MYRRHA
A Proof-of-Principle ADS Facilty

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ABSTRACT

Since 1998, SCK•CEN in partnership with IBA s.a. and many European research laboratories, is designing a multipurpose ADS for R&D applications – MYRRHA - and is conducting an associated R&D support programme. MYRRHA is an Accelerator Driven System (ADS) under development at Mol in Belgium and aiming to serve as a basis for the European experimental ADS to provide protons and neutrons for various R&D applications. It consists of a proton accelerator delivering a 350 MeV*5 mA proton beam to a liquid Pb-Bi spallation target that in turn couples to a Pb-Bi cooled, subcritical fast core.

In a first stage, the project focuses mainly on demonstration of the ADS concept, safety research on sub-critical systems and nuclear waste transmutation studies. In a later stage, the device will also be dedicated to research on structural materials, nuclear fuel, liquid metal technology and associated aspects and on sub-critical reactor physics. Subsequently, it will be used as fast spectrum irradiation facility and as radioisotope production facility.

A first preliminary conceptual design file of MYRRHA was completed by the end of 2001 and has been reviewed by an International Technical Guidance Committee that concluded that there are no show stoppers in the project even thought some topics such as the safety studies and the fuel qualification need to be addressed more deeply before concluding. At the end of 2004 a so-called DRAFT-2 design file has been completed where the remarks of the ITGC have been addressed. In this paper we will be presenting the state-of-the-art of the MYRRHA project and its perspectives for the next coming years.

INTRODUCTION

The ETWG (European Technical Working Group) on ADS concluded in April 2001 in its report "A European Roadmap for developing Accelerator Driven Systems (ADS) for Waste Incineration" [1] that the P&T in association with the ADS in combination with the geological disposal can lead to an acceptable solution from the society acceptance point of view for the nuclear waste management problems. Therefore it concluded also that a heavy support in this field from the EC and the national programmes is needed to develop and build an experimental ADS demo facility in Europe.

SCK•CEN in partnership with IBA s.a. and many European research laboratories, is since 1998 designing a multipurpose ADS for R&D applications –MYRRHA [2] - and is conducting an associated R&D support programme. MYRRHA is an ADS under development aiming to serve as a basis for the European experimental ADS to provide protons and neutrons for various R&D applications. It consists of a proton accelerator delivering a 350 MeV*5 mA proton beam to a liquid Pb-Bi spallation target that in turn couples to a Pb-Bi cooled, subcritical fast core.

PRINCIPLE FEATURES OF THE DESIGN OF THE MYRRHA FACILITY

The MYRRHA project is based on the coupling of a proton accelerator with a liquid Pb-Bi windowless spallation target, surrounded by a Pb-Bi cooled sub-critical neutron multiplying medium in a pool type configuration with a standing vessel (Fig. 1) [2,3]. The spallation target circuit is fully immersed in the reactor pool and interlinked with the core but its liquid metal contents is separated from the core coolant. This is a consequence of the windowless design presently favoured in order to use "low" energy protons on a very compact target at high beam power density in order not to loose on core performance.

The core pool contains a fast-spectrum sub-critical core cooled with Pb-Bi eutectic (LBE) and several islands housing thermal spectrum regions located in in-pile sections (IPS) in the fast core. The core is fuelled with typical MOX fast reactor fuel pins with total Pu-contents of 30% and 20% with an active length of 600 mm arranged in hexagonal assemblies of ~85.5 mm flat-to-flat (including the fuel assembly canister thickness). The three central hexagons are left free for housing the spallation module.

