IAEA 60 Years
Atoms for Peace and Development

Oak Ridge National Laboratory
Molten Salt Reactor Workshop 2017—
Key Technology and Safety Issues for MSRs

Overview of the IAEA activities on Advanced Reactor Technology and those related to MSRs

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October 2017

Overview

- The IAEA at a glance
- Main activities supporting advanced reactor technology development
- … few words on safety design requirements
- Activities on Molten Salt Reactors

  and the potential future role for the agency
- Concluding remarks


IAEA is an independent intergovernmental, science and technology-based UN organization that serves as the global focal point for nuclear cooperation

Established by the United Nations as an independent organization in 1957, the IAEA serves 168 Member States.

“Atoms for Peace” speech presented by US President Eisenhower to the United Nations General Assembly in 1953

The IAEA works to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world,

….. supporting the UN sustainability development goals

… while verifying its peaceful use

The Secretariat — the international body of staff tasked with running the IAEA — is made up of a team of 2300 multidisciplinary professional and support staff from more than 100 countries.

Nuclear & SDGs

SUSTAINABLE DEVELOPMENT GOALS

IAEA Departments

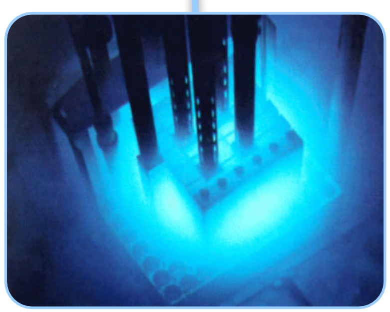
Member States Needs

Management

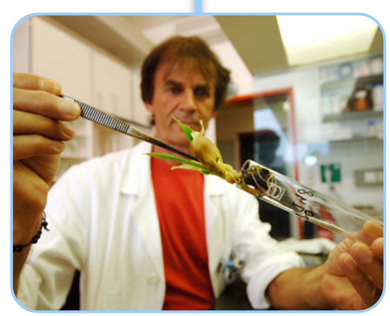
Technical Cooperation

Leading Technical Departments

Safeguards



Nuclear Safety
& Security



Nuclear Science
& Applications

Nuclear Energy

Nuclear Energy

Nuclear power, fuel cycle and waste management

The Department fosters the efficient and safe use of nuclear power by *supporting* existing and new nuclear programmes around the world, *catalysing* innovation and *building* indigenous capability in energy planning, analysis, and nuclear information and knowledge.

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Main activities supporting advanced reactor technology development

… also support new-comer member states with the focus on near-term deployment options

Advanced Reactors Technology Development

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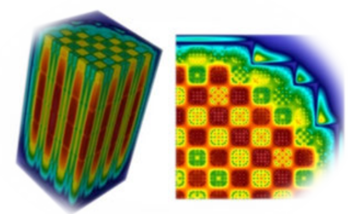
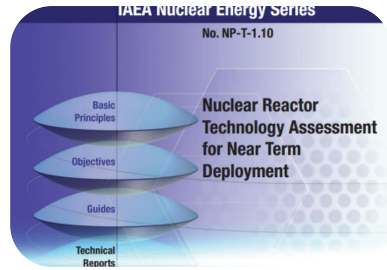
PUBLICATIONS | **TOOLS** | **MEETINGS** | **CRPs** | **TC**

