Implementation of ALFRED Demonstrator in Romania – Supply Chain Considerations

M. CONSTANTIN - RATEN ICN, Romania
ALFRED – LFR demonstrator and SMR features

Commercial Deployment Gen-IV
(European LFR Roadmap)

ELFR (FOAK)

Pro-LFR (Prototype)

SMFR (FOAK)

Anticipated SMFR commercial deployment (FALCON vision)

ALFRED
Advanced Lead-cooled Fast Reactor
European Demonstrator

Regional: Măgurele
Arges County
Region: 3 Sud-Muntenia

IAEA, INPRO Dialogue Forum, Supply Chain, July 2018
Planning

General Roadmap
- Main phases, milestones and timeline

Action Plan
- Main areas involved and major steps per phase

Implementation Plan
- Detailed list of tasks and measurable indexes
General Roadmap

Phase 1
- Viability
  - Considerations before a decision
  - ALFRED Feasibility study

Phase 2
- Preparation
  - ALFRED Project preparatory work
  - Lots definition for bidding

Phase 3
- Construction
  - Activities to implement ALFRED
  - ALFRED commissioning

Phase 4
- Operation
  - Pre-operational tests, connection to the grid

Infrastructure development programme

LFR technology demonstration programme

Commitment to ALFRED as major nuclear program
Ready to invite bids
Ready to commission and operate ALFRED

2015 - 2018 - 2023 - 2028
ALFRED, the Layout
ALFRED, an opportunity for Romania

- 2011, Romanian Government – Memorandum on the interest to host ALFRED
- 2014, Memorandum “ALFRED construction in Romania”, 2014, approved by Government
- 2014, Mioveni nuclear platform as reference site
- 2015, ALFRED in Smart Specialization Strategy
- 2016, ALFRED in National RDI Strategy, and National Energy Strategy
- 2016: Letter of Support (ANCSI and scientific community)
- 2017, Support of the industry (ROMATOM)
- 2017, Research and Education Partnership for ALFRED, CESINA
- 2017, ALFRED in Roadmap of Major Research Infrastructure (CRIC)
- 2018, Romanian “Position paper” on ALFRED
- the Government Programmes (for 2017-2020) mentions ALFRED
### Action Plan - General overview; Procurement actions

<table>
<thead>
<tr>
<th>Viability</th>
<th>Preparation</th>
<th>Construction</th>
<th>Operation</th>
</tr>
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<tbody>
<tr>
<td><strong>Governance</strong></td>
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<td>Management</td>
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<td>Financing</td>
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<td>Research</td>
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<td>Development</td>
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<td>Qualification</td>
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<td>Safety</td>
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<td>Siting</td>
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<td>Licensing</td>
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<td><strong>Engineering</strong></td>
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<td>Procurement</td>
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<tr>
<td>Construction</td>
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<tr>
<td><strong>Human resources</strong></td>
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<td>Education</td>
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<tr>
<td>Training</td>
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</table>

#### Viability
- **Project approval**
  - Financing assessment
  - Management assessment
- **Technology assessment**
  - Design evaluation and approval
  - Application to construction license
  - Application to siting
  - Site preparation
- **Preliminary dialogue with regulatory body and safety authorities**
  - Site characterization

#### Preparation
- **Evolution of Consortium to Legal Entity**
  - Allocation of funds
- **Technology qualification**
  - Fuel qualification
- **Definition of R&D programs for operation**
- **Application to operation license**
  - Application to operation license
  - Application to upgrade license

#### Construction
- **Construction of supporting facilities**
  - ALFRED Detailed design
- **ALFRED construction**
  - Fuel fabrication
- **Fuel delivery on-site**
  - Testing of operation procedures
  - Testing of maintenance procedures

#### Operation
- **Signature of joint research programmes**
  - Sustainability of the infrastructure
- **Demonstration of LFR technology**
- **Demonstration of safety claims**
  - Application to upgrade license

