Western European
WENRA RHWG
Nuclear Regulators Association

Summary Report

WENRA Safety Reference Levels 2014 – Implementation at the nuclear power plants, reasonably practicable safety improvements and benchmarking

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Background and Approach

In 2014 WENRA published the revised Safety Reference Levels (SRLs) as the result of a review in light of the learning from the TEPCO Fukushima Daiichi NPP accident. The first task for WENRA countries was to implement the new SRLs into their national regulations. Following this WENRA's Reactor Harmonization Working Group (RHWG) started to discuss options for a benchmarking process on the implementation of SRLs at the Nuclear Power Plants (NPPs).

During its fall meeting in 2017, WENRA advised that RHWG should combine the following tasks into a single task:

- Implementation of the 2014 SRLs at the plants,
- Safety improvements for implementation of the Vienna Declaration on Nuclear Safety (VDNS).

It was agreed that the task should look at the implementation of a subset of SRLs at a representative sample of existing NPP per country, covering the range of reactor designs in WENRA countries. WENRA suggested that RHWG should review the implementation of Issue F for plant faults with emphasis on severe accident management. The task should also look at:

- Implementation of the European Union Nuclear Safety Directive (NSD) articles 8(a) to 8(c) - especially 8(a),
- Benchmarking on specific safety improvements.

Concerning the task defined by WENRA, RHWG started its work in January 2018 by selecting SRLs F4.8 to F4.13 and F4.15 to F4.18 as candidates. These SRLs were selected as the ones that would provide the most fruitful insights, are linked to Article 8a and are particularly associated with preventing early and large releases.

After selecting the SRLs, a methodology was discussed and a pilot study was started in January 2019. It was then concluded from the pilot study that the chosen approach would be suitable for:

- data collection and evaluation of the implementation status of SRLs in NPPs on the basis of SRL specific lists of safety improvements,
- compiling related implementation time spans in the countries (it has to be emphasized that evaluations on the timeliness of the implementation of a safety improvement should only be carried out on a case-by case basis) and
- identifying different approaches in order to allow national authorities to learn from each other.

The chosen approach provided an overview of the current status of the implementation of the chosen SRLs in the NPPs. Different technical solutions to fulfil a SRL were compiled in order to allow learning from each other. It became clear that many safety improvements to comply with the selected SRLs had been implemented long before the NSD or VDNS. Due to the positive feedback from the pilot study, the task was continued for the other SRLs and benchmarking of the related underlying national self-assessments was performed in parallel.

Depending on the SRL, the lists may be different for the different reactor types to be considered in WENRA countries (i.e. AGR, BWR, CANDU and PWR)[1]. All existing reactor types that are still in operation are included in the exercise. Plants that are under construction but not yet in operation are not included (e.g. the EPR projects[2]) since the WENRA SRLs have been developed for existing plants. However, "deferred" plants such as Mochovce unit 3 & 4 are included.

Nuclear power plants in WENRA observer countries were included in the exercise to the extent that these countries wished to be. Thus, Japan participated with their PWR plants[3] and Canada provided some input for CANDU plants. It has to be emphasized that Ukraine did not have the opportunity to participate in or to contribute to the process after February 2022.

The objectives of the benchmarking process that started in May 2020 were:

- to share information on approaches to implement the SRLs in the NPPs and to enable learning across WENRA members;
- to evaluate the compliance with the safety objective of the SRL in the related NPPs.

Benchmarking exclusively concerned the SRLs F4.8 to F4.13 and F4.15 to F4.18 without consideration of the remaining SRLs of Issue F. The SRLs, however, need to be considered as a whole set. It should therefore be noted that the benchmark assessment did not review if the selection of DEC events and event combinations, to which RLs F4.8 to F4.18 refer, conforms with the complete set of SRLs in Issue F. The benchmarking process also did not include reviews of whether the SSCs used in DEC have the capacity and capability and are adequately qualified to perform their relevant functions as required by F4.2 for all DEC scenarios. Thus, it should be clear that the benchmarking that was performed cannot be seen as an in-depth review of the technical or analytical aspects of the various SRL related safety relevant aspects, nor can conclusions be drawn on the overall safety of the NPP. This kind of review and assessment is the duty of national safety authorities.

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1 For example, for SRL F4.10 ("*The threats due to combustible gases shall be managed.*") different lists of technical solutions have been prepared for each specific reactor type, whereas for F4.17 ("*Adequate power supplies during DEC shall be ensured considering the necessary actions and the timeframes defined in the DEC analysis, taking into account external hazards.*") one list is used for all reactor types.