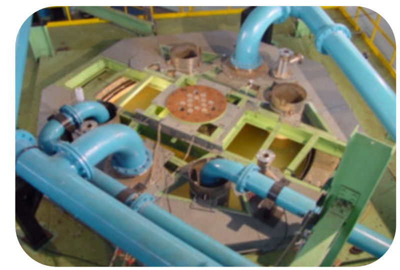
Information Exchange



Modelling and Simulations

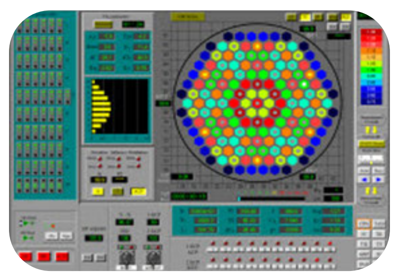


Development of Methodologies



Safety

Technology Support

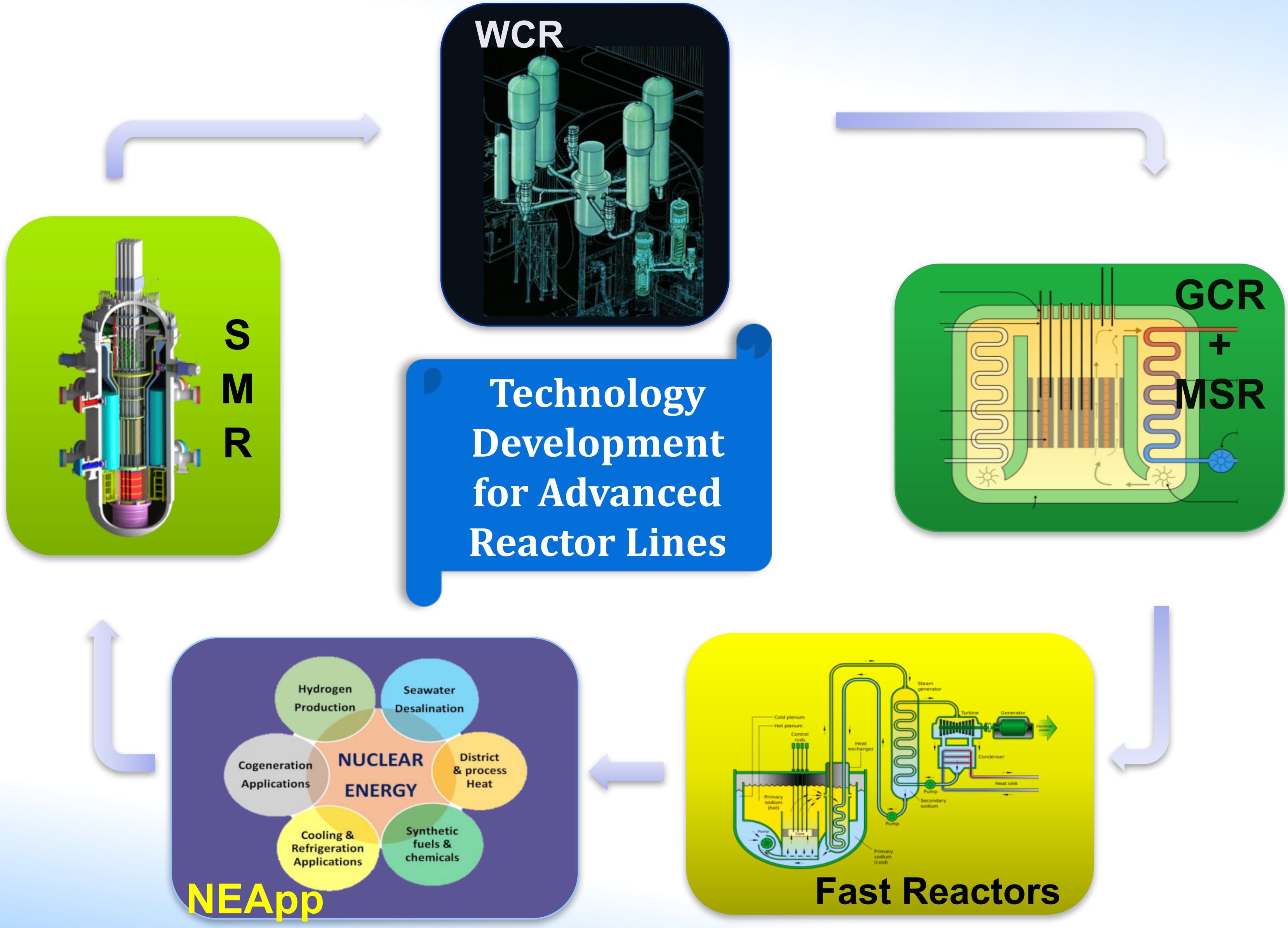


Education and Training

Knowledge Preservation

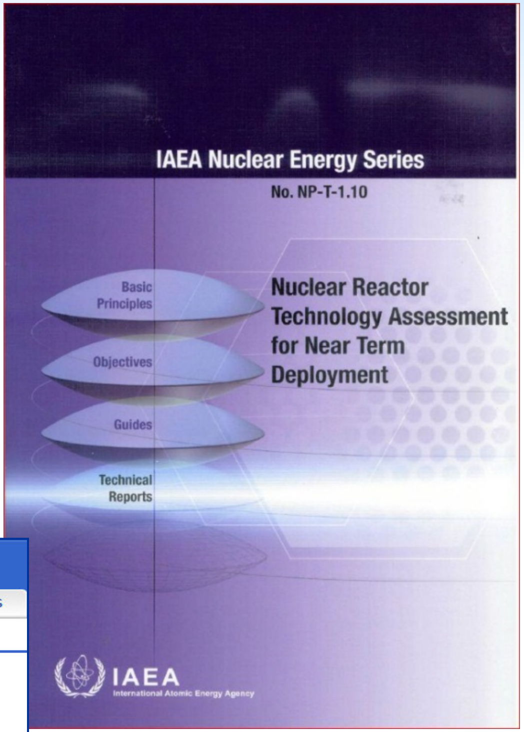
Assist MSs with national nuclear programmes; Support innovations in nuclear power deployment; Facilitate and assist international R&D collaborations

Nuclear Power Technology Development

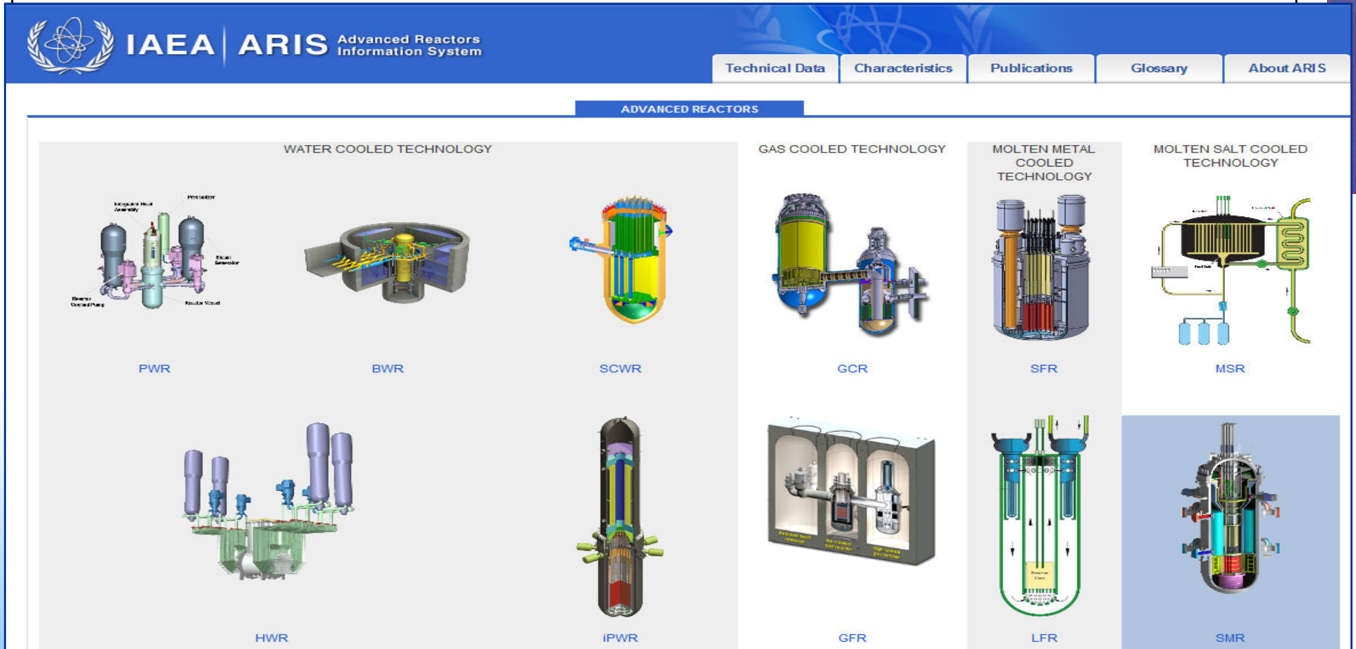


IAEA Technology Assessment

- Nuclear Reactor Technology Assessment for Near Term Deployment
  IAEA NE-Series Document # NP-T-1.10



- Formalized process
- Owner exercise
- ARIS database provides technical Design Descriptions of advanced NPPs



Advanced
Reactors
Information
System

HTGR focus areas : Support to MS

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CRPs

- HTGR Reactor Physics, Thermal-Hydraulics and Depletion Uncertainty Analysis
- Modular High Temperature Gas Cooled Reactor Safety Design
- HTGR Application for Sustainable Extraction and Mineral Product development Processes – with NEFW-NFCM

Example of Planned Publications

- TECDOC: Improving the Understanding of Irradiation-Creep Behaviour in Nuclear Graphite Part 1: Models and Mechanisms
- TECDOC: Graphite Oxidation in Modular HTGR
- TECDOC: Performance of German mixed Th-U and UO TRISO Fuels

Technology Development for HTGRs

Information Exchange:
- TWG-GCR
- Nuclear Graphite Knowledge Base
- Technology Needs for Increased Operating and Accident Temperatures

Further development of HTGR training and educational simulator specification
- Training workshop
- Draft specification (unfunded)

TC support:
- Indonesia experimental power reactor (BATAN and BABETEN)
- KA CARE (Saudi Arabia) on HTGR Technology

Portals / DB:
Support to ARIS, HTGR knowledgebase and Nuclear Graphite Knowledge Base

CRP: HTRs applications for energy neutral sustainable comprehensive extraction and mineral products development

CRPs

Overall Objective:

Study the use of process heat for mineral extraction (with U recovery)

Specific Objectives:

- Advocate total extraction of minerals (also from low grade ores) with thermal process
- Recover U/Th by-products to fuel the HTR
- Ensure clearer products and reduced NORM in waste streams
- Ex. Phosphate rock, REE, Tin slag, Copper etc.