#### Human resources
- **Definition of E&T programmes**
  - Launch of open access to HLM CoE
  - Hiring of management staff
- **Education of students**
  - Training of operators for supporting facilities
  - Hiring of scientific/technical staff
- **Training of operators for ALFRED**
- **Dissemination of results**
  - Launch of open access to ALFRED
  - Dissemination of results

#### Timeline
- **2015**
- **2018**
- **2023**
- **2028**
Actions planned for Viability Phase

AREA 4: Engineering, Procurement and Construction

- V4.11 Assessment of (inter)national suppliers of components/services
- V4.12 Analysis of national policy for local industrial involvement
- V4.13 Assessment of quality programmes for nuclear components/services
- V4.14 Analysis of requirements for nuclear components/services purchase
- V4.15 Development of consistent policies for nuclear procurement
Actions planned for Preparatory Phase

AREA 4: Engineering, Procurement and Construction

- P4.10 Determination of bid evaluation criteria
- P4.11 Establishment of contracting strategy
- P4.12 Realistic assessment of national and local capabilities
- P4.13 Analysis of supply chain schedule and quality requirements
- P4.14 Program to transition to national and local suppliers (where available)
Supply chain in the Risk management

- **7 categories** (grouping 98 risks)
  - Technical risks (1.1 – 1.23)
  - Financial risks (2.1 - 2.15)
  - Political risks (3.1 – 3.10)
  - Market risks (4.1 – 4. 4)
  - Management risks (5.1 – 5.26)
  - Relationship risks (6.1 - 6.12)
  - Governance risks (7.1 – 7.9)

  - Good practices and difficulties from similar projects

  - Prevention and Mitigation Strategy

  - Investigation supported by Euratom FP7 ARCADIA project, approach: matrix of risks (impact and likelihood)
## Major risks

<table>
<thead>
<tr>
<th></th>
<th>(C1) ARCADIA</th>
<th>Risk (averaged)</th>
<th>Corresp.</th>
<th>(C2) FALCON</th>
<th>Risk (averaged)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Difficulties to ensure the pre-financing planned amounts</td>
<td>51.13</td>
<td>1-1</td>
<td>Difficulties to ensure the pre-financing planned amounts</td>
<td>68.00</td>
</tr>
<tr>
<td>2</td>
<td>Delays and costs overruns</td>
<td>46.04</td>
<td>2-9</td>
<td>Unavailability (in time) of the equipment, components, materials</td>
<td>56.33</td>
</tr>
<tr>
<td>3</td>
<td>Maturity of the technology is not reached</td>
<td>43.78</td>
<td>3-20</td>
<td>Unavailable infrastructure for pre-licensing and licensing</td>
<td>56.00</td>
</tr>
<tr>
<td>4</td>
<td>Underestimation of expenses</td>
<td>41.34</td>
<td>4-5</td>
<td>Lack of some funding sources</td>
<td>53.67</td>
</tr>
<tr>
<td>5</td>
<td>International crisis introducing disturbances in supporting of projects</td>
<td>39.91</td>
<td>5-16</td>
<td>Underestimation of expenses</td>
<td>51.00</td>
</tr>
</tbody>
</table>
Supply chain risks – ranking

- Maturity of the technology is not reached (3)
- Uncertainty in the costs for the equipment, components and materials (13)
- Unavailability (in time) of the equipment, components, materials (17)
- Uncertainties concerning the delivery of nuclear fuel Inadequate qualification of materials and equipment (31)
- Low quality standards (41)
- Inadequate procurements (46)
- Too much external commitments (subcontracting) (47)
Lessons learnt from other experiences

**SUSEN project** (European funds, Czech context):
- difficulties in the procurement process due to many devices of the proposed research infrastructure are unique
  - low number of potential suppliers,
  - the existing rules of the national legislative framework request a minimal number of participants in the bid,
  - the repetition of the bid cannot guarantee the success.
- delays in the implementation generated by negotiation process (one year delay due to negotiations), and optimistic planning of the steps and activities.

