

Sustainable Nuclear Energy technology Platform: SNETP

Deployment strategy: DS 2015

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Status on July 8, 2015

NEA workshop on “Nuclear Innovation roadmap”

Purpose of DS 2015

With reference to the European energy context and nuclear energy challenges, DS₂₀₁₅ purpose is:

- To provide key elements for implementing the Strategic Research & Innovation Agenda (SRIA₂₀₁₃) of SNETP and the program of its three pillars:



- To reinforce SNETP global vision and alignment with nuclear energy challenges

- Prioritization
- Orientation
- Transversality - clustering

Optimized
R&D program

- To assess SNETP position in European nuclear fission R&D
 - R&D projects with high technical value
 - Wide nuclear R&D community

Ressources

The structure of DS 2015

OUTLINE

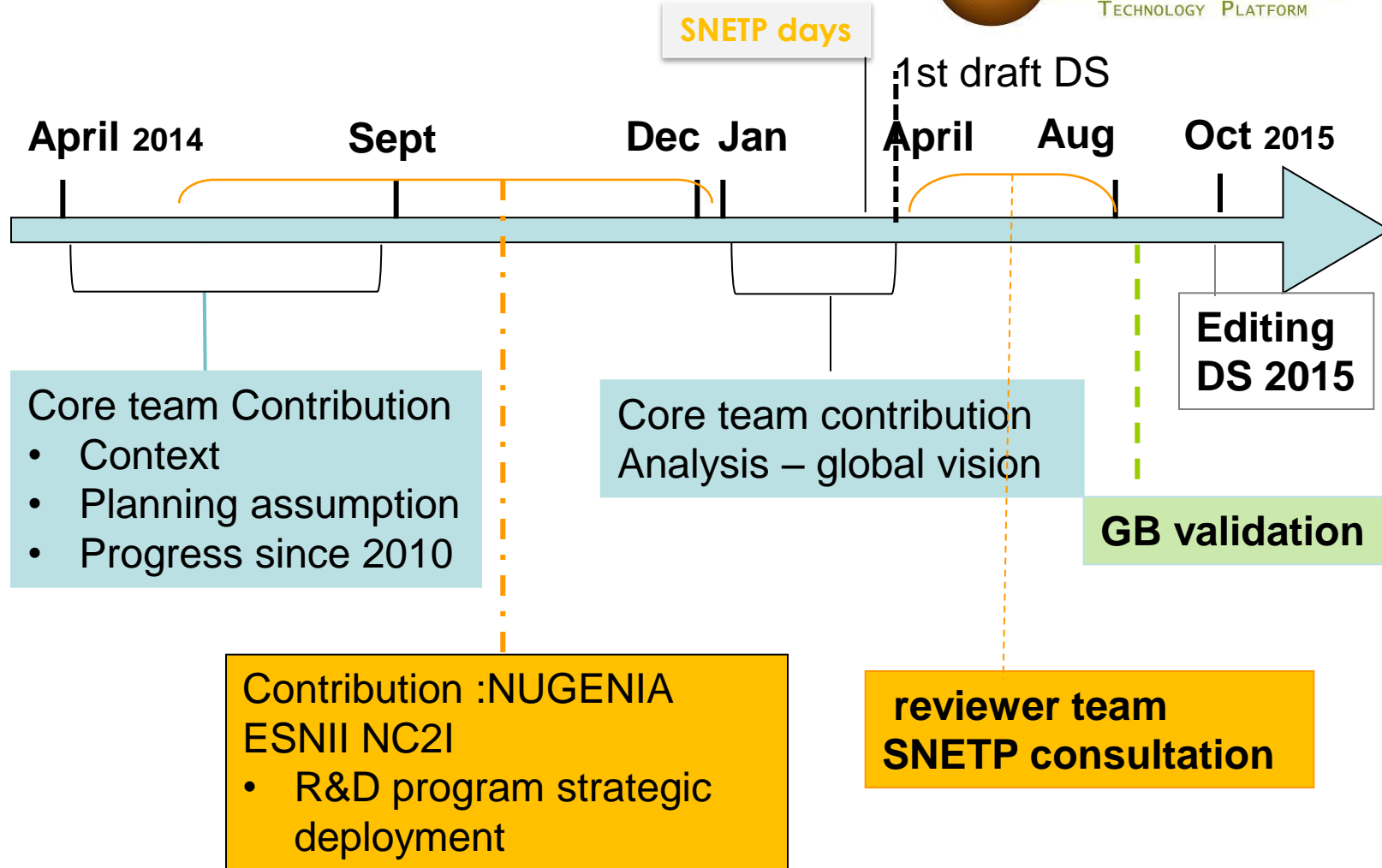
- Elements of context
- Challenges and planning assumptions for nuclear energy
- Major progress since last DS 2010
- Strategic vision for Research & Innovation deployment
NUGENIA – ESNII - NC2I
- Integrated vision and global deployment for SNETP



