Nuclear Innovation 2050

A NEA incubator
to accelerate R&D and market deployment
of innovative nuclear fission technologies
to contribute to a sustainable energy future

MARCH 2017

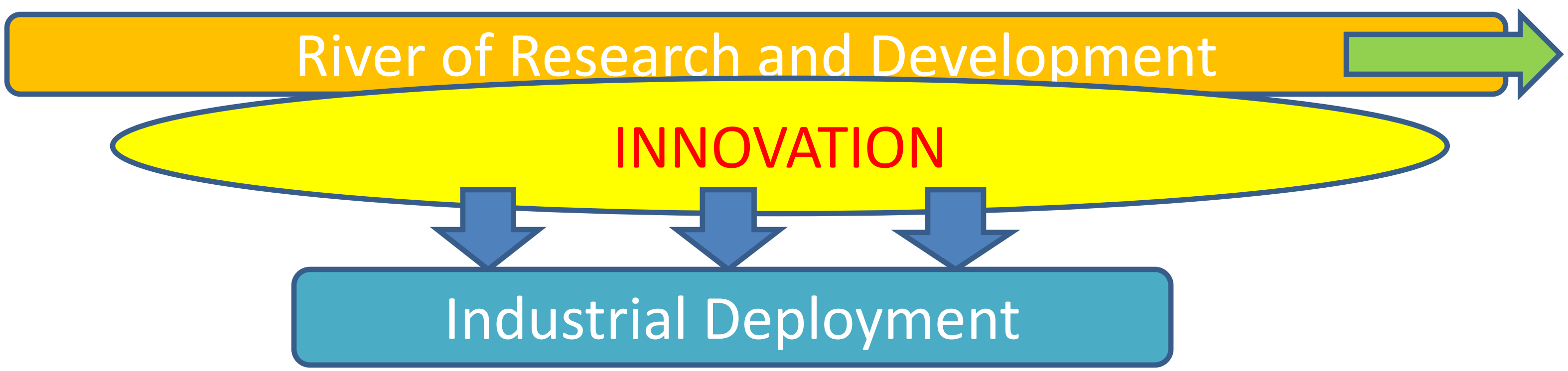
WHY NI2050 ???

Why is industry and the financial market not innovating and moving ahead with more investments in building new plants and financing the development of the next generation nuclear reactors ???

Double stake:
- **Safety** (and waste): political and regulatory environment
- **Economics**, in particular in liberalized energy markets

Need to act on these two fronts **(ambition in safety and economics)** for accelerating innovation

Innovation leading to effective industrial deployment of technologies is vital for **nuclear research and development**