**ELI-NP** (European funds, Romanian context):
- Delays due to some suppliers, risks for the finalization of the project and final payments
Other resources for learning

- MYRRHA, pre-licensing efforts, certification experience
- PHENIX and SuperPhenix, fast reactor technology, supply chain
- BREST – agreement LEADER-Rosatom (information exchanges)
What is needed?

- **Primary Coolant (Lead):** 5700 t pure lead
- **Nuclear fuel (MOX):** 1 core=6 t U + 2.2 t Pu
- **Reactor Control and Shutdown System**
  - Primary system:
    - Primary pumps: 8 (working in liquid lead 400-500°C),
    - Steam generators: 8
    - Reactor inner vessel
    - Reactor vessel (RV&SV) with cover
    - I&C associated to primary system
  - **Balance of Plant:** mechanical equipment, electrical equipment, piping materials, electrical materials, local instrumentation
  - **Emergency systems:** 8 DHRs
  - **Buildings and Civil Structures** including cooling towers
  - **Power supply**
  - **Auxiliaries:** waste processing, purification system, fuel handling and machine, handling equipment, fire protection,
ALFRED - Reactor Building: Vertical Section
## ALFRED – Configuration and Main Parameters

<table>
<thead>
<tr>
<th>ALFRED Main Characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical capacity:</strong></td>
<td>125MWe</td>
</tr>
<tr>
<td><strong>Thermal capacity:</strong></td>
<td>300MWth</td>
</tr>
<tr>
<td><strong>Primary Coolant</strong></td>
<td>Lead</td>
</tr>
<tr>
<td><strong>Primary Circulation</strong></td>
<td>Forced (8 mechanical pumps)</td>
</tr>
<tr>
<td><strong>Normal Operation</strong></td>
<td>Natural</td>
</tr>
<tr>
<td><strong>Primary System Pressure:</strong></td>
<td>&lt; 0.1MPa</td>
</tr>
<tr>
<td><strong>Primary System Temperature:</strong></td>
<td>400÷480 °C</td>
</tr>
<tr>
<td><strong>Primary System Flowrate</strong></td>
<td>26000 kg/s</td>
</tr>
<tr>
<td><strong>Secondary Coolant:</strong></td>
<td>Water/Superheated-Steam</td>
</tr>
<tr>
<td><strong>Secondary System Pressure:</strong></td>
<td>18 MPa</td>
</tr>
<tr>
<td><strong>Superheated Steam Temperature:</strong></td>
<td>450 °C</td>
</tr>
<tr>
<td><strong>Secondary Coolant Flowrate</strong></td>
<td>193 kg/s</td>
</tr>
<tr>
<td><strong>Fuel Material:</strong></td>
<td>MOX</td>
</tr>
<tr>
<td><strong>Fuel Cycle/Residence time:</strong></td>
<td>12 Months / 5 Years</td>
</tr>
<tr>
<td><strong>Residual heat removal systems:</strong></td>
<td>2 DHR systems, 4 loops each - Passive</td>
</tr>
<tr>
<td><strong>Design Life:</strong></td>
<td>40 Years</td>
</tr>
</tbody>
</table>
ALFRED - Core Configuration

<table>
<thead>
<tr>
<th>Power (MWth)</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Assemblies</td>
<td></td>
</tr>
<tr>
<td>Inner core</td>
<td>171</td>
</tr>
<tr>
<td>Outer core</td>
<td>114</td>
</tr>
<tr>
<td>Fuel type</td>
<td>MOX</td>
</tr>
<tr>
<td>Pu enrichment Inn/Out (at %)</td>
<td>21.7/27.8</td>
</tr>
<tr>
<td>Control/shutdown Rods</td>
<td>12</td>
</tr>
<tr>
<td>Safety Rods</td>
<td>4</td>
</tr>
<tr>
<td>Dummy elements</td>
<td>110</td>
</tr>
<tr>
<td>Fuel Batches</td>
<td>5</td>
</tr>
<tr>
<td>Fuel cycle length</td>
<td>365 EFPD</td>
</tr>
<tr>
<td>Peak/avg BU (MWd/t)</td>
<td>103/73.3</td>
</tr>
</tbody>
</table>
ALFRED – Fuel Pin & Fuel Assembly

