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# GENERAL REPORT ON THE TECHNICAL SESSIONS


International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios

Frank Carré – CEA/Nuclear Energy Division

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# FAST REACTORS AND RELATED FUEL CYCLE
# FR13 – Safe technologies and Sustainable Scenarios

## FR-13, Paris – March 4-7, 2013
## *(IAEA, CEA et al.)*


- Updates since FR09, current programs and future prospects
- > 600 participants, 34 countries, 378 papers & 187 posters
- Safe Technologies & Sustainable Scenarios
  - Sodium-FR + Lead-FR & Gas-FR
  - T1&2 - Advanced reactor designs & Technologies
  - T3 - Enhanced safety & Improved mgt of severe accidents
  - T4&5 - Advanced materials for Fuels, Structures & Components
  - T6- Reprocessing & Recycling (Hydro-, Pyro-) & Minor Actinide Management (Np, Am, MA…)
  - T7 – Data, Experiments & simulation *(safety, materials, fuels, reprocessing…)*
  - T8 – Deployment, scenarios & economics
  - T9 – Operation and decommisioning
  - T10 - Professional development & Knowledge management

→ *Panel-1: Safety Design Criteria*
→ *Panel-2: Sustainability and Advanced Nuclear Fuel Cycle*
→ *Young Generation Event*

# General Remarks

- Research & Projects on Fast Neutron Reactors & related Fuel Cycles remain at sustained level worldwide
- Active participation in Technical Oral & Poster Sessions & Sustained exchanges
- Emphasis on Safety in the aftermath of Fukushima accident
  → Gen-IV initiative on *"Common design/safety criteria"* in relation with the IAEA
- Diversity & Complementarity of National Projects of near term large power Fast Reactors & Technology Demonstrators of Next Generation Fast Reactors
  - Ambitious SFR deployment scenarios of Russia, India, China…
  - Near term Demonstrators of LFR technology in Russia
  - Active research, promising innovations and plans for demonstrations in all major nuclear countries on SFRs but also LFR, GFR, MSFR…
- Continuing improvements & Search for breakthroughs: two approaches with their own rationale & timeline that may complement each other in a global international roadmap. Key role of operating FRs for feedback & testing
- Increasing importance of numerical simulation and basic research
- Attractiveness of Gen-IV systems for Nuclear Education & Training

# NATIONAL & INTERNATIONAL FAST REACTOR PROGRAMS: (PLENARY SESSIONS)

## GIF & New Builds and New Projects of Fast Neutron Reactors

- Near term projects of SFRs:
  - India: PFBR (500 MWe) (2014, Kalpakkam) + *2 CFBR units (500 MWe)*
  - Russia: BN-800 (800 MWe) (2014, Beloyarsk-4) → *BN-1200*
    MBIR (150 MWth) (~2019)
  - China: CFR-600 (600 MWe) (2023)
- Near term projects of LFRs:
  - Russia: SVBR-100 (100 MWe) (2017)
  - Russia: BREST-300 (300 MWe) (~2020, Tomsk) → *BREST-1200*
- SFR Demonstrations & Research
  - Japan: Restart of MONJU, Safety tests & Continuing research
  - USA et al.: Continuing research on reactor, fuel & fuel cycle
- Gen-IV Systems Technology Demonstrators & Prototypes
  - France: ASTRID (~ 600 MWe SFR) (2020s) → *ESFR (1500 MWe)*
  - Europe: MYRRHA (~50-80 MWth LBE-FR) (~2020, Mol Belgium)
  - USA: SMFR (50 MWe)
  - Rep. of Korea: KALIMER (600 MWe)
  - Europe: ALFRED (~300 MWth LFR) → ELFR
  - Europe: ALLEGRO (~70 MWth GFR) (> 2025, CZ, SK, HR + PL)
  - …