Appropriate Research & Innovation program to contribute reinforcing the role of nuclear energy :

- Low carbon electricity generation
- Secure supply chain – competitive price of electricity
- Mature and reliable technology
- Continuously enhanced safety
- Innovation

Planning for DS release



DS 2015 outline

□ Elements of context

- Electricity demand evolution worldwide till 2050
 - Breakdown per technology

- Energy policy for Europe
 - EC targets: 2020 – 2030 - 2050
 - Evaluation of different low carbon scenarios :
energy mix - share of nuclear electricity around 15%-20%

- The nuclear electricity market evolution
 - Country specific energy policy
 - Renewable resources

- Societal challenges for nuclear products
 - Public acceptance
 - Environmental impact
 - Education & training- knowledge management
 - Growth – jobs

Input from

- EC publication
- ENEF
- FORATOM
- OECD/NEA
- IAEA

DS 2015 – outline (cont'nd)

□ Challenge and planning assumptions for nuclear energy

– Nuclear systems technology drivers : **safety & performance**

– Technology evolution of the products

• Gen II-III (LWR technology) : **EU fleet ageing** **New build**

• Gen IV : sustainable fuel cycle **Industrial deployment ≈ 2040 - 50**

• Co generation: **Process heat application**

– Fuel cycle – and waste management

Key issue for supporting the product evolution
→ **Switch from LWR to Fast Neutron reactor**

– Decommissioning & dismantling **Reactor & fuel cycle facilities**

– Energy Mix

• Increased share with renewable energy set out new requirements for NPP

– operation mode - usage factor (merit order)

– fuel management – cost economics

• Market sizing on nuclear power generation to be installed

DS 2015 – outline (cont'nd)

□ Major progress since last DS document (DS₂₀₁₀)

- SNETP structure endorsement
 - ESNII : Industrial Initiative endorsed in Nov 2010
 - NUGENIA association launched in December 2011
 - NC2I: task force activated in 2010 – Industrial Initiative
- Task Force following Fukushima (2011)
- Launching of R&D program within SNETP
 - ESNII - NUGENIA – NC2I
 - Support from FP7 (2013)
 - ESNII +
 - NUGENIA +
 - NC2I-R
- Strategic Research & Innovation Agenda SRIA₂₀₁₃
- A new European framework: HORIZON 2020
 - R&D funding instruments
 - Technology platforms

Coordination &
support actions

❑ Strategic vision for SNETP program deployment



- Support nuclear product and technology deployment through R&D projects of high technical value, while considering challenges and planning assumptions for nuclear energy



- NUGENIA: Gen II-III
- ESNII : Gen IV
- NC2I: co generation

- High level objectives
- Research & Innovation action
- Prioritization of R&D topics
- funding

- Transverse issues – clustering
 - including with other ETPs
- SNETP integrated vision



R&D deployment for: Gen II III (LWR)



- **NUGENIA:** program planned for the next 20-25 years
 - Ultimate goal: Secure the safe operation of nuclear power plants while maintaining the competitiveness and contribution to the carbon emission reduction of nuclear power in the energy mix
 - Whole set of 8 technical areas featuring expertise field for covering all issues related to Gen II-III
 - Operated reactors and new built (LWR)
 - R&D scope & challenges described in all steps from design to long term operation, and decommissioning, all components, structural and fuel materials
 - 8 high level objectives and Cross cutting challenges to reinforce the transverse vision between TAs
 - Resources:
 - Public / private
 - Current collaborative R&D project portfolio equivalent to 80 M€: 40% from EC and 60% from national program & industry