Overall length 8000

Spike
Bottom Shroud
Funnel
Upper Shroud
Ballast

Overall length 1390
Active region 600
Gas plenum 550
Thermal insulator
Upper plenum (with spring) 120
Fuel pellet

Thermal insulator

Upper head
ALFRED - Upper and Lower Core Support Plates

Lower core support plate
Box structure with two horizontal perforated plates connected by vertical plates. Plates holes are the housing of FAs feet. The plates distance assures the verticality of FAs.

Upper core support plate
Box structure as lower grid but more stiff. It has the function to push down the FAs during the reactor operation. A series of preloaded disk springs presses each FA on its lower housing.

Hole for Instruments
**ALFRED - Reactor Control and Shutdown System**

- Two redundant, independent and diverse shutdown systems are designed for ALFRED (derived from MYRRHA design)

- **The Control Rod (CR) system** used for both normal control of the reactor and for SCRAM in case of emergency
  - CR are extracted downward and rise up by buoyancy in case of emergency shutdown (SCRAM)
  - During reactor operation at power CR are most of the time partly inserted allowing reactor power tuning (each rod is inserted for a maximum worth less than 1$ of reactivity)

- **The Safety Rod (SR) system** is the redundant and diversified complement to CR used only for emergency shutdown SCRAM
  - SR are fully extracted during operation at power
  - SR are extracted upward and inserted downward by the actuation of a pneumatic system (insertion by depressurization – fail safe)
  - A Tungsten ballast is used to maintain SR inserted

- Reactive worth of each shutdown system is able to shutdown the reactor even if the most reactive rod of the system is postulated stuck
**ALFRED - Reactor Vessel**

Cylindrical Vessel with a torispherical bottom head
Anchored to the reactor cavity from the top
Cone frustum, welded to the bottom head, provides radial support of the Inner Vessel

![Diagram of the reactor vessel]

**Main Dimensions**

- Height, m: 10.13
- Inner diameter, m: 8
- Wall thickness, mm: 50
- Design temperature, °C: 400
- Vessel material: AISI 316L
ALFRED - Inner Vessel

Inner Vessel has the main functions of core support and hot/cold plena separation. Fixed to the cover by bolts and radially restrained at bottom (replaceable). Core Support plate is mechanically connected to the IV with pins for easy removal/replacement.
ALFRED - Steam Generator

- Bayonet vertical tube with external safety tube and internal insulating layer
- The internal insulating layer (delimited by the Slave tube) has been introduced to ensure the production of superheated dry steam
- The gap between the outermost and the outer bayonet tube is filled with pressurized helium to permit continuous monitoring of the tube bundle integrity. High conductivities particles are added to the gap to enhance the heat exchange capability
- In case of tube leak this arrangement guarantees that primary lead does not interact with the secondary water
**ALFRED - Steam Generator Geometry & Performances**

SGs Tubes, X10CrMoVNb9-1, RCC-MRx code (T91 steel)

<table>
<thead>
<tr>
<th>Steam Generator Geometry</th>
<th>Steam Generator Performance</th>
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<tbody>
<tr>
<td><strong>Number of coaxial tubes</strong></td>
<td><strong>Removed Power [MW]</strong></td>
</tr>
<tr>
<td><strong>Slave tube O.D</strong></td>
<td><strong>Inlet Lead Temperature [°C]</strong></td>
</tr>
<tr>
<td><strong>Slave tube thickness</strong></td>
<td><strong>Outlet Lead Temperature [°C]</strong></td>
</tr>
<tr>
<td><strong>Inner tube O.D</strong></td>
<td><strong>Feed-water Temperature [°C]</strong></td>
</tr>
<tr>
<td><strong>Inner tube thickness</strong></td>
<td><strong>Steam Temperature [°C]</strong></td>
</tr>
<tr>
<td><strong>Outer tube O.D</strong></td>
<td><strong>SG steam/water side global Δp [bar]</strong></td>
</tr>
<tr>
<td><strong>Outer tube thickness</strong></td>
<td></td>
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<tr>
<td><strong>Outermost tube O.D</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Outermost tube thickness</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Length of exchange</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Number of tubes</strong></td>
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</tbody>
</table>