- 16 member states
- 2014- 2018
- with NEFW division

Increased sustainability of ores and extraction processes while cleaning products and waste

Safety design requirements

… a different safety approach warrants different safety requirements

Why the need to be different

- Advanced reactors often claim to have enhanced safety characteristics compared to the current fleet of nuclear power plants
- …and therefore also claim that a simplified safety evaluation and licensing process should be applied.

- High temperature gas cooled reactors are one of these that indeed possess many salient and inherent safety characteristics
- Supporters of the technology have for a long time been advocates that a different licensing approach and therefore also a different set of safety requirements should be developed and applied.

Modular HTGR safety

"No fuel failure for loss of coolant flow and coolant accidents, or for all foreseeable reactivity events, even with no corrective actions"

Syd Ball (ORNL)

How is the safety approach different…

- HTGRs have favorable inherent safety characteristics:
  - High quality ceramic coated particle fuel
  - Single phase helium as coolant
  - Strong negative reactivity coefficients
  - Slow transients due to large mass of graphite in the core
- modular HTGR designs that are based on design principles that ensure:
  - no significant radionuclide release are conceivable even if all coolant are lost / no active forced convection systems.
  - The residual heat removal is ensured solely through physical processes (thermal conduction, radiation, convection).
- To achieve this we typically need a design with:
  - Low power density
  - Long slender core and/or annular design
  - Reactor Cavity Cooling System external from the reactor to remove the decay heat

No early or large FP release

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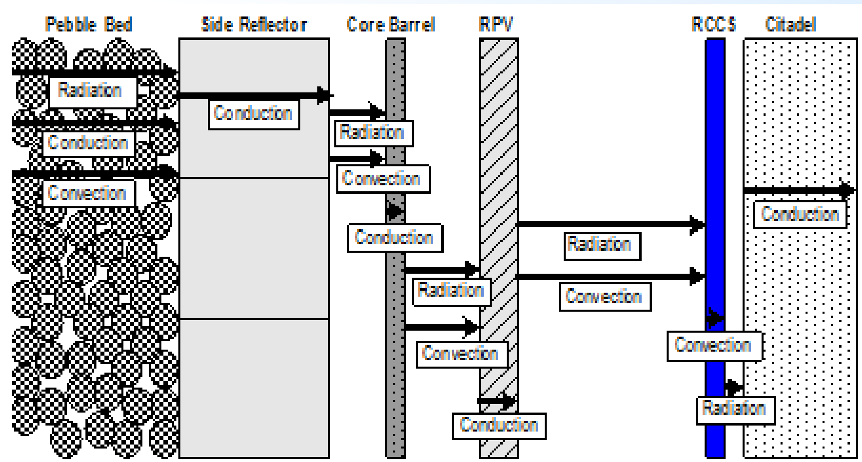
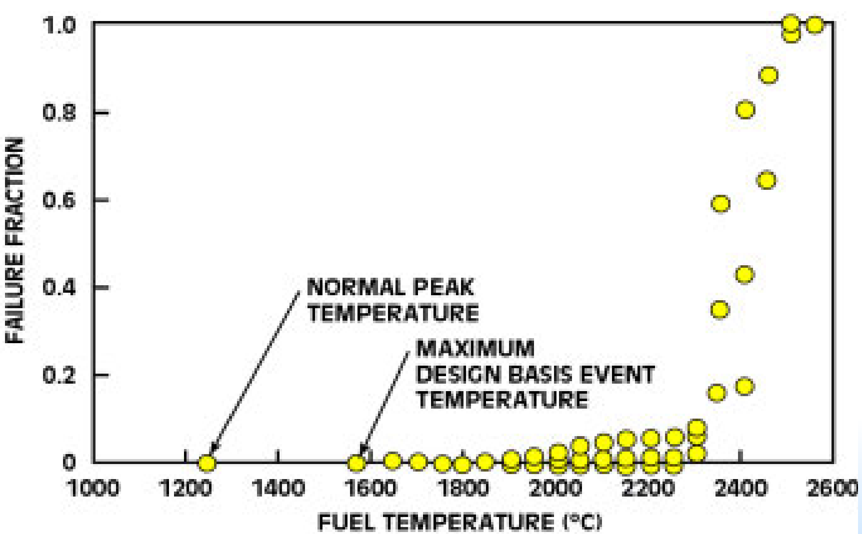
Ceramic fuel retains radioactive materials up to and above 1800˚C

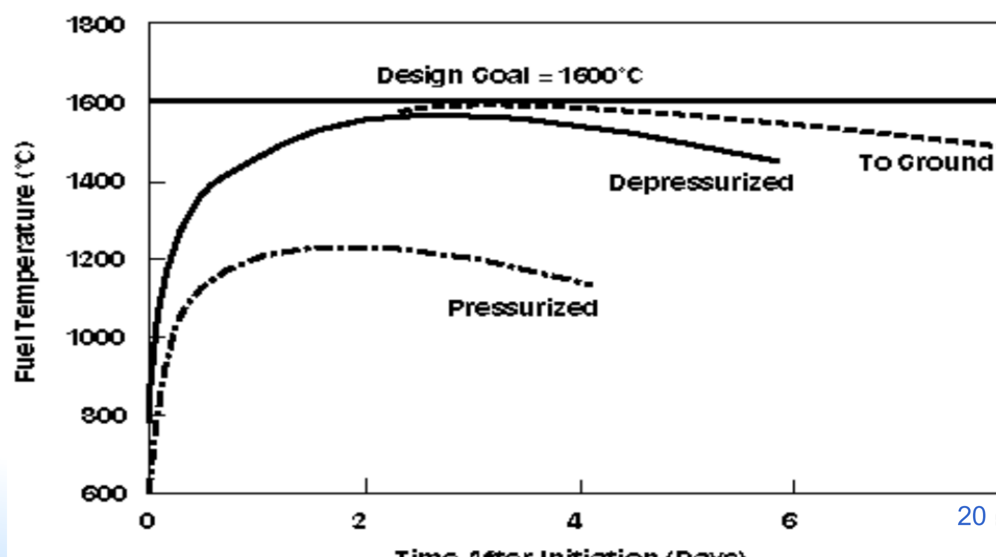
Heat removed passively without primary coolant – all natural means