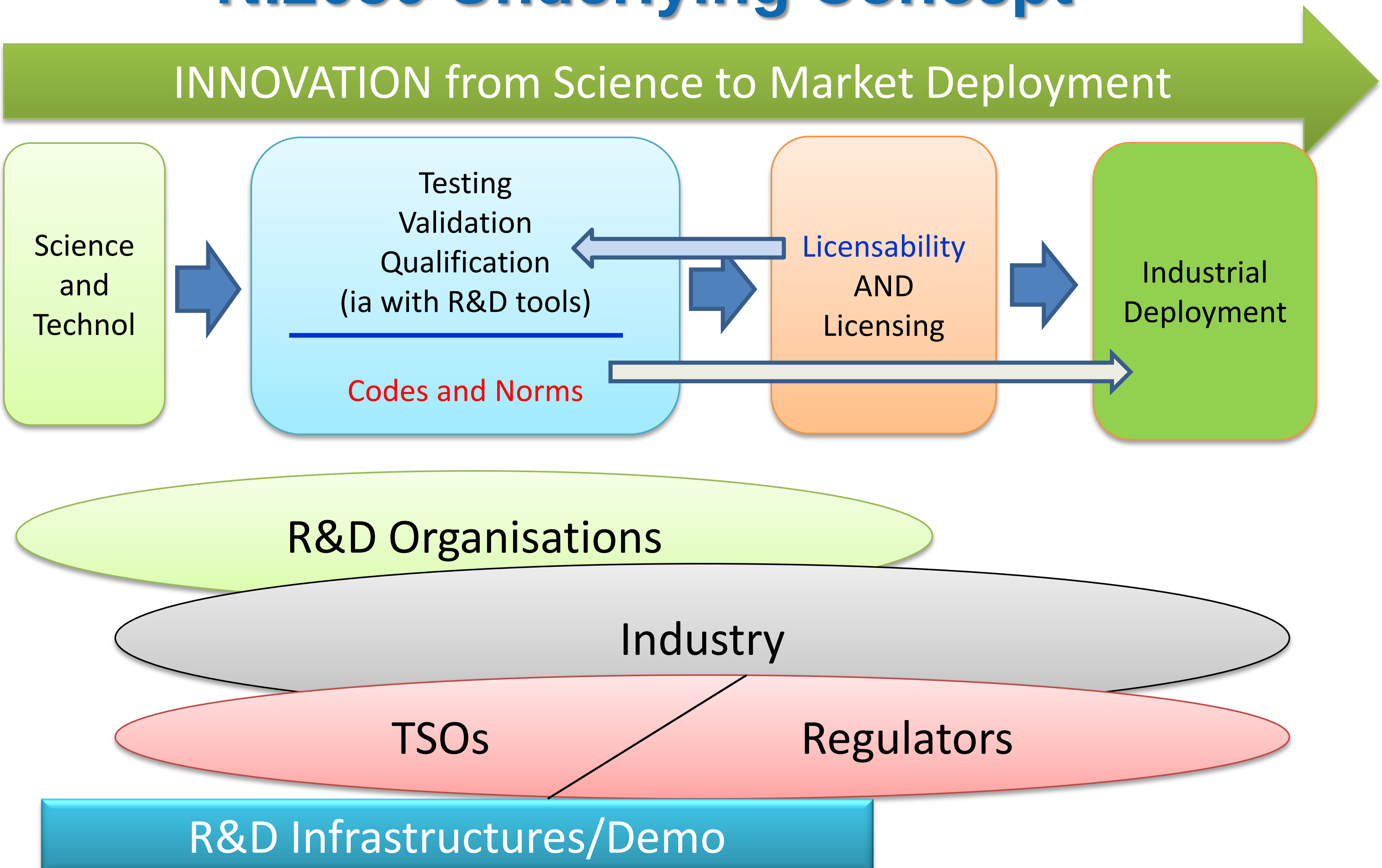


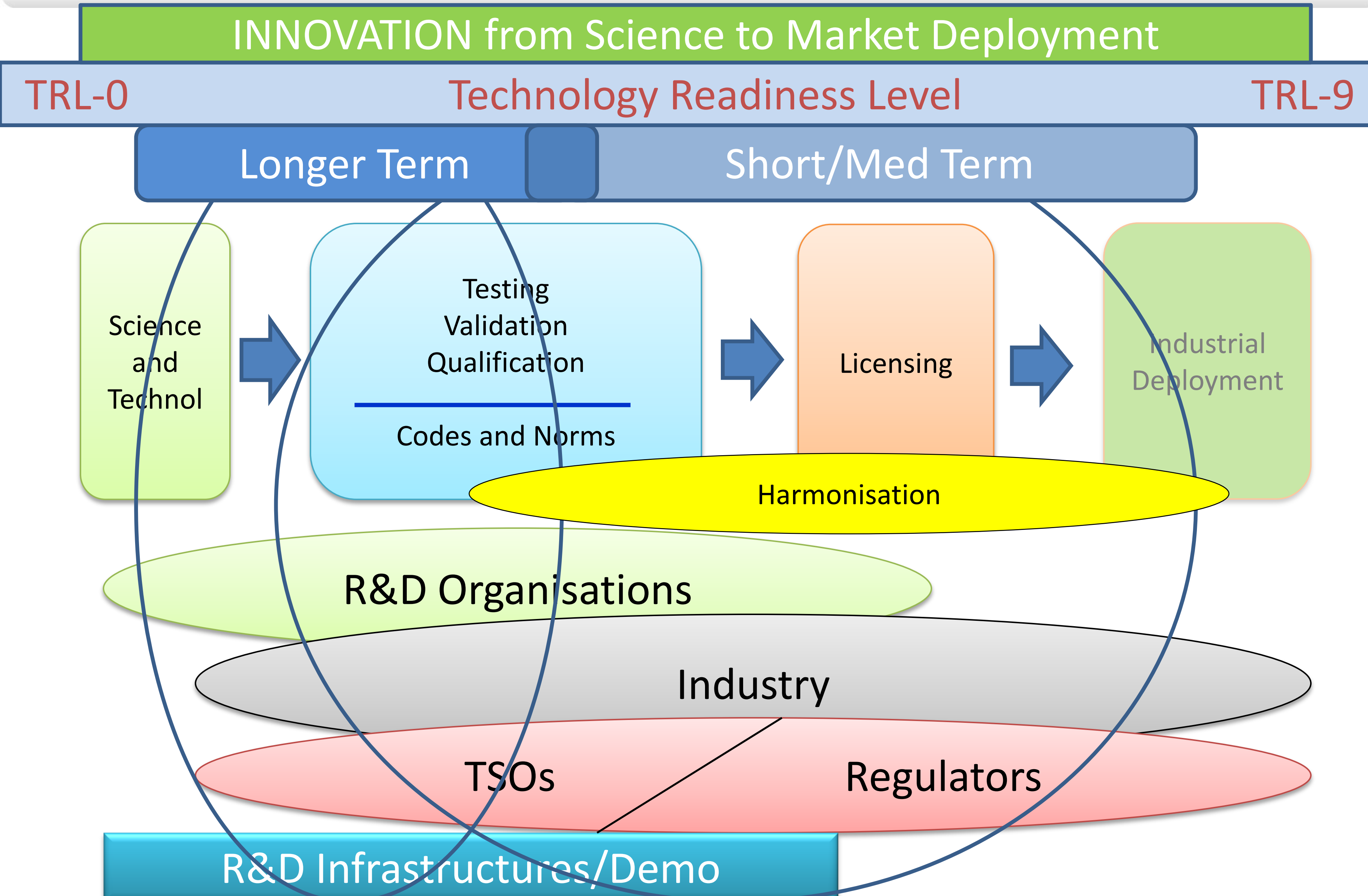
Elements of NI2050 Vision

- Break the « standard » lengthy approach to nuclear innovation
  - Not viable anymore
- Align actions with accelerated timelines (« mandate of leaders»)
  - Accelerate innovation in 5-10 years: Cut larger programmes in slices.
- Use parallel tracks for R&D timeline
  - Avoid lenghty sequential R&D/testing/qualification/licensing approach
- Work in cooperation with other member states
  - Share resources to gain time and reduce costs
  - Foster harmonisation to broaden the market base for subsequent deployment
- Use existing R&D facilities and infrastructures
  - In particular generic multipurpose ones
  - Be selective in fostering new and costly facilities (preferably multipurpose)
- Combine and optimise experimental testing and validation with modelling and simulation
  - Optimise time sequences and reduce the need for expensive specific experimental installations and integral tests

…….

NI2050 Underlying Concept




INNOVATION from Science to Market Deployment
TRL-0
Technology Readiness Level
TRL-9
Longer Term
Short/Med Term
Science and Technol
Testing
Validation
Qualification
Codes and Norms
Licensing
Industrial Deployment
Harmonisation
R&D Organisations
Industry
TSOs
Regulators
R&D Infrastructures/Demo

NI2050 Aim

NI2050 – Nuclear Innovation 2050 is a broad NEA Initiative

aiming at incubating (selecting and developing) large scale R&D and market uptake programmes of actions (projects and infrastructures)

for proposing them for further implementation by stakeholders (governments, R&D bodies, industry, TSOs and regulators, financing institutions)

to accelerate the readiness of innovative technologies and help them reach competitive deployment in time to contribute to the sustainability of nuclear energy in the short/medium (2030) to long term (2050)

Grand Challenges and Opportunities for Nuclear Energy

- **Safety and waste** management are **necessary** for nuclear energy, ia for the **public confidence**

- Nuclear **needs** to be **competitive** with other energy sources

- Win-Win approaches on **safety AND economics need** to be pursued. Innovation (= developing and deploying innovative technologies) needs a conducive **regulatory framework** (reducing barriers) **AND costs reduction.** Where possible **harmonisation** is widening the market base.

