Report of the Technical Meeting on Next Generation Reactors and Emergency Preparedness and Response

Held in IAEA, Vienna, between February 13 and 17, 2017

1. BACKGROUND

A continuously increasing interest in nuclear power is been observed over the past years, in several countries with already established nuclear power programmes, as well as in countries in various stages of preparation or initiation of a nuclear power programme. According to *IAEA Nuclear Technology Review 2016*, the "*Agency's projections show a growth in nuclear power capacity between 2% (lowest case) and 70 % (highest case) by the year 2030*". While current nuclear power plants under operation, commissioning or construction are mostly water cooled thermal reactors, some with advanced nuclear technology capabilities started developing innovative nuclear reactors, supposed to be commercially available and deployed in the next decades.

There are presently a number of innovative nuclear reactor concepts[1] under research and development, characterized by different design approaches, technologies and safety features, e.g.: Sodium Fast Reactors (SFR), Very High Temperature Reactors (VHTR), Lead Fast Reactors (LFR), Gas Fast Reactors (GFR), Super-critical Water Reactors (SCWR), Molten Salt Reactors (MSR), Small Modular Reactors(SMR) [2]etc. SMR is a concept that may be applied to different types of these next generation reactors.

Although differing in individual solutions, next generation nuclear power reactors concepts will be subject to the "safety by design" approach. The current IAEA safety requirements for Nuclear Power Plants' design [IAEA SSR-2/1 (Rev. 1), 2016] indicate that "*The design shall be such as to ensure that plant states that could lead to high radiation doses or to a large radioactive release have been practically eliminated, and that there would be no, or only minor, potential radiological consequences for plant states with a significant likelihood of occurrence*." Moreover, the IAEA Fundamental Safety Principles state the concept of defence in depth (DiD) as the primary means of preventing and mitigating the consequences of accidents.

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[1] For the purpose of this Technical Meeting and for this document, these are to be called "next generation" reactors.

[2] IAEA defines SMRs "as advanced reactors that produce electric power up to 300 MW(e), designed to be built in factories and shipped to utilities for installation as demand arises."

The concept of DiD is implemented primarily through the combination of a number of consecutive and independent levels of protection, including the fifth level, which is to mitigate, through off-site emergency preparedness and response (EPR), the radiological consequences of radioactive releases that could result from an accident.

As stated in various publications issued by research and development organizations, fora on next generation reactors, etc., next generation nuclear power reactors are being designed to satisfy a broad spectrum of objectives: economic competitiveness, high level of safety, proliferation resistance, and reduced nuclear waste stream. As described in the Annual Report 2013 of Generation IV International Forum (GIF), the following safety and reliability goals have been defined for Generation IV reactors, as part of next generation reactors, will: "*i) excel in safety and reliability; ii) have a very low likelihood and degree of reactor core damage, and iii) eliminate the need for off-site emergency response.*"

Worldwide experience accumulated over 60 years of operation of nuclear power plants and from the response to few severe nuclear accidents has revealed the crucial importance of off-site EPR, as ultimate level of DiD.

While one of the design objectives for the next generation nuclear power reactors is that the necessity for off-site protective actions to mitigate radiological consequences be limited or even eliminated in technical terms, fundamental safety principles and concept of DiD should be properly addressed. Further, the IAEA requirements on EPR require in relation to the hazard assessment for nuclear power plants the consideration of "on-site events, including those not considered in the design" [IAEA GSR Part 7].

Therefore, even though the developers of next generation nuclear power reactors are working to design and implement advanced solutions able to meet the ambitious design objectives, discussions are to be held whether and to what extent there is a need for off-site EPR arrangements and capabilities for these reactors.

Answering these questions necessitates concerted efforts for the years to come by experts from regulatory bodies, emergency response organizations, design and research organizations, vendors, and potential operators. Analysis of feasibility and complexity of off-site EPR arrangements and capabilities for next generation power reactor designs will need to be conducted to reach a sound, balanced and widely supported answer to those questions.

2. TECHNICAL MEETING SCOPE AND OBJECTIVES

The fundamental objective of this Technical Meeting (TM) was to address the use of fifth level of DiD and IAEA safety requirements on EPR for development of next generation nuclear power reactors. In particular, the following points were addressed:

- Sharing Member States experience on implementation of IAEA fifth level of DiD and safety requirements for EPR;
- Presenting next generation nuclear power reactors design concepts and safety features that could be of relevance in relation to off-site emergency response;
- Presenting IAEA activities in support of next generation nuclear power reactors;
- Sharing current approaches and practices on EPR in relation to next generation nuclear power reactors.
- Starting taking actions to set the way forward for defining a sound, balanced and widely supported criteria regarding off-site EPR arrangements for next generation reactors

The design of these next generation reactors is, in most of the cases, just being developed at a conceptual or basic level. In the most advanced cases, there are some designs being currently developed as pilot cases aimed at gaining experience on these new reactors, at all levels (construction, commissioning, regulations, operating experience)[3]. However, no consistent technical and operational experience exists on how the expectations linked to these new reactors will be met in a practical sense.

In this environment, this TM is considered as a starting point of the above-referred discussion, and the expectations were focused in paving the way to allow an adequate discussion unfolding in the near future. This debate should bring together all the technical data and expertise from different fields (technology developers, safety assessment, EPR) to develop an acceptable and commonly shared approach to define off-site EPR arrangements to be applied to these new next generation nuclear reactors. Hence, the main goal was to have an open debate on the different topics presented in the TM.

In this regard, this Report should be considered as an initial setup of this discussion, wrapping up the main aspects (considering the specific perspectives of the different fields of expertise involved) to be taken into account for further developments in the EPR field and defining suitable new steps to be taken in the mid-term.

3. TM REPORT

The session's facilitators, based on the reports prepared by the session's rapporteurs, have prepared the draft TM report. Refer to the attached list of facilitators and rapporteurs. The TM participants subsequently reviewed the draft report and contributed to the final version. The facilitators also made resolution of comments.

For better understanding of the contents of this TM Report, please refer to the attached Agenda of the TM.

A. OPENING SESSION

[3] There are some SFR in operation for several decades, however they cannot be considered as next generation reactors since they don't include the new design and safety features that are being considered for Generation IV reactors based on this concept

In his opening remarks, the Deputy Director General, Head of the Department of Nuclear Safety and Security Department set the background, context and expectations of the TM, emphasizing the importance of a strong consideration of safety as a crucial aspect necessary for peaceful nuclear power development. In addition, he emphasized the need for a balanced consideration of all the elements involved in the debate about EPR for these next generation reactors. The complete text of these opening remarks is attached to this report.

There were two main topics addressed during the session, which was aimed at an overarching level of discussion: definition and implementation of the DiD concept, including the latest state-of-the art developments on the concept after Fukushima Daiichi accident; and a summary of the Generation IV International Forum (GIF) design concept and road map towards its development and implementation.

Some aspects may be highlighted from the referred presentations and the subsequent debate that took place:

- DiD concept has been reviewed to incorporate lessons learned from Fukushima Daiichi accident. The conclusions of the review suggest some changes to be incorporated in the concept to provide additional robustness to the different DiD layers, but the basic features of the concept remain valid.

- EPR still is included as 5th layer of the DiD concept, and it’s expected to remain as ultimate level to mitigate consequences to public and the environment from significantly harmful radioactive releases caused by a nuclear accident, should the previous levels fail in fulfilling their aim.

- EPR protection level should consider events involving conditions beyond design.

- Next generation reactors are aimed at incorporating reinforced safety features that are expected to provide outstanding level of safety and make very unlikely the occurrence of large radioactive releases.

- On this safety perspective, one of the design goals of these next generation reactors is claimed to be the elimination of the need for off-site EPR.

- The elimination of off-site EPR should be considered as a design goal. The definition of EPR arrangements needed by these new reactors should not be necessarily bound by this design goal. The analysis to define those EPR arrangements should be made on a graded approach while considering low probability events beyond design.

