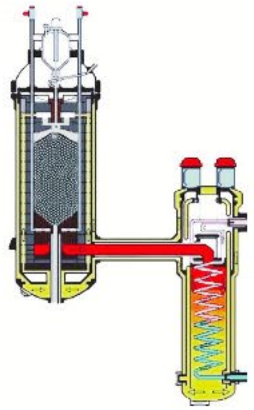
MDEP

High-Temperature Gas-Cooled Reactor (HTGR) Workshop

18-20 March 2024
Online



SESSION 1

VERIFICATION AND VALIDATION (V&V) COMPUTER BENCHMARKING FOR HTGR

Monday, 18 March 2024

KEY INSIGHTS FROM EXPERIENCE

- The benefit of seeing benchmarking as a process
- The high-importance of experimental data for V&V
- The benefit of public material from IAEA to conduct V&V
- The need for data to be integrated to materials when using computational codes.
- For the time being, AI seems only capable of assisting in development, not in verification, and it is not likely to happen soon due to the many challenges involved.
- The importance of the use of digital twins for developing simulators.
- The importance of MDEP as a platform to anticipate for HTGR developers over the world

CHALLENGES AND RECOMMENDATIONS

- Need of very good computer software representations of physical models and of mathematical equation simplification
- Challenges regarding the applicability of verified Gen-III Codes and limitations on Generation IV Reactor Verified codes
- All programs used for justifying and ensuring the safety of nuclear facilities must be certified.
- The challenge and need of obtaining new experimental data aimed at verification and validation of computer codes for HTGR (e.g. thermo-hydraulics, neutron physics, etc.)
- Simulation of behavior of materials and phenomena over long periods of time as a key challenge
- Challenge of analysing system behavior when subjected to extreme conditions
- Benefit of using shared databases of codes
- Simulation of physical characteristics for fuel elements as a challenge
- Need for international collaboration in code benchmarking

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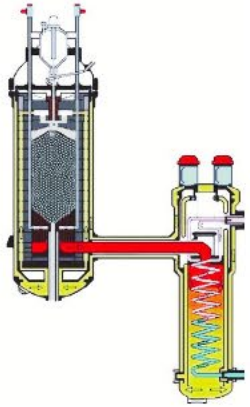


SESSION 2

FUEL SAFETY

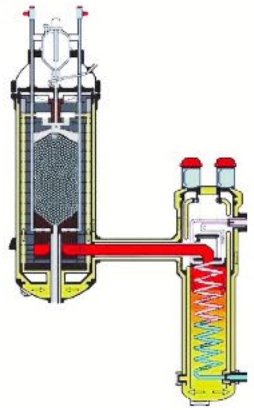
Monday, 18 March 2024

KEY INSIGHTS FROM EXPERIENCE

- Safety objectives of the TRISO Fuel is to adequately maintain its integrity to contain fission products under operating and accident conditions
- Key safety properties of the TRISO Fuel, including mechanical, geometrical, and chemical properties, should be properly managed and regulated for both irradiated and un-irradiated fuel
- The performance of the fuel under normal and accidental conditions is the key to the safety of the HTGR/SMR
- It is essential that the design, fabrication and qualification of the fuel is adequately and properly regulated by the regulatory body to ensure that the fuel meets the required high level of safety performance.
- HTGR fuel qualifications requires from several months to beyond one year on average.
- There are special safety considerations for TRISO fuel fabrication facilities.

CHALLENGES AND RECOMMENDATIONS

- To define an adequate and proper procedure for the regulation of design, fabrication and verification of the fuel by the regulatory body.
- To apply the PSA method in the safety assessment for the design and manufacture of the fuel to improve the regulatory capacity in the regulation of the new fuel.
- To collect, share and analyze the fuel test results to have a better understanding of the fuel behavior to improve the safety of the fuel at the international level.
- Develop safety strategy for accident management
- Need to investigate on special accidents for TRISO fuel
- It might be interesting to do a benchmark on the differences in safety properties between prismatic fuel and pebble fuel



SESSION 3

RESEARCH NEEDS RELEVANT TO HTGR

Tuesday, 19 March 2024

KEY INSIGHTS FROM EXPERIENCE

- Wide-scale R&D work has been deployed in the following key areas:
  - tryout of technology aimed at manufacturing of fuel and key components of the reactor core;
  - high-temperature resistant materials and reactor-grade graphite;
  - computer code verification and qualification
- Since the reactor and the chemical plant are 200 meters apart, hazards relevant to hydrogen production would be considered as external.
- The term graphite oxidation was chosen in frame of severe accident analysis with graphite burning following the assumption that there is no flame involved and the temperature does not exceed 680 C degrees.
- Calculated radiation doses of potential release in case of considered severe accident are not excessive and do not require evacuation of population.
- Hydrogen diffusion is considered possible only when microdefects are present or in unsealed sections of the structure.
- Helium loss was analysed and adapted into design.