NUGENIA roadmap 2013 – 2015

R&D deployment : Gen IV

- **ESNII:** support and promote technology development for Gen IV systems
 - Ultimate goal: Increase sustainability of nuclear energy by making a more efficient use of nuclear fuel resources, minimising the high level radioactive waste and optimising their management
 - **Fast neutron reactors with closed fuel cycle**
 - Industrial deployment from around 2050
 - Highlight of the R&D program :
 - To support design - license, and construction of:
 - » ASTRID prototype and MYRRHA research facility
 - » ALFRED demonstrator
 - To support the feasibility of ALLEGRO
 - Fuel fabrication – recycling – P&T option
 - » selection of MOX fuel (pelletized) for the harmonization of fast reactor fuel R&D in Europe .
 - Resources: mostly public / public partnership

R&D deployment : co-generation

NC2I Concept paper (on going)

www.SNETP.eu

- **NC2I:** co-generation of heat and electricity
 - Ultimate goal: to develop the flexibility of nuclear reactors for electricity generation and to provide co-generated heat for non-electric applications
 - First step: steam production
 - Highlight of the R&D program
 - Demonstrator
 - » High Temperature Gas reactor
 - » Nuclear process steam supply system
 - Technology R&D
 - » Material for structural component: IHX
 - » Power conversion system
 - » Fuel manufacturing & qualification
 - » Fuel cycle and waste challenges (Graphite)
- Resources: public / private

Prioritization of R&D program for each pillar

- **NUGENIA milestones: 5-10y 10-15y 15-25y**
 - Prioritization according to 8 high level objectives crossed with the priorities of the 8 TAs:
- **Base techno** : *structural component – fuel - systems – operations (normal & accidental)*
- **Drivers**: *enhanced safety – performance – harmonization - innovation*
- **ESNII milestones: 10y 20y 30y**
 - Prioritization between the prototypes development AND roadmap for each prototype
 - Fast reactor MOX fuel fabrication and recycling
 - Transmutation
- **NC2I milestones: 5y 10y 20y**
 - Roadmap for nuclear prototype construction: HTR
 - » Technology R&D in support : material – fuel – power conversion system – waste management
 - Nuclear process steam supply system and transport

Transverse issues - clustering

- Purpose: to identify common trunks between the Nuclear Systems and with other ETPs (*Example of*)

Base technology
Gen II III IV

Examples:

- material
- Instrumentation
- Digital system
- Manufacturing & assembly technology
- Research infrastructure
- Calculation code

Fuel cycle and waste management

- **NUGENIA – ESNII global optimization on MOX fuel fabrication (different PU content) and recycling technology-**
- **Scenario with a multi national approach on a transition period LWR →→FNR**
- **SNETP – IG-DPT interface for optimizing spent fuel and ultimate nuclear waste specificities – graphite waste**