- Number of coaxial tubes: 4
- Slave tube O.D: 9.52 mm
- Slave tube thickness: 1.07 mm
- Inner tube O.D: 19.05 mm
- Inner tube thickness: 1.88 mm
- Outer tube O.D: 25.4 mm
- Outer tube thickness: 1.88 mm
- Outermost tube O.D: 31.73 mm
- Outermost tube thickness: 2.11 mm
- Length of exchange: 6 m
- Number of tubes: 510

- Removed Power: 37.5 MW
- Inlet Lead Temperature: 480 °C
- Outlet Lead Temperature: 400 °C
- Feed-water Temperature: 335 °C
- Steam Temperature: 450 °C
- SG steam/water side global Δp: 3.3 bar
ALFRED - Primary Pump

**LEADER Option:** axial mechanical pump, always running at constant speed, with blade profile designed to achieve the best efficiency

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ALFRED</th>
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<tbody>
<tr>
<td>Flow rate, kg/s</td>
<td>3247.5</td>
</tr>
<tr>
<td>Head, m</td>
<td>1.5</td>
</tr>
<tr>
<td>Outside impeller diameter, m</td>
<td>0.59</td>
</tr>
<tr>
<td>Hub diameter, m</td>
<td>0.39</td>
</tr>
<tr>
<td>Impeller speed, rpm</td>
<td>315</td>
</tr>
<tr>
<td>Number of vanes</td>
<td>5</td>
</tr>
<tr>
<td>Vane profile</td>
<td>NACA 23012</td>
</tr>
<tr>
<td>Suction pipe velocity, m/s</td>
<td>1.12</td>
</tr>
<tr>
<td>Vanes tip velocity, m/s</td>
<td>9.8</td>
</tr>
<tr>
<td>Meridian (at impeller entrance and exit) velocity, m/s</td>
<td>2.0</td>
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**New option:**

**Screw Pump Type**
- Promising design
- Low relative speed
- Good performance
Passive cooling - DHR Systems

- Normal decay heat removal following the reactor shutdown: the secondary system used in active mode of operation

- Two independent, passive, high reliable and redundant safety-related Decay Heat Removal systems (DHR N1 and DHR N2):
  - DHR N1: 4 Isolation Condenser (ICs) systems connected to four out of eight SGs
  - DHR N2: 4 Isolation Condenser systems connected to other four SGs

Each IC loop consists of:
- One heat exchanger (Isolation Condenser), constituted by a vertical tube bundle with an upper and lower header
- One water pool, where the isolation condenser is immersed
- One condensate isolation valve (battery actuated)

Features:
- Independence: 2 different systems with nothing in common
- Redundancy: 3 out of 4 loops sufficient to fulfill the DHR safety function even if a single failure occurs
Cladding materials/coatings for safety features

- **Critical issue:**
  - Corrosion in pure lead, over 550 °C
  - Erosion by lead circulation

- **Short term strategy:** proven material, protected by corrosion resistant coating; e.g. 15-15Ti (proven in Phenix) as base material + Al₂O₃ based by PLD- Pulsed laser deposition (well proven)
  - the coating shows high corrosion resistance to Pb attack,

- **Long term strategy:** Completely new materials without protective coating.
  - Possible Material options:
    - Advanced austenitic
    - Alumina forming austenitic
    - Cr-Si oxides forming steels

**Needs:** extensive irradiation campaigns aimed to the complete qualification up to 100 dpa by neutrons
Research Infrastructure for Demonstration, Q., V&V
- 100 mil. Euro, Commitment of Ro Gov

| RI Project 1 (2017-2021) | • ATHENA  
|                          | • ChemLab  
|                          | • HELENA-2 |
| RI Project 2 (2021-2023) | • ELF  
|                          | • Meltin’Pot  
|                          | • HandsON |
| Hub (2022-2023)          | • Hub  
|                          | • Lead School |

ALFRED

Major Project
- Strategic Doc  
- Negotiation EU

Design
- Engineering  
- Pre-Licensing

Licens.
- Siting  
- Construction

Constr.