B. SESSION 1: *Implementation of IAEA fifth level of defence in depth (DiD) and safety requirements for emergency preparedness and response (EPR)*

During this session, it was provided an overview of the existing EPR arrangements in different Member States (MS), together with a summary of relevant requirements and guidance existing in international safety standards for EPR. Discussions took place on different aspects pertaining to those topics and also about how to deal with EPR aspects when they come to next generation reactors. Main aspects addressed may be summarized as follows:

1. Most of the MS existing EPR arrangements are aligned with IAEA Safety Standards on Emergency Preparedness and Response. Also a trend in MS harmonization of national EPR arrangements based on those safety standards exists and it’s making progress. MS are continuously working on the enhancement of their EPR arrangements to improve their effectiveness of response with account given to their own experience, experience obtained from past emergencies and lessons learned from the exercises and trainings carried out at different levels.
   However, this experience is currently limited to the operating reactors existing today (with designs developed in many cases decades ago). No meaningful experience exists regarding EPR requirements for these next generation reactors.

2. A number of issues/difficulties when implementing the EPR arrangements were emphasized that also should be considered when performing emergency response planning for the next generation reactors:
   - Need in harmonization of EPR arrangements with neighbouring countries (especially for the cases when the plant is located close to the border);
   - Need of resources (e.g. financial, human, technical) for implementation of EPR programme and the implementation of protective actions that in many cases require the use of important capabilities and resources to maintain them;
   - Importance of information exchange and communication during the emergency response.

3. GSR Part 7 Requirements have been issued recently, encompassing relevant experience on the implementation of EPR for different type of facilities and activities, including NPP, and from relevant emergencies that happened in the past. These requirements are applicable to all type of facilities and activities. Hence, the criteria set forth in GSR Part 7 are fully applicable to the definition of EPR arrangements needed for next generation reactors, on the basis of hazard assessment and graded approach.

4. IAEA is currently working on the development of new Safety Guides, and technical guidance (EPR series documents) to provide further guidance on GSR Part 7 Requirements implementation by MS. As well as the IAEA Safety Requirements GSR Part 7, the new Safety Guides will be applicable for all types of reactors irrespective of the design.
   However, it was pointed out the lack of specific technical guidance that could be useful for defining EPR arrangements for these next generation reactors. Also it was acknowledged that, regarding NPP, most of the technical guidance issued by the IAEA on EPR refers to facilities with large Light Water Reactors (LWRs). It would be very useful the development of a new EPR Series Publication providing detailed technical guidance for these new next generation reactors, taking

properly into account their new safety features that could be relevant for EPR. Also MS are encouraged to suggest their ideas and raise their needs to the IAEA.

5. This new guidance would be needed to explain in more detail how to deal with the requirements of the GSR Part 7 on hazard assessment for these new kind of next generation reactors and methodologies for the establishment of sizes of emergency planning zones and distances, concepts that will also be applicable for the new next generation reactors. Some aspects to be considered in this new guidance could include the following:
   - types of events to be considered;
   - criteria/factors to be considered when selecting emergency scenarios;
   - criteria/factors to be considered when making the decision about the size of emergency planning zones and distances;
   - type of the analysis to be used for deriving the emergency planning zones and distances, including definition of the source term;
   - etc.

6. EPR arrangements need to be developed accounting for events of very low probability, events comparable to the ones that already have happened in the past and events that are beyond the design. Security events should also be considered. The design and additional safety functions of the next generation reactors may influence the source term, onset and duration of the release, and consequently the sizes of the emergency planning zones and distances, concept of operations regarding EPR arrangements, and other important EPR related aspects. However it was pointed out that, according IAEA Safety Standards EPR is about protecting public and the environment from unexpected events and circumstances beyond design for which the design provisions are not enough to ensure proper protection of public safety and the environment against radioactive releases caused by these events (either accidental or due to malevolent acts) .

C. Session 2: *Next generation nuclear power reactors design concepts and safety features*

During this Session, different papers were dedicated to activities on the next generation reactors implemented in IAEA and member-states, including description of relevant design, safety and operational features to be taken into account for determining the relevant EPR aspects pertaining to these reactors. The contents of the presentations given and the discussions held are summarized below.

1. Relevant IAEA activities on advanced reactor technologies of next generations were highlighted. These activities cover the following reactor technologies:
   - Fast reactors with liquid metal coolants (sodium, heavy liquid metal – lead, lead-bismuth alloy);
   - Gas-cooled reactors;
   - Advanced light water reactors, including super-critical water reactors (SCWR);
   - Small modular reactors (SMR);
   - Molten salt reactors (MSR) (start of IAEA activities on MSR in 2016).

Technical Working Groups are created on fast reactors (FR) with liquid metal coolants (TWG-FR), on gas-cooled reactors (TWG-GCR), on light water reactors (TWG-LWR) and on heavy water reactors (TWG-HWR).

Regarding fast reactors with liquid metal coolants, the following was mentioned:

- Organization of periodical IAEA Conferences (FR09 in Kyoto in 2009, FR13 in Paris in 2013, FR17 in Yekaterinburg in June of 2017);
- Creation of advanced reactors information system (ARIS) database;
- Creation of liquid metal cooled fast neutron systems (LMFNS) experimental facilities database;
- GIF-IAEA collaboration on safety of GEN-IV sodium-cooled fast reactor (SFR).

It was also mentioned existing programs involving development of training courses and workshops, which are implemented on innovative nuclear energy systems (NES) for FR, HTGR, and SCWR.

Reference was made as well to the implementation of analyses of non-electric application of advanced reactor technologies: cogeneration, hydrogen production, desalination, etc.

There are some Co-ordinated Research Projects (CRP) under implementation on advanced reactors or being planned, some of them could be important for EPR related aspects. In particular:

- CRP on radioactive release from the prototype fast breeder reactor under severe accident conditions;
- CRP on understanding and prediction of thermal-hydraulics phenomena relevant to SCWR;
- CRP on uncertainty in design and safety analysis of HTGR;
- CRP on safety features of SMR;
- Planned CRP on development of approaches, methodologies and criteria for determining the technical basis for EPZ for SMR.

2. INPRO activities in support of the development of these next generation reactors were also described with indication that INPRO Methodology is a holistic multidimensional sustainability assessment metric derived from the "UN Brundtland Commission Report" ("Our Common Future", 1987) on sustainable development. It was underlined that INPRO Methodology sustainability criteria for nuclear energy systems (NES) are not the same like safety standards, but nevertheless they should be "consistent" with IAEA safety standards when touching on safety items and therefore they should not disagree with IAEA safety requirements.

   NES Sustainability assessment using INPRO Methodology addresses EPR in a straightforward manner in its draft updated assessment methodology in reactor safety area: "EPR is a prudent institutional measure that is always required and should be fully consistent with applicable national regulation and international (IAEA) Safety Standards". However, INPRO doesn't address EPR beyond this position since LER issues are beyond threshold for a sustainability assessment.

3. Specific views from MS regarding development of different types of next generation reactors were presented, including relevant technical and safety features to be taken into account.

    - India presented the current status of emergency planning in India and the discussions being initiated about a possible framework for elimination of emergency planning for their advanced reactor in public domain. Inherent safety features and passive safety systems that could potentially provide elimination of emergency planning were described, in particular on the example of the design of an Indian advanced heavy water reactor (AHWR) of 300 MWe.

    - Romania presented estimates on source term for lead-cooled fast reactor (LFR) of the 4th generation, which was described based on the demonstration ALFRED reactor design that is planned to be built in Romania.

    - A presentation was given by the Russian Federation describing safety-related features of Molten Salts Reactors (MSR). Also, main design parameters of the SMFR (France/EU) and MOSART (Russia) were described. Analysis of radioactivity release after a severe accident with rupture of the main fuel salt pipe and the fuel discharged to the reactor cell bottom was presented.

    - On behalf of China, a description of the analysis carried out for determining EPR arrangements for a demonstration plant with the next generation High Temperature Gas Cooled Reactor (HTR-PM) being under construction was given. Laws, regulations and national standards with requirements related to EPR in China were described as well key design features and parameters of the HTR-PM and current status of activities on its construction were explained. Power operation of the HTR-PM is expected in 2018. Main results on the determination of the size of EPZ were also explained. They showed that, according the safety analysis provided by the operator, the HTR-PM does not require off-site emergency plan from a technical viewpoint. However, the authorities decided keeping the sizes of EPZs as defined by LWR power units located at the same site. Future plans on development of these reactors in China were explained. In particular, the HTR-PM600 with 6 reactor modules is under development.

- A paper was presented by India dedicated to application of probabilistic and deterministic safety assessment methodologies for the analysis of EPR items. Evaluating the DiD concept in relation to EPR, it was explained that the 5^{th} level of DiD is aimed at mitigation of radiological consequences of potential release of radioactive materials under severe accident conditions.