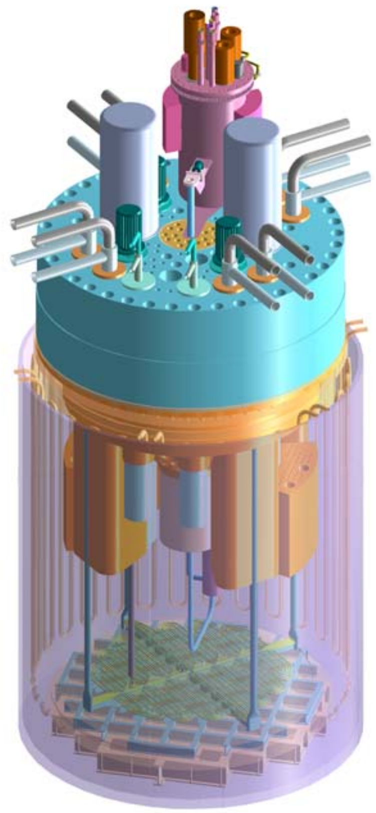

Fig. 1: MYRRHA 3-D Vertical View

The core structure will be mounted on a central support column coming from the lid and being stabilised by the diaphragm, the separating septum between the cold and hot LBE coolant, which is fixed ultimately to the rim of the double-wall vessel. Since access from the top is very restricted and components introduced into the pool will be buoyant due to the high density of the LBE, the loading and unloading of fuel assemblies is foreseen to be carried out by force feed-back controlled robots in remote handling from underneath. The pool will also contain the liquid metal primary pumps, the heat exchangers using presently water as secondary fluid and the two fuel handling robots based on the well known rotating plug technology of fast reactors.

The spallation circuit connects directly to the beam line and ultimately to the accelerator vacuum. It contains a mechanical impeller pump and a LM/LM heat exchanger to the pool coolant (cold end). For regulation of the position of the free surface on which the proton beam impinges (whereby this defines the vacuum boundary of the spallation target), it comprises an auxiliary MHD pump. Further on, it contains services for the establishment of proper vacuum and corrosion limiting conditions.

The device shown in Fig. 1 with the double-wall pool containment vessel (inner diameter of 4.4 m and height close to 7 m), is surrounded by biological shield to limit the activation of the surrounding soil as the MYRRHA sub-critical reactor will be installed in an underground pit. This shield will be closed above the vessel lid by forming an α-compatible hot cell and handling area for all services to the machine.

TASK PROFILE

Along the above design features, the MYRRHA project team is developing the MYRRHA project as a multipurpose irradiation facility for R&D applications on the basis of an Accelerator Driven System (ADS). The project is intended to fit into the European strategy towards an ADS Demo facility for nuclear waste transmutation as described in the PDS-XADS FP5 Project [4]. As such it should serve the following task catalogue:

- *ADS concept demonstration*
- *Safety studies for ADS*
- *MA transmutation studies*
- *LLFP transmutation studies*
- *Medical radioisotopes*
- *Material research*
- *Fuel research*

The present MYRRHA concept is driven by the flexibility and the versatility needed to serve the above applications. Some choices are also conditioned by the objectives of willing to make MYRRHA as demonstrative as possible for the final objective of having the means for assessing the feasibility of an industrial ADS prototype. The MYRRHA project team has favoured as much as possible mature or less demanding technologies in terms of R&D. Nevertheless, not all the components of MYRRHA are existing. Therefore, a thorough R&D support programme for the innovative components or technologies has been started since 1997 and has been updated since 2002.

DESIGN FEATURES AND PARAMETERS AND THEIR JUSTIFICATION

MYRRHA: Critical reactor versus ADS

Regarding the listed applications above, one could ask why not to go for a critical reactor? Indeed, nowadays material and fuel research is conducted in critical MTR, radioisotopes are produced in these machines, transmutations studies could be conducted in critical reactors, but choosing the ADS route will trigger the possibility of demonstrating the ADS concept and will make available higher flux levels (thermal and fast) as these are driven by the spallation source. The R&D of an innovative ADS project will be an asset for attracting a new generation of scientists and engineers towards the nuclear sector. For all these reasons and particularly complementarily to a future European thermal spectrum MTR, SCK•CEN considers the ADS orientation as the most relevant option for a new fast spectrum R&D facility.

The main design parameters of MYRRHA primary system and spallation target

The performances of an ADS in terms of flux and power levels are dictated by the spallation source strength, which is proportional to the proton beam current at a particular energy and the sub-criticality level of the core. The sub-criticality level of 0.95 has been considered as an appropriate level for a first of kind medium-scale ADS. Indeed, the maximum reactivity injection due to incidental conditions in the MYRRHA systems have been evaluated to about 3000 pcm that would lead to a maximum keff of 0.98 that leaves still 2000 pcm margin to the criticality.

Fixing the sub-criticality level and the desired neutron flux in the position of the irradiation location for MA transmutation, determines the required strength of the neutron spallation source. In order to achieve the needed performances at a modest total power level of few tens of MW, we have to limit the central hole diameter to a maximum diameter of ~100 mm. As a consequence of this constraint and on the other hand having the need of a minimum lateral Pb-Bi target volume for allowing an effective spallation process, the proton beam external diameter is limited to 72 mm. The required spallation source intensity to produce the desired neutron flux at this location is close to 2.10^{17} n/s. At the chosen proton energy of 350 MeV, this requires 5 mA of proton beam intensity and this in turn would lead to a proton current density on an eventual beam-window of order of 150 μA/cm². This is by at least a factor 3 exceeding the current density of other attempted window design for spallation sources which already have high uncertainties with regard to material properties suffering from swelling and radiation embrittlement. As a result, we favoured the windowless spallation target design in MYRRHA [5, 6, 7, and 8].