new material with JPNM



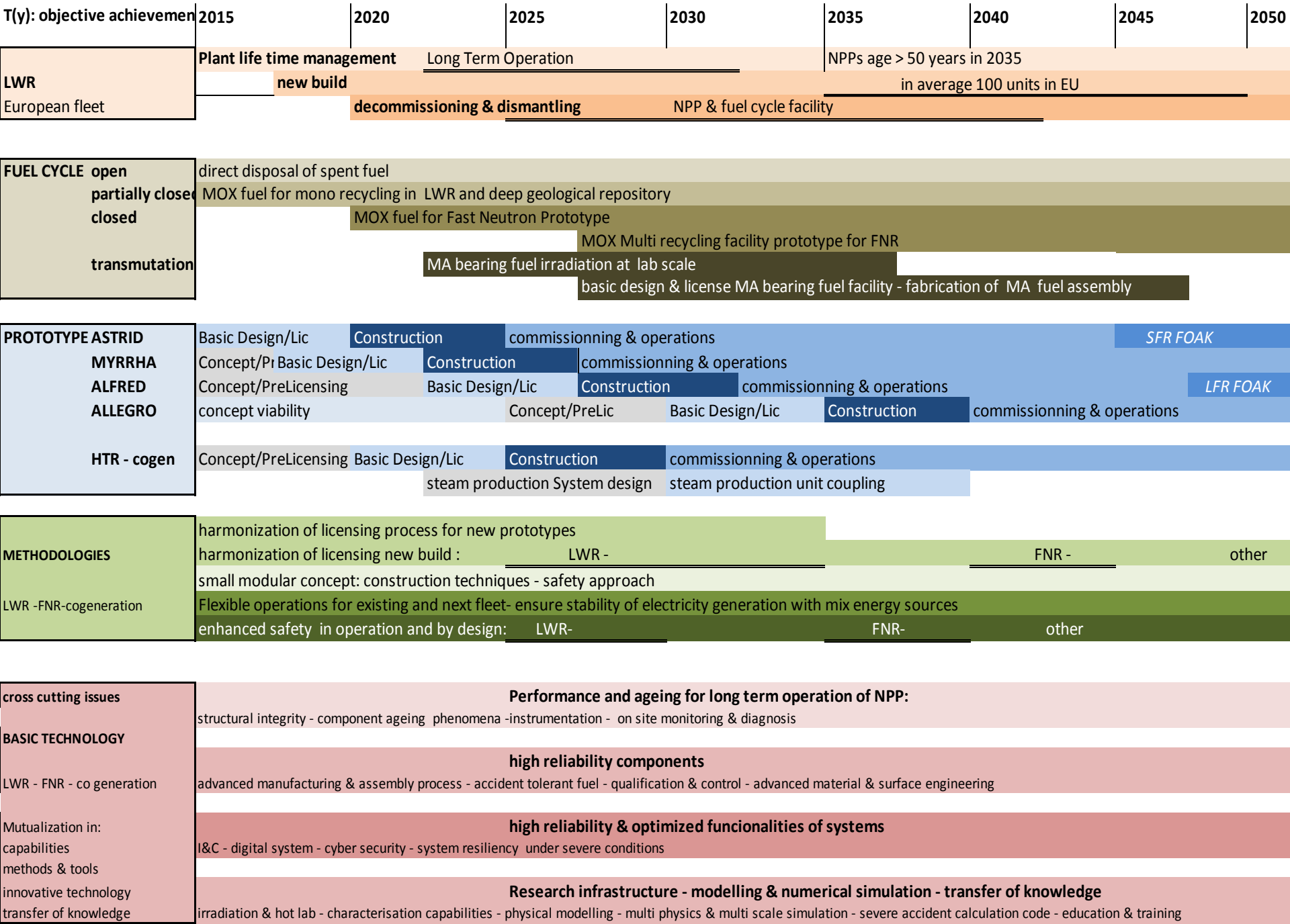
Waste management

Method

- **Enhanced safety – in operation and by design**
- **Harmonization – licensing of new prototypes**
- **Flexibility issues for accomodating energy mix requirements**
- **Small modular concept**



Integrated vision of SNETP Gen II III IV Co-generation - Best case scenario



APPENDIX

PRIORITIZATION AS ESTABLISHED

FOR EACH PILLAR OF SNETP

| High level objective | Technical objective | (TA specific) challenge | Expected major milestone (T0 + X y) |
|--|--|---|-------------------------------------|
| Improve safety in operation & by design | Minimize the impact of internal and external loads and hazards on the safety functions | Improve methodologies to assess impact on barriers, structures, systems and components considering single and multiple events, | T0 + 5 - 10y |
| | Eliminate accidental sequences that could yield in very important consequences | Developing methods to better assess the probability of rare events and their consequences | T0 + 5 - 10 y |
| | Develop advanced safety assessment methodologies | -Integrating deterministic and probabilistic safety assessments in order to better quantify safety margins with best estimate methods -Dynamic PSA | T0 + 10 y |
| | | Implementation of stress test in Europe | T0 + 5 - 10 y |
| | New systems for mitigation of consequences of severe accidents | -Identification of solution -Validation & qualification | T0 + 5 -10 y |
| High reliability & optimized functionality of systems | Operational excellence | Innovative asset management approaches, sharing of best practices | T0 + 5 - 10 y |
| | Reliability and security of digital systems | Maintaining the necessary cybersecurity level by continuous improvement | T0 + 5 - 10 y |
| | Reliability of NPPs as complex socio-technical systems | Development of system resiliency concept (interaction of safety- human organization capabilities– I&C systems) | T0 + 5- 10 y |