CHALLENGES AND RECOMMENDATIONS

- The main challenge for R&D area is the need of further developments for the consequent safety justification of a new NPP.
- Relevant R&D should be continued with focus on the appropriate high-temperature resistant materials, reactor-grade graphite, verification of calculation models, consideration of uncertainties and thorough safety analysis of a new NPP.
- There are minor differences in the results of irradiation tests for prismatic reactors fuel and pebble fuel. It might be interesting to clarify those.

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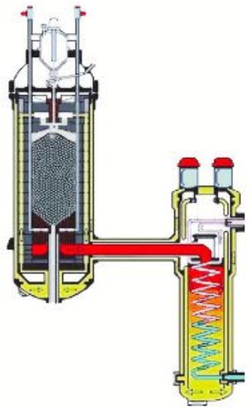

SESSION 4

PSA

Tuesday, 19 March 2024

KEY INSIGHTS FROM EXPERIENCE

- Since the deterministic safety requirements for HTGR have not been fully established, PSA can play a more important role in the design and licensing of HTGR with the support of deterministic method and engineering/expert judgment.
- PSA can also be used in the demonstration of safety objectives, categorization of event sequences in different plant states considered in the design, selection of important beyond design basis accident sequences and design extension conditions, demonstration of design alternatives, safety classification of structures, systems, and components, and evaluation of defense-in-depth (DID) adequacy.
- To issue practical regulatory principles and to have a clear regulations for defining the safety objectives and the boundary conditions by the regulatory body could be the meaningful measures to facilitate the design and commissioning of the HTGRs.
- To define reasonable metric for consequences (dose limit at the site boundary, as well as cumulative risk targets such as the annual dose and/or the risk for early/latent fatalities) could be a good input for performing PSA and demonstrating the safety of the HTGR design.
- The risk analysis addressing the HTGR passive system reliability or failure should not be neglected.

CHALLENGES AND RECOMMENDATIONS

- It is strongly recommended for the regulator to establish clear safety objectives, the the HTGR-specific requirements for PSA (such as the format and content of the probabilistic safety assessment report), and adequate consequence metric for quantifying the risk to facilitate the design and commissioning of HTGR.
- It was proposed to establish a component reliability database for HTGR SSCs at the international level to facilitate the further development of HTGR.
- To study and define the severe plant conditions and a list of accidents considered in the PSA of HTGR will be of common interest to both the designers and the regulators.
- It was recommended to initiate benchmark models for comparison of the computer programs used in the PSA for HTGRs.

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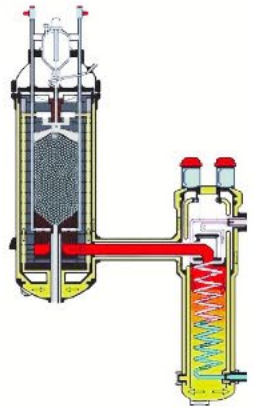


SESSION 5

DEFENSE IN DEPTH

Tuesday, 19 March 2024

KEY INSIGHTS FROM EXPERIENCE

MDEP
Multinational Design Evaluation Programme

- There were different positions on DiD: to keep the principle as it is currently defined (4 levels concerning the design, including severe accident conditions) or defining a different approach for HTGRs. In the first case, discussions on a case-by-case basis are needed to consider the specificities of the design (i.e., the type of accidents considered in the different levels). In the second case, new approaches may consider a different number of levels/sublevels, different requirements related to their independence etc.).

- In this respect, it was underlined that the public might not be favorable to define different basic principles for different designs.

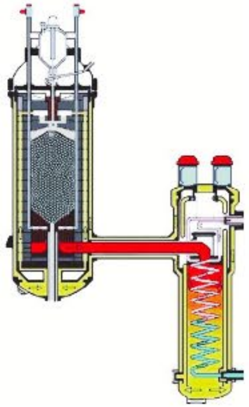
- Discussions were mainly focused on the 4th level of DiD and the definition of a severe accident for HTGRs. It was stressed that the potential for severe accident remains low for HTGR. A definition of a severe accident based on the fuel temperature was proposed ($T>1600$ °C).

- The role of passive systems was also discussed and the need to assess their reliability was stressed.