The Required Accelerator for MYRRHA

The proton beam characteristics of 350 MeV x 5 mA allow to reach a fast neutron flux of 1.10^{15}n/cm².s ($E_{>0.75\ MeV}$) at the MA irradiation position under the geometrical and spatial restrictions of the sub-critical core and the spallation source. These performances were regarded as being within the reach of the extrapolated cyclotron technology of IBA. Compared to the largest continuous wave (CW) neutron source – SINQ at PSI with its cyclotron generating a proton beam of 590 MeV and 1.8 mA – it is a modest extrapolation.

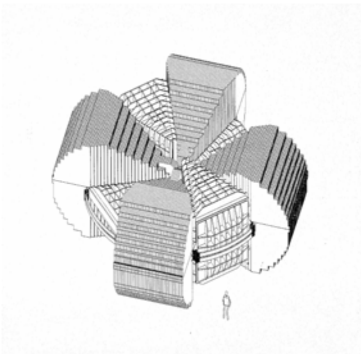

Fig. 2. MYRRHA High Power Proton cyclotron

The MYRRHA normal conducting cyclotron would consist of 4 magnet segments of about 45° (Fig. 2) with 2 acceleration cavities at ca 20 MHz RF frequency. The diameter of the active field is of order of 10 m, the diameter of the physical magnets of order of 16 m with a total weight exceeding 5000 t. Due to these very large dimensions, supra-conducting magnets cyclotron option has been evaluated by IBA and led to a reduction of the magnet diameter by a factor of 2.

Nevertheless, taking into account the conclusions of the PDS-XADS WP3 [9, 10] experts group related to the accelerator reliability to be achieved for the ADS application, the LINAC option is now the favoured solution for the MYRRHA accelerator. The present LINAC configuration is illustrated schematically in figure 3.

