NEW NPP RISK ZONING IN RELATION TO PSA AND RISK OF EXTERNAL EVENTS
(APPLICATION TO IRIS DESIGN)

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Abstract
The design basis for any plant and site is deeply related to the effects of any postulated external
events and the limitation of the plant capability to cope with accidents, i.e. perform safety
functions. As a prime example of an advanced reactor and Nuclear Power Plant (NPP) with
enhanced safety, the International Reactor Innovative and Secure (IRIS) has been considered in
this work. In the used Safety-by-Design™ approach, the Probabilistic Risk Assessment (PRA)
plays obviously a key role, therefore a Preliminary IRIS PRA has been developing along with the
design. For the design and pre-licensing process of IRIS the external events analysis includes
both qualitative evaluation and quantitative assessment. As a result of preliminary qualitative
analyses, the external events that were chosen for more detailed quantitative scoping evaluation
are high winds and tornadoes, aircraft crash, and seismic events. In general, applying the
quantitative assessment, bounding site characteristics can be used in order to minimize potential
future restrictions on plant siting and risk zoning.

1. INTRODUCTION

It has been observed that the Probabilistic Risk Assessment (PRA) methodologies to deal with
Emergency Planning Zones (EPZ) and external events have not reached the same level of
maturity as for internal events 1. In general, the emergency planning zones are defined as well as
plant site and arrangement structures are designed to minimize the potential for natural and
manmade hazards external to the plant from affecting the plant safety related functions, which
can affect nearby population and environment. This may include consideration of extreme winds,
fires, flooding, aircraft crash, seismic activity, etc. Thus the design basis for plant and site is
deeply related to the effects of any postulated external events and the limitation of the plant
capability to cope with accidents, i.e. perform safety functions.

While for the “older” plants accidents initiated by internal events were typically dominant,
PRAs for existing and advanced plants, with improved design of Nuclear Steam Supply Systems
(NSSS) and safety systems, have shown that external events may now account for a significant
fraction of the total public risk due to specific plant vulnerabilities. Moreover, evaluation of
external events can be used to determine if there are any unforeseen vulnerabilities in the design
that can be eliminated by design during the still evolving design phase of the reactor.

As a prime example of an advanced reactor with enhanced safety, the International Reactor
Innovative and Secure (IRIS) 2, 3 has been considered in this work. The IRIS plant has used the
Safety-by-Design™ philosophy and its design features significantly reduce the probability and
consequences of major design basis internal events. Therefore, in the external event analysis, the
focus is on PRA and Balance Of Plant (BOP) that has not yet been analyzed as extensively or
explicitly as the Nuclear Power Plant (NPP) accidents caused by internal events.

For the design and pre-licensing process of IRIS the external events analysis includes both
qualitative evaluation and quantitative assessment. As a result of preliminary qualitative analyses,
the external events that were chosen for more detailed quantitative scoping evaluation are high
winds and tornadoes, aircraft crash, and seismic events. In general for the quantitative assessment, bounding site characteristics can be used in order to minimize potential future restrictions on plant siting and risk zoning.

As the IRIS project clearly shows, accident prevention is the main driving force for advanced reactor designs. Several design innovations are currently aimed towards bringing down conditional core damage frequencies to an extent that makes the plant less vulnerable to accident scenarios related to internal events, extreme external events and even malevolent events such as terrorist attacks.

In general, even taking into consideration the expected large diversities in the design features of advanced reactors, siting and emergency requirements, as well as risk zoning criteria for advanced reactors appear to need some modifications, with respect to the conventional approach developed for older reactors. Recent efforts to get benefits from adopting a complete risk-informed, performance-based regulatory process 4 is a clear indication that advanced reactor designs are credited to be safer and a certain degree of recognition for the effort in increasing the safety level can be accomplished.

The IRIS reactor is being used as a reference example because of its remarkable safety induced by the Safety-by-Design™ approach that characterized this project from the very beginning and that makes IRIS the ideal test bed for a challenge towards the redefinition of EPZ for NPPs.

2. APPROACH FOR IRIS

2.1 Safety-by-Design™ Approach

The IRIS has used the Safety-by-Design™ philosophy from its inception in 1999. Such a designing approach has been outlined in detail in previous works 2, 3; here it is suffice to remember that the key idea of the Safety-by-Design™ concept is to physically eliminate the possibility of occurrence or to reduce consequences of accidents, rather than focusing only on the mitigation phase.

The most evident implication of this design approach is the choice of an integral reactor configuration, where the integral reactor vessel (containing eight internal steam generators and reactor coolant pumps), the consequential absence of large primary pipes, the recently introduced internal control rod drive mechanism and a secondary side designed for full primary pressure to the secondary isolation valves have either eliminated major design basis events such as Large Break LOCA or rod ejection and significantly reduced the consequences of them.