Coated particles stable to beyond maximum accident temperatures



Fuel temperatures remain below design limits during loss-of-cooling events



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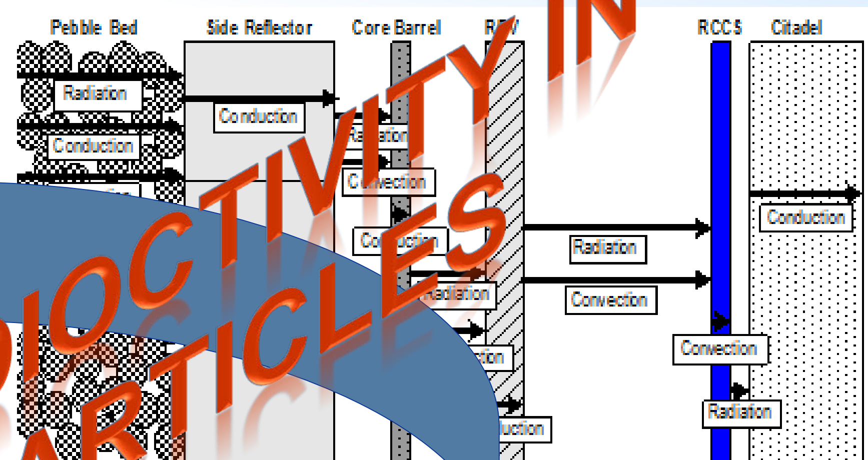
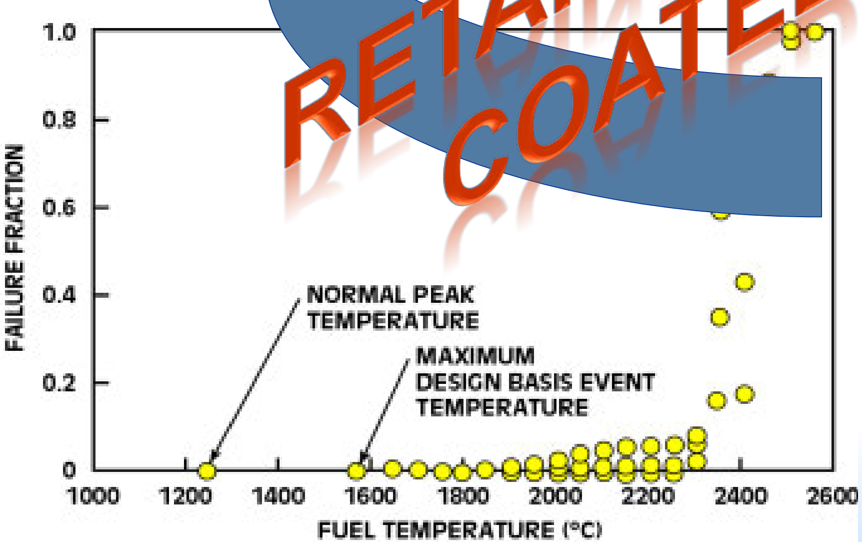


RETAINS RADIOCTIVITY IN COATED PARTICLES

Coated particles stable to beyond maximum accident temperatures



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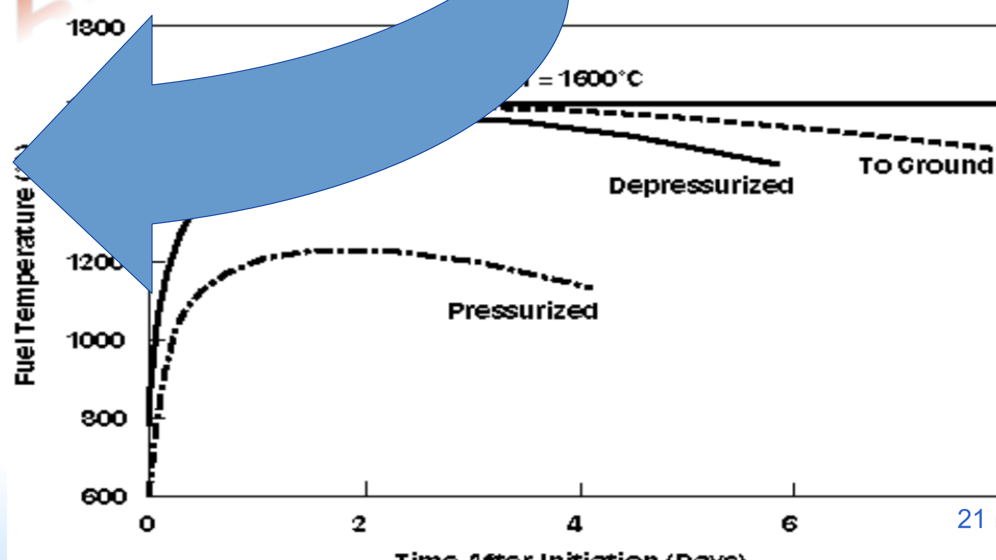

CRP: Modular High Temperature Gas-cooled Reactor Safety Design

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CRPs

Overall Objective:

Propose safety design criteria based on the unique safety features of HTGRs

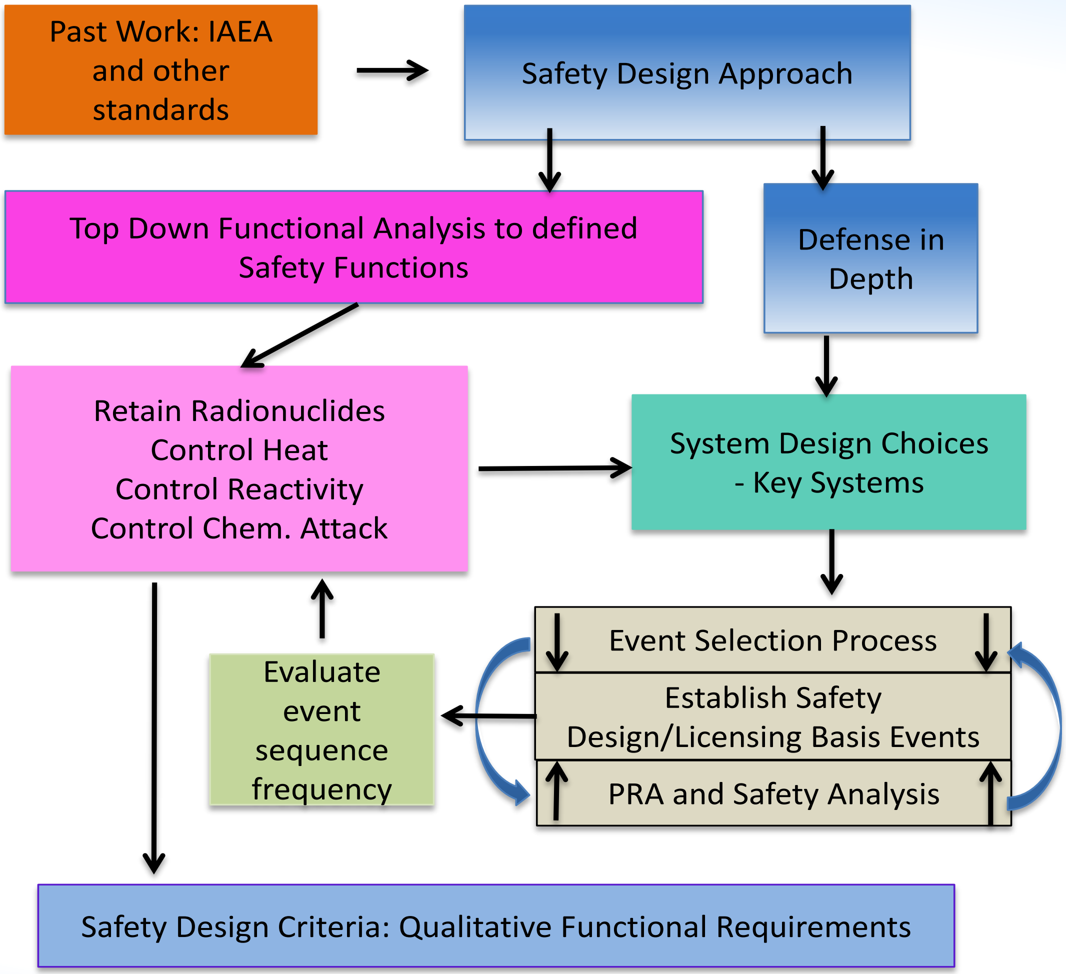
Specific Objectives:

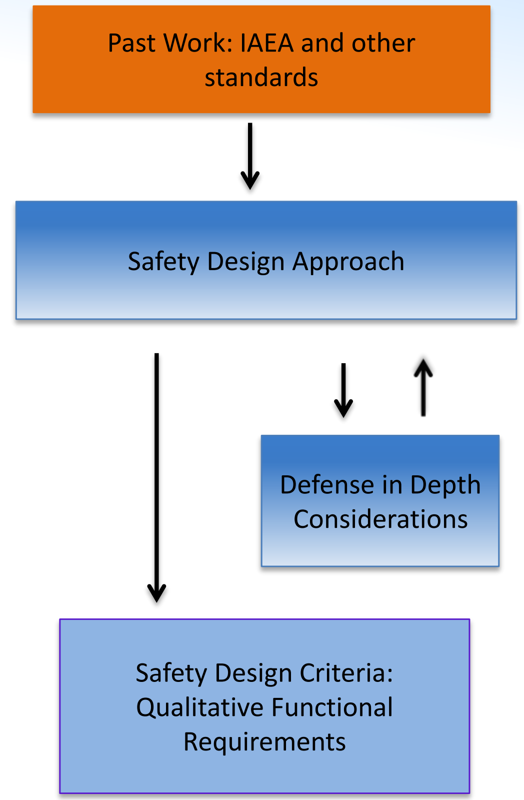
- Harmonize designers approach to modular HTGR safety design
- Clarify LWR specific concepts such as design extension conditions (with core melting)
- Include multiple reactor modules and co-generation considerations

Safety analysis and Licensing is often singled out as one of the main challenges to the deployment of new advanced reactors.

- 10 member states
- 2013- 2017

Two-Approaches:



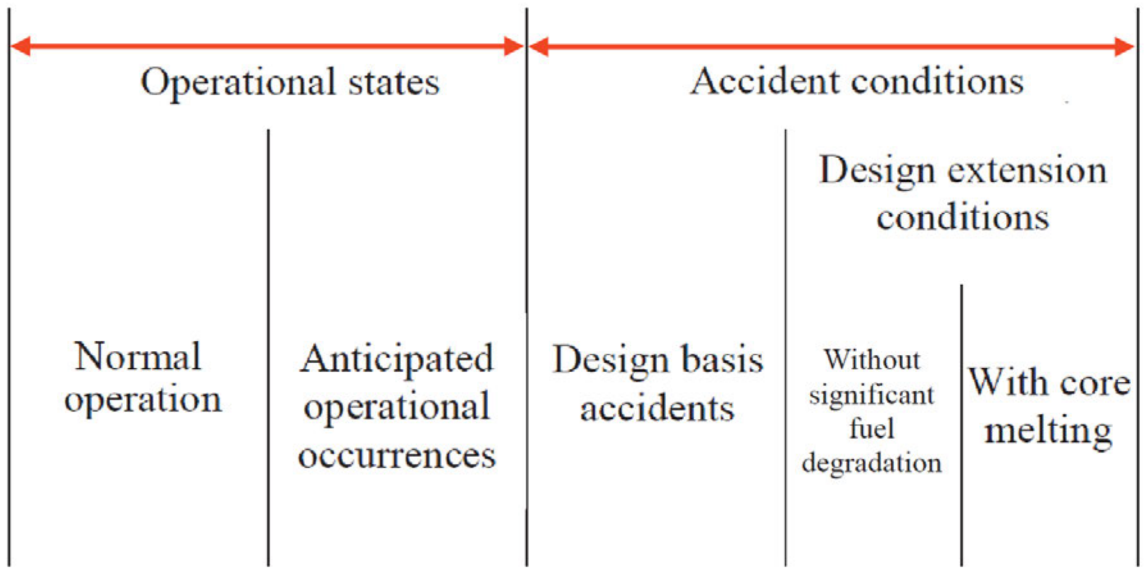


Approach 1
"Bottom-Up" approach:

Approach 2
"Top-down" approach: Review IAEA SSR-2/1

Revised requirements example

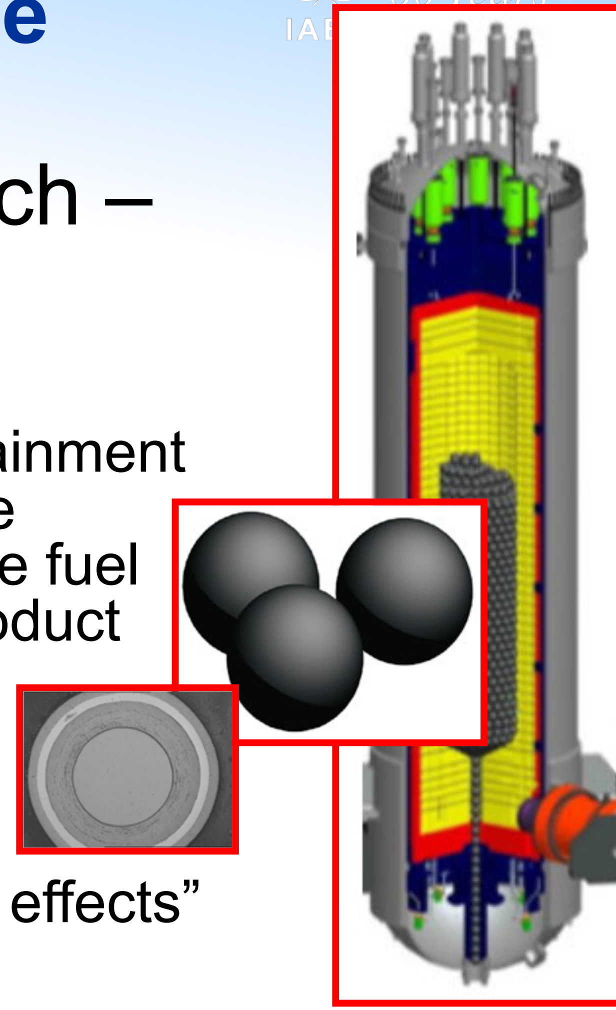
- design extension conditions “with core melting”



- Fuel handling …. designed to be dropped … more robust

Revised requirements example

- Containment function approach – with a non-condensable gas



- the focus of the requirements on the containment function and structures needs to stress the dominant role played by the coated particle fuel as the most important barrier to fission product release.

- No “cascading cliff edge effects”

- the requirements of multiple barriers and the implementation of defense in depth should be considered carefully, but also clearly differently.

CRP: Modular High Temperature Gas-cooled Reactor Safety Design

Implementation started December 2014

Good support for the CRP

10 participating organizations from 9 member states: China, Germany , Indonesia, Kazakhstan, Korea (Republic of), Japan , UK, Ukraine, USA

- 1st RCM took place 9-12 June 2015
- 2nd RCM took place 13-17 June 2016
- 3rd RCM took place 19-23 June 2017 (with GIF participation)

Planned outcomes:

- NE series report: Modular High Temperature Gas-cooled Reactor Safety Design Criteria
- TECDOC: Modular High Temperature Gas-cooled Reactor Safety Design Methodology and Implementation Examples
- GIF proposed to use the outcomes as basis for VHTRs

Safety requirements for MSRs

- Clearly a technology dependent (or non-water cooled) safety design criteria will also benefit the future deployment of MSRs
  - atmospheric or low pressure
  - Increased passive safety due to the inherent properties of the salt that reduce the potential source term release
  - passive decay heat removal
  - lack of cliff-edge phenomena means the requirements on safety systems may be relaxed

- Approach already being implemented in the USA with the "Advanced Nuclear Technology Development Act of 2017"
  - a plan for developing an efficient, risk-informed, technology-neutral framework for advanced reactor licensing.

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Activities on Molten Salt Reactors and the potential future role for the agency

… considering launching a new project on molten salt and molten salt cooled advanced reactors;”

welcoming the increased participation …

Recommends that the Secretariat continue to explore activities in the areas of innovative nuclear technologies,

… alternative fuel cycles (e.g.thorium, recycled uranium)

…. and molten salt nuclear reactors…

….strengthening the efforts aimed at creating an adequate and harmonized regulatory framework so as to facilitate the licensing, construction and operation of these innovative reactors;

IAEA actions taken

2015: Initiated activities on Molten Salt Reactor technology based on increased member state interest

Meetings held

- Consultancy Meeting on Molten Salt Reactors: Status and possible role for IAEA to facilitate Technology Development (Nov 2015)
  - Invited 11 participants from 9 member states to advise the agency
  - Czech Republic, France, Japan, Netherlands, Russian Federation, Switzerland, UK, USA and European Union
- Technical Meeting on the Status of Molten Salt Reactor Technology (Oct / Nov 2016)
  - 35 participants from 18 member states
  - Also Australia, China, Canada, Denmark, India, Indonesia, Italy, Turkey and Venezuela
- Consultancy Meeting on the development of the TECDOC on Molten Salt Reactor Technology (Sept 2017)
  - 14 participants from 11 member states
  - Review of draft TECDOC

During 2016 actively invited contributions of SMR designs to ARIS

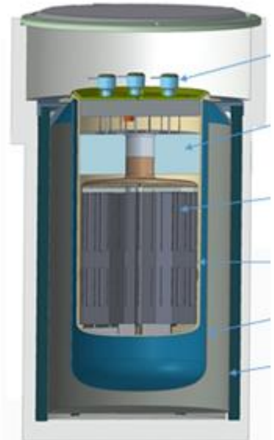
Interest in MSRs / booklet

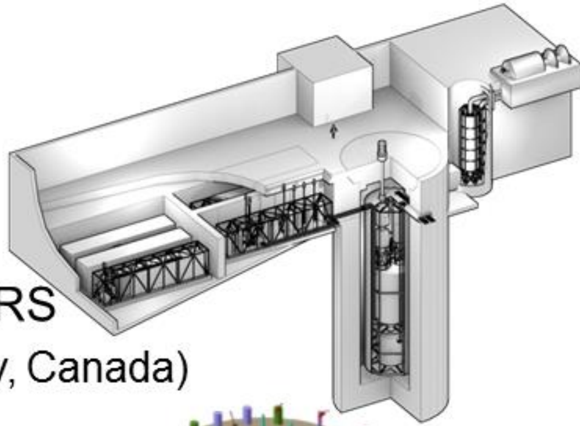
- Contributions
  - 8 designs submitted to the SMR booklet
  - More detailed descriptions also added into ARIS
- Active research and design proposals
  - Many development projects only in the USA
  - Canada
  - China
  - France / EU programs
  - Russia
  - India
  - Indonesia
  - UK
  - Many with some R&D
  - Many more interested
  - International consortiums

