicity of the current & flux measurement:
      - No data-treatment
      - No additional time constants are introduced during the measurement
  - Close to critical reactor instrumentation

Current-to-power reactivity indicator (2)

- Characteristics (continued)
  - Sensitivity to the actual source multiplication and not to the effective multiplication factor
    - Conversion to effective neutron multiplication by source importance factor via interim calibration

$$\frac{\rho_2}{\rho_1}=\frac{\varepsilon_2}{\varepsilon_1}\frac{\varphi_2^*}{\varphi_1^*}\frac{C_1}{C_2}=\frac{\varepsilon_2}{\varepsilon_1}\frac{\overline{\Psi_{f_1}}}{\overline{\Psi_{f_2}}}\frac{C_1}{C_2}=\frac{\left\langle\sigma_D\varphi_s\right\rangle_2}{\left\langle\sigma_D\varphi_s\right\rangle_1}\frac{\left\langle\varphi_0^+,\nu F\varphi_s\right\rangle_1}{\left\langle\varphi_0^+,\nu F\varphi_s\right\rangle_2}\frac{C_1}{C_2}=f_{MSM}\frac{C_1}{C_2}$$

  - Absolute reactivity determination: accuracy: <10%
    - Depends on the calibration method
      - Interim cross-checking: response to reactor trip
      - “zero”-power calibration: PNS, Noise techniques
  - Relative reactivity determination:
    - Precision on current & flux measurement: <1% ?
    - 10% change in reactivity gives a 10% change in reactivity indicator
    - Precision on reactivity indicator: 1%
    - Accuracy: depends on the monitoring of the stability of parameters influencing the source importance
      - ♥ Spallation source position: axial and horizontal
      - ♥ Proton energy

Needs for ADS criticality and reactivity monitoring

- On-line and continuous sub-criticality monitoring
- Low uncertainty between detection and real effects
- Robust absolute reactivity assessment

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Methodology for on-line reactivity monitoring and Absolute reactivity assess

- Step-wise approach
- **Current-to-power indicator as an on-line indicator**
  - Uncertainty on relative deviations of about 1%.
  - Proportionality constant is checked regularly by interim cross-check
- **Interim cross-check**
  - verification of the proportionality constant of the current-to-power indicator:
    - Proton beam tripping
    - Slope fitting technique (Kp ?, exponential Fitting : 2 or 3 ?)
    - Frequency: at every beam trip or fixed repetition frequency
- **In-depth calibration to determine kinetic parameters**
  - No rod-drop/MSM techniques and noise techniques with intrinsic source are applicable
  - PNS area method techniques with a pulsed source : YES
  - Noise Analysis to be checked with CW beam excitation before deciding

Achievements in MUSE

- **No on-line method yet established**
- **Regular proportionality check I_p / ϕ_n established** : Response to beam trip in fast system,
- **Absolute reactivity assessment established: PNS Area method for instance**, Other promising techniques should be re-assessed in CW beam conditions

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Recommendations for the future:

- **On-line techniques in** CW conditions (**YALINA (BELARUS) in FP6**) I_p/ϕ_n **should be** established and **demonstrated in**:
    - **Start up conditions**
    - **Nominal conditions at various K_{eff} values**
    - **Shutting down conditions**
- **Absolute reactivity assessment** : a priori **non promising techniques (in MUSE** conditions pulsed mode) **should be revisited in** (CW conditions) (**Noise techniques**)
- Complementarities with RACE (USA) and SAD (Russia) should not be forgotten.

I&C Approach in MYRRHA

- The I&C has not been worked out yet in MYRRHA and need to be addressed urgently
- A diagram principal scheme has been established based on FBR approach with instrumentation foreseen at the outcome of (each) FA to monitor:
  - Temperature
  - Neutron Flux
  - Coolant velocity
  - Pressure
- O_2 Control in the reactor pool is needed

ISI&R Approach in MYRRHA

- To achieve the 65% availability for MYRRHA, Remote Handling approach is mandatory due to:
  - High activation level in the MYRRHA Hall (neutron streaming through the Beam line)
  - Potential a-contamination in the MYRRHA Hall due to ^{210}Po
  - Inert gas environment in the MYRRHA Hall to avoid the Pb-Bi contamination by O2 (PbO sludge formation)
- No real experience within the team => contracted a feasibility study by OTL Ltd (JET, UK)