The superb safety and high reliability of the IRIS reactor provide one important benefit. Its enhanced safety and significantly reduced accident probability provide a technical basis to achieving licensing with a reduced or eliminated emergency planning zone. This will enable placement closer to users and reduce infrastructure cost, as well as improve public confidence in nuclear power 2.

The Safety-by-Design™ approach, used by the designers of IRIS to eliminate the possibility of occurrence of certain severe accidents caused by internal events, is being extended to the external events. The focus is on the balance of plant that has not been analyzed as extensively or explicitly as NPP accidents caused by internal events. However, since extreme external events have one of the largest contributions to the degradation of the defence in depth barriers, the external events represent a major challenge to the designer in order to determine siting parameters and reduce the total risk.
2.2 PRA Application

In the Safety-by-Design™ approach, the Probabilistic Risk Assessment plays obviously a key role, therefore a Preliminary IRIS PRA was initiated already three years ago, and so far developed with the design, in an iterative way. This unprecedented application of the PRA techniques in the initial design phase of the reactor and the deep impact that this is having in the development of the project has been described in already published papers 2, 3, 5. We can here summarize this process by looking at the initial effort that was focused on internal events.

The success of the IRIS Safety-by-Design™ and PRA-guided design in the internal events assessments 3 is due to the effective interactions between the IRIS Design team and the IRIS PRA team (see Figure 1). The main task of the PRA team is to identify high risk events and sequences.

Figure 1. IRIS Design and PRA Team Interactions

The IRIS Design team provides information concerning the IRIS plant and site design. It updates IRIS component/system description and design data. PRA team identifies assumptions concerning IRIS plant and site design requirements. The design team then reviews assumptions concerning IRIS plant and site design requirements.

A preliminary evaluation of internal and external events was performed in the Preliminary IRIS PRA, to determine if there were any unforeseen vulnerabilities in the IRIS design that could be eliminated by design during the still evolving design phase of the reactor. The preliminary analysis of external events included both quantitative and qualitative analyses. For the quantitative analyses, bounding site characteristics were used in order to minimize potential future restrictions on plant siting.

Referring to Figure 2, it can be seen that the initial PRA for internal events resulted in a Core Damage Frequency (CDF) of $2.0 \times 10^{-6}$. The PRA team then worked with the IRIS design team in order to implement design changes that improved plant reliability and to identify additional transient analyses that show no core damage for various beyond design basis transients. The resulting CDF around $1.2 \times 10^{-8}$ is therefore obtained thanks to a combination of the Safety-by-
Design™ features of the IRIS design, coupled with the insights provided by the PRA team regarding success criteria definition, common cause failures, system layout, support systems dependencies and human reliability assessment.

Being still in a design development/refinement phase, the PRA is kept constantly updated with the evolution of the design; moreover, all the assumptions required to have a reasonable complete PRA model capable of providing quantitative insights as well as qualitative considerations, were accurately tracked down and the uncertainties connected with such assumptions were assessed. These refinements of the Preliminary IRIS PRA yielded a predicted CDF from internal events around $2.0 \times 10^{-8}$.

![Figure 2. IRIS Design CDF History](image)

The same method can be extended also to the external events. In comparison to events dominant in other plant PRA, the IRIS plant is expected to be significantly less vulnerable to some external events. In general, the IRIS plant arrangement structures are designed to minimize the potential for natural and manmade hazards external to the plant from affecting the plant safety related functions. The external events PRA insights are expected to help taking full advantage of the potential safety oriented features of the IRIS design, this will imply probabilistic consideration of extreme winds, fires, flooding, aircraft crash, seismic activity, etc. In addition, it can be shown that estimation of risk measures is related to the site size and can be the input for emergency zone planning. In external events PRA, the focus currently was set on the plant BOP, that has not been analyzed as extensively or explicitly as accidents caused by internal events.

### 2.3 External Event Analysis

Due to the early design phase of the IRIS BOP, some assumptions have been made for PRA. Specifically, assumptions were made in the qualitative evaluation of the external events impact, due to the absence of all the site-specific information theoretically necessary for this analysis.

The preliminary qualitative analysis and screening of external events considered for the IRIS PRA was, in general, based on the external events PRA methodology developed by the American Nuclear Society (see reference 6) and on the PRA’s of other NPPs (e.g. see reference 7).
For the quantitative analyses, bounding site characteristics were used in order to minimize potential future restrictions on plant siting. The following four separate steps were performed in order to identify external events to be considered:

1. Initial identification of external events to be considered.
2. Events with similar plant effects and consequences are grouped.
3. Screening criteria are established to determine which events are risk insignificant and can therefore be excluded from detailed quantitative evaluation.
4. Each event is evaluated against the screening criteria to determine if the event is risk-significant and thus requires further quantitative evaluation.

