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Importance Ranking of Diverse Safety Issues for Operating NPPs

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ABSTRACT

Any operating nuclear power plant (NPP), as a facility with potential for radioactive release, is subject to numerous safety reviews with different purposes and objectives. Some of the safety reviews are, by their nature, general and extensive in terms of different safety factors or safety attributes which are covered. An example of such a review is a Periodic Safety Review (PSR) which is promoted by the International Atomic Energy Agency (IAEA) and a number of national safety authorities in Europe and worldwide. PSR is many times used as a means for verifying whether a plant which has been operated in long term (e.g. over decades) is still as safe as originally intended and particularly in the context of new safety standards which have come into place after the time of plant's initial operation. The other reviews may, depending on the objective, be targeted at particular safety factor (e.g. ageing management or equipment qualification or safety analyses). The reviews may be initiated and implemented by various stakeholders, including utilities, industry and regulators. Both of the mentioned cases (single general review or multiple targeted reviews over a time period) can generate an inventory of safety issues which need to be addressed but may be very different in their nature and implications, as well as in benefits or resources associated with their resolutions. While some of the issues may be directly related to operational safety (e.g. non-compliance with single failure criterion or aging-related degradation of safety features), for some others the link to operational safety may not be explicit (e.g. comparison of safety bases against the newly emerging methodologies or issues observed with regard to so called "soft factors").

The paper discusses types of safety issues which may emerge from general or targeted safety reviews and outlines some basic principles for comparison and importance ranking of diverse issues, as needed many times in order to develop an action plan for keeping or improving the plant safety level.

Keywords: *operating NPP, safety review, safety issues, ranking*

1 INTRODUCTION

Any operating nuclear power plant (NPP), as a facility with potential for radioactive release, is subject to numerous safety reviews with different purposes and objectives. Some of the safety reviews are, by their nature, general and extensive in terms of different safety factors or safety attributes which are covered. An example of such a review is a Periodic Safety Review (PSR) which is promoted by the International Atomic Energy Agency (IAEA) and a number of national safety authorities, [1], [6], [14], [15] and [16]. PSR is many times used as a means for verifying whether a plant which has been operated in long term (e.g. over decades) is still as safe as originally intended and particularly in the context of new safety standards which have come into place after the time of plant's initial operation. The other reviews may, depending on the objective, be targeted at particular safety factor (e.g. ageing management or equipment qualification or safety analyses). The reviews may be initiated and implemented by various stakeholders, including utilities, industry and regulators. Both of the mentioned cases (single general review or multiple targeted reviews over a time period) can generate an inventory of safety issues which need to be addressed but may be very different in their nature and implications, as well as in benefits or resources associated with their resolutions.

Safety issue generated by a review can usually be characterized in terms of the three general attributes:

- Directly connected to nuclear safety (for considered issue, a direct link to nuclear safety can be established; for example, an observed deviation from the requirements relevant for nuclear safety); category will here be referred to as "DS";
- Re-evaluation of nuclear safety basis (e.g. adequacy with regard to safety assessment standards or methods); category will here be referred to as "RS";
- Related to "soft factors" (e.g. human factors engineering, organization for safety, safety culture and similar) or non-nuclear safety issue (e.g. industrial hazard); category will here be referred to as "SF".

Each issue can usually be related to at least one of these three general attributes. Some issues may relate to more than one.

When assessing and ranking, a separate path (e.g. criteria) would need to be applied, in principle, with regard to each of the three general attributes. The key is that ranking with respect to particular general attribute results with certain score or rank (which can for this purpose be referred to as a "significance number"), and that the scores / ranks ("significance numbers") for the three general attributes are directly comparable to each other, on the same scale. The rank (significance number) can be assigned by evaluating the issue of concern through multiple layers of ranking, with respect to predefined criteria. In the case that more than one ranking path (general attribute) applies, a rule can be set to take the highest significance number as a final score.

One possible approach is generally discussed in this paper.

2 OUTLINE OF A GENERAL APPROACH

Basic concept in nuclear safety is 'defense in depth' which is defined as a philosophy to ensure that successive measures are incorporated into the design and operating practices for nuclear plants to compensate for potential failures in protection and safety measures, [2],[3], [4] and [5]. All safety activities, whether organizational, behavioral or equipment related, are subject to layers of overlapping provisions, so that if a failure should occur it would be compensated for or corrected without causing harm to individuals or the public at large. This idea of multiple levels of protection is the central feature of defense in depth (DID).