# FAST REACTOR DESIGNS & TECHNOLOGIES: GOALS AND PATHS OF PROGRESS (TRACKS-1&2)

## Large Power Medium-Term Fast Reactor Projects & Technology Demonstrators of Next Generation Fast Reactors

- Main goals for improvement:
  - Safety → Safety by design
  - Sustainability, Economics, Security, Public acceptance
  - Improved performances *(availability, operability, fuel burnup, power conversion…)*

## Progress on SFR Designs

- Fuel form (oxide, nitride, metal): maybe more "performance" oriented than "safety oriented"
- Core Design
  - Common approach in France (ASTRID) & Russia (BN-1200) for a *"low void effect"* core designed to favour a natural prevention of core melt/energetic sequences
  - Specific provisions for conventional "positive void effect" core (JSFR, CFBR)
  - Passive + Diversified shutdown systems (considered in all projects)
- System design
  - (Passive decay heat removal + Air as heat sink) are considered in all projects
  - Management of severe accident + Core catcher
- Design revisited after FKS : done for JSFR/addition of gas turbine for diversification of energy source
- "Confinement", rarely detailed in the presentation – not a concern ?

# FAST REACTOR DESIGNS & TECHNOLOGIES: GOALS AND PATHS OF PROGRESS (TRACKS-1&2)

## Progress on LFR Designs *(LBE or Pb cooled)*

- Need to increase the maturity : lead/Bi in a first step, lead on the longer term
- Some demonstrators are in a strategy of “niche” (SMR for SVBR-100, ADS prototype for Myrrha, Clear)
- Unit power limited for commercial size reactor? *[BREST-300 → BREST-1200]*

## Other systems

- GFR,
  - Roadmap exists, R&D + Allegro in Central Europe
- MSFR
  - R&D first, safety approach is to be build (application of DiD, safety case..)

Diversity & Complementarity of National Programs through a wide range of reactor types and candidate technologies

Gen-IV initiative on “Common design/safety criteria underway in relation with the IAEA.

# Fast reactor Safety

- Post Fukushima lessons
  - Better integrate external hazards/events into safety analysis *(air plane crashes, earthquakes, flooding…)*
  - Revisiting safety framework *(beyond design basis accidents, residual risks, practical exclusion, cliff-edge effects…)*
  - Improve emergency preparedness *(off-site power supply and cooling capabilities)*
- FRs to match at least safety goals anticipated for contemporary Gen-III LWRs
- Gen-IV nuclear systems safety goals
- Make best use of past and present reactors' operating feedback
- Improve prevention, management and mitigation for severe accidents
  - Severe nuclear accidents
    - *Low reactivity effect of coolant void*
    - *Practical elimination of core compaction & prompt criticality*
    - *Efficient & Reliable decay heat removal*
    - *Advanced core catcher technology*
  - Large chemical accidents
    - *Sodium/Water, Sodium/Water/Air*

    → *Robust protection of sodium systems and steam generator technologies?*

    → *Gas power conversion systems: nitrogen, SC-$CO_2$…? Related R&D needs?*

# Fast reactor Safety

- Enhanced Safety/Reliability of operation
  - Enhanced/Extended principles of Defence-in-Depth principles
  - Redundant & diversified safety systems *(Active, Passive, "Natural safety"…)*
  - Extended surveillance/monitoring/safeguards
  - In Service Inspection & repair (ISIR)
  - Improved detection *(gas bubbles, sodium/water interaction, cladding failure…)*
  - Improved prevention, detection & repair of sodium leaks

  → *Innovative instrumentation + Post accidental instrumentation*

- Examples of application of extended safety approaches
  - MONJU Safety upgrade + Safety demonstrations
  - JSFR, BN-1200, ASTRID…
  - ALFRED → ELFR
  - …

- Progress toward a harmonized safety framework

  → Gen-IV Forum Initiative on SFR "Common Design/Safety Criteria"
  - Enhancing international cooperation on safety related research