  The safety approach for future reactors is based on provision of a practical elimination of the failure of the 4^{th} level of DiD. Nevertheless, it is proposed to cover EPR as a complementary step, even as the safety goal of these designs is to eliminate the need for emergency response as a DiD level.

  EPR is performed based on deterministic considerations, which may be complemented by probabilistic studies that take into account probability distribution for uncertain parameters (atmospheric condition, source term condition, etc.). Some recommendations on the development of the protection strategy in case of severe accidents were proposed, including definition of:

  - Emergency Action Levels (EALs);
  - Operational Intervention Limits (OILs);
  - Emergency planning zones (Precautionary Action Zone PAZ, Urgent Protective Action zone UPZ) and distances (Extended Planning Distance EPD and Ingestion and Commodities Planning Distance ICPD);

  - Response actions (Precautionary urgent protective actions, Urgent protective actions, Early protective actions) for each EAL/OIL;
  - Generic Criteria (GC) in terms of projected and received dose

- A presentation was given describing the main design features and parameters of a gas-cooled fast reactor Energy Multiplier Module (EM2) currently being developed by an USA supplier. Underground location negates many physical threats and improves safety and security of the EM2. Application of uranium carbide fuel with SiC fuel pin claddings allows to enhance significantly the safety of this reactor by incorporating DiD with multiple barriers to prevent fission products release and multiple means to protect these barriers. Passive safety features are used against all abnormal and accident conditions including beyond design basis accidents (BDBAs). Risk-informed licensing approach with bases for top level regulatory criteria starts for the EM2.

- A presentation was devoted to issues related to severe accidents analysis for liquid metal-cooled reactors that can be important for EPR corresponding to Gen IV reactors. Experience shows that the coolant, in addition to good thermal and neutronic properties, must have a good compatibility with structural materials and be friendly to the environment. The coolant has two less physical barriers to its release than radioactive materials located in fuel pins. Therefore, if the coolant itself is a radioactive material, it creates an additional threat to personnel, the public and the environment. The same applies for toxicity of the coolant. Burning, and still more explosion, of the primary circuit coolant can intensify the release of radioactive materials in BDBAs and makes more difficult the control of their release into environment. In the author's opinion, water and helium are the best coolants from viewpoint of their compatibility with structural materials and environment.

  The main problem of sodium coolant is due to its fire- and explosive interaction with air and water. This is a reason for consideration of relevant accidents with sodium leakages in the primary and secondary circuit for substantiation of the safety of sodium-cooled fast reactors (SFR).

One of the important problems of two-circuit NPPs with heavy liquid metal coolant (HLMC) is a high pressure in the secondary circuit that requires a very thorough analysis of accidents with leaks in the steam generator heat-exchanger tubes. Regarding beyond design basis accidents (BDBAs) with loss-of-heat-sink for reactors with HLMC, it should be paid attention to accidents with meltdown of fuel pins and control rods cladding, and sequential floating up of molten steel and absorbing elements in heavy coolant, which provides insertion of a large positive reactivity.

- It was described a history of evolution of a very innovative concept of the nuclear burning wave (NBW) reactor concept developed for the U-Pu fuel cycle as well as the Th-U fuel cycle. It was highlighted the intrinsic stability of the reactor owing to the negative reactivity feedback inherent to NBW concept. This feature allows the reactor to cope safely with accidents that in other fast breeder reactors would cause positive reactivity insertion, like accidents involving loss of heat sink.. This design is in a very preliminary stage of development.

- The progress made by ANL in the development of a Mechanistic Source Term (MST) for the pool-type SFR with metal-alloy fuel was presented. There were identified gaps in knowledge concerning radionuclide release from failed metal fuel into sodium. There is no cohesive radionuclide transport modeling computational tool. It is planned to develop tool for modelling realistic radionuclide release fractions from failed metal fuel to primary sodium. Now it was performed a trial MST analysis that covered:
    - Transient scenario modelling;
    - In-pin radionuclide distribution;
    - Failed pin radionuclide release;
    - Radionuclide bubble transport;
    - Off-site dispersion analysis;
    - Containment region analysis;

- Cover gas region analysis; and
- Sodium pool radionuclide release.

This work also included a sensitivity analysis.

- A paper was presented for describing the activities carried out in the USA on establishing sizes of EPZ for SMRs, to properly taking into account relevant safety features of these next generation reactors regarding EPR. The presentation provided different hints on these points, emphasizing the use of the best estimate considerations in this sizing process.

During this session, also intense discussions took place, in the Questions & Answers slot allocated after every presentation and at the end of the day as well. From these discussions, the following points are highlighted:

- Regarding a question related to uncertainty in source term when the containment of a fast reactor maintains its integrity, it was answered that in the scope of the CRP on source term simulation of FR is limited to a simplified model not providing real data for EPR.

- Concerning different scope of the INPRO and GIF sustainability metrics, it was underlined that sustainability topics are also analyzed within the GIF, but mainly with focus on nuclear fuel utilization and waste minimization. In the case of INPRO, concept of sustainability is much broader and complete. It additionally includes topics of resource depletion (considering also fuel utilization), environmental impact of stressors and waste management, among other topics. As regarding to weighting factors for different categories of the INPRO sustainability, it was announced that there are no “weight factors”, it is a uniform gap assessment across all sustainability items.

- About which criteria should be used for addressing the acceptable consequences of different plant states considering their relative frequency , it was explained that different criteria are used in the Member States.

Maintaining fuel integrity and coolability are relevant criteria for not exceeding acceptable doses for Normal Operation (NO), Anticipated Operational Occurrences (AOOs) and Design Basis Accidents (DBAs) and Design Extension Conditions (DEC) without core damage. In this case maximum fuel pin cladding temperature is one of the relevant and common variables for meeting dose limits. .

- During the discussion, an opinion was expressed that the elimination of EPR will not be possible for reactors since potential source term is present. It was responded that, at the design level, improvements in safety of next generation reactors need to be targeted for potential elimination of off-site EPR. The design goal is to have inherently safe, passive and robust systems which can potentially result in no need for emergency planning offsite at any time. Improvement of level 3 and 4 of DiD will be critical in eliminating EPR, i.e. the 5th level of DiD. From the design perspective, this goal may be achievable by providing appropriate safety level of assurance. However, the standpoint of likelihood of conditions beyond design events, emergencies stemming from security events, etc., this would require definition of appropriate off-site EPR arrangements that should be available at the operational level. The debate should then be focused in the adequate extent of those off-site EPR arrangements. This is certainly the hard core of the debate among technology developers for these next generation reactors and the EPR community.

- Clarifications regarding Advanced Heavy Water Reactor (AHWR) design against earthquakes, especially the use of large water pools on top of the containment and necessity of venting system were raised. It was explained that seismic criteria must include enveloping scenario developed by standard methodology for deciding design basis ground motion for reactor structures and components and safety related systems, which considers history, fault lines analysis, etc. Design of structures need to be done for enveloping cases. Regarding venting system, it was explained that hard vent systems need to be hardened for this reason and its failure will be next level in multiple failures. The venting will be required after pressurization and at the expense of the enthalpy of the passive decay heat removal pool, which can provide sufficient time for emergency measures. For example, for AHWR and in the case of severe accident, it takes 10 days for the pressurization of containment and the eventual need for controlled venting. Restoration of the Gravity Driven Water Pool (GDWP) inventory can extend this requirement further.

- It was discussed whether the EPR criteria shall be based on a maximum credible accident. It was responded that PSA is a very good tool to support decisions on EPR requirements. However, one problem was mentioned regarding the lack of operational experience in these new next generation reactors that involve the existence of relevant uncertainties in PSA models.

- During discussion of the Lead Cooled FBR, it was asked if hydrogen from corium–concrete reaction is considered as a potential source of hydrogen generation. It was announced that hydrogen production is possible by molten corium–concrete interaction (MCCI), but this is the late phase of severe accident and the sequence to reach this phase was not identified. This scenario requires more investigation.

- On this same subject, a comment was made that possible production of radioactive gases due to the cooling of the reactor and of the safety vessel should be taken into account.

  It was commented that the molten core is at higher temperature than the coolant. Contacting with lead, it can be solidified and produce flow blockage before it gets on top. This should be considered.