PRA Guides and PRAs of existing plants were used as sources of external events in order to ensure that all external events already recognized as possible threats for a NPP were taken into consideration. The resultant set of external events represents a consensus listing of external events. Next, the list was reviewed in order to group all the external events that are likely to have the same impact on the plant.

The following list in the evaluation process consists in the establishment of the screening criteria for determining which events are risk-insignificant and could be excluded from quantitative analysis.

The criteria used for excluding external events from detailed quantitative analysis are:

1. The plant design encompasses events of greater severity than the event under consideration. Therefore, the potential for significant plant damage from the event is negligible.
2. The event cannot occur close enough to the plant to have an effect on the plant’s operation.
3. The event has a significantly lower mean frequency of occurrence than other events with similar uncertainties and could not result in worse consequences than those events.
4. The event is included, explicitly or implicitly, in the occurrence frequency data for another event (internal or external).
5. The event is slow in developing, and it can be demonstrated that there is sufficient time to eliminate the source of the threat or to provide an adequate response.

The final step in the qualitative evaluation process is the evaluation of each external event against the screening criteria to determine if the event is risk-insignificant and could be excluded from further analysis. The external events identified as described above are screened in order to select the significant events for detailed risk quantification.

Some external events may not pose a significant threat of a severe accident, if they have a sufficiently low contribution to core damage frequency or plant risk. As a result of the qualitative evaluation or siting criteria application for each of the external event groups, the identified external events that need further quantitative scoping evaluation to determine their impact on the core damage were aircraft crash, high winds and tornadoes and seismic events.

This list of external events that require an additional analysis was consistent with previous PRAs and with what was suggested for analysis and the individual plant examination of external events (see reference 8). In general, a few so called area events such as internal flooding and internal fires are also considered for IRIS. An external event that was included in the IRIS PRA and was analyzed quantitatively and considered here as an example related to risk zoning is non-
screened event whose cause is external to all systems associated with normal and emergency operations situations, i.e. impact of aircraft crash.

2.4 Impact of Aircraft Crash

Within the analysis of a aircraft or other flying device (helicopter, balloon etc.) crash, as a rule, unintended aircraft accidents are examined while terrorist actions or other not ordinary human activities are excluded. Statistically, the analyzed frequency of aircraft crashes depends on the intensity of flights near the target object, the technical condition of the aircrafts, the experience of crew, the navigational elevated aids (radio beacons), the meteorological conditions and other factors.

The initial data for defining the aircraft crash probability includes:

- Distance of the NPP from civil or military airports;
- Arrangement of air transport corridors and their distance to the NPP;
- Intensity of flights in air transport corridors for the aircrafts with weight less than \( W \) and with weight \( W \) and higher (e.g. widely used limiting weigh \( W = 5700 \text{ kg} \));
- Distribution of flying aircrafts by types;
- Generalized world statistics for aircraft crashes by weight and types;
- Statistical data on serious incidents at the state.

2.4.1 Relation to Site Size

Plant site location with respect to airports and aircraft flight routes is the dominant factor in the potential for an aircraft impact at the plant site. Proper siting should result in aircraft hazards being a negligible contributor to core damage frequency for an IRIS plant. Specifically, a site in US can be treated as acceptable for IRIS without further review if the distances from the plant meet the following requirements:

- The plant-to-airport distance \( D \) is between 5 and 10 statute miles, and projected annual number of operations is less than \( 500D^2 \) flights, or the plant-to-airport distance \( D \) is greater than 10 statute miles, and the projected annual number of operation is less than that \( 1000D^2 \) flights.
- The plant is at least 5 statute miles from the edge of military training routes, including low-level training routes, except for those associated with a usage greater than 1000 flights per year, or where activities (such as practice bombing) may create unusual situations.
- The plant is at least 2 statute miles beyond the nearest edge of Federal airway, holding pattern, or airport approach pattern.

If above site proximity acceptance criteria are not met, or if sufficiently hazardous military activities are identified, an estimation of the aircraft crash occurrence and a detailed review of hazards must be performed to qualify a specific site for the plant.

Aircraft crash occurrence probabilities in relation to site design parameters can be estimated using model of aircraft crash. For aircraft crash probability estimation, when flying route distance from the object territory is \( s \), the following mathematical model was applied:
\[ P(s) = P_l \cdot N_e \cdot A \cdot \frac{g}{2} \cdot e^{-g \cdot s}, \]

where \( P \) is aircraft strike probability per year, \( P_l \) is aircraft strike frequency per flight kilometre, \( N_e \) is flight number per year, \( A \) is considered area, \( g \) - a constant dependent on type of aircrafts and describing likelihood of close crash (for passenger \( g = 0.23 \), for military aircrafts \( g = 0.63 \), and for transport \( g = 1.00 \)).