→ Papers from IAEA, Europe, India, Russia, USA…

# Fast Reactor Materials: Achievements and New Challenges

- Structural materials with improved resistance *(HT, dpa, corrosion, 60y lifetime…)*
  - Advanced Austenitic Steels
  - Advanced Ferritic/Martensitic Steels
  - → Understanding ageing mechanisms *(creep, fatigue, creep-fatigue…)*
- Low swelling steels for fuel cladding
  - Advanced Austenitic Steels
  - Advanced Ferritic and Ferritic/Martensitic Steels
  - Oxide Dispersed Strengthened Steels *(ODS)*
  - $SiC_fSiC$
  - + Good internal and external corrosion resistance
  - + Compliance with reprocessing processes
- 9 Cr F/M steel for large components *(Steam Generator…)*
  - Codification research for mechanical design in progress
- Gen-IV systems specific materials issues
  - SFR: alternative coatings for the replacement of stellite
  - LFR: control of steel corrosion in lead-alloys
  - GFR: $SiC_fSiC$ as fuel cladding, 9 Cr F/M steel for the vessel, Ni-alloys for HX…

# Fast Reactor Fuels

- Flexible actinide management
  - Efficient Burning/Breeding of plutonium
  - Security *(Non-proliferation…)*
  - Managing minor actinides? *(cost/benefit…)*
- Performance oriented choice of fuel
  - MOX: France, Russia, India (PFBR), China
  - Metal: USA, China, India, Rep. of Korea
  - Carbide: India (FBTR), Nitride: Russia
  - → Increasing role of basic research and numerical simulation in R&D
  - → Better understanding of factors that determine performance and safety
- Fuel fabrication
  - MOX fuel fabrication facilities projected in France, Russia, India, China?
  - Active R&D on MOX fuel: powder metallurgy (granulation), pressing, sintering adapted to MOX FR fuels *(Pu isotopy, concentration, fuel geometry)…*
  - Active R&D on metal fuel fabrication by new casting technology
- Nuclear fuel performance & Innovation
  - High burn-up, long fuel irradiation campaign
  - Heterogeneous fertile/fissile fuels, molten fuel discharge inner duct…
  - Low swelling cladding steel *(F/M Steels, ODS…)*

# Fuel Cycle Processes

- Hydro process *(France, Russia, Japan, USA…)*
  - 30 years of experience in France:
    - FR fuel cycle, already demonstrated at low scale for oxide fuel, has to be improved with R&D programs, but will not be on a critical path for the development of industrial Fast Reactors
    - New project facility for front-end processing of FR fuels (France)
  - A detailed methodology (US) for evaluating and categorizing nuclear energy systems will be helpful in order to define the fuel cycle technology program objectives, which in turn help identifying priority R&D needs
  - New ideas of closed fuel cycle (Russia) with combination of both pyro-hydro processes, in terms of economics, environment attractiveness and safety
- Pyro process *(USA, Russia, Rep. of Korea, Japan…)*
  - Important progress in pyro-processing technology (Rep. of South Korea) with the new PRIDE facility (PyRoprocessing Integrated inactive DEmonstration facility), still in inactive conditions
- Varied Timelines for Advanced Fuel Cycle Demonstrations
  - Medium term (2020s…)
  - Long term for breakthroughs *(~mid of 21st century)*

# Partitioning and Transmutation

- Transmutation fuel
  - Minor actinide fuels are not ready yet for industrial use
  - International research is still needed to develop safe, efficient and affordable MA bearing fuel forms:
    - Basic physical & chemical properties
    - Fabrication, irradiation testing, reprocessing…
  - Good progress on fabrication of Am bearing target-blanket
- Partitioning
  - Good progress in France and Europe on partitioning processes
    - TRU, Am-Cm, or Am only
    - Development towards a possible implementation at high scale, but
    - Large efforts are still necessary in R&D
- P & T scenarios studies
  - Feasibility of MA fuel cycle:
    - Fabrication, partitioning plant, transports
    - Curium issue
  - Quantitative assessment of P&T on HLW repository, the French case by ANDRA