1. PROJECT OVERVIEW

- Define the plant
- Define the working environment
- Define the task requirements
- Define the remote handling system requirements
- Decide a remote handling approach
- *Derive a remote handling concept & plant layout*
- *Validate the remote handling concept*
- *Estimate costs of implementing and running the systems*
- *Establish any technological areas requiring further development*
- *Deliver written report and a VR model of the proposed concept*

2. PLANT DEFINITION

- **Spallation Loop**
- **Core Support Tube**
- **Heat Exchangers**
- **Main Pumps**
- **Internal Robots**
- **Lid**
- **Diaphragm with chemical insert module**
- **Emergency Heat Exchanger**
- **Beam Line in MYRRHA Hall**
- **Experimental devices**
- **Pb-Bi vessel (for decommissioning)**

3. ENVIRONMENT DEFINITION

- **100% inert atmosphere**
- **0% humidity**
- **Particulate and gaseous contamination**
- **Max normal dose rate exposure of 7 Gy/hr**
- **Worst case dose rate exposure of 21.5 Gy/hr**
- **Total dose of 46500 Gy**

4. TASK REQUIREMENTS

- Removal and replacement of plant items
- Plant maintenance (e.g Spallation zone replacement)
- Decontamination of plant items
- Packaging of waste items
- Recovery from failure during plant handling (e.g jamming)
- Recovery of a failed Ex-vessel Fuel Transfer machine
- Recovery of debris from PbBi

5. REMOTE HANDLING SYSTEM REQUIREMENTS

- Fully remote
- System Availability >95%
- Fail-safe system
- Recoverable after failure
- Perform replacement of Spallation loop within a 3 month shutdown
- Reach and examine all parts of the MYRRHA Hall
- Be easy to operate
- Be easy to support and maintain
- Be able to deal with unexpected tasks
- Minimise the secondary wastes
- Operate in the specified radiation environment for 30 yrs.
- Manipulate loads up to 60 tonne
- Perform specialist operations (e.g cutting, welding, 3-D metrology)

6. REMOTE HANDLING APPROACH

- Man-In-The-Loop using a Bi-lateral, force-reflecting, Master-Slave Servomanipulator.
- Robotic features to ease operation
- Cameras for visual feedback
- Independent craneage for lifting heavy loads
- Independent tool service system
- All remote handling work to be done within the same hall
- Remote equipment and tooling to be stored and maintained within the same hall
- Use of air-locks for transfers between areas

7. PLANT LAYOUT AND INFRASTRUCTURE

- **MYRRHA Hall**
- **Contamination control**
- **Commissioning, Assembly, Test and Mock-up facilities**
- **Decontamination**
- **Waste Packaging**
- **Active workshop**
- **Remote handling control rooms**
- **Health Physics Laboratory**