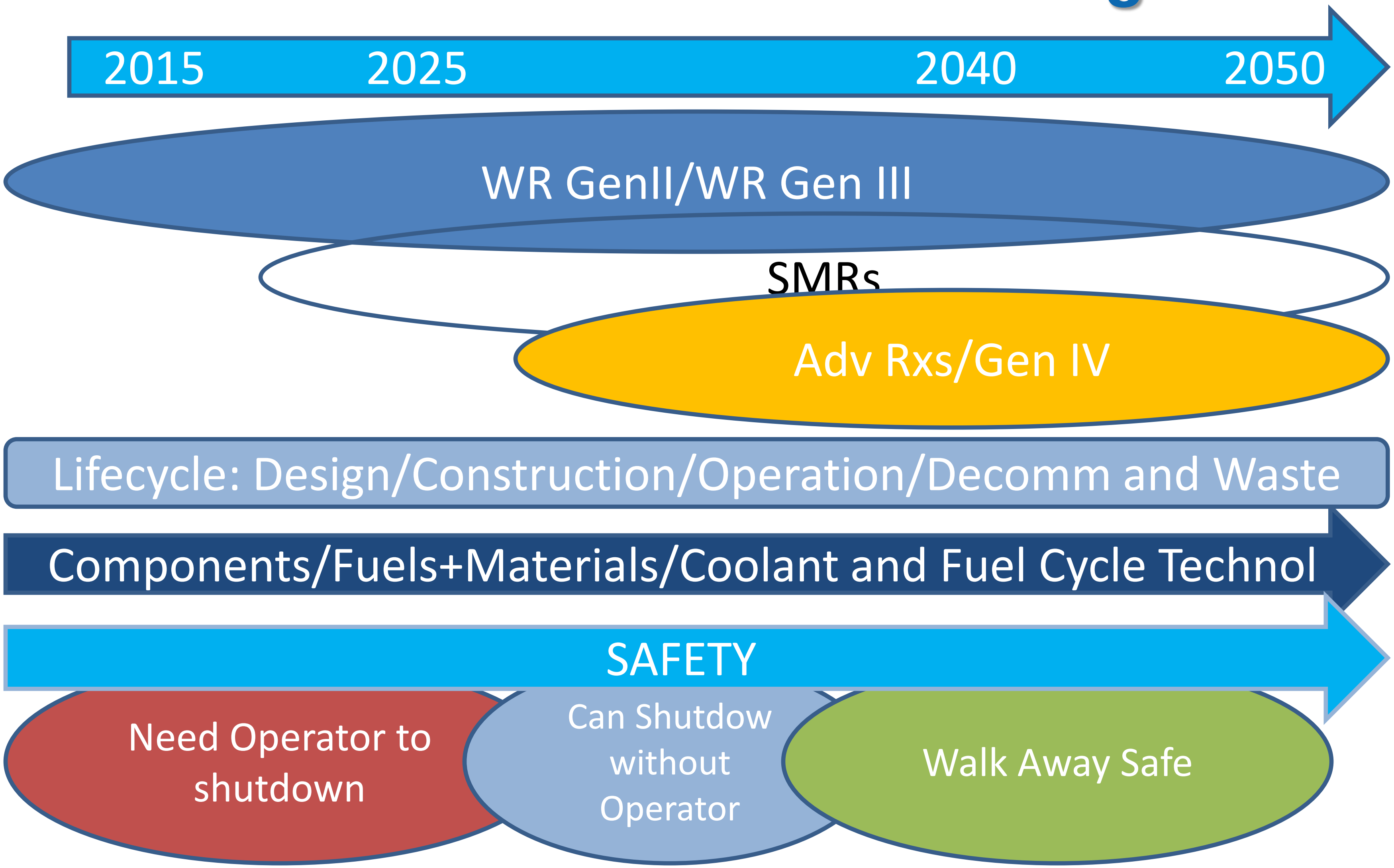
- The nuclear sector **needs** to use innovative **enabling technologies**

- Nuclear energy **needs** to be **integrated into low-carbon energy mixes**

- Nuclear power **needs** to make the **best use of resources**

- The nuclear sector **needs competent people and R&D infrastructures**

NI2050 Domain of Technologies



NI2050 as an Incubator

Challenge

- For a **Topical Area** to tackle a Challenge for the sustainable future of nuclear energy (short/medium or long term):

Enabler
Based on enabling technologies and means/tools (existing or new)

Game changer
Define the way/breakthrough to bring these technologies to the market faster and more effectively

Impact
To lead to a measurable impact

Benefit
Resulting into an identified benefit

Action Plan

- **Programme of Actions (projects and infrastructures)** necessary for the game change - for further submission to stakeholders for implementation

Output of Incub for Topic Areas: Template

- **1. The issue (Challenge/Opportunity) to tackle and objectives to reach**
  Explain what are the problems to be solved and the associated objectives to reach.