# Modelling & Numerical Simulation

- Advanced numerical simulation
  - Design studies *(neutronics, thermalhydraulics…)*
  - Safety/Severe accidents Analyses
  - Nuclear fuel
  - Significant international benchmarks: AIEA, NEA, GIF, bilateral collaboration
  - More intensive and standard utilisation of Monte-carlo simulation techniques
  - Priority research on decay heat removal, prevention-mitigation of severe accidents
  - → Numerical demonstration of SFR passive core cooling by natural convection
  - Availability of reactor data *(Superphenix…)* to qualify computational tools used for operating transient analyses of Gen-IV SFR designs
- Path for progress
  - Multi-physics coupling
  - High performance computing
  - Reduction of uncertainties
- Modelling extension to more basic phenomena
  - Understanding and modelling of more basic phenomena
  - Extension of numerical simulation versatility and predictability
  - Adjustment of associated experimental programs *(analytical research, validation…)*

# Fast Reactor Desirable Features & Plans for Deployment

- Economic competitiveness
  - Safe and reliable operation
  - 60 year lifetime with high availability factor
- Conditions for a successful deployment
  - Security: Non-proliferation, Safeguards, Physical protection
  - International Centers of Fuel Cycle Services
  - Country-dependent plans for TRU management
- Plans for deployment
  - 100% FNRs or Symbiotic FNR/LWR fleet?
  - China: from CEFR (25 MWe) in 2011 to CFR-600 (600 MWe) in 2023 + CFR-1000 (1000 MWe) and 240 GWe in 2050 *(out of 400 GWe NPPs)*
  - Russia: from BN-600 & BN-800 to 14 GWe by 2030 & 34 GWe by 2050 *(out of 100-140 GWe NPPs)*
  - India: from FBTR to PFBR (500 MWe) + 2 x CFBR (500 MWe) + MFBRs (1000 MWe) from carbide to oxide fuels towards with metallic fuel w. pyroprocessing + Thorium?

# Extended Feedback of Sodium Fast Reactor Operation

- Operation of SFR is an industrial reality
  - 26 years of operation experience in FBTR,
  - 30 years of operation experience in BN 600,
  - Life extension in preparation for both reactors,
  - Reprocessing and multiple-recycling demonstrations in Phenix
  - Inspection and repair under sodium (Joyo…)
  - Replacement of large components (Phenix...)
- Targets for improvements
  - Low activation and purity control of primary sodium
  - In service inspection and repair *(Ultrasonic sensors, Xtomography…)*
  - Under sodium imaging
  - Instrumentation *(surveillance, safety, safeguards + post accidental*
  - Shortened fuel handling outage *(simplication of process, reliable equipment…)*
- Significant feedback from SFR decommissioning
  - Minimization of radioactive waste and radioactive effluents
  - Minimization of doses to workers

  → *Advanced dismantling techniques*
  - Disposal of waste generated

# SKILL CAPABILITIES, PROFESSIONAL DEVELOPMENT, KNOWLEDGE MANAGEMENT (TRACK-10)

## Education & Training

- Active to support Education and Training on SFRs worlwide
  - Attractiveness of Gen-IV nuclear systems *(challenging scientific topics, projects of technology demonstrators and prototypes, international dimension…)*
  - Sharing information through experimental studies or operation feedback
  - Sharing a standardized information on safety
  - Development of dedicated simulators
  - → Supported by schools, seminars, workshops, exchanges of professors
- Knowledge preservation and management
  - Data preservation programs for FFTF in the U.S., Superphenix in France …
  - IAEA FR knowledge preservation inititiative (FR-KOS application)
  - How to attain higher levels of KM maturity in a FR R&D organisation?
- Examples of new Education & Training activities
  - The ENEN-III project: European Fission training schemes on GenIV reactors
  - Knowledge passing in France in the perspective of the next –generation SFR demonstrator ASTRID

## FR13 Conference

- **FR13 –** An effective framework to share updates on national programs of Fast Reactor developments, projects of new builds and plans for the future
- **FR13 –** A special emphasis put on *Fast Reactor Safety*, *Sustainability of nuclear fuel cycle* and *Young Generation perspective*
- FR13 – A catalyst for further collaborations and alliances

→ **FR17 Conference**

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