  It was asked if release of lead was considered as a danger. The release of lead vapor has to be in the existing limits established by the Romanian regulations on atmospheric releases. This is an issue, and it has to be considered during the licensing process.

- During the discussion of the paper regarding MSR, it was asked about the capability of the fuel salt to retain fission products and how water impurities impact on the releases of fission products from the fuel salt. It was clarified that there are no exothermal reactions of the fuel salt with water. Fission products oxides have low volatility. Therefore, interaction of the fuel salt with water was not taken into account in modelling. It was asked, if the MSR can be designed as breeder. It was answered that both fast and thermal spectrum MSR breeder options are possible. The MSR breeder will need full scale fuel salt processing with the removal time of soluble fission products of 1-3 months at the thermal spectrum and more than 1 year for the fast and epithermal spectrum in a homogeneous core without moderator.

- It was noted during the discussion on the presentation dedicated to HTR-PM that this kind of reactor has a long grace period to provide safety measures in case of a severe accident. In this regard, a question was if it was considered by designers what happens if relevant safety measures are not realized during that grace time. It was answered that mitigation measures are always required. The accident transient progresses very slowly, radioactivity release is limited, therefore, there are long time to take appropriate measures. These measures can be taken after several days.

- Regarding presentation on applications of PSA and deterministic analysis related to EPR for these new reactors, it was asked whether application of the approach is applicable for preparedness or response. It was explained that this approach can be used for preparedness as well as at the response stage of EPR. However, applicability of the approach is more valuable during the response as it provides clear guidance regarding actions especially in the early stage of the accident when information about the accident is less and evolution of other parameters like meteorological are difficult to predict accurately. Clarification about whether the Generic Criteria (GC) are specified in the code was asked. It was informed that the GC are specified in the regulatory codes.

- Questions to the paper presented on Gas Cooled Fast Reactors (EM2) were mainly corresponding to fuel reprocessing. It was explained that heavy metal loading in the EM2 is about 40 ton in form of uranium carbide fuel. The choice of the carbide fuel type is to increase heavy metal loading that can achieve core criticality. The reprocessing method being considered for recycling of spent fuel is a dry process which could be an AIROX type process possibly supplemented by electro-magnetic separation technology. A closed fuel cycle will be definitely possible if a wet reprocessing technology is used to take away 40% to 60% of fission products from spent fuel. Development of the dry reprocessing technology for separation of fission products is required. The estimated maximum neutron damage of fuel pin cladding is 300 dpa with an average value of 150 dpa. Currently for SiC it has been obtained up to 80 to 100 dpa. In regards to water temperature in DRACS loops, it is about 100-150°C.

- During discussion of the paper related to the influence of the type of coolant on EPR, a comment was made that for the case of gas-cooled reactor (modular HTR or VHTR). The temperature of the fuel and its integrity is not dependent upon the type of coolant, but it depends on external air cooling, level of power density, thermal fuel capability, and core design. The fuel temperature limit in case of the loss of coolant for VHTR, will not be exceeded.

- Regarding the presentation on the nuclear burning wave reactor, it was asked what types of coolant had been considered for possible design development. It was explained that sodium, lead-bismuth and helium had been considered.

- Concerning the presentation done on mechanistic model of source term for the FBR, a sensitivity analysis was discussed that included uncertainties in calculation the methods such as the impact of application of a simplified codes based on fractional releases. The ANL team used RASCAL code (USNRC code) for off-site releases and investigated dose caused by both external dose and land contamination. The variables examined in the sensitivity analysis included variations in a burner vs. breeder reactor inventory, release fractions from the fuel, bubble/vaporization fractions, aerosol deposition rates, and leakage rates from the cover gas region and containment.

Answering the question about how significant a difference is in isotopic release fractions for metal vs. that oxide fuels. It was explained that the largest difference between metallic and oxide fuels would be at the initiation and transition phases of a severe accident. Due to very high thermal conductivity of metallic fuel, failure would fairly and predictively occur near the top of fuel column (where cladding temperature is the highest), and post-failure motion of the molten fuel would provide a negative reactivity effect. For significantly hotter oxide fuel, failure would arise closer to the core mid-plane and molten oxide fuel would more likely create coolant boiling and blockage due to refreezing. Therefore, an energetic re-criticality that could challenge the reactor vessel and even the containment integrity is more likely for oxide fuel.

- In discussions of the presentation on the graded approach for sizing of emergency planning zones (EPZs) for SMR, the first question was on the position of the US regulatory body regarding adopting SMR-specific EPZ sizes. The US regulator recognizes the potential appropriateness of a “right-sized” scalable SMR-specific EPZ. This is substantiated by the Nuclear Regulatory Commission (NRC) document, SECY-11-0152, which notes the NRC staff’s intent to develop a technology-neutral, dose-based, consequence-oriented emergency preparedness framework for light-water SMR designs. The SECY document notes an expectation that the emergency preparedness framework would account for reactor design variation, modularity, co-location and EPZ size. The NRC is currently proceeding with rulemaking to address emergency preparedness for SMRs and other new technologies, such as non-LWRs.

It was also asked about the theoretical and regulatory basis for the deposition phenomena discussed. Current NRC guidance (Regulatory Guide 1.183) allows the use of aerosol natural deposition correlations to quantify post-accident nuclear containment decontamination factors. Correlations for large LWR have previously been developed to quantify the contribution of natural phenomena to post-accident aerosol decontamination. Specific correlations must similarly be developed to support the safety analyses of PWR SMRs. Preliminary analytical studies show that the smaller containment vessel volume to surface area ratio, coupled with the thermal hydraulic properties of SMR plants, would significantly enhance decontamination factors for these smaller plants. The proposed experimental design will quantify the amount of decontamination from natural phenomena for a range of SMR physical and thermal hydraulic characteristics. A set of preliminary assessments showed that diffusiophoresis, thermophoresis and hygroscopic effects are the major areas with a research gap for PWR SMR plants, hence these three areas are foci of the research.

- More general questions were also raised. One regarding the cost drivers that contribute to the overall cost to be attributed to the implementation of the scalability of EPZs. In this specific USA case, it was explained that there are capital costs, fees (NRC and Federal Emergency Management Agency), and operating and maintenance costs involved. The cost includes the cost of emergency services, KI pills, etc. There was a detailed study by Idaho National Laboratory that discussed the cost drivers within an EPZ. The document title is “Opportunities in SMR Emergency Planning,” published in October 2014 (INL/EXT-14-33137).

  The US regulator is considering a graded approach in right-sizing EPZs for SMRs, which could eliminate up to the extent feasible or minimize off-site EPR arrangements. On this regard, a conversation from a subjective and qualitative discussion on the benefits of SMR designs could lead to a more objective and quantitative description of the respective safety systems. This will help in making a case to support and advance the SMR framework emergency preparedness in developing adequate rulemaking by the regulators.

- Comment for future consideration was made that other actions should be considered for new generation reactors, such as change the process, also societal aspects (like risk perception) should be taken into account.

Summarizing results of Session 2 with focusing on EPR aspects, it can be said that the key design goal of next generation reactors is to eliminate the necessity of emergency off-site response, in particular evacuation of the population, in case of severe accidents. In general, agreement existed that it is necessary to maintain off-site EPR, i.e. 5th level of DiD, however the specific scope of these offsite arrangements should be determined in a graded approach and should be commensurate to the decrease in hazard level that these new reactors may be able of demonstrating.

D. Session 3: *Relevant lessons from past emergencies*

The presentations given during this session addressed the relevant lessons from important emergencies having happened in the past, both from the standpoint of EPR improvements identified and for safety aspects relevant to prevent repetition of similar accidents. Special emphasis was put on the Fukushima accident, where very relevant lessons have been identified as included in the Fukushima Daiichi Accident Report published by the IAEA in 2015 [The Fukushima Daiichi Accident-Report by the Director General, IAEA, 2015]. It was highlighted that the lessons from past severe NPP emergencies, regarding EPR arrangements definition and implementation, have been identified and described in detail in several publications (such as the IAEA Fukushima Report previously mentioned). The most relevant aspects of these lessons identified are reflected in the International Safety Standards for Emergency Preparedness and Response [in particular, General Safety Requirements Part 7: Emergency Preparedness and Response, IAEA, 2015].