As civil aircrafts compose the major number of flights, values of coefficient \( g \) can be taken 0.23, which at the considered case is the most conservative from the above mentioned. This means that probability of the aircraft to deviate 10 kilometres aside its initial trajectory during the accident is 10 times less than to crash on it. This value was also used in some references, e.g. 9.

A model to estimate aircraft crash probability on different hazardous zone, i.e. on a circle with radius \( r \) (see Figure 3) was developed.

![Figure 3. Model to estimate aircraft crash probability](image)

Aircraft crash probability onto radius \( r \) of zone \( Z \) with the condition that the aircraft loses control and start to fall in distance \( s \) is expressed by:

\[ P_r(s) = \int_{-\infty}^{\pi} p(s) ds d\varphi = \frac{\pi \cdot g}{2} \cdot e^{-g \cdot s}, \]

and such \( p(s) = \frac{\pi \cdot g}{2} \cdot e^{-g \cdot s} \), that \( \int_{-\infty}^{\infty} s \cdot p(s) ds d\varphi = 1 \).

As an example, if the aircraft passes the 50 kilometre zone on a straight line touching the 10 kilometre zone around the NPP, the distance \( s \) of the aircraft from the NPP is equal to:

\[ s = \sqrt{x^2 + y^2}, \quad y = 10 \quad \text{and} \quad x \in (-50, 50). \]

Then the total aircraft impact probability on the NPP is estimated using the following equation:

\[ P = \frac{N_e \cdot P_l \cdot r^2 \cdot g^2}{2} \int_{-D}^{D} e^{-g \cdot \sqrt{s^2 + 100}} \, dx. \]

For the investigation of zone and aircraft size influence, calculations with different types of aircrafts and values of hazardous zone radius \( r \) are made (see Figure 4).
As some initial conditions and parameters of air crash models are not well-known or have different values for different types of aircrafts, an uncertainty and sensitivity analysis was also performed for the created model.

The PRA in relation to aircraft crash events can be conservatively related to different groups based on aircraft weight (see Table 1).

### Table 1. Initiator related to different aircraft

<table>
<thead>
<tr>
<th>#</th>
<th>Aircraft class</th>
<th>Weight, kg</th>
<th>Structural damage</th>
<th>Failure event description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light aircraft (design based)</td>
<td>&lt; 5700</td>
<td>Switchyard, power lines</td>
<td>Loss of off-site power</td>
</tr>
<tr>
<td>2</td>
<td>Heavy aircraft (design based)</td>
<td>≥5700 ≤ 5700*100</td>
<td>All, except auxiliary building</td>
<td>Loss of site water sources</td>
</tr>
<tr>
<td>3</td>
<td>Extremely heavy (beyond design)</td>
<td>≥5700*100</td>
<td>Auxiliary building</td>
<td>Structures collapse</td>
</tr>
</tbody>
</table>

Note: Presently there is no aircraft that would fit in the 3rd category.

The conditional CDF for these events can conservatively be calculated using the PRA model. Because IRIS is relying on Safety-by-Design™ and passive systems, a prolonged loss of off-site power and other similar effects is not foreseen to have a major impact on the plant. In addition, the plant arrangement structures are designed to withstand the additional effects (e.g. missiles) of any postulated external events such as aircraft crash without loss of capability to perform safety functions.

### 2.4.2 Assessment Considering Uncertainty

Here a part of the state of knowledge quantification related to the assessment considering uncertainty of model parameters is presented (for more details see references 10, 11). The uncertainties identified as potentially important and the subjective probability distributions together with their parameters specified for illustrative application are presented in Table 2.

The main parameters, which may impact the calculation uncertainty, can be divided into two main groups related to the initial conditions and to the model parameters.
Table 2. Selection of parameters, which may impact the uncertainty of calculation results

<table>
<thead>
<tr>
<th>#</th>
<th>Parameter</th>
<th>Ranges</th>
<th>Reference (mean m)</th>
<th>Standard deviation</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min.</td>
<td>Max.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Initial conditions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$P_l$, aircraft impact frequency per 1 km</td>
<td>$1.2 \cdot 10^{-9}$</td>
<td>$1.0 \cdot 10^{-7}$</td>
<td>$5.1 \cdot 10^{-8}$</td>
<td>$3.29 \cdot 10^{-8}$</td>
</tr>
<tr>
<td>2</td>
<td>$N_c$, flight number per 1 year</td>
<td>20000</td>
<td>50000</td>
<td>35000</td>
<td>10000</td>
</tr>
<tr>
<td></td>
<td><strong>Model parameter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$r$, aircraft impact radius, km</td>
<td>0.010</td>
<td>0.200</td>
<td>0.015</td>
<td>0.003</td>
</tr>
<tr>
<td>4</td>
<td>$g$, aircraft impact deviation coefficient</td>
<td>0</td>
<td>0.46</td>
<td>0.23</td>
<td>0.15</td>
</tr>
</tbody>
</table>

This analytical input related to variation of model parameters clearly does require an expert judgment. However, it is the only instance where a subjective enters the analysis. Referring Wilks formula and uncertainty methodology investigated 11, there were performed 100 numerical tests simulating different aircraft crash variations.