| High level objective | Technical objective | (TA specific) challenge | Expected major milestone (T0 + X y) |
|--|--|---|--|
| High reliability of fuel | Accident tolerant fuel | Identification of candidate materials for fuel & cladding & component | T0 +5 y |
| | | Advanced material assembly in test reactor | T0+ 10 y |
| | | Production of lead test assembly on accident tolerant fuel type | T0+ 20 y |
| High reliability of structural component | Increased resistance of materials under severe and/or more stringent conditions | <ul style="list-style-type: none"> - Advanced surface engineering technology -Advanced capabilities for in depth characterization and long life time assessment -Advanced /innovative material including with multi functions - | <p>T0 + 5 – 10 y</p> <p>T0 + 5 – 10 y</p> <p>T0 + 10 – 15y</p> |
| | Increase integrity of components | Develop improved methods for assessing integrity of systems, structures and components | T0 + 5 – 10 y |
| | Improved and advanced process for fabrication - manufacturing and assembly - mitigation solution | <ul style="list-style-type: none"> -As low as possible defect in component fabrication, especially for large component - Improve numerical simulation of manufacturing and assembly process -Master finishing operations -Qualify Powder metallurgy process for nuclear application | <p>T0 + 5 – 10 y</p> <p>T0 + 5 – 10 y</p> |
| | Equipment qualification & control | <ul style="list-style-type: none"> -Advanced NDE -Instrumented component from design & fabrication to installation -Advanced methods for on site surveillance | <p>T0 + 5-10 y</p> <p>continuous</p> |

| High level objective | Technical objective | (TA specific) challenge | Expected major milestone (T0 + X y) |
|--|--|--|---|
| Improve modelling phenomena in NPPs | Fully validated codes for severe accidents | -Improved modelling of severe accidents phenomenology and management -System code and CFD codes validation - support existing facilities and build new ones when necessary | Continuous T0 + 5 – 10y and continuous |
| | Develop predictive software platform based on multi physics and multi scale modelling | Advanced capabilities & methods in material behavior – neutron physic – fluid dynamics- chemistry -Coupling between different phenomena - Provide accurate test results for validation and qualification - | T0 + 5-10y and continuous evolution |
| Efficient integration of NPPs in the energy mix | Define NPPs role in a country-specific generation mix | Assessment of functions for stabilization of transmission grid | T0 + 5 y |
| | Identify consequences of higher flexible operations on NPP management and cost | -Impacts of dynamic loading on material ageing -Improvement of core and fuel management -Impacts on performance characteristics and development of economic strategies | T0+ 5-10 y |
| | Implementation of flexible operations on existing plants – Flexibility by design for new | Continuous plant modification : I&C – component management – fuel cycle - Implement measures allowing | T0 + 5 – 15 y |

| High level objective | Technical objective | (TA specific) challenge | Expected major milestone (T0 + X y) |
|---|---|--|---|
| Performance and ageing of NPPS for long term operation | Demonstrate structural integrity of NPPs components at regular intervals throughout life time | <ul style="list-style-type: none"> - Reliable design curves valid for environmental conditions -Plant data to underpin the safety case sin structural integrity by surveillance programs -Advanced capabilities for load evaluation: fluid to structure interaction – Pressurized thermal shock..... -Advanced capabilities and methods for accurately predicting material ageing with best estimate margin (chemistry – irradiation – thermal ageing – fatigue – crack initiation...) | T0+ 5-10 y T0+5-10y T0+ 5 – 10y |
| | Develop on line /on site monitoring & diagnostic - NDE | - Support PLIM- PLEX in implementing structural health monitoring | T0 + 5-10y |
| | | Instrumented component from design & fabrication to installation | T0 + 10 - 15y |
| | | - Crack detection beyond 60 years | T0+10 -15y |
| | | Update In core measurement - SPND | T0 + 5 - 10 y |
| Prepare the future to avoid technology obsolescence | Continuously update technology and practices Foster harmonization | <ul style="list-style-type: none"> -Ensure technology transfer and dissemination -Incorporate innovative technology -Update codes & standards through pre normative research | continuous |
| | | New information channels and use of | T0 + 5 y |