- A specific point was discussed regarding the possibility of a nitrogen injection in the containment in case of air ingress. One of the designers stated that, if the amount of air is not significant enough to promote graphite oxidation and potential TRISO failure, there is no need for nitrogen injection. If the amount of air is significant, nitrogen injection is not effective and another solution is needed.

CHALLENGES AND RECOMMENDATIONS

- A key challenge is to harmonize regulatory frameworks from a technology neutral standpoint (as far as possible). This includes the difficulty to define a DiD approach that is applicable to different technologies and designs.
- Regarding HTGRs, a challenging point is to analyze how the different roles of the barriers can affect DiD.
- The definition of a severe accident and 'practically eliminated' situations for HTGRs remains a source of debate.
- A difference of views also remains regarding the need of an emergency planning zone for HTGR versus eliminating the need for offsite emergency response.
- The products of other international platforms such as the IAEA SMR regulators forum or the Generation IV international forum is a good starting point to be considered by MDEP, especially the work related to DiD.
- The definition of a risk-informed approach as a combination of DSA and a PSA developed following the logic of DiD was suggested.
- Incorporating to regulations full functional independence of DiD levels instead of independence as far as feasible has also been proposed.
- It was proposed that MDEP should establish regulatory expectations for safety classification of plant equipment at different Defence in Depth levels.
- Proposal to develop a system of requirements/ classification of equipment based on DID levels.



SESSION 6

MATERIAL SELECTION

Wednesday, 20 March 2024

KEY INSIGHTS FROM EXPERIENCE

- A design concepts of mobilized GCMR, the design input of RPV, RPV material selection principle, the work for material selection analysis, and the verification of material performance of the selected 316H has been introduced.
- Based on the data collected from the verification process for 316H, there are following initial results :
  - The stress rupture of 316H with specific melting method was higher than the values stipulated in the code;
  - The carbide precipitated along grain boundary after 7000h at 550℃, whereas no brittle phase precipitated, thus the thermal aging effect is not sensitive;
  - The irradiation damage at the required fast neutron fluence (0.01dpa) can be negligible;
  - The corrosion effect in the helium with impurities in certain range can be negligible.
- The high temperature environment affects the lifespan of the materials and components, thus it is significantly shorter than for PWR.

CHALLENGES AND RECOMMENDATIONS

- According to the widely used ASME III-D5 code for material selection, it lists limited types of materials that can be used in HTGR, which has limited the development of HTGR.
- It is suggested to develop a guideline at the international level for the introduction and verification of new materials for HTGR.
- Due to the high temperature design properties of HTGR and the special requirements for the material, it is highly recommended to initiate benchmark on the material selection to have more knowledge about different options of materials for HTGR.
- Clear guidance on safety grade classification for the structure systems and components for HTGR reactors is required for designers and regulators.

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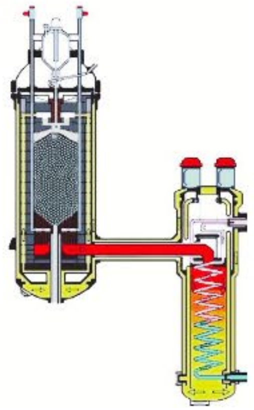

SESSION 7

REGULATORY FRAMEWORK

Wednesday, 20 March 2024

KEY INSIGHTS FROM EXPERIENCE

- Generation-IV International Forum (GIF) has developed Safety Design Criteria (SDC) for Gen-IV VHTR systems
- VHTR SDC aims to establish reference requirements for safety design of structures, systems, and components consistent with high-level GIF safety goals and RSWG safety approach
- SDC report considers unique VHTR safety principles and design features to assure safe operation and prevention of events, as well as for procedures and organizational processes that are required for mitigating the consequences of such events should they occur
- Deleting requirements may have a negative effect in public perception.
- There are still some work on accident analysis to be performed, which requires more data

CHALLENGES AND RECOMMENDATIONS

MDEP Multinational Design Evaluation Programme

- It is necessary to take into account specific features in terms of nuclear fuel, core configuration and system of heat removal, specific accident processes, impact of the technological part.
- Need to amend regulatory framework for the Nuclear Power and Process Station (NPPS) with HTGR design development.
- Gaining experience in licensing of a new type of nuclear power stations operated for power and process sector remains one of the main objective.
- Since some regulators do not accept the principle of dynamic containment, this has to be part of discussions during the licensing and pre-licensing process.
- A difference of views also remains regarding the containment systems and practical elimination, which will require more discussions, especially between GIF and MDEP.
- Further discussion on containment vs confinement can help to develop the methodology and best practice to determine the radionuclide inventory of the primary circuit, and further the potential radioactive dose to the public. The discussion should consider IAEA TECDOC requirements.