As quantitative uncertainty measures two-sided statistical tolerance limits (with given probability $u = 0.95$ and confidence $v = 0.95$) were chosen for each of the model results of interest. These limits contain at least 95% of the combined influence of all quantified uncertainties at a classical statistical confidence level of at least 95%. Two sided tolerance limits formed by sample extremes are $1.4 \cdot 10^{-9}$ and $5.9 \cdot 10^{-8}$.

The empirical distribution function is presented together with fitted Gamma distribution, which can be used as quite good approximation of model output. The minimum, maximum, mean, standard deviation and other characteristics of the model output sample are presented in Table 3. The lower and upper confidence limits are 5% and 95% quantiles derived from suitable observations by classical statistics. The 95% quantile, for instance says that the appropriate result value is below this quantile value with the 95% degree of belief.

Table 3. Main statistical characteristics of aircraft impact model output sample

<table>
<thead>
<tr>
<th>Result with (0.95, 0.95) tolerance limits</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Confidence limits (5%, 95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{aircraft impact}$ probability per year</td>
<td>$1.4 \cdot 10^{-9}$</td>
<td>$5.9 \cdot 10^{-8}$</td>
<td>$1.7 \cdot 10^{-8}$</td>
<td>$1.2 \cdot 10^{-8}$</td>
<td>Lower: $3.4 \cdot 10^{-9}$ Upper: $3.8 \cdot 10^{-8}$</td>
</tr>
</tbody>
</table>

Sensitivity estimations (Figure 5) evaluated from statistic analysis describe how aircraft crash initial conditions and model parameters influence the results. From the sensitivity results it is seen that the parameter $P_l$ has the highest (correspondingly the parameter $g$ has the lowest) influence on the results. The radius of aircraft crash impact zone is approximately in the middle.
The sensitivity factors (see Fig. 5), which are a by-product of the probabilistic analysis, tell the analyst which sources of uncertainty are contributing most to the uncertainty in the predicted performance. Thus, the analyst can determine which variables (model parameters) should be regulated and controlled better in order to decrease an unfavourable event occurrence. Alternatively, the analyst can determine which tolerances could be relaxed without substantially affecting system risk.

Summarizing, the maximal and minimal values of air crash per year probability are equal to $5.9 \cdot 10^{-8}$ and $1.4 \cdot 10^{-9}$, respectively. The average value of the aircraft crash per year probability is equal to $1.7 \cdot 10^{-8}$, the standard deviation is equal to $1.2 \cdot 10^{-8}$. The Gamma distribution is used to represent the obtained results. The main results of simulation are presented in Figure 6.

Estimation of air crash per year probability, with confidence levels that correspond to 5% and 95% quantile, is in the interval between $3.4 \cdot 10^{-9}$ and $3.8 \cdot 10^{-8}$.

Calculations showed that probability of external events, and more specifically probability of analysed aircraft crash occurrence is negligible, however the event occurrence and propagation can be sufficiently uncertain. Some events occurrence is unlikely probable, however similar events are analysed due to high negative consequence of impact. Even in case when the event analysis show rather limited danger, the sensitivity analysis can identify the highest influence factors. The possible variations of them can be significant for safety requirements and risk-based decisions making.
2.5 Designing Features

The Safety-by-Design™ approach, used by the designers of IRIS to eliminate the possibility of occurrence of certain severe accidents caused by internal events, has been extended to the external events.

The normally operating IRIS systems and their non-safety, active backup systems are typically located within substantial structures that can withstand some degree of external event challenges. This equipment includes the backup diesel generators. IRIS has non-safety related backup diesels for normally available active equipment that can bring the plant to cold shutdown conditions.

IRIS plant safety features, once actuated, rely on natural driving forces such as gravity and natural circulation flow for their continued function. These safety systems do not need diesel generators as they are designed to function without safety-grade support systems (e.g. AC power, component cooling water, or service water) for a period of 7 days.

All the IRIS safety related equipment including the batteries that provide emergency power, and the passive habitability system are also located within concrete structures. The reactor, containment, passive safety systems, fuel storage, power source, control room and backup control are all located within the reinforced concrete auxiliary building and are protected from on-site explosions.

Actually, IRIS has a very low profile, which is very important when considering aircraft crash, especially by terrorists. The IRIS containment is completely within the reinforced concrete auxiliary building and one-half of it (13 m) is actually underground. The external, surrounding building is only about 25 m high, thus offering a minimal target. The integral vessel configuration eliminates loop piping and external components, thus enabling compact containment (see Figure 7) and plant size.