- **2. What is done/exist already, who is doing what, what are the means (resources and infrastructures), what are the bottlenecks, why does it not go faster…**
  In most cases, R&D and/or demonstration/validation/qualification programmes and infrastructures already exist and can be briefly described. The reason why more is necessary, identifying in particular difficulties, delays and bottlenecks, justifying the inclusion of the topic in NI2050, should be explained.

- **3. What can be done to improve/accelerate (ia through cooperation)**
  *Explain conceptually how to go beyond what is done under 2, what are the **enabler(s) - game changer(s)** to overcome difficulties, delays, bottlenecks, to improve and accelerate R&D and market deployment (**impact and benefit**).*

- **4. Action plan and necessary means (resources and infrastructures)**
  *Provide an Plan of Actions (scope, sequence and timeline) to implement the concepts described in 3. This should allow the extraction of **concrete large projects, with definition of necessary means and infrastructures for implementation.***

To Start: Examples of Topical Areas

Short/Med Term: focus on acceleration for industrial deployment (and licensing)

- Challenge Safety and Economics: **ATF** (Gen II and III), with **Modelling and Simulation** as an enabler
- Challenges Integration of Nuclear in the Low C Energy Mix + Safety and Economics: **Cogeneration – Heat production at 550/600°C**.
- Challenge Economics: Optimisation of Design, Construction, Operation, Maintenance and Outage, **40y LTO Programme**, Decommissioning, with **BigData/PLM** as an enabler

Longer Term: focus on acceleration of R&D with perspective of industrial deployment

- Challenges Safety and Economics + Better Use of Resources: **Advanced Fuels and Materials** (Gen IV), with **Modelling and Simulation** as an enabler
- Challenge Safety and Economics (+ Better Use of Resources): **Gen IV Reactors**
- Challenges Integration of Nuclear in the Low C Energy Mix + Safety and Economics: **Cogeneration – Heat production up to 1000°C**

Example: Accident Tolerant Fuel

Challenge

- Safety and Economics - Public Acceptance - Reduce Severe Accidents: ATF developed and licensed in less than 10 years

Enabler

Advanced modelling & testing

Game changer

Internationally shared testing and qualification processes, based on modelling extrapolation capacities, and structuring an updated licensing process

Impact

Reallocation of safety margins

Benefit

Improved safety & economy

Action Plan

- Propose a Programme of Actions (projects and infrastructures) necessary for the game change - for further submission to stakeholders for implementation

Template: Accident Tolerant Fuels for LWRs

- **1. The issue (Challenge/Opportunity) to tackle and objectives to reach**
  Challenge: *Gain safety margins by increasing the fuel resistance in case of severe accidents, providing more coping time, reducing the risk of radioactive releases. Increasing safety margins on fuel may free safety margins elsewhere, leading to a global economic gain.*
  Objective: *ATF with a increased coping time in commercial reactors in 2025.*

- **2. What is done/exist already, who is doing what, what are the means (resources and infrastructures), what are the bottlenecks, why does it not go faster…**
  NEA NSC has an Expert Group EGATFL dedicated to the subject matter. Diverse cladding materials are proposed by different participants, some with a short term deployment potential (10-15 years), others longer term (15-25 years). Activities cover basic properties analysis, out-of-pile testing, in-pile testing (from normal conditions low and high burnup to transient conditions), up to lead test assemblies in commercial reactor. As of today the state of play is as follows:… (to be filled: who develops what, at which "TRL level", which main infrastructures involved…)
  The number of open options and the sequential approach to experimental testing and validation, and further qualification and licensing, explains the length of time before deployment in commercial reactors.

- **3. What can be done to improve/accelerate (ia through cooperation)**
  The process of testing and validation, towards qualification and licensing needs to be accelerated. For this, most promising cladding materials should be selected and testing, validation and qualification programs fastened – by determining and acting on the critical paths. The potential of Modelling and Simulation to accelerate validation and qualification is to be evaluated and integrated if effective. TSOs and Safety Authorities need to be involved in the process from the early start. Where applicable international benchmarks should be used – broadening the potential for international qualification and licensing of ATF. For this the following infrastructures are necessary … (to be filled - to be compared with the list of available infrastructures to determine the adequacy and need for new facilities).

- **4. Action plan and necessary means (resources and infrastructures)**
  (Provide an Plan of Actions (scope, sequence and timeline) to implement the concepts described in 3. This should allow the extraction of concrete projects, with definition of necessary means and infrastructures for implementation.)