2 This is also the case for the EPR in Olkiluoto that in the meantime started commercial operation.

3 It has to be noted however, that the information given for the Japanese PWRs is valid only for those plants that obtained restart permission after the Fukushima accident up to 2019.

During the test benchmarking it became clear that, as the SRLs are intended to be technologically neutral, multiple technical solutions have been implemented at the plants that fulfil the same safety objectives identified in the SRLs. Furthermore, it has to be noted that answers provided in the national self-assessments for the implementation status at the plants represent the up-to-date situation, notwithstanding the time frame for implementation and the continuous improvement process. For example, the objective of a SRL could have been complied within the initial design of the NPP, but a modification could have been implemented after a reassessment with the objective to improve safety. Thus, answers given by the countries provide a snapshot of the current situation and of recent improvements, even though the corresponding SRL could have been fulfilled already before a modification.

The benchmarking was done by mutually checking the information given in the national self-assessments, by reviewing whether this information was considered as detailed enough, comprehensible and consistent with the understanding of the safety functions to be fulfilled by the different technical solutions, and, finally, sufficient to confirm that the SRL as a whole is implemented in the related NPPs.

Countries that received questions were required to provide answers to the related Benchmark Group (and to the country that addressed the questions). The benchmarking was then performed by the Benchmark Groups during RHWG meetings.

The benchmarking results are based on the information provided by the participating countries. However, it should be noted that the situation in the plants themselves has not been verified.

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Results

In the following, the implementation status of the chosen Safety Reference Levels (F4.08 to F4.13 and F4.15 to F4.18) in the NPPs of the participating countries is presented, together with SRL specific observations and potential topics for future activities.

SRL F4.08: *Isolation of the containment shall be possible in DEC. For those shutdown states where this cannot be achieved in due time, severe core damage shall be prevented with a high degree of confidence. If an event leads to bypass of the containment, severe core damage shall be prevented with a high degree of confidence.*

This SRL is implemented in all participating countries and their related NPPs.

Observations specifically addressed in the benchmarking:

- Containment isolation function is available during DEC, as well as during total Station Blackout (SBO) and natural hazards (earthquakes) more severe than the design basis in all NPPs. This was already reassessed during the EU stress test and resulting safety improvements were implemented.

Potential topics to be considered in RHWG's future activities:

- Shutdown states with the equipment hatch open:
  When closing the equipment hatch is not achievable in due time, severe core damage shall be prevented with a high degree of confidence. A future activity of RHWG could be to exchange information on the implementation of provisions to achieve such a degree of confidence.

SRL F4.09: *Pressure and temperature in the containment shall be managed.*

This SRL is implemented in most countries – for a few countries (Czechia and Hungary) it is "partially" implemented but planned to be fully installed in 2024 at the latest.

In Czechia, this is the case because a vacuum breaker system inside the containment (WWER-440) and a filtered containment venting system (WWER-1000) are under construction.

In Hungary, this is the case because an external independent water source for the long-term containment cooling system is still under construction (WWER-440), it will be implemented with the SAMG update in 2024.

Observations specifically addressed in the benchmarking:

- A Containment spray system (CSS) is installed in most NPPs (design specific) and is adequately qualified. The need for this system may differ according to the safety demonstration.
- Long-term heat removal by sump re-circulation and cooling is installed in all PWR and Romanian CANDU NPPs.
- Containment external spray system is installed in two PWRs (in the WWER-440 in Finland and in Slovenia).

SRL F4.10: *The threats due to combustible gases shall be managed.*

This SRL is implemented in all participating countries.

Observations specifically addressed in the benchmarking:

- Passive Autocatalytic Recombiners (PARs) inside the containment (PWR) are installed at all PWR NPPs and designed with margin in their total efficiency. PARs are not planned in the BWRs in Finland and Sweden, where the containment is N_2-inerted, but installed in those BWRs where accessibility of the containment or parts of it is needed during power operation. PARs are also installed in the CANDU NPPs in Romania.

  In the discussions during the benchmarking it was highlighted that functioning of the PARs should be regularly tested and confirmed under appropriate test conditions; adequate testing procedures and intervals should be defined and included in the inspection procedures.
- Monitoring systems inside containment for hydrogen concentration (PWR and PHWR/CANDU) is installed at all NPPs to serve as an indication for possible threats to the containment integrity but not necessarily used for decision making.
- Hydrogen igniters are not needed in general, although they are installed in some PWR, PHWR/CANDU and BWR containments as a complementary measure to PARs to control hydrogen.