The emergencies at NPPs in the past show that severe accidents have happened and can happen. Pre-established EPR arrangements play a key role to allow for adequate , response measures to be implemented in order to protect the public and the environment, should such accidents occur. The requirements defined for EPR framework and arrangements are defined in the IAEA Safety Standard Series GSR Part 7, which considers the main lessons identified from those past emergencies. Among those lessons identified from past emergencies, it must be highlighted the need to properly consider and improve some relevant components of EPR for applicability to the next generation reactors, such as:

- Hazard assessment and consideration of the different emergency preparedness categories.
- Justified and optimized protection strategy.
- Criteria to protect emergency workers and helpers.
- Effective communication to address public concerns.
- Proper consideration of especially vulnerable population groups.
- Involvement of the medical community.
- Arrangements to deal with the waste generated during the response.

The need for an all-hazards approach was another key element addressed during the session. However, a detailed quantification in this regard is difficult, and different factors need to be considered, including dose consequence to the public, societal and economic factors affecting EPR. The consideration of non-radiological consequences was also highlighted as being very relevant according the experience of past emergencies. Other aspects were also discussed based on two examples:; the decontamination and associated generation of waste following an accident and the size of emergency planning zones and distances. The all hazards approach may require including additional experts from other areas of expertise into the discussion. Determining the right balance between all hazards lies outside of the scope of this TM. However consideration of this criterion is of paramount importance for adequate implementation of EPR aspects as indicated, for example, in GSR Part 7.

In GSR Part 7 it's mentioned that emergencies similar to the ones actually having occurred in the past should be considered in the Hazard Assessment to be carried out for the definition of the EPR arrangements. As an example, current off-site EPR arrangements for LWR are in most of the cases commensurate to the consequences of Fukushima Daiichi accident, and this is an important factor for having the existing arrangements for LWR NPP reasonably similar in many MS. Regarding next generation reactors, since no relevant experience exists, this aspect should be further assessed and additional guidance provided to allow for an harmonized approach being implemented in different MS.

Other important aspects were raised regarding specific lessons learned from Fukushima Daiichi accident:

- Fukushima accident was a multi-hazard and multi-unit accident. In this regard, these aspects should also be mentioned and considered for setting an optimized and effective EPR system. Adequate arrangements (in terms of number of qualified personnel and amount of equipment and supplies etc.) shall be made to manage all the units if each of them is under emergency conditions simultaneously. Furthermore, these aspects should also be considered for next generation reactors

- One of the main lessons learned from Fukushima accident is the proper consideration of vulnerable population groups while setting EPR capabilities. In this regard, a comment was made regarding the need for revising the practical guidance of the IAEA (IAEA EPR Series EPR-NPP-PPA-2013) has included foetus dose criteria for determination of emergency planning zones. It was said that the assumption included in this document that equivalent dose to an adult from inhalation is approximately equal to the equivalent dose to the foetal thyroid could not be justified. Hence, to make EPZ determination on more realistic bases, further research should be initiated to correctly estimate the actual dose received by the foetus

E. **Session 4**: ***EPR and next generation nuclear power reactors***

The presentations of this session tried to dig in how to analyse the improved safety features expected for next generation reactors to adequately determine the required EPR arrangements with due consideration to those features and ensure proper public and environment safety.

The effects of new reactor technology were presented by various experts, showing a significant variation in the estimate of potential off-site consequences, ranging from emergency preparedness category I to III. This would result in significantly different off-site EPR arrangements, ranging from very small off-site EPR arrangements, to similar EPR arrangements as those established for current generation reactors.

Some presentations were focused on the precautionary action zone, without consideration of the remaining emergency planning zones and distances established in IAEA Safety Standards Series No GSR Part 7. In addition, not the full range of required response actions was addressed in most of the presentations.

The need to provide an incentive for new next generation reactor developers was also discussed. Reduction of EPR arrangements in recognition of new reactor designs was presented as a possibility, but was also questioned. Providing specific criteria to the developers at which a reduction of EPR arrangements may be reasonable, was also suggested by one of the presenters.

There seemed to be a general agreement that offsite EPR arrangements may need to be adapted in order to be commensurate and appropriate to potential hazards stemming from new reactor designs. Regarding the possibility of deletion of offsite EPR arrangements for these next generation reactors, in general it was acknowledged that eliminating this 5th layer of DiD should be out of question. However, some different opinions were expressed regarding the practical feasibility of this design goal of next generation reactors. In any case, developers and operators will have to provide proof for their claims of improved safety to the regulators, who are ultimately responsible for the safety of the public. Specifically in the United States, the NRC is considering rulemaking for new technology designs where the plume exposure pathway EPZ size is scalable in proportion with potential accident consequences; the potential exists for this EPZ to be contained within the site boundary, thereby impacting offsite response.

The discussion also addressed the use of deterministic vs probabilistic analysis. No clear agreement was reached. In the discussion, participants expressed different opinions as explained below:

- The probabilistic approach provides a comprehensive approach for consequences assessment, and it can be used for preparedness as well as response stage of EPR.
- The probabilistic method is more valuable during response as it provides clear guidance regarding the actions especially in early stage of accident when the information about the accident is less and development of other parameters like meteorology are difficult to predict accurately. Use of information from the PSA are required for new plant designs to inform accident sequence selection, determine release timing and release magnitude, and for determining off-site doses.
- In summary, the probabilistic approach should be used; there is a need for using it in preparedness; it also helps to deal with public health issues; however, considering the lack of operating experience of these new generation reactors, PSA information should be used with due precaution until having more validated data.
- It was stated that, the deterministic approach is used for determination of the source term. If next generation reactors prove they have “practically eliminated” events leading to large releases, it doesn’t mean that there will be no need for emergency planning. Elimination of EPR will not be possible for these reactors just on this basis since their source terms are potential for off-site dose consequences. However, graded approach should be always a key criterion for defining the scope of the necessary EPR arrangements.

- It was also mentioned that security related events will have an important contribution to risk and hence to the determination of appropriate off-site EPR arrangements. Security events should only be addressed using deterministic approaches.

It was pointed out that improvements in the safety of next generation reactors need to be targeted, as a design goal, for potential elimination of EPR in off-site. Finally, it was generally agreed by the participants that there should be a combination of deterministic and probabilistic approaches to tackle the need for preparedness and the need for having a plan in place to pursue these approaches.

It was also generally agreed that there is a need for more conversation between two groups: EPR and designers/operators. There should be a link between design concepts on how to make the EPR analysis for next generation reactors since conceptually they use different technologies.

There was general agreement that more detailed technical guidance and planning for public protection should be prepared for supporting MS to deal with next generation reactors. It was suggested to the IAEA that, in order to develop EPR Series publications[4] on this topic, first analysis has to be done for customizing the emergency preparedness for next generation reactors. The Agency's mechanism of Coordinated Research Project (CRP) could be considered in support of such documents.

The need for further coordination on this topic was agreed on by many of the participants.

4. TM CONCLUSIONS

[4] Initially it was suggested the need for at least one EPR Series document, but considering that EPZ determination approach for all new generation reactors would be a difficult task due to design differences that would result in wide variation of potential off-site EPR needs, the development of several EPR Series documents was also suggested by different participants.

Detailed presentations were given and fruitful discussions and exchange of views were held during the TM. Some relevant conclusions may be drawn to be considered in the way forward to reaching consensus so that this debate about Next Generation Reactors (NGR) and EPR can be settled in a technically adequate and sociably acceptable fashion.

It was acknowledged that the main achievement of the TM was bringing together, for the first time experts from the technology developers of next generation reactors, from the safety assessment field and from the EPR field. This has allowed for open exchanges of information and views, better understanding of each other’s perspective, and building trust among experts belonging to different communities. This forum should be continued in the future, by different ways: by promoting participation of experts from other fields, as adequate, in relevant technical debates of each community of expertise; by developing more detailed technical guidance with the participation of experts from different areas; and by organizing future follow up meetings on this EPR topic to consolidate the agreements reached in the process.

There are some overall aspects regarding NGR and EPR stemming from the TM presentations and discussions that should be taken into account in moving towards settling this debate:

1. Regarding the Defence in Depth concept, after being thoroughly reviewed in view of the Fukushima Daiichi accident, general consensus exists that the model is valid. Some reinforcements have been defined in all layers, to make them more robust and mutually independent. Regarding EPR, it remains at the last layer to protect the public and the environment from unacceptable consequences of NPP severe accidents, irrespective of its origin (this means, for example, that security triggered accidents should be considered). The need for EPR arrangements should be defined in advance (preparedness) to cope with accidents beyond design basis and beyond design extension conditions, continues being the hard core of this layer of protection. Also some additional aspects has been raised to strengthen this 5th layer, such as reinforcing the all hazard approach and the consideration of combined events

that may simultaneously trigger the accident and harm the capabilities for response.