Example: Cogeneration

Challenges

- Coupling of nuclear reactors with industrial processes for direct nuclear heat supply. Lowering costs and projects risks for investors
- Precompetitive cooperation and generic licensing to streamline further national licensing processes

Enabler

- Sharing data and experience on HTRs

- International cooperation for demonstration

Game changer

- Demonstration of the coupling and

- Optimisation of the licensing

- Going higher in temperature

Impact

Improving the expected business case to help penetration in the worldwide market

Benefit

Deployment of cogeneration matching safety and market expectation for GHG reduction

Template: Cogeneration/Heat Production

- **1. The issue (Challenge/Opportunity) to tackle and objectives to reach**
  Challenge: *Nuclear energy is nearly solely used for electricity production. Only some limited low temperature applications for district heating and desalination are presently pursued. There is an enormous potential to also contribute to the direct production of higher temperature heat for industrial processes.*
  Objective: *For 2030, demonstration of 550°C nuclear generated heat supply to an industrial process . For 2045, demonstration of 1000°C nuclear generated heat supply to an industrial process.*

- **2. What is done/exist already, who is doing what, what are the means (resources and infrastructures), what are the bottlenecks, why does it not go faster…**
  A number of high temperature reactor concepts have been built and operated in the past, ia HTGRs, MSRs and fast reactors. But always for the production of electricity. It is also the case for the Chinese HTR-PM under construction. In recent years the US have developed and qualified high quality TRISO fuel for HTGRs and built pilot fuel fabrication plant, and MoX fuel technology for fast reactors is available. In Japan JAEA, HTTR has operated at 900 °C for 50 days. The facility is shutdown and restart/relicense is under post-Fukushima investigation.
  What has never been demonstrated till now is the coupling between an HTR and an industrial direct heat user process, which needs to be tested and licensed in the short term, to lead to commercial deployment of cogeneration for 2030.
  For the longer term, the availability of adequate fuels, materials and specific components, able to resist high temperature and dpa conditions is a central issue to solve. Also to be further studied and tested is the issue of transport of very high temperature heat between the reactor and distant user facility.

- **3. What can be done to improve/accelerate (ia through cooperation)**
  For the short term, first demonstrate and license the coupling. Then build one or a few FOAK installations serving as collaborative demonstrators for potential large commercial deployment .
  For the longer term the central issue is to accelerate the development, testing, qualification of fuels and materials which can resist to extreme temperature and high burnups/dpa conditions. As well as develop means to efficiently transport high temperature heat.

- **4. Action plan and necessary means (resources and infrastructures)**
  2015-2025: *Licensing, testing, and demonstration of HTTR coupling with a high temperature H2 IS production facility at JAEA site – to support the establishment of collaborative FOAK demonstration projects of cogeneration – commissioning in 2030.*
  Longer term: advanced fuels, materials, components and heat transport systems development, testing, qualification.

Next STEPS

- **Process of Selection of Topical Areas – which Criteria to use**
- **Topical Areas – List to be discussed**
- **Agreement on first Topical Areas to trial the NI 2050 Incubator on**
- **Tasking for the Templates**
- **Organisation of Review**

Process of Selection of Topical Areas: Using Existing Information

Starting from Existing Roadmaps, NI2050 Survey and Expert Meetings

- NEA/IEA Nuclear Technology Roadmap
- NI2050 Experts Meetings (Templates) and Adv Panel Identified Challenges
- NEA Working Groups…
- GIF Roadmap and ESNII
- SNETP and IGDTP Strategic Agenda
- NUGENIA Action Plan
- NC2I/NGNP/GEMINI Roadmaps
- National Roadmaps and Action Plans (presentations during Adv Panel meetings)

Discussed Elements for developing Criteria for Selection (of Priorities) – no order just list

- Improves Safety AND Economics
- Effectiveness to accelerate innovation by reducing timeline to results
- Effectiveness to accelerate innovation by fostering investment
- Area as a necessary element in a chain – complementarity; critical path…
- Necessary R&D infrastructure – replacement of ageing infrastructure, multipurpose,…
- Potential for cooperation – identification of lead/host country
- Area of cross-cutting nature
- Area of precompetitive nature…

Process of Selection of Topical Areas: The Criteria

Criteria for Selection (of Priorities): « The proposed Topical Area… »

