Contribution of the European Commission to a European Strategy for HLW Management through Partitioning & Transmutation

Role of Accelerator Driven Strategy and MYRRHA and associated FP7 projects ARCAS, CDT, MARISA, MAX, FREYA and MAXSIMA

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Nuclear energy in Europe

- 152 reactors in 15 countries in EU-27, producing 31% of EU’s electricity
- The largest source of low carbon energy
- Excellent safety record
- Europe, a world leader – but competition is building up (Russia, Japan, USA, China, India)

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Power generation infrastructures

- Fossil and nuclear power generation plants are ageing

- Need to invest in plant lifetime management and

- Large investments are necessary to build new plants to satisfy demand
  - For nuclear, Gen III reactors (Finland, France)

- Action is needed now for paving the road for Gen IV!

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Nuclear fission contributes today 31% of EU electricity – the largest low carbon energy source

2020: Maintain competitiveness in fission technology and provide long term waste management solutions.

For the longer term as indicated in the SET Plan, we need to act now to:

- Complete the demonstration of Gen IV with closed fuel cycle for increasing sustainability,
- Enlarge the nuclear fission applications beyond electricity production, namely towards H₂, Heat, H₂O desalination.

Ambitious R&D and Demo programme need to start now to meet the required breakthroughs.

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HLW dimension and issues in EU

• Used fuel annual production: 2500 t/y
  – 25 t of Pu
  – 3.5 t of MA (Np, Am, Cm)
  – 3 t of LLFP

• No European policy but national policies:
  – Closed fuel cycle (reprocessing + GD)
  – Open fuel cycle (direct GD)
  – Wait & see: temporary intermediate storage
  – R&D on advanced options for HLW mgt through P&T
European Strategy for P&T

The implementation of P&T of a large part of the high-level nuclear wastes in Europe needs the demonstration of its feasibility at an “engineering” level. The respective R&D activities could be arranged in four “building blocks”:

1. Demonstration of the capability to process a sizable amount of spent fuel from commercial LWRs in order to separate plutonium (Pu), uranium (U) and minor actinides (MA),
2. Demonstration of the capability to fabricate at a semi-industrial level the dedicated fuel needed to load in a dedicated transmuter (JRC/ITU),
3. Design and construction of one or more dedicated transmuters,
4. Provision of a specific installation for processing of the dedicated fuel unloaded from the transmuter, which can be of a different type than the one used to process the original spent fuel unloaded from the commercial power plants, together with the fabrication of new dedicated fuel.

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Motivation for transmutation of spent fuel

- Transmutation of spent fuel
- Spent fuel reprocessing
- No reprocessing

Uranium naturel

Relative radiotoxicity

Time (years)

Duration Reduction 1.000x

Volume Reduction 100x

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Fast Neutron are unavoidable for transmutation

- To transmute MAs, we need to fission them
- The ration Fission/Capture is more favourable with fast neutrons
Why sub-criticality?

Both Critical reactors as well as ADS can be used as MAs transmuters.

Nevertheless, critical reactors, heavily loaded with MAs, can experience severe safety issue due to reactivity effect induced by a smaller fraction of delayed neutrons.

ADS can operate in a more flexible and safer manner even if heavily loaded with MAs hence leading to efficient transmutation therefore we say that **sub-criticality is not a luxury but a necessity.**

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Even with completely different national NE policies
European solution for HLW works with ADS

Scenario 1 objective: elimination of A’s spent fuel by 2100
A = Countries Phasing Out, B = Countries Continuing

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P&T inspired many Euratom FP projects

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28 M€ 31 M€ 31 M€
ARCAS Project

• Aim: Technical and economical comparison of Fast Reactors and ADS for transmutation of minor actinides
• Type: Supporting Action, Duration: 2 years, Budget: 500 k€
• EC Officer: R. Garbil
• Partners: SCK•CEN (BE), KIT (DE), NRG (NL), CIEMAT (ES), UPM (ES), CNRS (FR), NRI (CZ), NNL (UK), Transnubel (BE), EC-JRC-ITU, UNIMAN (UK)
Based on technical work in FP6-PATEROS, FP6-EUROTRANS, FP7-ESFR

Estimation of MA stream in representative group of countries

Estimation of required installed capacities (ADS, FR)