![Figure 7. IRIS Containment](image)

The Refuelling Water Storage Tank (RWST) which is the plant’s ultimate heat sink, will be also protected from some external events by locating it inside the reinforced concrete auxiliary building structure. In addition, the IRIS RWST is designed to be replenished by alternative water sources such as fire trucks, therefore being completely independent by the plant power resources.
Because of these and other reasons, it is expected that the impact of external events at the site will be lower than that for current plants. In addition, summarizing, typical design approaches, that could contribute to achieve such robustness in advanced NPPs design are:

- Capability to limit reactor power through inherent neutronic characteristics in the event of any failure of normal shut-down systems, and/or provision of a passive shut-down system not requiring any trip signal, power source, or operator action.
- Availability of a sufficiently large heat sink within the containment to indefinitely (or for a long grace period) remove core heat corresponding to above-mentioned event.
- Availability of very reliable passive heat transfer mechanisms for transfer of core heat to this heat sink.

It was observed that the implementation of innovative design measures needs to be supported (and encouraged) by a rational, technical and non-prescriptive basis to define severe accident (core melt need not be presupposed to occur). The rational technical basis should be derived from realistic scenarios applicable for the plant design. Most of the innovative reactor designs aim to eliminate the need for relocation or evacuation measures outside the plant site, through the use of enhanced safety features in design. Many of these designs also aim to take advantage of these advanced safety characteristics to seek exemption from maintaining a large exclusion distance around the nuclear power plants.

3. RISK ZONING

In fact, in the context of some severe external events, the assumption of continued availability of infrastructure required to administer emergency measures (for example roads and bridges) may not be valid. Under such situation, it is more effective to enhance the quality of the other levels of defence in depth. There is therefore, a need to define the scope of off-site emergency planning activities for advanced reactors, consistent with the ability of these reactor designs to meet enhanced safety objectives.

In some cases, such as the presence of a nearby airport, consideration of the hazards may change risk zoning or eliminate a site from further consideration for an NPP, but most external hazards are either screened out from the necessity of being considered further or are taken account of in plant design and siting. Siting and risk zoning is a matter for:

- The uncertainties of risk measures and influence to the public perception;
- Economic consideration (where power is needed, the availability of existing grid);
- Social and political factors;
- Topography affecting the dispersion of radio-nuclides through the atmosphere, rivers and ground-water;
- Political and safety consideration;
- Demographic characteristics;
- Hazards (natural and man made).

Some IAEA Member States only address the risk to an individual member of the public, others have requirements to consider the potential aggregated effects to the population as a whole – societal risk.
Off-site emergency measures are still seen as part of the Defence in Depth approach, which is mainly understood in deterministic sense, but to take full advantage of new reactor designs it should be moved towards a more probabilistic approach performing risk, sensitivity and uncertainty analysis. The full benefit of innovative and evolutionary NPP requires the ability to licence without the need of an off-site Emergency Planning Zone.

In general, the desirability or possibility of reducing or eliminating emergency response plans for accidents depends not only on the reactor type but also on a number of complex and intertwined factors including technical, societal, economical and cultural. The subject cannot be coupled directly and solely to the requirements for the external events but requires a separate consideration. Under the same subject also the risk-informed decision making related to the design basis accidents and severe accidents are considered with the intent of moving away from postulated risk zones and towards mechanistically calculated risk zones. Without such a change, related procedures and criteria, the issue of the emergency response plans cannot be resolved. In particular, in order to deal with external events and apply the risk-informed approach for plant design and siting, it is desirable to couple the PRA with techniques of civil engineering.

3.1 Current national practice

The general objectives of emergency planning are to: prevent serious deterministic health effects and reduce the likely stochastic health effects of ionising radiation (cancer and other radiation-induced cases). In case of a radiological accident (due to internal or external events) in a nuclear power plant, in enterprises and facilities using nuclear sources, transporting radiological materials, the territory may be contaminated by radioactive substances. In order to evaluate the extent and consequences of radiological contamination in detail, the National emergency response plan is currently usually singled out from the rest of emergency response action plans. It gives a comprehensive description of possible consequences and actions of civil protection institutions and the population during the general accident. However, for the future licensing we need to promote enhanced licensing that should treat risk due to NPPs in the same way it is treated for other industrial facility.

As an example of the current regulation and planning, in the National emergency response plan of Lithuania, in the event of a radiological accident at a NPP, provided measures become operational as soon as the accident happens and when radioactive substances are spread or may be spread beyond the boundary of the NPP sanitary protection zone.

This Lithuanian plan provides means of protecting the population, their scope, terms, assignment of responsibilities, and implementation procedure. The plan is needed for organisation and co-ordination of actions taken over by ministries, other State Administration institutions, county and local municipal authorities for taking protective measures for arrangement of immediate response actions, for the operative notification of neighbouring countries of a nuclear accident or radiological emergency.