Potential topics to be considered in RHWG's future activities:

- Accident conditions potentially resulting in high hydrogen peaks locally in the containment: In case that accident conditions may result in locally high hydrogen concentrations, igniters may be considered helpful as diverse means to the PAR concept, depending on the containment design and the plant specific transient. Care has to be taken not to increase steam condensation inside the containment and thus enable reaching hydrogen flammabil-

ity limits by severe accident management measures (e.g. actuating the containment spray system) as long as high hydrogen concentrations may be possible.

SRL F4.11: *The containment shall be protected from overpressure. If venting is to be used for managing the containment pressure, adequate filtration shall be provided.*

SRL F4.11 is implemented in all participating countries. At those plants where venting is used, filtration is provided.

In Ukraine (WWER-1000 units), the implementation of filtered containment venting systems (FCVS) on some power units of the Zaporizhzhia NPP has not been completed due to the occupation of the NPP by the Russian Federation in March 2022. In the United Kingdom, a filtered venting system is planned to be installed at the PWR and work is on-going to develop the design to consider hydrogen combustion inside the venting system. For the AGR plants safety release valves and a filtered blow-down route was installed as part of the basic design.

Observations specifically addressed in the benchmarking:

- FCVS: reducing the possibility for hydrogen combustion inside the venting system:
  - FCVS piping may be pre-inerted during normal NPP operation.
  - FCVS preheating may exclude hydrogen combustion that can become possible after condensation of the vapour in the piping.

Potential topics to be considered in RHWG's future activities:

- Solutions regarding reduction of the possibility of hydrogen combustion inside the venting system (see observations).
- Provisions to avoid containment overpressure in the case of an earthquake more severe than the design basis earthquake.

SRL F4.12: *High pressure core melt scenarios shall be prevented.*

This SRL is considered as implemented in all participating countries with the exception of Ukraine, where "partially" implemented is reported. There, in particular, the discussion about qualifying existing equipment for superheated steam conditions continues.

Observations specifically addressed in the benchmarking:

- All NPPs have means to prevent high pressure core melt scenarios by ultimate opening of safety and relief valves (diverse I&C) even in the case of SBO.
- In addition, to prevent core damage at PWRs there are two strategies that can be applied:

- Strategy 1: strengthening the cooling function of the primary circuit by the steam generator, with dedicated diverse means even in case of a SBO.
- Strategy 2: feed and bleed strategy (note, in SBO scenarios this strategy is not available in all countries).

SRL F4.13: *Containment degradation by molten fuel shall be prevented or mitigated as far as reasonably practicable.*

This SRL is implemented in all participating countries with the exception of Bulgaria and Czechia, where "partially" implemented is reported.

In Bulgaria and Czechia, this is the case because means to ensure long term corium cooling in the reactor cavity are under construction (WWER-1000 NPPs).

Observations specifically addressed in the benchmarking:

- Plants have different safety strategies (this may include one or a combination of in-vessel, ex-vessel, wet pit, dry pit) to prevent or mitigate containment degradation by molten fuel as far as reasonably practicable. These are dependent on design specific features and based on retrofit capability.

SRL F4.15: *Adequately qualified instrumentation shall be available for DEC for determining the status of plant (including spent fuel storage) and safety functions as far as required for making decisions.*[43]

[43] *This refers to decisions concerning measures on-site as well as, in case of DEC B, off-site.*

This SRL is implemented in all participating countries.

Observations specifically addressed in the benchmarking:

- Instrumentation is appropriately qualified and available also during SBO in all countries. There are different requirements and approaches between instrumentation dedicated to DEC A and DEC B. Instrumentation dedicated for DEC A is often the same as for DBA. DEC B instrumentation is often different due to different parameter sets or ranges expected in DEC B and different qualification requirements. The approach to the qualification depends on the plant specific accident management strategy.
- In the spent fuel pool (SFP), severe accidents are considered extremely unlikely with a high degree of confidence in all countries. Due to this, dedicated SFP instrumentation for DEC B is not considered as essential. Nevertheless, all NPPs have measurements for either water level and/or temperature. In some countries, dosimetry measurement is available as a pos-

sible diverse option for decision making or obtaining information about the status in the SFP.

- The required information is available in:
  - The main control room (MCR).
  - The monitoring and control location that is physically, electrically and functionally separate from the main control room – "emergency control room" (ECR).
  - The emergency control centre or emergency response centre (ERC) which have the same or almost the same information available as in the MCR and ECR; some countries have their ERC bunkered while others have their technical support centre/operation support centre located in different buildings.
  - Other locations (on and/or off-site).
- Terminology used for the different control room or other centre locations varies from country to country.

SRL F4.16: *There shall be an operational and habitable control room (or another suitably equipped location) available during DEC in order to manage such situations.*

This SRL is implemented in all participating countries with the exception of the Netherlands, where "partially" implemented is reported.