TRL analysis of systems

Economic analysis (using G4-ECONS & CNRS code)

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Main outcomes

- 2.3 – 6 tonnes/year of MA to be transmuted (PATEROS Group A)

- Transmutation rates
  - EFIT: 35 kg/TWhth
  - ESFR – homogeneous (2.5%): 2.8 kg/TWhth
  - ESFR – heterogeneous (20% in 84 targets): 0.6 kg/TWhth
Main outcomes

• Fuel reprocessing + MA fuel/target fabrication
  – Very low Technological Readiness Levels -> much more R&D needed
  – MA transmutation will have large impact on shielding + operation (remote handling)

• Fuel transportation
  – High capacity of ADS requires less transport

• Large uncertainties on costs (due to FOAK + low TRLs) for both FR burner (homo/hetero), ADS and fuel cycle facilities
CDT Project

- Coordinator: SCK•CEN
- Partners: 19
- Total budget: 3,8 M€ (2 M€ EC contribution)
- 242 man.months
- 3 year project (starting 1 April 2009)
- ~8 man.year/year
- Del Fungo withdrew from CDT

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CDT Project

Objectives

• Designed as an Accelerator Driven System to serve as:
  – A demonstrator for the ADS concept as a precursor of the industrial transmuter EFIT and a demonstrator for efficient transmutation
  – A flexible fast spectrum irradiation facility
  – To contribute to the demonstration of LBE technology
MYRRHA/FASTEF objectives

- To be operated as a flexible fast spectrum irradiation facility working in subcritical and critical mode allowing for:
  - fuel developments for innovative reactor systems;
  - material developments for GEN IV systems;
  - material developments for fusion reactors;
  - radioisotope production;
  - industrial applications, such as Si-doping;
  - To allow the study of the efficient transmutation of high-level nuclear waste (MA) requesting high fast flux intensity ($\Phi_{>0.75\text{MeV}} = 10^{15} \text{ n.cm}^{-2}\text{s}^{-1}$);

- To demonstrate the ADS full concept by coupling the three components (accelerator, spallation target and sub-critical reactor) at reasonable power level to allow operation feedback, scalable to an industrial demonstrator;

- To contribute to the demonstration of LBE technology and to demonstrate the critical mode operation of a heavy liquid metal cooled reactor as an alternative technology to SFR

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CDT - Project

**Purpose**

- Build on what has been accomplished up till now in the FP5, FP6 projects and national programmes projects related to this topic (starting from MYRRHA/XT-ADS)
- Obtain an advanced design of a flexible fast spectrum irradiation facility working in sub-critical mode (ADS) and critical mode
- Set up of a centralised multi-disciplinary team
  - Based at the Mol-site (core group)
  - Members from industry and research organisations

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Main results

• With CDT the MYRRHA design progressed to an advanced engineering level:
  – Primary system:
    • review of subcritical operation and with introduction of critical operation
    • Advanced design with incorporation of return of experience of past fast reactor programmes and R&D efforts on LBE with input of experts from many European partners
  – Safety aspects on core and primary system studied in detail
  – First significant activities in Balance of Plant (building, peripherals) for refining cost estimate
MYRRHA Design evolution

- Draft 2
  - 2005

- XT-ADS
  - 2009

- FASTEF
  - (aka rev. 1.4)
  - 2012

- Rev. ?
  - 2014

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In-Vessel Fuel Handling Machine
Fuel Recovery
Remote Handling

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Cooling systems

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MARISA Project

Key project information

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<td><strong>Main Objective</strong></td>
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| **Duration**         | 3 years  
                        From September, 1\textsuperscript{st} 2013 to August, 31\textsuperscript{st} 2016 |
| **Coordinator**      | SCK•CEN (H. Aït Abderrahim) |
| **Consortium**       | 16 organisations |
| **Granted EC contribution** | € 3.269.480,- |
| **Total budget**     | € 3.413.696,- |

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MARISA Project structure and WPs

MARISA Project Management

MARISA WP 1
MARISA General Project Coordination

MARISA WP 8
MARISA Project Communication & Dissemination of Information

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MARISA Project structure and WPs

Task 2.1: Development of a roadmap for the integration of MYRRHA as a European Fast Spectrum Facility in advanced fuel cycle and waste management programmes