For the accident types, emergency response takes place over two distinct areas: sanitary protection zone and the area beyond the sanitary protection zone. Sanitary protection zone (SPZ) means the area surrounding the facility, which is under the immediate control of NPP in Lithuania.

The area beyond the sanitary protection zone is divided into three main zones: Precautionary action zone (PAZ), Urgent protective action planning zone (UPZ), and Longer-term protective action planning zone (LPZ). Precautionary action zone (PAZ) goal is to substantially reduce the risk of deterministic health effects of ionising radiation before radionuclides emission into the environment. Urgent protective action planning zone (UPZ) means a predesignated area around
the facility where a plan for urgent protective measures is made in advance. Longer term protective action planning zone (LPZ) means a predesignated area around the facility farthest from the facility and including the urgent protective action planning zone. It is the area for the actions to reduce the long-term doses from deposition and ingestion should be developed in advance.

These zones are roughly circular areas with NPP in the centre. The size of the zones (see Table 4) in Lithuania has been determined by an analysis of international practice.

<table>
<thead>
<tr>
<th>Name of the Zone</th>
<th>Sanitary protection zone (SPZ)</th>
<th>Precautionary action zone (PAZ)</th>
<th>Flight prohibition zone (FPZ)</th>
<th>Urgent protective action planning zone (UPZ)</th>
<th>Longer term protective action planning zone (LPZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from NPP</td>
<td>3 km</td>
<td>5 km</td>
<td>10 km</td>
<td>30 km</td>
<td>50 km</td>
</tr>
</tbody>
</table>

As the zones can be defined only for national territory (in spite that the NPP can be located near the border of country), in Lithuania UPZ and LPZ are evenly divided into 16 sectors, with the starting point from the geographical co-ordinates of the NPP. The angle of every sector is equal to 22.5 degrees. Each sector in its turn is further sub-divided into 6 segments: 3-5 km, 5-10 km, 10-15 km, 15-20 km, 20-30 km, 30-50 km from NPP.

The international co-operation of the Republic of Lithuania in the sphere of civil protection is based on universally recognised international principles of civil protection, human rights protection, environmental protection and common welfare following international treaties and other legislative acts. In case of a radiation accident in NPP, the Civil Protection Department shall immediately notify neighbouring countries on the incident and its expected consequences.

Information on the occurrence of the radiological accident or the exceedance of radiation in the Republic of Lithuania is passed to foreign countries and international organisations in the manner and size as required by the 1986 IAEA Convention On Early Notification of a Nuclear Accident in accordance with Governmental Regulation No 972 “On the Accession to the 1986 Convention On Early Notification of a Nuclear Accident” dated on 13 October 1994. To enforce the requirements of this resolution, in the event of a nuclear accident in the NPP, the Ministry of Environment shall present to the regulatory body (VATESI) current and forecasted hydro meteorological information, results of environmental gamma monitoring, on-going and planned radiation protection measures beyond the area of the sanitary protection zone, the expected time of the release of radioactive substances into the environment. The Radiation Protection Centre presents to VATESI the information on ongoing or planned population protection measures.

In case of a nuclear accident due to internal or external events, in its turn VATESI shall provide the IAEA and, directly or through the IAEA, the neighbouring countries, with which bilateral or multilateral co-operation agreements or treaties are signed, in accordance with the established format by the 1986 Vienna Convention the information on:

- time, exact geographical co-ordinates of the INPP and nature of the accident;
- possible or determined cause of the accident as well as the forecasted development of the accident, related to possible transboundary radioactive contamination;
• characteristic features of radioactive contaminants, including their nature, possible physical-chemical form, quantity, composition and effective emission height;
• current and forecasted hydrometeorological conditions in order to predict transboundary radioactive contamination;
• results of gamma environmental monitoring, in relation to transboundary radioactive contamination;
• on-going and planned radiation protection measures beyond the area of the sanitary protection zone;
• expected changes in emissions of radioactive substances over time.

In case of any change of the emergency situation, these data are updated, corrected and also provided to the IAEA and neighbouring states directly or through the IAEA and to the countries, with which bilateral or multilateral co-operation agreements or treaties are signed.

As Lithuania has joined the Europe Union, currently national regulations are taking into account the EU system on urgent exchange of information on radiation (ECURIE).

3.2 Further Work to Achieve Enhanced Licensing

The ultimate objective for advanced NPPs is to establish an enhanced approach to licensing, reflecting improved safety characteristics of advanced reactors, that is expected to justify and enable revised (reduced or eliminated) emergency planning requirements, while providing at least the same level to protection to the public as the current regulations. Ideally, the emergency planning zone would coincide with (or be contained within) the site boundary, thus, there would be no need for off-site evacuation planning, and the NPP would become, relative to the general population, the same type of facility as any other industrial enterprise.