In the Netherlands this is because the operability and habitability of a control room during DEC is currently rediscussed in the 2023 PSR.

Observations specifically addressed in the benchmarking:

- As already mentioned under F4.15, the terminology used for the different control room or other centre locations varies from country to country.
- Operability and habitability of the MCR is ensured in all countries including in the case of severe accident and extreme external natural hazards. Some countries installed additional equipment to manage DEC conditions in the MCR and the protection of the personnel against radioactivity or dangerous substances.
- All countries have an ECR or remote shutdown station or panel. In some countries, this workplace can be used in the event of inhabitability of the MCR and extreme natural hazards or severe accident conditions. The safe accessibility of the ECR/remote shutdown panel is assessed in all countries depending on the previously mentioned approach for ECR/remote shutdown panel use.
- In the event of SBO, all MCR can be used for some time using batteries. After that, most countries rely on emergency diesels, some countries portable devices and manually activated systems.

SRL F4.17: *Adequate power supplies during DEC shall be ensured considering the necessary actions and the timeframes defined in the DEC analysis, taking into account external hazards.*

This SRL is implemented in all participating countries with the exception of Hungary, where "partially" implemented is reported.

In Hungary, this is the case because diverse diesel generators and their availability in case of natural external events more severe than the design basis is not yet completed (2023-24), as well as the 72 hours site autonomy.

Observations specifically addressed in the benchmarking:

- Deployable Back-Up Equipment (DBUE):
  For cases where the timeframes defined in the DEC analysis show that there is enough time for fuel and other auxiliary material that is stored in areas protected from potential natural hazards to be flown in or trucked in from support centres in due time, the DBUE approach is considered as a solution that may help to increase the reliability of power supply in case of external natural events more severe than the design basis events. This approach makes use of existing on-site equipment (that is not reliant on electrical power, e.g. diesel powered or steam-driven feed pumps) so it would increase the timeframes to bring additional portable equipment to the site.

  Although there is a minimum site autonomy expectation of 72 hours in the event of external natural hazards more severe than design basis events, the licensees are also expected to make arrangements for a prolonged SBO beyond that. The use of DBUE will be helpful or could complement potential stationary back-up solutions in case of a prolonged SBO.

SRL F4.18: *Batteries shall have adequate capacity to provide the necessary DC power until recharging can be established or other means are in place.*

This SRL is implemented in all participating countries.

Observations specifically addressed in the benchmarking:

- Battery unloading times differ depending on the power supply strategy.
- Battery capacity and recharging is considered sufficient in all countries. Different power sources are available for ensuring sufficient DC power supply. All countries use one or more mobile diesel generators to do recharging, beyond the available design equipment.
- Some countries introduced procedures for prolongation of the batteries capacity via load reduction/loadshedding. In this case, it has to be emphasized that procedures for the re-

lated manipulation under DEC conditions need to be prepared. Load reduction (to save battery capacity) using disconnection of equipment needs adequate assessment and decision making criteria. This has to be well documented, with training provided and should be supported by adequate PSA analyses.

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Summary and Conclusions

In 2017 WENRA requested RHWG to select SRLs from Issue F and to review and benchmark the implementation at the plants.

This report presents the results from the benchmarking, which included the following:

- data collection and evaluation of the implementation status of SRLs in NPPs on the basis of SRL specific lists of technical solutions that were compiled at the beginning of the exercise,
- a period of questions and answers on technical solutions,
- compiling related implementation time spans, and
- identifying different implementation solutions.

Through this process RHWG gathered insight and reached common understanding on the situation in WENRA countries with respect to implementation status.

It can be concluded that, in general, the implementation of SRLs considered here is complete in most countries' NPPs and that the technical solutions for implementing the SRL may be different depending on the characteristics of the plant. In some countries, full implementation is not yet achieved, but work is underway to achieve this. A number of potential topics for future discussion were identified during the exercise; in the opinion of RHWG, further consideration of these topics may reveal opportunities for additional safety improvements or harmonisation.

Complying with the SRLs included in this study is essential in achieving the goals set out in the NSD and the Vienna Declaration. The exercise shows that in many cases, related technical measures were implemented before the NSD and the Vienna Declaration came into force. It can therefore be noted that the WENRA countries were already following the principle of continuous improvement. Complementary to continuous safety improvement in European NPPs, which is an ongoing process overseen by national regulators, up to date SRLs are key to harmonized nuclear safety standards in Europe.

Developing and undertaking an adequate benchmarking process was a complex and time consuming task. For similar exercises in future, optimisation of the process should be considered.