2. It was acknowledged that NGR are aimed at having more robustness in the 4 first layers (prevention and mitigation of accidents involving potential for large releases), that certainly could make less likely the occurrence of large releases and also lower the source term to be released should a severe accident occur. This should be properly taken into account in the hazard assessment that is the basis, on a graded approach, to formulate the required off-site EPR arrangements to be implemented as appropriate.

3. Regarding the goal mentioned in the NGR design about the elimination of the need for off-site EPR, this should be considered as a design goal. Nevertheless, considering the uncertainties in different design analysis, the possible occurrence of events not addressed in the design, the existing threat about security initiated events, etc., off-site EPR arrangements will be needed to be in place for these NGRs. The scope of these arrangements may vary within a wide range of possibilities, both in the type of protective actions considered and in the planning zones affected. The challenge for both communities (EPR and technology developers) is reaching consensus in the definition of adequate EPR arrangements needed to provide appropriate public and environment protection while avoiding extrapolation of current EPR arrangements defined for large LWR.

4. Additionally, regarding the possible downsizing of off-site EPR arrangements, it will be very important to communicate adequately to the public the grounds for less demanding EPR arrangements, by clearly linking such reduction to the strengthened safety features of NGRs and clarifying that public and environment safety are not diminished but rather strengthened.

5. International Safety Standards provide adequate basis for design requirements to be implemented in NGRs. However, additional guidance could be needed and it its development should be considered as NGR designs make progress and, if possible, before the projects for deployment of these

new reactors begin. On this regard, it was noted that there are important differences in the timeline of development of the different concepts of NGR.

6. Regarding International Safety Standards in EPR, it was acknowledged that GSR Part 7 requirements are fully applicable to NGR and provide the frame for defining the adequate off-site EPR arrangements to be implemented. However, it was also acknowledged that the development of more detailed technical guidance for EPR for NGRs would be helpful.

7. Among important safety features that should provide for a potentially lower off-site consequence impact of severe accidents in NGR, it was highlighted:
    - Lower source terms based on different inherent features, depending on the specific NGR design
    - Longer time to core melt that allows more effective mitigating actions to be implemented, before significant core damage occurs. Hence, allowing for further decrease in the likelihood of large releases.

8. NGR designs are being developed in an international technically cooperative environment and with different degrees of development of the different types of NGR. EPR considerations should be incorporated in proper design stages and adequate safety cases be developed in this regard. This should foster public confidence if properly explained and communicated.

9. It was acknowledged that significant uncertainties exist regarding hazard assessment needed to develop EPR arrangements for these NGR. Basically these uncertainties are linked to:
    - In many cases of NGR, the design is in a very preliminary status that makes difficult the existence of technically solid grounds for this assessment
    - There is no operational experience about next generation reactors. Only some laboratory prototypes are in operation so far. This creates high uncertainties regarding PSA models.

- Security events should always be considered. The uncertainties regarding security threats and their potential to trigger events involving large releases are difficult to narrow.

It should be expected that many of these uncertainties may be tackled as the design and operational experience evolve.

As main conclusions for future developments in the debate on EPR for NGR, it should be highlighted:

- **Mutual understanding and cooperation between both EPR and NGR development experts is crucial.**

- **The TM has met the goal of being a first milestone in this debate. The ultimate goal is to build a technically sound and fair consensus in addressing EPR for NGRs.**

- **Basic consensus seems to exist regarding some overarching aspects :**
  - ✓ Off-site EPR arrangements should still exist for NGR reactors, with an adequate scope defined on a graded approach.
  - ✓ In the NGR design there is a potential of significantly improved safety features. Proper consideration to these safety features should be given in determining off-site EPR arrangements.
  - ✓ The off-site EPR arrangements should be based in the consideration of events beyond design basis and design extension conditions. In addition, events caused by malevolent acts should be considered.

- **It’s important having defined a consistent approach, adequate terminology and/or clarification of design goals for NGR regarding EPR, the new regulations in EPR to be issued, and the implementation of adequate off-site EPR arrangements. Communication to the public should convey a consistent message on all these topics.**

As way forward after this TM, there are some important aspects to be taken into account as future steps, which should allow making progress in the mid-term:

- Developing research activities focused on different aspects to further examine the different technical aspects of this debate.
- Developing technical guidance at the international level that could be useful for MS in the regulatory decision making process
- Taking practical steps to make sure that both EPR and technology developers communities cooperate and keep each other mutually aware about relevant developments that could be made in the above points.
- Organizing follow-up TM meetings on this topic, as appropriate.

ATTACHMENTS

- Opening speech (DDG-NS) and Closing speech (Director NENP on behalf DDG-NE)
- TM Agenda and Facilitators and Rapporteurs list
- TM attendees list

ATTACHMENT 1

A. Opening remarks by Mr. Juan Carlos Lentijo, DDG, Head of Nuclear Safety and Security Department, IAEA

Ladies and Gentleman:

It's my pleasure to welcome you on behalf the IAEA to this TM on Next Generation Reactors and EPR. Thanks a lot for attending to and participating in this important TM. In this year we are commemorating the 60th anniversary of the creation of the IAEA. In this regard, it's worth to remind IAEA's motto: "Atoms for peace and development", and also what important is to guarantee an adequate level of safety in all the applications of nuclear and radioactive technologies.

This TM is, somehow, and special meeting because the topic to be addressed let me further explain this point. As you know, one key element for the safety of nuclear power reactors is the concept of defence in depth. This concept provides for different layers of protection that, should one of them fail, it's expected to have other subsequent layers providing adequate protection to the safety of the public and the environment. The last layer of defence in depth is precisely EPR, which is expected to ultimately provide protection to minimize, up to a reasonably acceptable level, the impact of any nuclear accident on the public health and safety. We had several examples in the history of nuclear power about the importance on EPR in this regard.

In the recent years there is taking place some growth in construction of new plants, mainly based in evolution of proven designs conceived years ago, including some improved safety features. However, for these evolutionary reactors basically the provisions on EPR as the last layer of the defence in depth concept are basically equivalent or even reinforced to the existing ones for the reactors of past decades.

Along with this trend, we are observing in the recent years and, for sure, we will also observe in the years to come new reactor designs being developed, with a dual purpose: being more efficient and also safer. These innovative designs, known commonly as "Next Generation Reactors", encompass novel design features, departing from the traditional designs of LWR and HWR, such as Fast Breeder Reactors, Small Modular Reactors, High Temperature Gas Cooled Reactors, etc. These new concepts are expected to allow for better efficiency, reduced construction period and other advantages from the economic standpoint. But in many cases they also claim to have new, streamlined safety features, which may introduce new elements in the debate about the EPR arrangements needed for these new reactors designs. Since EPR requirements to be put in place regarding a specific facility should be defined on a graded approach and based on the assessment of the hazard stemming from the facility, this approach certainly deserves attention.

Owing to these new safety features of the Next Generation Reactors, it’s claimed that the likelihood of severe or major accidents could be very low. Along with this idea there have been raised also some expectations about the possibility of making significantly diminished the need for offsite emergency arrangements or even making them unnecessary.

Certainly, it could be considered as legitimate to raise these expectations from the standpoint of the developers of the technology, since offsite EPR involves relevant burden for the existing NPP and also currently for new build plants. On the other hand, there is a consensus that we should learn from the lessons drawn from past accident and be aware that strong safety attributes, including EPR, are essential for NPP operation. Thus, a debate should be set to address this point to be ready to reach in the future an adequate consensus and make sound decisions when the moment arrives for having these new generation reactors operational.

Let me raise some considerations about the IAEA’s view of this debate. As “Atoms for peace and development organization”, we certainly provide support to peaceful uses of nuclear and radioactive applications, as NPP. But we are strongly convinced that adequate, consistent and strong safety levels should be achieved and maintained to allow for fair and sustainable NPP operation. “Safety first” is much more than a simple phrase for the IAEA Secretariat. Among other features of the safety levels that should be guaranteed for proper NPP operation, adequate and robust EPR arrangements are of paramount importance to protect public safety. This debate is just starting, and precisely this TM should be a first milestone to address the referred topic. That’s why this meeting is special as I mentioned before.