2025

CoE
RIs and Licensing

- **ATHENA**: large pool to test equipment and at scale thermal-hydraulics
- **ChemLab**: lead and cover gas chemistry and auxiliary systems development
- **HELENA 2**: testing of FAs and CRs, Portion of core with full-scale FA and CR/SR dummy elements.
- **ELF**: electric simulator of the reactor, Long-running system tests (endurance)
- **HANDS ON**: Core simulator for S/As manipulation and handling tests in air
- **Meltin’Pot**: Fuel-(clad)-coolant interaction, fuel dispersion and fission products retention, fuel transport in naturally circulating lead
Supply Chain Investigation and Activities:

1. Identification of critical components, materials, and equipment: pumps (materials, characteristics, reliability), SGs, nuclear fuel
2. Identification of potential suppliers
3. Focus on: fuel fabrication (MOX suppliers), pump development (discussion with Czech partners)
4. Consortium resources
5. Requirements of CNCAN (accepted industrial standards and codes) – certification of Quality Management System, dialogue FALCON-CNCAN
6. Transportability (to reference site)
7. Involvement of national industry
FALCON –CNCAN dialogue

- FALCON: a preliminary list of codes and standards applicable in a conceptual design phase was presented (to CNCAN) for nuclear systems, structures and components

- The list of codes and standards applicable to ALFRED design activities was accompanied by a preliminary judgement about the level of applicability of each code, standard or guide and is being traced in a dedicated database developed by Ansaldo Nucleare

- CNCAN: adoption of existing rules and standards (ASME, RCC-MRx, etc.) for the nuclear island is considered appropriate, although still requiring a thorough applicability analysis.
QMS certification

- The applicant for design authorization must have QMS license.
- Any organization performing project activities having a safety related relevance (e.g., codes development or V&V, analysis, experimentation) shall have a separate QMS license.
- Each organization involved in the design activities shall have to be licensed by CNCAN for design activities (NMC 05). In addition, if a company coordinates the whole set of activities, acting as design manager, the company has to apply also to project management for design activities (NMC 02).
- The applicant of the design certification may be different than the applicant for construction.
- All FALCON organizations have their quality management system certified according to ISO 9001: 2008 standard and if not already acquired, are in the process to obtain the certification according to ISO 9001: 2015.
- The extension of Ansaldo Nucleare QMS certification to software use and design activities (safety related) is currently under discussion at company level.
In, April 2017 ROMATOM issued a position paper, titled “Why ALFRED Project in Romania?”, in support to the implementation of the Project:

«In the ALFRED project implementation as a demonstrator, all the Romanian national nuclear industry is expected to be involved. In this sense, ROMATOM sustains and encourages the development and implementation of this project as a major and priority national project. The national nuclear industry is ready to become an active factor in infrastructure LFR RD&D [...] in the ALFRED project, by supporting FALCON Consortium [...]»
Involvement of national industry

1. Romanian experience in development of nuclear fuel (natural Uranium), D2O, and equipment
2. CITON design, FECNET (equipment for Nuclear Programme)
3. Accessing structural funds to strengthen the equipment industry - Project RDI involving industry (coordinator Walter Tosto): equipment for next generation nuclear systems, materials, tolerances, 3D machining simulation, codes compatibility, lubricants/coolants,
4. Participation in international and national projects
ALFRED project – some conclusions

- Long term project, Major investment, International environment
- Supply chain one of the important concern for the Preparatory Phase
- Critical issue: the pumps (suppliers, design and tests, duration), the fuel (time constraints)
- Key issues: human and financial resources
- Major step – demonstration of the technology – towards the commercial deployment
- International and national support
Thank you for your attention!