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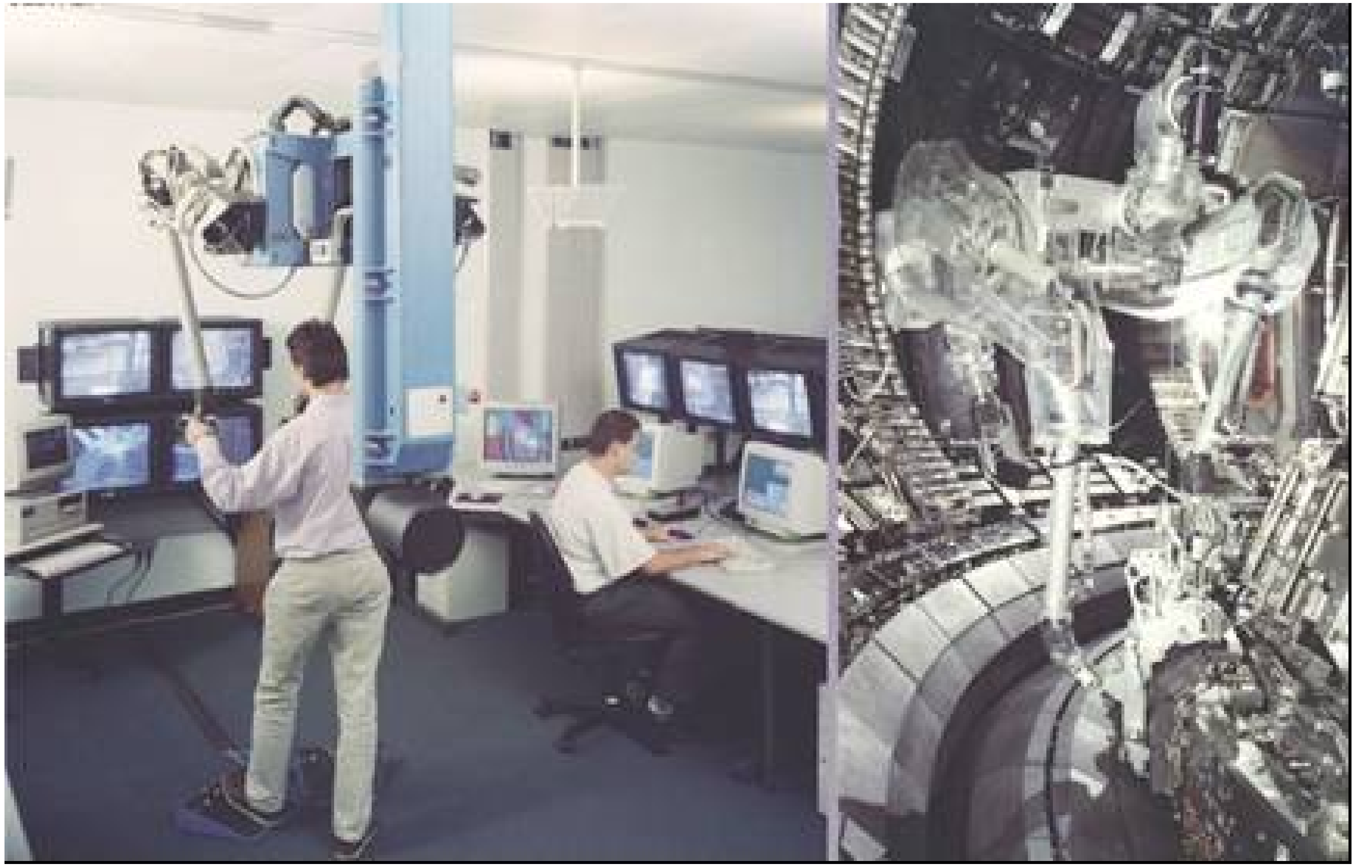
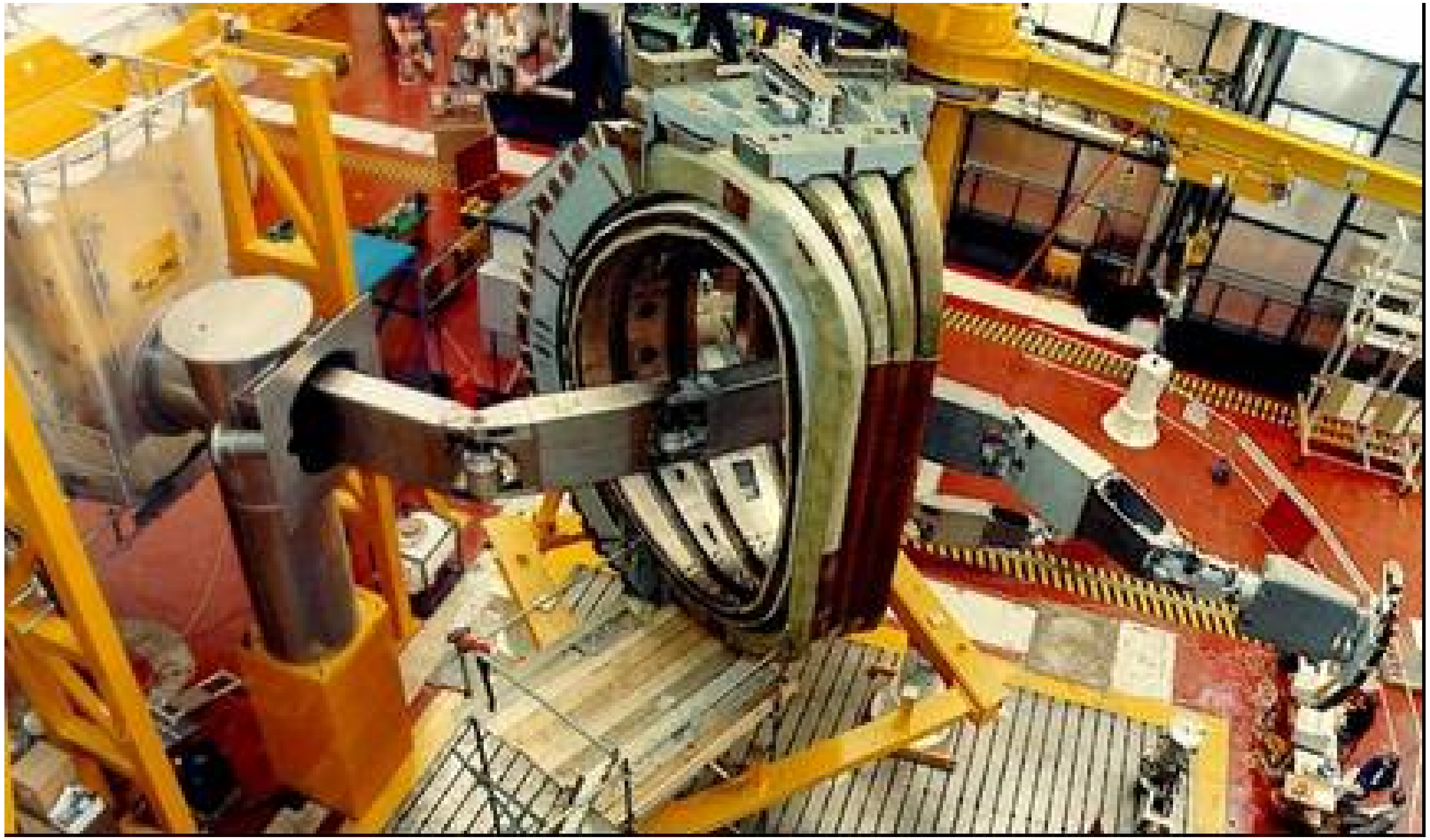
Science Fiction or Reality?