R&D program in support to prototype – demonstrator – research facility construction

| | T0 + 10 y. | T0 + 20 y. | T0 + 30 y. |
|---|--|---|--|
| ASTRID | Basic design – license and start construction | Commissioning and operations – integration of feedback experience | Basic design , license and start construction of FOAK SFR |
| MYRRHA | Basic design – license and start construction | Commissioning and integration of feedback experience from operations | |
| ALFRED | Conceptual design – start basic design and licensing | Complete basic design – construction and commissioning | Basic design , license and start construction of FOAK SFR |
| ALLEGRO | Viability of GFR concept | Conceptual- basic design and licensing | Start construction and commissioning |
| Fast reactor MOX fuel cycle facility | Basic design- license and start construction of FR MOX fabrication | Conceptual design – licensing of a reprocessing/ recycling facility | Start construction and commissioning of advanced recycling facility |
| | | | Extend capacity of FR MOX fuel fabrication for FOAK FR |
| Transmutation | Fabrication of Am bearing segment of fuel pin per year | Conceptual – basic design and licensing of a pilot plant of capacity one full Am (or MA) fuel assembly per year | Start construction and commissioning of pilot plant for Am / MA fuel fabrication |

| Technical challenge | T0 + 5 y. | T0 + 10 y. | T0 + 20 y. |
|---|--|--|--|
| Demonstration plant construction | Design of the reactor operating at 750C core outlet temperature in steam cycle. | Analysis of remaining fuel cycle issues, such as TRISO reprocessing | Waste management (with focus on graphite) |
| | | Chemical reactors supplied by nuclear heat | Hydrogen production technologies |
| | | Innovative structural materials | |
| Materials | Analysis of graphite behavior under irradiation and mechanical stress. | Design and performance tests of components for Demonstrator | |
| | Material for Structural component and Heat exchanger | Composite material for high temperature | High reliability structural component |
| | Materials for non nuclear components | | |
| Fuel | Fuel properties assessment | Development of preparation and production fuel processes | Improvement of performance and cost economic of fuel manufacturing process |
| | Modeling of particle failure and fission product release | Fuel testing focus on: manufacturing, irradiation and accident | |
| | Thermo-mechanical solving or simulation of fuel particles of HTR | | |
| Decommissioning and waste management | | Design of waste management system in demonstrator plant | |
| | Development of clean separation methods of TRISO particles from the graphite matrix at low temperature | Development of industrial recycling of the graphite separation (based on applications required for the high quality of graphite) | Adapted conditioning processes to long-lived radioactive waste from a new generation of nuclear reactors |
| | Development of non conventional purification process for core and out of core materials | Design of waste management system in cogeneration plant | |

| Technical challenge | T0 + 5 y. | T0 + 10 y. | T0 + 20 y. |
|-------------------------------------|--|--|--|
| Nuclear process steam supply system | | Detailed design of nuclear process heat supply system based on steam | |
| | | Development of superheated steam transport system | |
| Site selection, licensing issues | Development of the licensing strategy, including requirements for documentation and applications | Actions for preparing site selection and licensing | |
| Power conversion system | Development of helium turbine and gas compressor - magnetic bearing supported rotor | Development of performant heaters, recuperators and pre-coolers dedicated to closed Bryton cycle | Improvement of reliability and control of the closed-cycle gas turbine system. |
| Hydrogen production | Assessment of hydrogen production cycle | | Design and performance tests of nuclear heat supply system. Development of hydrogen storage and transport systems |