Task 2.2: Integration of national programmes and initiatives in order to maximise the use of MYRRHA as a European large research infrastructure

Task 2.3: Establishing of the MYRRHA international consortium

Task 2.4: MYRRHA as an international open users facility for different categories of users including the definition of MYRRHA research portfolio and conditions for access

MARISA WP 2
Strategic Planning

MARISA WP 3
MYRRHA Consortium Legal Aspects

MARISA WP 4
MYRRHA Consortium Governance

MARISA WP 5
MYRRHA Consortium Financial Aspects

Task 3.1: Identification of the legal basis and structure for the establishing of the MYRRHA organisation

Task 3.2: Drawing-up of intergovernmental agreements for participation in MYRRHA

Task 3.3: Drawing-up of Articles of Association for participation in MYRRHA

Task 3.4: Definition of the MYRRHA organisational structure and management structure

Task 3.5: Definition of principles and rules for in-kind contributions to the MYRRHA project

Task 3.6: Management of Intellectual Property Rights (IPR) relating to MYRRHA procedures for Human Resources Management including the definition of MYRRHA research portfolio and conditions for access

Task 4.1: Establishing of the MYRRHA Project and QA Manual (including principles and approaches for the management of the MYRRHA scope, planning and budget)

Task 4.2: Implementation of the MYRRHA Management Instruments (definition of Work-breakdown Structure, project schedule, budget baseline, IPR and information management)

Task 4.3: Development of policies, principles and procedures for Human Resources Management

Task 5.1: Definition of MYRRHA Financing and Funding Mechanisms for different project phases (In-kind and in-cash contributions)

Task 5.2: Definition of MYRRHA Financing and Funding Mechanisms for different project phases

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Task 3.6: Management of Intellectual Property Rights (IPR) relating to MYRRHA

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MAX project information

• MAX is a 3-year Collaborative Project, FP7 grant nr. 269565
• goals:
  – to consolidate the conceptual design of the superconducting linear accelerator for MYRRHA (MLA) with its reliability target as the principal focus.
  – to initiate the engineering design of selected accelerator components, preparing for adequate prototyping activities.
  – to investigate the feasibility of future oriented solutions to specific open questions.
• coordination: CNRS/IPNOOrsay — Secretary Amélie KALININE, kalinine@ipno.in2p3.fr
• budget & partners:
  – total budget = 4.967 M€, EU contribution 2.931 M€
  – total # partners = 11
  – main partners (84% budget): CNRS (FR), IAP (DE), SCK-CEN (BE), INFN (IT)

http://ipnweb.in2p3.fr/MAX/

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MAX main achievements

- final choice of injector frequency: 176 MHz
- final choice of the RFQ type: 4-rod
- validated reliability model of comparable accelerator → readiness for model-based reliability analysis for MLA
- benchmarking of various beam dynamics simulation codes → readiness for start-to-end beam simulations and error studies
- engineering design of the MLA spoke cryomodule
- realisation of the thermal mock-up section of the 4-rod RFQ
- advances in digital Low Level RF programming
- advances in the prospection of Solid State RF power amplifiers at 704 MHz
MAX contribution to ADS

• The outstanding challenge regarding the accelerator for an industrial ADS = extreme reliability. Also in a demo ADS (MYRRHA) the reliability of its accelerator has to be top priority, and the corresponding achievement unprecedented.

• The entire MAX research program is defined around the topic of ADS-level accelerator reliability
  – through fundamental design
  – through simulations
  – through prototyping

• The defined pathway has been validated by an International Review Committee.
A few MAX recent achievements

- First source-to-target integrated beam simulation (CNRS, IAP, CEA, SCK•CEN)

- Definition of beam time structure & power control strategy (CNRS, SCK•CEN)

Figure 4: Proposed MYRRHA beam time structure for full power (~2.4 MW) nominal operation: long 4 mA blue pulses are sent to the reactor (2.28 MW mean power) while short red ones are sent to the ISOL facility (114 kW mean power).