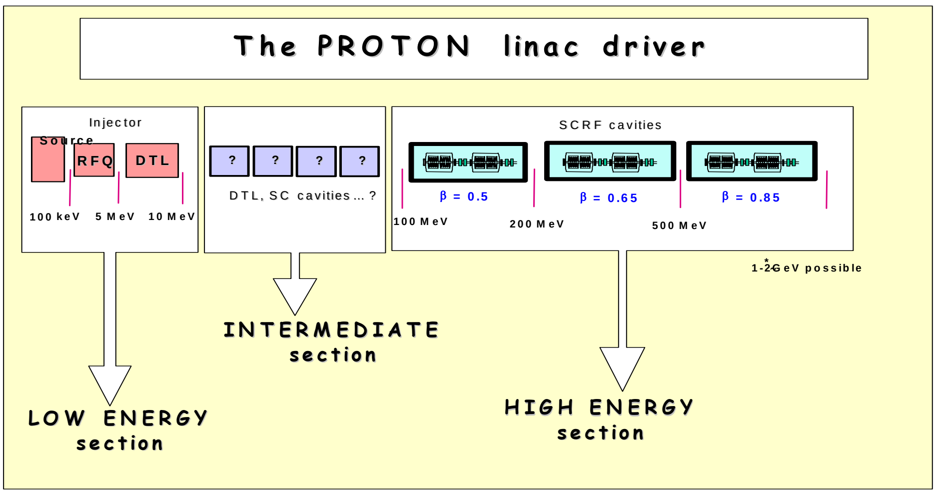

Figure 3: LINAC sketch for ADS

MYRRHA Sub-Critical Core Configuration

The neutronic design of the MYRRHA sub-critical core is based on MOX classical fast reactor fuel technology. The fuel assembly design had to be adapted to the Pb-Bi coolant characteristics especially for its higher density as compared to Na. The core configuration has been conceived with typical Na FR hexagonal fuel assembly with a modified cell pitch to answer the LBE constraints. The fuel assembly has a 85.5 mm flat-to-flat external dimension, with 91 fuel pins per assembly allowing a larger flexibility in the core configuration design. Indeed, the reactivity worth in the MYRRHA core of such a fuel assembly is ranging between ~450 to 1600 pcm.
The active core height is 600 mm and the maximum core radius is 1000 mm with 99 hexagonal positions. Not all the positions are filled with fuel assemblies. They could contain moderating material (to create thermal neutron flux trap with $\Phi_{th} = \sim 1.10^{15}$ n/cm².s) or used as fast spectrum irradiation positions. A typical MYRRHA configuration with Keff of 0.95 can be achieved by using 45 to 50 fuel assemblies. There are 19 core positions accessible through the reactor lid capable of housing experimental devices equipped with their own operating conditions control supplied by services above the reactor lid. All the other position can be housing either fuel assemblies or non-on-line serviced experimental rigs.
The expected performances [11] in terms of fast and thermal fluxes, linear power in the core and total power in MYRRHA are summarised in the table 1 below.
The MYRRHA operation fuel cycle will be determined by the Keff drop as a function of the core burn-up. The targeted operating regime is 3 months of operations and 1 month for core re-shuffling, loading and maintenance. This will lead to a drop in Keff of about 1000 pcm at maximum which has only a minor effect at the locations for MA transmutation.

MYRRHA Primary System configuration

When considering the liquid metal option two designs were possible: the loop and the pool options. The loop option has been discarded due to the very high vessel exposure, the risk of LOC and LOF accidents, the difficulty of the interlinking of the spallation target loop with the primary reactor cooling loop. Finally one should mention the desired flexibility in loading and unloading experimental devices that can be more easily achieved in the pool design.
The pool design has been favoured because it avoids the penetration from beneath of the spallation target circuit into the main vessel and thus enhances the safety of the design. It allows also having an internal interim storage easing the fuel handling. The natural circulation for the extraction of the residual heat removal in case of loss of flow (LOF) and loss-of-heat-sink (LOHS) is demonstrated to be feasible, particularly with the large thermal inertia that is also an argument in favour of this design. With an emergency cooling system based on natural circulation both on primary and secondary sides, the core coolability can be ensured practically infinitely, even in situation of complete pumping power loss.

Table 1 MYRRHA facility performances

Neutronics Parameters	Units	MYRRHA values
Proton beam energy	**MeV**	**350**
Accelerator current	**mA**	**5**
Proton beam heating	**MW**	**1.43**
Source neutron yield per icident proton		**6.0**
neutron source Intensity	**10^{17} n/s**	**1.9**
Initial fuel mixture	**MOX**	**$(U\text{-}Pu)O_2$**
Initial (HM) fuel mass (m_{fuel})	**Kg**	**514**
Initial Pu-enrichment (Pu/HM)	**wt%**	**30**
K_{eff}		**0.95521**
K_s		**0.96007**
MF = 1 / (1 - K_s)		**25.04**
Source importance: φ*		**1.127**
Thermal Power (‡) (P_{th})	**MW**	**51.75**
Specific power	**kW/kgHM**	**101**
Peak linear Power (hottest pin)	**W/cm**	**352**
Av. Linear Power (hottest pin)		**272**
Max Φ_{total} in the fast core (near the hottest pin)	**10^{15} n/cm²s**	**4.1**
Max $\Phi_{>1\ MeV}$ in fast core (near the hottest pin)		**0.8**
Max $\Phi_{>0.75\ MeV}$ in fast core (near the hottest pin)		**1.0**
(‡) E_f = 210 MeV/fission		

Safety considerations and analysis

Even if for ADS one of the main characteristics that are desired is to achieve an inherent safety of the system, one should not underestimate the safety considerations for preparing the licensing of such an innovative system. As stated above, a number of reactivity perturbation initiating events have been studied in the MYRRHA system. They either lead to negative reactivity effects or to a reactivity increase. The latter cases were taken care off in the design to avoid their occurrence.

From the safety point of view, the aim is to reduce the probability of the events and their associated off-site consequences in order to avoid the need of extensive counter-measures and to offer the licensing authorities the possibility of simplifying or declaring not necessary the off-site emergency planning. This is the well know "in depth defence safety approach" that is followed in the MYRRHA design.

A common approach for safety analysis of the PDS-XADS projects has been established [14] and has been also applied for the MYRRHA project for assessing its behaviour in DBC and DEC situations. The list of protected (P) and unprotected (U) transients relevant to MYRRHA has been established (see table 2 below) and a RELAP5.3 model for MYRRHA has been developed to simulate these transients [15].