- **Matches a Top Level Goal:**
  - adds value for a positive impact on Safety, Sustainability, Public Acceptance AND Economics
  - helps sustainability of infrastructures, know-how, skills and competences needed for realising nuclear projects
  - has the potential to attract investment

- **Serves an Enabling Goal:**
  - reduces the risks of the innovation process by solving challenges through pre-competitive international cooperation
  - reduces the time to results

- **Increases Effectiveness**
  - is a breakthrough
  - fills a gap or is necessary element in a chain
  - is cross-cutting (ia nuclear related instrumentation)
  - has the maturity to raise interest of users and regulators

- **Is a necessary Tool**
  - is a necessary R&D infrastructure (hardware and/or software)

Topical Areas/Enablers

Safety

- Accident Tolerant Fuels
- Severe Accident Knowledge and Management
- Passive Safety Systems
- …

Rx Design/Construction/Operation + Fuel Cycle

- LTO Gen II 80 Years: Ageing Mechanisms and Monitoring
- Fuel Economics and Maintenance/Outage/Overhaul Optimisation
- Design/Manufacturing/Construction of SSC (Civil Works, Mech, I&C,…)
- Advanced Fuels and Materials (vs Coolant)
- Advanced Components (vs Coolant)
- Fuel Cycle Chemistry/Recycling
- …

Decommissioning and Waste

- Decommissioning
- Waste Management Geological Disposal
- …

Topical Innovative Areas/Enablers

Integration in the Energy System

- Heat Production and Cogeneration 550 deg C

- Heat Production and Cogeneration 1000 deg C

- Hybrid Systems

-…

Enablers

- Modelling and Simulation (ia ATF, Fuels and Materials, Rx Design,…)

- Big Data Collection and Management - PLM (ia Maintenance/Outage Optimisation)

- I&C; Measurement Techniques (ia in support of R&D Programmes – testing, validation)

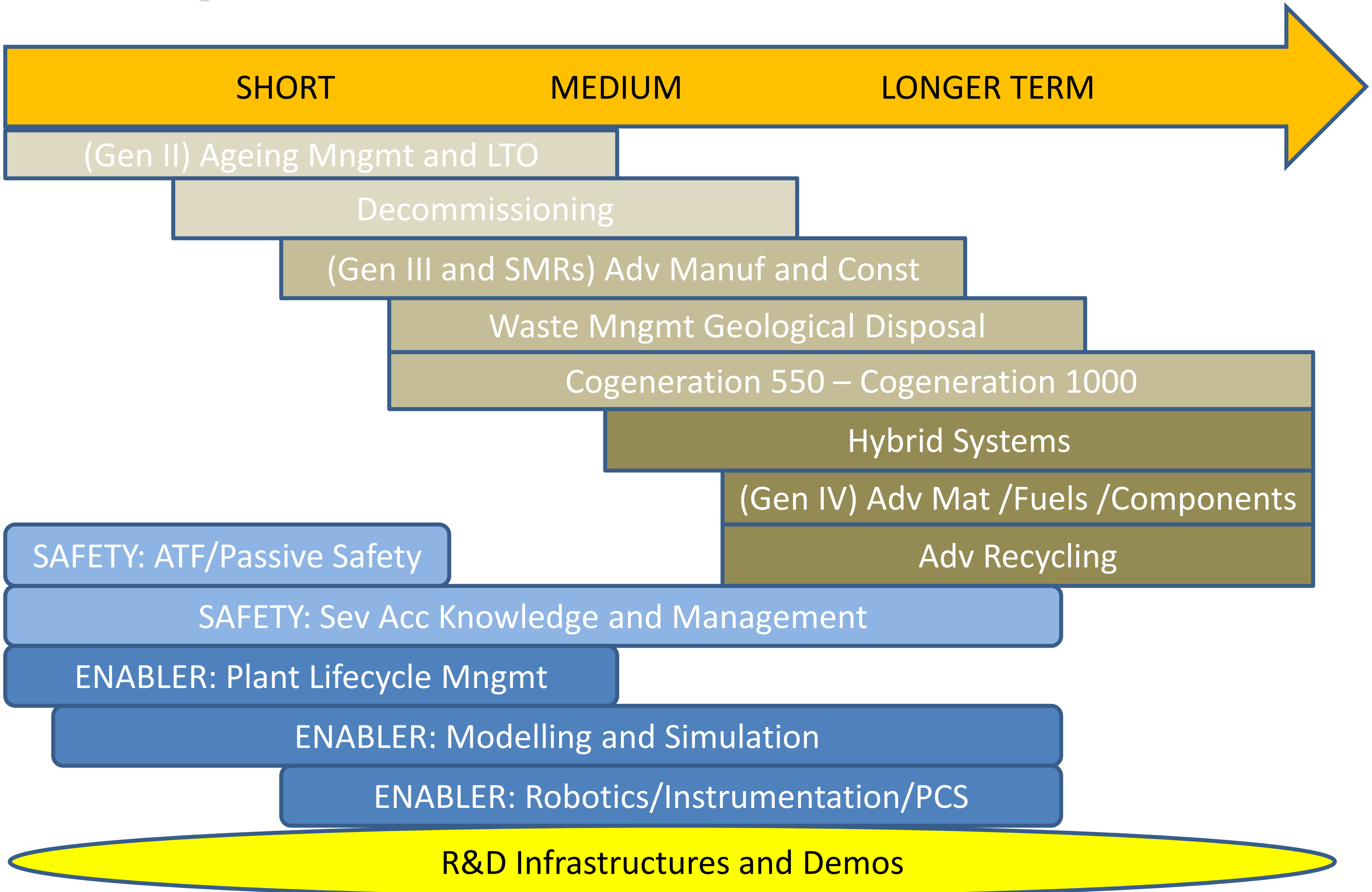
- Robotics (ia Maintenance, Waste, Decomm,…)