In order to contribute toward achieving this ultimate objective by addressing some of the relevant issues there is a need to consider the following research tasks:
• Critically evaluate current regulations to identify what changes are necessary to enable advanced licensing.
• Identify criteria based on technical, quantifiable parameters that may be used in support of the objective.
• Identify approach, based on a combination of deterministic, probabilistic, and risk management, that will enable assessment of advanced plants based on their key design operational and safety characteristics with respect to adequate emergency planning requirements.
• Prepare site-specific representative data (e.g., meteorological).
• Perform probabilistic analyses needed to support the proposed approach.
• Perform deterministic / dose evaluation analyses needed to support the proposed approach.
• Perform a detailed evaluation of the representative reactor utilizing the combined proposed approach.
• Identify, discuss and quantify the benefits attainable through the implementation of this objective, i.e., licensing with reduced emergency planning requirements.
In order to perform these tasks with the ultimate goal of developing a technology-independent approach, the design of IRIS is used as a testbed. IRIS is representative of innovative reactors, but because it is a LWR, its possible sequences and its behaviour under accident conditions is much better understood and predicted than that of some more distant new technologies. Moreover, it has the necessary prerequisite, excellent safety, due to its Safety-by-Design™ approach.

The further work is within the scope of activities defined within the International Atomic Energy Agency (IAEA) Co-ordinated Research Project (CRP) on Small Reactors with no or infrequent on-site refueling. Specifically, it is relevant to “Definition of the scope of requirements and broader specifications” with respect to its ultimate objective (revised evacuation requirements), and to “Identification of requirements and broader specifications for NPPs for selected representative regions” considering specific impact on countries with colder climate and increased interest for district heating co-generation.

As a part of this CRP Lithuanian Energy Institute (LEI) will contribute to the overall objective by performing research related to a subset of the above listed tasks. It is expected that other tasks may be addressed by other participants within the IAEA CRP. LEI will review the current licensing regulations in Lithuania and identify necessary changes. It is expected that these results, supplemented by similar results obtained within this CRP by other member countries, would contribute to ultimately defining a generic, country-independent approach. This will support development of justification for reduced emergency planning through PRA analyses of external events and support activities performed primarily to PRA analyses.

In addition LEI initiated a study of the economic impact of revised licensing requirements on district heating. This work will determine potential economic benefits of revising the evacuation requirements and enabling NPP-based district heating. Thus the task is to perform economic study to evaluate positive economic effect on the nuclear district heating co-generation option, due to revised siting requirements with reduced emergency planning, which would allow placement of NPPs closer to population centers and allow them to be attractive generation option in the Lithuanian energy supply market.

As part of this IAEA CRP, the Polytechnic of Milan is involved in the development of a methodology for revising the need for relocation and evacuation measures unique for NPPs for Innovative SMRs. Within this framework the information gathered from the PRA (both internal and external events) will be used to provide a basis for the redefinition of the EPZ defining criteria. The proposed approach consists of coupling the PRA results with deterministic dose evaluations associated to each relevant PRA sequence considered, and thus achieving a technically sound bases for the definition of a plant specific EPZ. In this approach the two basic components of risk (i.e. probability of occurrence and consequences of a given accident) are therefore explicitly combined. The EPZ radius will then be defined as the distance from the plant such that the probability of exceeding the dose limit triggering the actuation of emergency procedure is equal to a specified threshold value. To identify this threshold value, detailed analysis of existing installations will be performed to infer the risk associated with the current EPZ definition.

It must be noticed that the use of existing regulations and installations as the basis for this redefinition will not in any way impact the high degree of conservativism inherent in current regulations. Moreover, the remapping process makes this methodology partially independent from the uncertainties still affecting probabilistic techniques. Notwithstanding these considerations, it is still expected that applying this methodology to advanced plant designs with improved safety features will allow significant reductions in the emergency planning.
requirements, and specifically the size of the EPZ. In particular, in the case of IRIS it is expected that taking full credit of the Safety-by-Design™ approach of the IRIS reactor will allow a dramatic reduction in the EPZ requirement, while still maintaining a level of protection to the public fully consistent with existing regulations.

Acknowledgments

Due to the international nature of the team developing the IRIS project, the cooperation can be treated as a trade mark of the IRIS project. This is even truer for the IRIS PRA. The author wish to acknowledge the co-author of this paper A. Maioli and the large support and valuable assistance of the IRIS heads M. D. Carelli and B. Petrovic as well as of other members of the IRIS PRA team, especially D. J. Finnicum and C. L. Kling. We also want to acknowledge the advises and useful discussions with L. E. Conway and L. Oriani from the IRIS design team. And last but not least we would like to extend thanks to J. Augustis and M. Ricotti for the great personal support provided during the initial stage of PRA related research.

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