Table 2 : Descriptions of the Protected and Unprotected Transients considered for MYRRHA

TRANSIENT NUMBER	TRANSIENT	DESCRIPTION	BURNUP STATE	CALCULATION CODE
P-1	Protected LOF	loss of forced circulation in primary, secondary systems and target systems	EOC*	RELAP
P-2	Protected TOP	410 pcm jump in reactivity at HFP	EOC	SITHER
P-3	Protected TOP	410 pcm jump at CZP		
P-4	Protected LOH	loss of secondary cooling system	EOC*	RELAP
P-5	Protected LOH + LOF or Station Blackout	loss of SCS and loss of forced convection in PCS	EOC*	RELAP
P-6	Protected LOCA	primary vessel leaks, level in primary drops by 30 cm (partial) loss of nat. circ. in primary	Not yet treated	
P-7	Protected Over-cooling of primary side	SCS inlet temperature drops to 40°C in 0s	BOC	RELAP
P-8	Protected Inlet Blockage of SA w/o radial heat transfer	flow area of peak SA reduced to 2.5%, no radial heat transfer assumed	EOC	SITHER
P-9	Protected Blockage of SA with radial heat transfer	flow area of peak SA reduced to 2.5%, radial heat transfer assumed	Not yet treated	
P-10	Spurious beam trips	beam trips for 1, 2, 3 ... 10 sec intervals	EOC	SITHER
P-11	Protected HX tube rupture	secondary water leaks into primary side	Not yet treated	
U-1	Unprotected LOF	loss of forced circulation in primary, secondary and target systems	EOC*	RELAP
U-2	Unprotected TOP	410 pcm jump in reactivity at HFP	EOC	SITHER
U-4	Unprotected LOH	loss of secondary cooling system	EOC*	RELAP
U-5	Unprotected LOH + LOF	loss of SCS and loss of forced convection in PCS	EOC*	RELAP
U-6	Unprotected LOCA	primary vessel leaks, level in primary drops by 30 cm, (partial) loss of nat. circ. possible	Not yet treated	
U-7	Unprotected over-cooling of primary side	SCS inlet temperature drops to 40°C in 0 s	BOC	RELAP
U-8	Unprotected blockage of SA w/o radial heat transfer	flow area of peak SA reduced to 2.5%, no radial heat transfer assumed	EOC	SITHER

Transient Number	Transient	Description	Burnup State	Calculation code
U-9	Unprotected inlet blockage of SA with radial heat transfer	flow area of peak SA reduced to 2.5%, radial heat transfer assumed	Not yet treated	
U-11	Unprotected HX tube rupture	secondary water leaks into primary side	Not yet treated	
U-12	Unexpected beam start-up	Beam power jump to 100% at CZP	BOC	SITHER

Following conclusions were found in foregoing transient analysis concerning the protected transients. No thermal feedback mechanisms such as Doppler coefficient were taken into account, which tend to soften the transient results:

- The PPLOF-transient consecutive to one pump trip is totally acceptable from the point of view of safety. The LBE in the EHXs starts however to freeze after about 15 minutes if no counter measures in the ECS are taken.

- The PPLOF-transient consecutive to an EHX check valve failure is expected to be more penalizing than the previous PPLOF (one pump trip), but less penalizing than a PTLOF-transient. As this last one is completely acceptable (see below), results of this transient are not provided in the present report.

- The PTLOF transient causes some peaking in the fuel and cladding temperature, however no safety limits are violated. The ECS performs the task it was designed for well.

- The overpower transient initiated by a reactivity insertion is obviously expected much less penalizing in the protected case than in the unprotected situation. For this last one a maximum possible reactivity insertion of 410 pcm was considered (resulting from a steam or void ingression in the core) and the results indicate that the consequences on the core behaviour are minor (see further). Therefore results for the protected case are not provided here.

- The PPLOH-transient poses no threat to the safety of the machine. No safety criteria are violated. However, if no precautions are taken, the current design of the ECS will cause freezing of the LBE inside the EHXs after about 28 minutes.

- The PTLOH-transient does not pose any threat to the machine safety either. Due to the total absence of SCS cooling, the temperature decrease of the primary system is slower than in the PPLOH and the risk for freezing of LBE in the EHXs is much delayed, however it is still present on longer term.

- The PTLOHTLOF-transients with both ECS circuits or only one ECS circuit available are totally acceptable. There are no safety limits violated. We can conclude that the redundancy of the ECS system is sufficient.