MYRRHA

Reality



Reality



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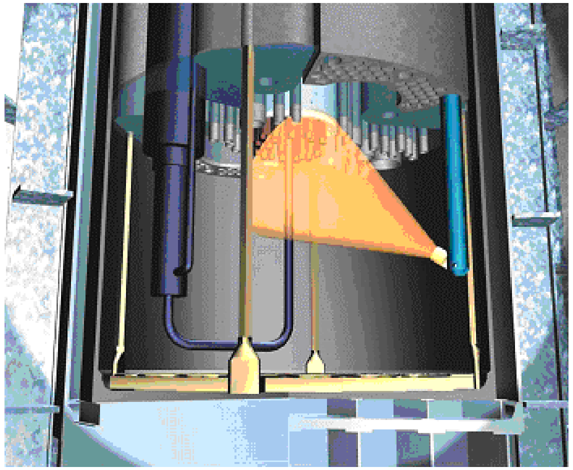
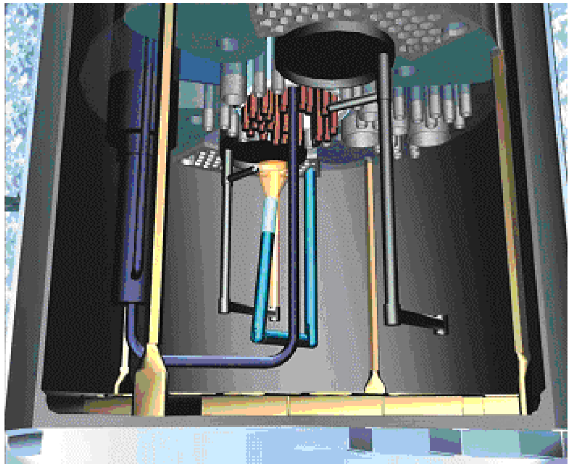
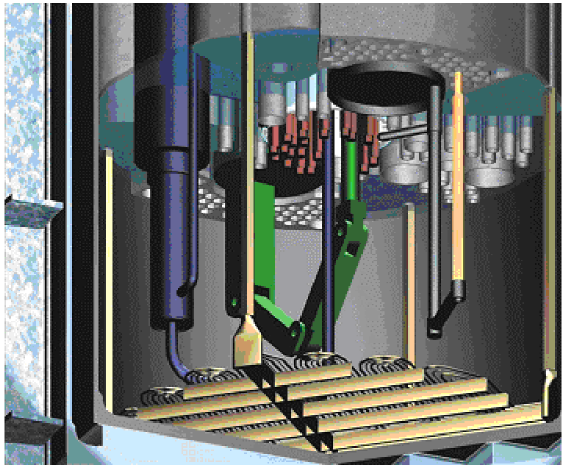
Design of MYRRHA
In-service inspection and repair