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FISA 2013

A few MAX recent achievements

- Construction of RFQ (left) and CH (right) prototypes achieved, ready for tests (IAP)

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A few MAX recent achievements

- 700MHz power couplers (left) conditioned & ADS prototypical cryomodule (right) ready for high-power test (CNRS, INFN)

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Activity/Area: Management of Radioactive Waste: Partitioning and transmutation
Topic: Fission-2010-2.3.1: R&D activities in support of the implementation of the Strategic Research Agenda of SNE-TP

Fast Reactor Experiments for Hybrid Applications

Coordinating person: Anatoly Kochetkov
Management assistant: Margot Degreve
SCK•CEN

Duration: 2011-2016
Budget: 5.1 M€

Objectives:

• To validate the methodology of on-line reactivity monitoring initiated within the GUINEVERE project in FP6
• To support the development and operation of new reactor concepts such as:
  • MYRRHA (critical and subcritical)
  • Lead Fast Reactor

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## Participants

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Working packages and tasks

WP1: ADS on-line reactivity monitoring
- Task 1.1: SC2 and SC3 cores (Keff = 0.95 and Keff ≥ 0.97)
- Task 1.2: Deep subcritical experiment
- Task 1.3: Source positioning and core flexibility experiments
- Task 1.4: Methodologies for on-line reactivity monitoring

WP2: MYRRHA subcritical
- Task 2.1: Mock-up definition
- Task 2.2: Core characterisation
- Task 2.3: MYRRHA mock-up reactivity effects
- Task 2.4: MYRRHA subcriticality monitoring
- Task 2.5: Transfer results to the MYRRHA

WP3: MYRRHA critical
- Task 3.1: Mock-up definition
- Task 3.2: Core characterisation
- Task 3.3: MYRRHA mock-up reactivity effects

WP4: LFR
- Task 4.1: LFR Mock-up definition
- Task 4.2: LFR Core characterisation
- Task 4.3: LFR mock-up reactivity effects

WP5: Training and Education

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FISA 2013

FREYA progress

- 03/2011: start FREYA project
  VENUS-F critical core

- 10/2011: Sub-critical VENUS-F core coupling with GENEPI-3C, ADS mode

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General information

- Topic: Fission-2012-2.3.1: R&D activities in support of the implementation of the Strategic Research Agenda of SNE-TP
- Call Identifier: FP7-Fission-2012
- Funding scheme: Collaborative Project
- Title: Methodology, Analyses and eXperiments for the “Safety In MYRRHA” Assessment
- Acronym: MAXSIMA
- Duration in months: 72
- Objective: to contribute to the safety in MYRRHA assessment
- Total budget: € 10,087,542
- EC contribution: € 5,500,000

Vilnius, 14-16 October 2013
### General information

#### List of beneficiaries

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Work Packages: overview

• 5 Technical Work Packages
  – WP2: Safety Analysis in support of MYRRHA
  – WP3: Core component safety
  – WP4: Steam generator and cooling safety
  – WP5: Fuel safety
  – WP6: Enhanced Safety by Design for HLM reactors

• 2 non-technical Work Packages
  – WP1: Consortium management
  – WP7: Education and training

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Hydraulic tests of fuel channel/IPS components (T.3.2)

- Isothermal loop facility
- Representing one fuel channel/IPS at full height
- Interchangeable test modules

Specifications
- 150 – 400 °C
- 770 litres of LBE
- Gas cover
- Wide range of flow rates

Instrumentation
- Flow and velocity measurements
- Fast and slow pressure measurements
- Vibration analysis
- Temperature measurements

Status
- Mechanical and electrical design completed
- Contract for mechanical construction awarded
- Operational in June 2014

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MAXSIMA contributes to the European Strategy for P&T

MAXSIMA

- Contributes to the safety assessment of MYRRHA as a key European Research Infrastructure for the demonstration of the feasibility of P&T (3rd Pillar of the European Strategy for P&T)

Vilnius, 14-16 October 2013
Conclusions

• The EC strategy for preparing the implementation of P&T as a HLW management approach complementing the geological disposal is reaching an interesting stage of pilot scale demonstration
  – This is nearly done for the first building block (Advanced reprocessing) at ATALANTE in France
  – The second building block has made a major step thanks to ITU at Karlsruhe which is preparing Advanced MALAB able to handle up to 250 kg (Pu + MA)
  – The third building block of dedicated burners is responded through 2 project the ASTRID SFR prototype under dev. In France and the MYRRHA ADS project under dev. In Belgium
  – The fourth block is not heavily addressed in Europe, this should be the case in the future for all programme of advanced reprocessing such as Pyro-reprocessing

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