- The shut down of the reactor in case of an overcooling event has a negative impact, as expected. The term 'protected' does not really fit this core reaction. Given the specific nature of the considered overcooling event we conclude that the grace time of only one minute for the PHXs should be augmented with typical time constants for realistic overcooling initiating events. These depend on the characteristics of the SCS. Also, the time periods will be longer if the overcooling transient does not reach 40°C in the SCS. During this rapid transient, the ECS does not pose a risk to cause LBE freezing. However, once the temperature of the medium plenum diminishes with about 20°C, risk of freezing will be present in the EHXs. If the SCS transient is sufficiently slow, the freezing might occur first in the EHXs, rather than in the PHXs.

- It appears that the blockage of a fuel assembly is potentially damaging for the fuel element cladding, at least with the flow reduction factor considered in this study (2.5%). No fuel melting has to be feared, provided of course that the proton beam shuts off. The temperature elevation in the materials, and in particular in the cladding, strongly depends on the delay between the accident initiation and the proton beam cut-off: the shorter the delay, the lower the temperature elevation, but anyway temperature peaks lower than 1000°C in the clad are not conceivable with flow reduction factors as small as that one considered here. In these circumstances creep failures of the cladding seem unavoidable. A blockage in a fuel assembly should be detected as early as possible in order to limit the temperature elevation. This means that each fuel assembly should be instrumented adequately.

- In case of spurious beam interruption the temperature variations in the materials (fuel, clad, coolant) strongly depend on the interruption duration. The clad temperature, which is of the main interest in the present case, undergoes a maximum variation of more than 200°C when the beam interruption duration is 10 s. A structural analysis should be undertaken to assess the consequences of such repetitive transients on the mechanical behaviour of the cladding.

For the unprotected transients analysis the following conclusions were found:

- Both the UPLOF-transients cause no real problems. The result of a failure of one EHX check valve depends however on the primary pump characteristics.
- The UTLOF-transient creates major problems to the cladding temperature. The hotspot jumps in 25 seconds to 1060°C, other cladding temperatures reach more than 700 °C. Although the total natural convection is about 17 % of the nominal flow rate, the corresponding temperature jump for the cladding might be too high in a too short period.

- For the unprotected overpower transients the maximum possible reactivity insertion is 410 pcm, which yields a power increase by 8% in the core. The consequent temperature elevations in the materials are rather low, so that no real problem has to be feared with this type of accident.

- The UPLOH-transient causes no real problems. The system loses half of its heat sink but recovers from that after about 50 minutes. The temperature gradient on the fuel is weakened by the thermal mass of the lower plenum. Both the temperature limits for the fuel and cladding are respected.

- The conclusion of the UTLOH is that the emergency cooling system is not capable of backing up the complete normal cooling system. The water starts boiling after about 20 minutes. However, the maximum cladding temperature reaches its criterion temperature of 700°C already after 9 minutes. Given the fact that this temperature is at the inside of the cladding, it is instructive to see that the maximum outer cladding temperature reaches 700°C 1 to 2 minutes later. The maximum fuel temperature of 2500°C is not reached. The grace time of this transient is around 9 to 10 minutes, due to the cladding integrity..

- The UPLOHPLOF-transient causes no real problems, no safety limits are violated.

- The UTLOHTLOF-transient is the most severe transient thinkable in the category of overheating transients. We can conclude that this very severe transient condition can only be accepted during a few seconds, perhaps tens of seconds. The lack of flow through the core causes a rapid temperature increase in the fuel and cladding. The emergency cooling system, which is not designed to cope with these transients, cannot provide for sufficient cooling or natural convection in the primary system. Although this transient is believed to be unrealistic and sufficient lines of defence are present, its analysis learns us about the inherent safety characteristics of MYRRHA's primary system.

- Given the specific nature of the considered overcooling-transient we conclude that the above mentioned grace times of 5 minutes for the EHXs and 14 minutes for the PHXs should be augmented with typical time constants for realistic overcooling initiating events. Also, these time periods will be longer if the overcooling transient does not reach 40°C in the SCS. Current analysis shows however the sensitivity for overcooling in the ECS.

- An assembly affected by a blockage (flow area reduced to 0.025) in unprotected situation will not survive to such type of accident. This is in particular the case if the blockage is not detected. Although the damages are limited to one assembly and do not affect the whole core, a significant fission products release in the primary system will occur.

- A spurious start-up of the proton beam has no real negative effects on the core, with the exception maybe of a thermal shock on the cladding. However, as the frequency of such type of accident is in principle very low, no damage to the fuel rods would have to be feared. In any case the temperatures in the core do not exceed their nominal values.