Advanced Reactor Information System

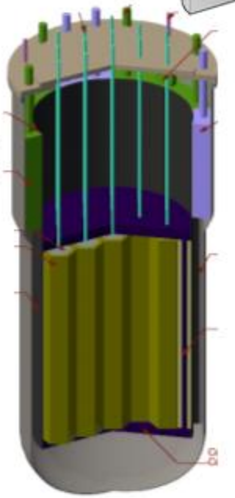
Next SMR booklet update Q1/Q2 of 2018

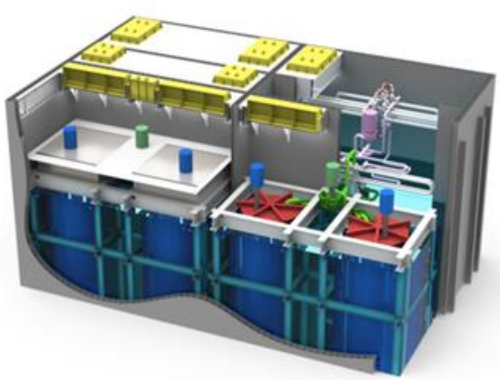
Submissions 2016

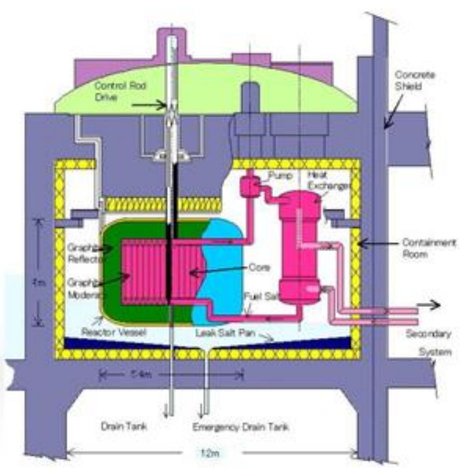


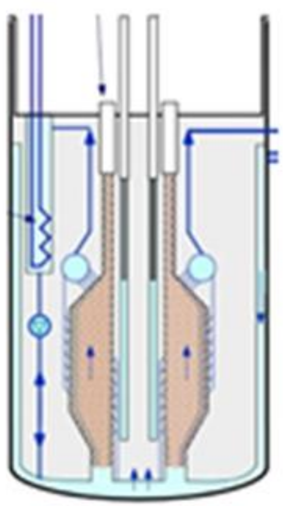


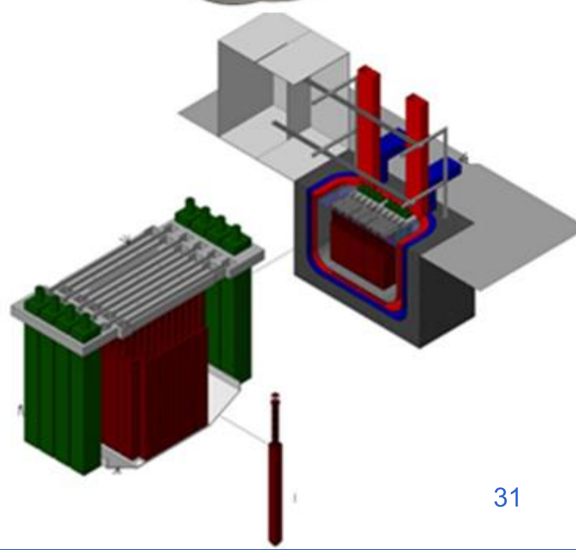
- MOLTEN SALT SMALL MODULAR REACTORS
  - Integral Molten Salt Reactor (Terrestrial Energy, Canada)
  - MSTW (Seaborg Technologies, Denmark)
  - ThorCon (Martingale, International Consortium)
  - FUJI (International Thorium Molten-Salt Forum, Japan)
  - Stable Salt Reactor (Moltex Energy, United Kingdom)
  - SmAHTR (Oak Ridge National Laboratory, USA)
  - Liquid Fluoride Thorium Reactor (Flibe Energy, USA)
  - Mk1 PB-FHR (UC Berkeley, USA)











SMR for Non-Electric Applications

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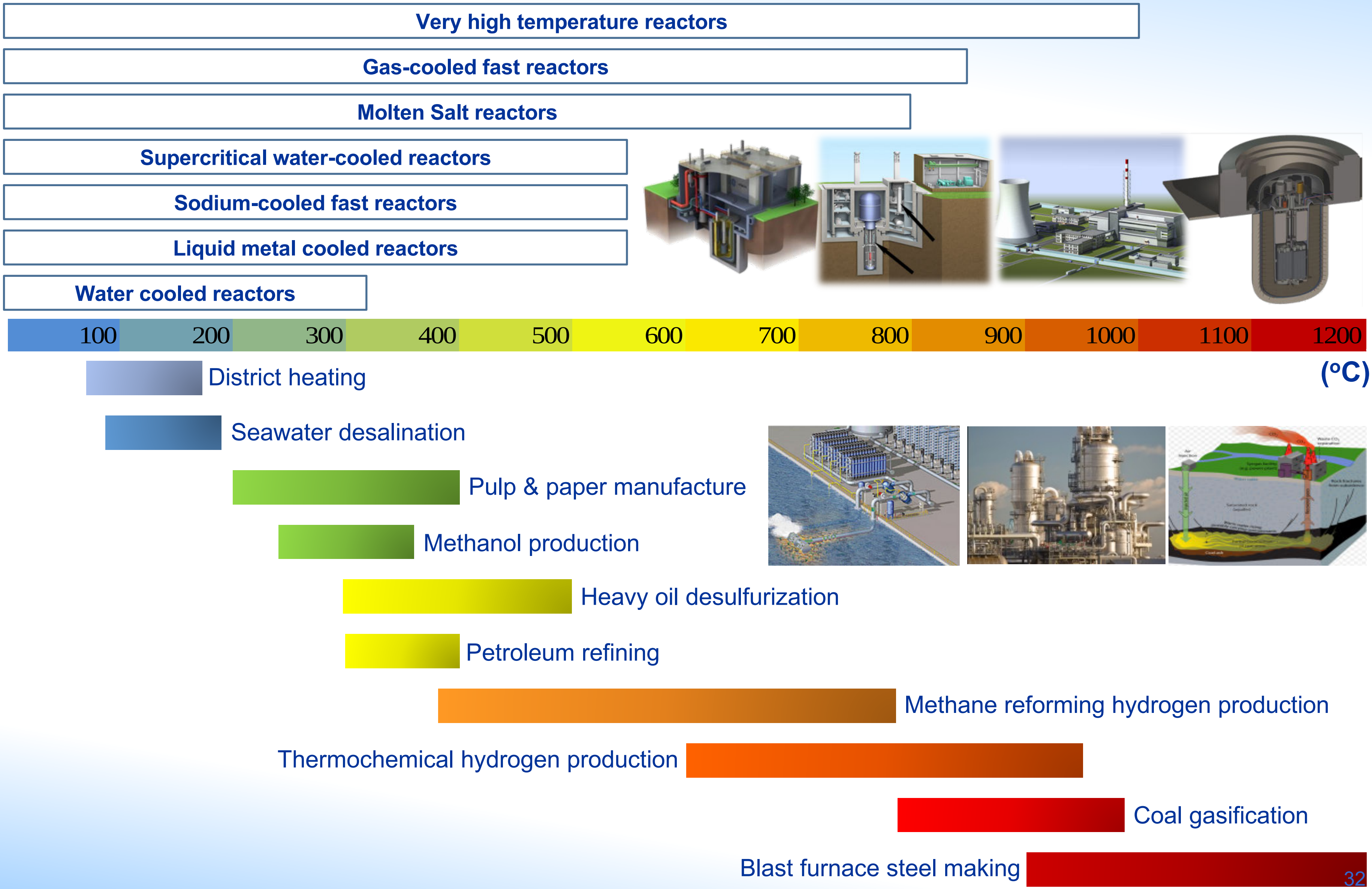