Two permanently installed *inspection* manipulators with US camera to provide a general *overview*. (periscope type device with three degrees of freedom)



The second *inspection* manipulator positions the camera close to critical components for *detailed* inspection. (anthropomorphic type device with five degrees of freedom)



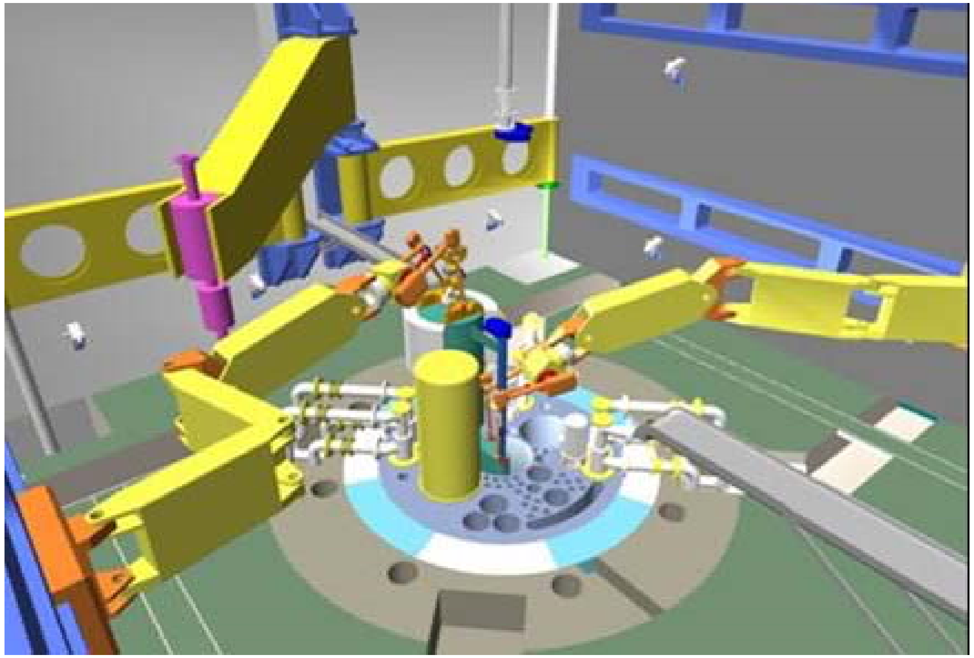
The *repair* manipulator recovers debris or deploys specialised tooling for repair. (anthropomorphic type device with eight degrees of freedom)

O.T.L. concludes positive on the feasibility of the proposed RH approach.

Design of MYRRHA
Remote handling

All MYRRHA maintenance operations on the machine primary systems and associated equipment is performed by remote handling, which is based on the *Man-In-The-Loop principle*:

- force reflecting servomanipulators
- Master-Slave mode: the slave servo-manipulators are commanded by remote operators using kinematically identical master manipulators
- supported with closed-cycle TV (CCTV) feedback



O.T.L. concludes positive on the feasibility of the proposed RH approach.

Conclusions

- MYRRHA being an irradiation facility has dictated the choices of the remote handling as a first choice for achieving an availability factor of 65% which compatible with operational cost that would be affordable.
- The fact of being a first-of-a-kind has also conditioned some design option in terms of operation cycle and the allowable beam trip mitigation via a preventive maintenance made repetitively during the shut down periods between cycles.
- The k_{eff} drop being limited per three months cycle make it manageable by a policy of fuel reshuffling supplemented by the use of burnable poisons or void boxes.
- The instrumentation and control is sketched and is not very different from the classical one of a classical reactor but need urgently further development.
- The sub-criticality monitoring is addressed and a promising route for the on-line monitoring is proposed.