In organizing this TM our aim was at bringing together relevant representatives from many different MS belonging to the different technical fields involved in this topic: On the one hand, we have attendees belonging to the EPR field who are expected to bring their expertise regarding the current arrangements to make EPR more effective and better protecting he population and the environment, and also the lessons learned that have allowed to build robust EPR arrangements based on international Safety Standards. On the other hand, we have attendees belonging to the technical community that is developing the design concepts for these Next Generation Reactors. And we expect to have them bringing relevant information on how those features should be taken into account in the definition of the EPR arrangements to be put in place regarding these reactors, especially for offsite emergency plans. We have also attendees coming from the safety assessment field, whose contributions are expected to be relevant for providing information that should frame the debate by setting the safety goals that are expected to be fulfilled by Next Generation Reactors. This TM encompasses relevant presentations from different perspectives that are expected to provide suitable basis for a fruitful debate taking place.

Also we expect that in the debate we could identify other relevant elements to be taken into account, as societal perspective, for example. EPR provides not only for real protection, but also provides reassurance to the people to be protected, so in setting EPR arrangements this point should definitively be taken into account. In the end, decision making regarding EPR arrangements and framework is not only up to the regulators or to the operators, but rather up to the government of every MS.

For sure, since this is the first step to address in this ambitious fashion this debate, and since the topics involved are quite complex, we don't expect that the conclusions of this TM providing an answer to these questions. They should be settled in the long term considering all the complex elements involved that I've referred to previously. We expect this TM be a valuable first step towards building a consensus on the approach to be adopted regarding this relevant point for future reactors.

I encourage you to actively participate in this TM which should provide basis for unfolding this debate in the years to come. I thank everybody for the contributions provided already in advance, which have allowed for configuring an important set of presentations from many relevant experts. I'm also very grateful for all the contributions that I'm sure you will provide during the discussions to be held during this TM.

I wish you a very fruitful meeting and a pleasant stay in this city of Vienna.

B. Closing Remarks by Mr. Dohee Hahn (Director NENP Division)

Good morning, Ladies and Gentlemen,

Now we have completed a week long intensive discussions on *Next Generation Reactors and Emergency Preparedness and Response*.

On behalf of the IAEA, I would like to thank you for your valuable contributions to make this important TM a success.

This meeting represents the first attempt to create an effective channel of communications between safety experts and the community developing next generation reactors.

Experiences and lessons learned regarding emergency at nuclear power plants, and implementation of EPR approaches and practices have been shared during the meeting. And, developers and designers of advanced reactor concepts have presented, safety features of these systems, consideration on the source term in case of severe accidents, as well as current approaches to reduce EPR requirements.

There was also a valuable opportunity to hear about, how some regulators are considering EPR from the perspective of licensing next generation reactors. Last but not least, it was beneficial for us to review status of development of the SFR safety design criteria and guidelines within the Generation IV International Forum.

Overall, the meeting was very useful for EPR experts to understand main safety features of next generation reactors, and for the next generation reactor developers to consider EPR issues at an early stage of reactor design. All these elements, along with your valuable recommendations and suggestions, have been well captured and reflected in the Summary of the meeting. It will represent a good basis for future initiatives in this area, including follow-up meetings to be organized by the IAEA.

Let me also emphasize that this event represents another example of one-house approach at the IAEA. The Department of Nuclear Safety and Security took the lead in organizing this important technical meeting, and it has been pleasure for the Department of Nuclear Energy to collaborate for the success of the meeting.

From this point of view, I would like to express my appreciation to the IAEA secretariat, Mr Ramon De La Vega, Mr Vladimir Kriventsev, Ms Adriana Baciu and Mr Mikhail Koroshev.
Of course, this event could not be successful without valuable contributions from all participants.

I look forward to your continuous involvement in the Agency activities, and hope to see you again here, in Vienna.

Wishing you all a safe trip back home, I declare the Technical Meeting on 'Next Generation Reactors and Emergency Preparedness and Response' now closed.

ATTACHMENT 2

A. Meeting Agenda

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

Technical Meeting on
Next Generation Reactors and
Emergency Preparedness and Response

13-17 February 2017, IAEA Headquarters, Vienna, Austria

FINAL PROGRAMME

	Monday 13 February 2017
10:00 - 13:00	Registration (Vienna International Centre, Room **M4**, M building)
14:00 - 17:30	**Opening Session**
14:00 - 14:20	Welcome and Opening remarks: *J.C. Lentijo, DDG-Department of Nuclear Safety and Security, IAEA*
14:20 - 14:40	Meeting scope, objectives & associated logistics *R. De la Vega, Meeting Scientific Secretary, IAEA*
14:40 – 15:00	IAEA role on enhancing global nuclear safety *G. Caruso, IAEA*
15:00 - 15:30	***Coffee Break***
15:30 - 16:10	Keynotes 1: ***Concept of defence in depth as fundament for safety of nuclear power reactors*** *J. Yllera, IAEA*
16:10 - 16:50	Keynotes 2: ***Current developments for next generation nuclear power reactors*** *I. Ashurko, Russian Federation*
16:50 – 17:30	**Discussions and feedback**

Tuesday 14 February 2017

09:30 - 17:30	**Session 1: *Implementation of IAEA fifth level of defence in depth and safety requirements for emergency preparedness and response (EPR)***
09:30 - 10:00	Keynotes 3: ***Strategic approach for protecting the public in a general emergency at a nuclear power plant*** *M. Tkavc, Slovenia*
10:00 – 10:30	Emergency Action Levels as indicators of status of defence in depth *V. Kutkov, Russian Federation*
10:30 – 11:00	***Coffee Break***
11:00 – 12:00	***Member States presentations on implementation of IAEA safety standards on Emergency Preparedness and Response***
11:00 – 11:20	Strengthening of the Belarussian EPR system in the framework of the Belarussian NPP construction *Y.A.Buhrou, Belarus*
11:20 – 11:40	The evolution and improvement of external emergency plan of Angra Dos Reis NPP *J. B. Araujo, Brazil*
11:40 – 12:00	Implementation of IAEA safety standards on Emergency Preparedness and Response in Slovakia *A. Sokolikova, Slovakia*
12:00 – 12:30	**Discussions and feedback**
12:30 – 14:00	***Lunch Break***
14:00 – 14:30	Keynotes 4: ***GSR Part 7 international requirements on EPR for ensuring protection of the public*** *S. Nestoroska-Madjunarova, IAEA*
14:30 – 15:00	Actions to protect the public in a nuclear emergency (based on EPR - NPP Public Protective Actions) *P. Vilar-Welter, IAEA*
15:00 – 15:30	***Coffee Break***
15:30 – 16:00	Future development of Safety Standards on Emergency Preparedness and Response *M. Breitinger, IAEA*
16:00 – 17:00	***Member States presentations on implementation of IAEA safety standards on Emergency Preparedness and Response***
16:00 – 16:20	Emergency Preparedness and Response approaches and practices in relation to next generation NPP in Kenya *E.K. Kiema, Kenya*
16:20 – 16:40	Implementation of IAEA safety standards on emergency preparedness and response in Pakistan *Z.A. Khan, Pakistan*
16:40 – 17:00	Strengthening of EPR framework in South Africa *A. Muller, South Africa*
17:00 – 17:30	**Discussions and feedback**
18:00 – 20:00	**Social event** *A&B Room, VIC*