Overview of draft TECDOC:

"Status of Molten Salt Reactor Technology"

- Classification of MSRs
  - To illustrate variety of designs and technologies required
- Major country programmes / technology developers
  - China with smTMSR
  - France / EU with MSFR
  - Russian Federation with MOSART and U-Pu cycle
  - United States with FHR-DR and FHRmk1
- Member State activities
  - Summary of history, current and planned activities
  - 21 member states and 2 organizations identified to contribute
- Appendix with submitted design summaries
  - ARIS / SMR booklet submissions
  - All other "known" vendors / design organizations will be invited
- Current draft already ~150 pages
- Updated draft by end of 2017 – publication targeted in Q2/2018

Future possible activities

- In Technology development section
  - Expansion of MSRs designs in ARIS and IAEA publications (such as SMR booklet)
  - Update of technology assessment document to include MSRs
  - Establish a formal program on MSRs
    - CRP projects on benchmarking, uncertainties, V&V, etc
    - Development of further technical publications
    - Knowledge preservation
    - Training simulator….
- Need member state specific requests and funding (RB and/or EB)

- Consider participation in the CRP to define EPZ for SMRs – starting 2018

CRP: Determining the Technical Basis for Emergency Planning Zone for Small Modular Reactor Deployment

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CRP I31029

Overall Objective:

Address aspects of emergency preparedness & response (EPR) specific for SMR deployment, particularly the size of Emergency Planning Zones (EPZs)

Specific Objectives:

- Development of Approaches, Methodologies and Criteria to determine EPZ and actions needed for SMRs (including HTGRs, MSRs and co-located facilities for cogeneration)
- Determining the need for off-site Emergency Preparedness and Response
- Provide technically sound and consistent information that could be used as an input into the new guidance on EPR arrangements for SMRs.

➢ You are invited to participate

➢ Please send proposals before end October 2017

➢ To Start in 2018

➢ Joint CRP with NS

Recommended future activities

The member states identified a clear role and need for the agency:

- to expand and fully integrate the initiated MSR nuclear power development efforts with agency activities in the areas of
  - safeguards,
  - security,
  - and safety

- … consider supporting a safety approach which reflects the inherent characteristics of MSRs.

- … coordinate with OECD-NEA in particular in the areas of international standards and databases.
- … coordinated with GIF MSR activities to avoid duplication (already done as part of annual interface meeting)

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Concluding remarks

… IAEA support Member State Needs

Concluding remarks

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- The interest in advanced molten salt reactor technology clearly warranted the IAEA initiatives
- The IAEA serves a wider community of member states
  - coordination with OECD/NEA and GIF will clearly be beneficial
- Activities initiated by the Nuclear Power Technology Development Section (NPTDS) but the characteristics of MSRs requires early engagement and the action from the safeguards, safety and security departments within the agency
- The agency have a clear mandate to assist newcomer countries interested in advanced reactor technology

- I invite you to make contributions to ARIS, the SMR booklet and the TECDOC
- Consider participation in the CRP to establish the methodology to determine the EPZ for small modular reactors
- Make your wishes and needs known to your government to support IAEA efforts in establishing a formal program on MSRs

More information on IAEA website

Nuclear Power Technology Development

https://www.iaea.org/NuclearPower/Technology/about.html

- **Small and Medium Sized Reactors (SMRs) Development, Assessment and Deployment**

  https://www.iaea.org/NuclearPower/SMR/index.html

- **Support for Demonstration of Modular High Temperature Gas Cooled Reactors (HTGRs)**

  https://www.iaea.org/NuclearPower/GCR/index.html

- **Advanced Reactors Information System (ARIS)**

  https://aris.iaea.org/

The New CRP:

Development of Approaches, Methodologies and Criteria for Determining the Technical Basis for Emergency Planning Zone for Small Modular Reactor Deployment (I31029)

https://www.iaea.org/newscenter/news/new-crp-development-of-approaches-methodologies-and-criteria-for-determining-the-technical-basis-for-emergency-planning-zone-for-small-modular-reactor-deployment-i31029

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Thank you!

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Molten Salt Reactors
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Member State GC resolutions on MSRs

No specific program currently exists but the activities undertaken are based on the 60th and 61st General Conference resolutions:

GC60:

- "Encourages the Secretariat to explore, in consultation with interested Member States, the need for closer collaboration in technology development for advanced reactor lines by hosting a workshop with the aim of considering launching a new project on molten salt and molten salt cooled advanced reactors;"

GC61

- (n) Welcoming the increased participation at the meeting, organized in November 2015, to "present and share important information on the interest and status of technology developments in the area of molten-salt and molten-salt cooled advanced reactors" and welcoming the meeting that took place in November 2016, and

- 20. Recommends that the Secretariat continue to explore, in consultation with interested Member States, activities in the areas of innovative nuclear technologies, such as alternative fuel cycles (e.g.thorium, recycled uranium) and Generation IV nuclear energy systems including fast neutron systems, supercritical water-cooled, high-temperature gas cooled and molten salt nuclear reactors, with a view to strengthening infrastructure, safety and security, fostering science, technology, engineering and capacity building via the utilization of existing and planned experimental facilities and material test reactors, and with a view to strengthening the efforts aimed at creating an adequate and harmonized regulatory framework so as to facilitate the licensing, construction and operation of these innovative reactors;

More information on CRP I31029

- **Development of Approaches, Methodologies and Criteria for Determining the Technical Basis for Emergency Planning Zone for Small Modular Reactor Deployment**
- **CRP Overall Objective**
  - The main goal of the CRP is to develop approaches, methodologies and criteria for determining the technical basis for EPR arrangements, focusing on the size of EPZ for SMR deployments based on international safety standards.
- **Specific Research Objectives**
  - Formulate criteria for the events and technical aspects to be considered for defining EPR arrangements for SMR, focusing on EPZ sizing. This should be based on the results of the research and implementation of defence-in-depth in the design of SMRs, including small power, smaller source term, increased safety margin, enhanced engineered safety system, smaller fission product release, and consequent reduced potential for radiation exposure to population in the vicinity of the plant;
  - Develop approaches and methodologies which enable relating safety features of SMRs with the extent of offsite arrangements needed, particularly the size of EPZ, by comparing design- and site-specific technical basis to be provided by SMR developers, nuclear regulators, emergency planners and users/utilities;
  - Provide suitable technical basis, as an input into the development of IAEA technical guidance (EPR series report) on EPR arrangements for SMRs. Also additional input into new guidance regarding source term definition and assessment could be derived on that basis, as appropriate.