- Power Conversion Systems

- Main R&D Infrastructures and Demonstrators – existing and new (list to be established) (ia multipurpose research reactors and associated – all with question marks: Halden, JOYO, JHR, MBIR, TREAT, MYRRHA, HTTR, HTR PM, BN600,…; fuel cycle and PIE facilities…; loops and test benches for materials and SSCs,…; real decomm case and real GD case,…)…

-…

Topical Areas/Enablers and Timeline



Tasking for Templates

Safety

- **Accident Tolerant Fuels – K Pasamehmetoglu, NSC ATF SM,…**
- **Severe Accident Knowledge and Management – G Bruna ETSON, CSNI SAREF KF,…**
- **Passive Safety Systems – ??? G Bruna ETSON,…**
- **…**

Rx Design/Construction/Operation + Fuel Cycle

- **LTO Gen II 80 Years: Ageing Mechanisms and Monitoring – G Bruna ETSON, NUGENIA MD,…**
- **Fuel Economics and *Maintenance/Outage/Overhaul Optimisation* – PLM: Utilities MD,…**
- **Design/Manufacturing/Construction of SSC (*Civil Works*, Mech, I&C,…) – DI**
- **Advanced Fuels and Materials (vs Coolant) – N Chauvin, NSC WPFC SC, L Malerba, JPNM, GIF**
- **Advanced Components (vs Coolant) - ??? H Kamide for Gen IV, GIF**
- **Fuel Cycle Chemistry/Recycling – NSC WPFC SC**
- **…**

Decommissioning and Waste

- **Decommissioning – M Pieraccini, RWMC MG, ??? KIT**
- **Waste Management Geological Disposal – P Lalieux, RWMC MG, IGDTP, ??? SKB/Posiva**
- **…**

Tasking for Templates

Integration in the Energy System

- Heat Production and Cogeneration 550 deg C – D Hittner, NC2I/NGNP/HTTR, MD KF

- Heat Production and Cogeneration 1000 deg C – idem

- Hybrid Systems – INL, Kemal MD

- Power Conversion Systems - ???

-…

Enablers

- Modelling and Simulation (ia ATF, Fuels and Materials, Rx Design,…) **– T Valentine NSC TI**

- Big Data Collection and Management - PLM (ia Maintenance/Outage Optimisation)

- Measurement Techniques and I&C (ia in support of R&D Programmes – testing, validation)

- Robotics (ia Maintenance, Waste, Decomm,…)

- Main R&D Infrastructures and Demonstrators – existing and new (list to be established) (ia multipurpose research reactors and associated – all with question marks: Halden, JOYO, JHR, MBIR, TREAT, MYRRHA, HTTR, HTR PM, BN600,…; loops and test benches for materials and SSCs,…; fuel cycle and PIE facilities…; real decomm case and real GD case,…)…

NSC TI and MD

-…