It has also to be pointed out that the proton beam is supposed to be maintained at full nominal power for the whole duration of the transients under consideration. When relatively long grace times exist, they offer the possibility of taking the necessary actions on the accelerator (or other possible equipments) to cut off the proton beam and hence to come back to a safe situation.

Remote Handling Operation

Due to the high activation dose on the top of the reactor and the high potential of α-contamination, the MYRRHA team has decided from the very beginning to design MYRRHA as to be operated remotely thanks to robots. The proposed MYRRHA project at SCK•CEN will be operated thanks to remote handling for all maintenance operations on the machine primary systems and associated equipment. Experience from similar projects [17, 18] has shown the importance of considering the implications of remote handling on the design of the plant from the earliest stage. Oxford Technologies Ltd (OTL) has been granted a contract for studying the implications of remote maintenance on the design of the MYRRHA machine and the overall project management. The study was conducted and reported herein following the first four steps of the whole life-cycle approach that has previously been used successfully by Oxford Technologies Ltd for the implementation of the remote maintenance system for the JET Tokamak [19].

A remote handling system based on the Man-In-The-Loop principle implemented with two bi-lateral force reflecting servo-manipulators working under Master-Slave mode has been recommended. The manipulators will have additional robotic capabilities to maximise operational capabilities. The slave manipulators will be positioned close to the task environment by means of remotely controlled transporters with sufficient reach and degrees of freedom to position the slaves at all relevant locations around the MYRRHA machine. The concept relies on the ability of the servo-manipulators and the video feedback systems to create a sense of presence for the operators at the task location. In practise all of the MYRRHA maintenance tasks will be performed directly by personnel using the arms, a range of cameras and cranes in much the same way as if they were next to the MYRRHA machine themselves (Figure 4)

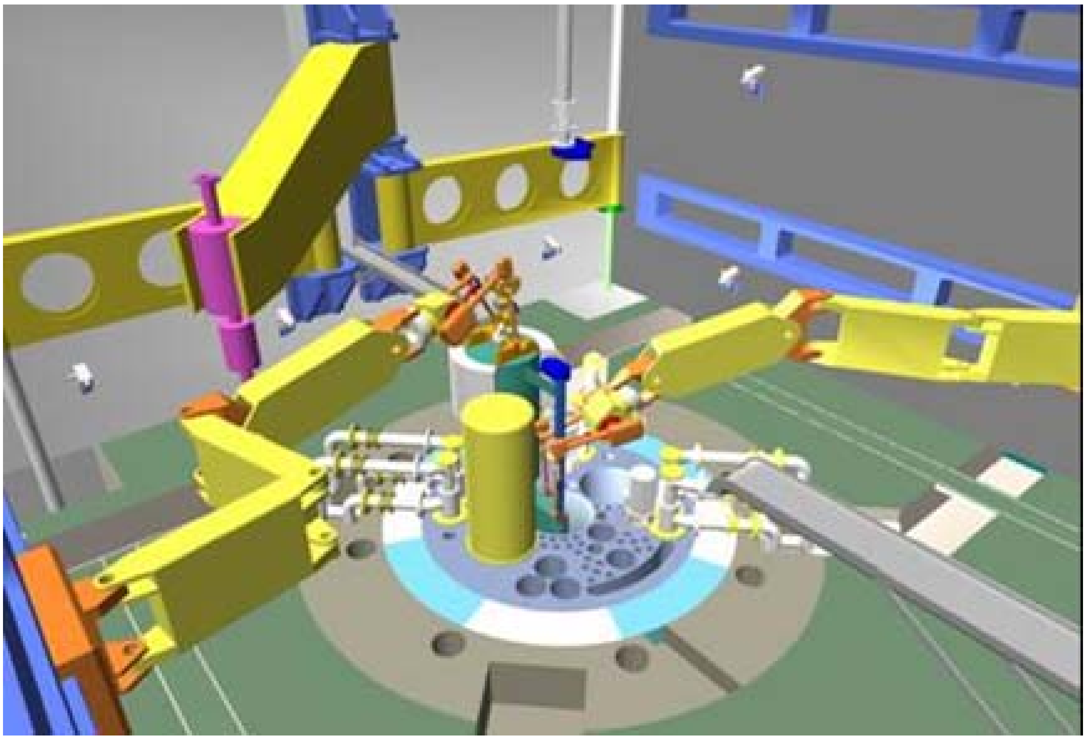

Figure 4 : Remote Handling Concept (based on JET Experience) for MYRRHA

In-Service Inspection & Repair (ISI&R) is also addressed by means of robotics based on In-Vessel Inspection Manipulator, periscopes or articulated arms equipped with ultrasonic cameras to be deployed when needed inside the MYRRHA vessel. The development of the ultrasonic sensors operating under LBE at temperatures up to 500°C and radioactive aggressive environment (gamma and neutrons) is going on in collaboration with the Kaunas University UltraSonic Institute [20, 21 and 22].