Wednesday 15 February 2017	
09:30 - 17:30	**Session 2: *Next generation nuclear power reactors design concepts and safety features***
09:30 - 10:00	**Keynotes 5: IAEA activities in support of development of next generation energy systems** *S. Monti, IAEA*
10:00 - 10:30	INPRO activities *J.Phillips, IAEA*
10:30 - 11:00	***Coffee Break***
11:00 - 12:00	***Member States presentations on next generation nuclear power reactors design concepts and their safety features in relation to off-site emergency response***
11:00 – 11:15	Advanced nuclear reactor design concepts and safety features for elimination of emergency planning and response in public domain *M.T. Kamble, India*
11:15 – 11:30	Some aspects of the source term formation in GEN IV LFR systems and the potential of the design to eliminate off-site emergency response needs *M. Constantin, Romania*
11:30 – 11:45	Safety features of the next generation of molten salt reactor systems *V.V. Ignatiev, Russian Federation*
11:45 – 12:00	The Chinese HTR-PM approach to Emergency Preparedness and Response *Fu Li, China*
12:00 – 12:30	**Discussions and feedback**
12:30 - 14:00	***Lunch break***
14:00 - 14:30	**Keynotes 6:** ***Application of probabilistic and deterministic safety assessment methodologies for EPR purposes*** *J. Koley, India*[5]
14:30 – 15:30	***Member States presentations on next generation nuclear power reactors design concepts and their safety features in relation to off-site emergency response***
14:30 – 14:50	Technology development for gas-cooled fast reactors *Choi, H., USA*
14:50 – 15:10	The approach of the FBU "SEC NRS" to the evaluation of the influence of the type of reactor coolant for emergency preparedness and response *V. Pivovarov, Russian Federation*
15:10 – 15:30	Nuclear burning wave reactor and its response on external actions *S. P. Fomin, Ukraine*
15:30 – 16:00	***Coffee Break***
16:00 – 16:30	Sodium Fast Reactor Mechanistic Source Term Development *T. Sofu, USA*
16:30 – 17:00	Establishing right sizes for SMR Emergency Planning Zones *S. Talabi, USA*
17:00 - 17:30	**Discussions and feedback**

[5] Given on his behalf by M.T.Kamble

Thursday 16 February 2017

09:00 - 11:00	**Session 3: *Relevant lessons from past emergencies***
09:00 - 09:30	Keynotes 7: ***Impact of past nuclear accidents on international requirements on emergency preparedness and response*** *W. Weiss, Germany*
09:30 - 10:30	***Member States presentations on experiences in learning lessons from past emergencies***
09:30 – 09:50	French experience on main causes and factors that have affected the reactor safety in past accidents *Y. Flauw, France*
09:50 – 10:10	Feedback from past accidents for improving safety features and safety analysis of CFBRs in India *P. Chellapandi, India*
10:10 – 10:30	Lessons learned from past emergencies: Bulgarian experience *K. Ivanova, Bulgaria*
10:30 – 11:00	**Discussions and feedback**
11:00 – 11:30	**Coffee Break**
11:30 – 12:30	**Poster Session**
12:30 - 14:00	***Lunch break***
14:00 - 17:30	**Session 4: *EPR and next generation nuclear power reactors***
14:00 - 14:30	Keynotes 8: ***Generation-IV International Forum (GIF) SFR Safety Design Criteria and Guidelines*** *T. Sofu, USA*
14:30 – 15:30	***Member States presentations on EPR in relation to new design power reactors***
14:30 – 14:45	Proposed Coordinated Research Project on Small Modular Reactors (SMR) Emergency Planning Zones sizing *Xinjian Liu, China (presented by Mr Fan Li)*
14:45 – 15:00	Current issues and prospects on emergency preparedness in Korea *N.Y. Kim, South Korea*
15:00 – 15:15	Current EPR approach in France for reactors under construction and/or approval, with particular reference to next generation reactors *Y. Flauw, France*
15:15 – 15:30	Next generation reactors and emergency preparedness and response: an NRC perspective *A.O. Costa, USA*
15:30 – 16:00	***Coffee Break***
16:00 – 17:30	***Panel Discussions on future need for off-site EPR in relation to next generation reactor***

Friday 17 February 2017

09:30 - 12:00	**Closing Session: *Way forward***
09:30 - 10:30	Summary of the meeting • Individual session summaries *Sessions' Raporteurs* • Final conclusions and way forward *R. De La Vega, Meeting Scientific Secretary, IAEA*
10:30 - 11:00	***Coffee Break***
11:00 - 12:00	Closing remarks *D.Hahn, Director NENP, Department of Nuclear Energy, IAEA*

B. List of Meeting's Facilitators and Rapporteurs

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

Technical Meeting on Next Generation Reactors and Emergency Preparedness and Response

13-17 February 2017, IAEA Headquarters, Vienna, Austria

Assignments Facilitators/Rapporteurs

Monday 13 February 2017

14:00 - 17:30 **Opening Session**

Facilitator: R. De la Vega, IEC
Rapporteur: J. Yllera, NSNI

Tuesday 14 February 2017

09:30 - 17:30 **Session 1:** ***Implementation of IAEA fifth level of defence in depth and safety requirements for emergency preparedness and response (EPR)***

Facilitator: R. De la Vega, IEC
Rapporteur: Katerina Kouts, IEC

Wednesday 15 February 2017

09:30 - 17:30 **Session 2:** ***Next generation nuclear power reactors design concepts and safety features***

Facilitator: Iurii Asurko, Russian Federation
Rapporteur: Vladimir Kriventsev, NE / Mikhail Khoroshev, NE

Thursday 16 February 2017

09:00 - 11:00 **Session 3:** ***Relevant lessons from past emergencies***

Facilitator: R. De la Vega, IEC
Rapporteur: Philip Vilar Welter, IEC

14:00 - 17:30 **Session 4:** ***EPR and next generation nuclear power reactors***

Facilitator: Vladimir Kriventsev, NE
Rapporteur: Mikhail Khoroshev, NE

Friday 17 February 2017

09:30 - 12:00 **Closing Session:** ***Way forward***

Facilitator: R. De la Vega, IEC

ATTACHMENT 3

List of Attendees

Technical Meeting on Next Generation Reactors and Emergency Preparedness and Response, 13 – 17 February 2017, Vienna			
Country	**Salutation**	**First Name**	**Last Name**
Armenia	Mr	Artem	Petrosyan
Belarus	Ms	Viktoryia	Dziamyanchyk
Belarus	Mr	Yury	Buhrou
Brazil	Mr	Araujo	Jefferson Borges
Bulgaria	Ms	Krasimira	Ivanova
Canada	Mr	Ki Cheung	Leung
China	Mr	Fan	Li
China	Mr	Fu	Li
Croatia	Mr	Sasa	Medakovic
Czech Republic	Mr	Josef	Koc
Democratic Republic of the Congo	Mr	Leonard	Woto Makontshi
Egypt	Mr	Mohamed	Gaheen
Finland	Mr	Mikko	Ilvonen
France	Mr	Yann	Flauw
Germany	Mr	Roland	Styranowski
Hungary	Mr	Lasczlo	Csok
Hungary	Mr	Tamas	Pazmandi
India	Mr	Maheshkumar	Kamble
India	Mr	Perumal	Chellapandi
Indonesia	Mr	Dedik Eko	Sumargo
Iran	Mr	Behrouz	Rokrok
Italy	Mr	Giacomo	Grasso
Japan	Mr	Hirofumi	Ohashi
Jordan	Ms	Nida	Al Faraheed
Kenya	Mr	Edward	Kiema
Korea, Republic of	Mr	Sang Hyun	Park
Korea, Republic of	Mr	Nam Yeong	Kim
Lithuania	Mr	Evaldas	Kimtys
Malaysia	Mr	Faeizal Bin	Ali
Nigeria	Mr	Abubakar	Kabir
Pakistan	Mr	Zulfiqar Ahmed	Khan
Qatar	Mr	Mohammed	Al-Hijji
Romania	Mr	Marin	Constantin
Russian Federation	Mr	Iurii	Ashurko
Russian Federation	Mr	Valerii	Pivovarov

Russian Federation	Mr	Aleksander	Katsman
Russian Federation	Mr	Vladimir	Golubkin
Russian Federation	Mr	Sergey	Kharlampiev
Russian Federation	Mr	Alexey	Kosov
Russian Federation	Mr	Alexey	Kiselev
Russian Federation	Mr	Victor	Ignatiev
Slovakia	Mr	Eduard	Metke
Slovakia	Ms	Adriana	Sokolikova
Slovakia	Mr	Michal	Makovnik
Slovakia	Mr	Branislav	Hatala
Slovakia	Mr	Karol	Feik
South Africa	Mr	Alan	Muller
Ukraine	Mr	Sergii	Fomin
UK	Mr	Chris	Hall
USA	Mr	Edward	Roach
USA	Mr	Arlon	Costa
USA	Mr	Hangbok	Choi
USA	Ms	Raluca	Scarlat
USA	Mr	Sola	Talabi
Viet Nam	Mr	Xuan Khanh	Tao