CONCLUSIONS AND EUROPEAN PERSPECTIVE

MYRRHA is responding the objectives of the experimental ADS Facility in terms of demonstration and performance, and responding by design to some key issues related to the LBE ADS such as:

- the LBE corrosion by leaving the major parts of the system at "cold" conditions and limiting the LBE velocity below 2.5 m/s,
- criticality control during core loading by leaving the spallation target in position and loading fuel assemblies from underneath
- avoiding spallation target window break by choosing the windowless design
- addressing the ISI&R and the O&M from the conceptual design by means of robotics and ultrasonic visualisation leading to a reduced exposure of the personnel

In the frame of the integrated FP6 project EUROTRANS the MYRRHA design parameters and choices are opened to a larger European community to better meet the objectives of the presently experimental ADS for transmutation considered within the EUROTRANS community namely the XT-ADS facility. During the period of the next 4 years (2005-2008) corresponding to the FP6 EUROTRANS period where potential show stoppers towards the deployment of an experimental ADS and later on the industrial ADS (which prototype is called EFIT in the EUROTRANS project) should be answered, namely:

- In basic technological research: one should address the material selection problem for the internal core structures as well as for the spallation target module and fuel cladding in contact with LBE,
- The HLM technology should be answering the problems of LBE conditioning and filtering in pools design conditions,
- The development of the needed instrumentation for LBE quality monitoring in order to guarantee a safe and efficient operation of LBE cooled ADS (O_2-Meters, ultrasonic visualisation under LBE, HLM Free surface monitoring, sub-criticality monitoring, LBE velocity field measurement) should be answered,
- Key Accelerator components should be demonstrated, namely the reliable working for periods of 3 months of the injector, the building of both SC and normal conducting intermediate section of the LINAC, the construction and testing of a spoke cavity that would bring the proton beam to an energy level of circa 100 MeV and from there on the development, building and testing of a cryomodule based on Nb elliptic cavities for the high energy section,
- The spallation module based on the windowless concept (most promising of achieving high performance core) should be fully designed from the mechanical, thermal-hydraulic as well as vacuum aspects should be accomplished,
- The coupling of the ADS components (accelerator, spallation module and a sub-critical core) should be realised at realistic power that would allow to study the thermal feedback reactivity assessment, the on-line subcriticality monitoring and control at various k_{eff} values,
- Last but not least the design of the experimental ADS (now labelled XT-ADS in the EUROTRANS FP6 project) should be seriously advanced at the end of

EUROTRANS period (end 2008) in order to be in a position to address the licensing authorities on a serious basis.

- Prior or in parallel to this advanced design of the XT-ADS, a conceptual design of a modular industrial ADS unit would be addressed in order to make out of the XT-ADS a test bench as much as possible for the technological choices of the industrial scale system.

At the end of this still generic development 4 years period one should enter a project dedicated structure for the construction of an experimental ADS (XT-ADS) that would lasting 10 years for bringing the project to the full power operation of this facility. The foreseen main periods in the project are a first 3 years period for detailed engineering design of the facility, demonstration and testing of the reactor components and putting under beam the already established design of the spallation and finally preparing the construction site and the licensing file. The next period of 4 years would be dedicated to the construction of the components at the production sites and the realisation of the civil engineering work at the facility site during 3 years and the fourth year would be dedicated to the assembly on site of the reactor as well as the accelerator components. In 2016 the facility will be then undergoing the commissioning tests for reaching the full operation stage somewhere at the beginning of 2018. The facility will be already able to accept MA loaded assemblies. From then on the facility can be operated as an irradiation facility and for gaining feedback experience to the designer of the Industrial ADS prototype EFIT that would be constructed during the period 2025-2030. After a maximum of 10 years of operation of this prototype the deployment at industrial scale would be possible which is the needed time frame also for having the deployment of the advanced PUREX reprocessing that would allow the separation of the MAs as well as the deployment of the dry reprocessing (pyroreprocessing) for dealing with the heavily MA loaded fuel coming from the dedicated burners.

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