It then comes as natural to establish the approach for ranking of diverse safety issues in a way that it is based on assessing potential impact on defense in depth. In its essence, the approach would consist of "measuring" or assessing the depth of remaining defense or remaining mitigation capability, provided that considered safety issue remains unaddressed. The approach would map the issue of concern into the defense-in-depth structure (e.g. by failing or reducing the affected barrier capability) or into the accident sequences (e.g. by failing or reducing the affected mitigation function capability). Thus, both deterministic and probabilistic methods can be used. Particular attention is to be paid to robustness of individual levels of defense and to mutual independence of levels of defense as important properties of defense in depth.

The principles and elements of such approaches were, to various extents and levels of detail, used worldwide. For example, the approaches where remaining defense depth is estimated by counting of levels of defense were used to assess the safety of existing nuclear power plants and their elements are described in the IAEA publications such as [7], [8] and [9]. Similarly, the approaches where remaining mitigation capability is estimated (qualitatively, in terms of orders of magnitude) by mapping of the issue of concern into the related accident sequences are used in the US NRC Significance Determination Process (SDP), as originally described in references [10], [11] and [12]. Also, a similar approach is used in the industry risk informed applications (recognized also by the regulators) such as risk informed in-service inspection to determine the remaining mitigation capability (or conditional risk) following an assumed failure or degradation of a pipe segment, [13].

In the case of a larger number of issues to be ranked it can be expected that the process would be, for practical purposes, divided into two major steps, which can here be referred to as:

1. Broad ranking;

2. Detailed ranking

Broad ranking can be used for grouping of similar issues as well as for reviewing any particular issue in the light of other issues (from different areas of concern, such as PSR safety factors) which may be co-related. Sometimes, this may provide a different perspective on issue importance. By broad ranking, all issues from the inventory would be typically classified into several general categories of importance such as, for example: high (H), medium (M) and low (L).

The results of the broad ranking can also be used for initial pre-screening done in order to identify the issues which can be directly sent to a corrective action program (CAP) normally existing in any NPP. Such pre-screened issues which can be a direct input to a CAP usually are the issues of the two types:

- Issues requiring immediate attention and short term resolution such as those representing Technical Specification violation or violation of current licensing basis, if any of those; in principle, such issues, if any, would usually be broadly ranked with high (H) importance; for such issues no ranking is needed as their implementation is a must, in principle; this group of issues will here be referred to as “IRR” (immediate resolution requirement);
- Issues desirable to be resolved (i.e. no short term requirements), which can be resolved at minimum effort and in a short time frame. Although these can come from any importance category, it is expected that most of them would come from low significance (L) category, relating to matters such as changes to procedures in non-safety domain, corrections to plant drawings or documents and similar. This group of issues will here be referred to as “LSE” (low significance and effort).

All the remaining issues (i.e. those surviving pre-screening) would be subject to a detailed ranking. Some of them would be later input into a CAP, based on the rank and used criteria. General flow chart is illustrated by Figure 1.

Detailed ranking would, in principle, be based on assessing each issue against the three general attributes discussed above, “DS”, “RS” and “SF” and the predefined ranking criteria. In the process, particular issue would be initially related to one of these three general attributes (most of the issues) or to more than one (limited number of issues). It can be assumed that for each of those issues which are related to multiple general attributes the dominant general attribute can be identified, i.e. the one which would result with the highest safety rank / significance number. Certain regrouping / subsuming of the issues may be done with regard to this. The effect would be that each issue in its finally defined form would be prior to the detailed ranking evaluation related to a single general attribute, “DS”, “RS” or “SF”. Thus, the issues would be effectively divided into three groups (as related to the three general attributes) and for each attribute a separate ranking path would apply. Passing through the respective path would result with certain significance number assigned to the issue considered. The range of significance (the values of significance numbers) would be determined for each of the three paths / general attributes, so that the same scale can be used for all three paths. (For example, significance number value "3" represents the same safety significance regardless of whether the path is "DS", "RS" or "SF".)

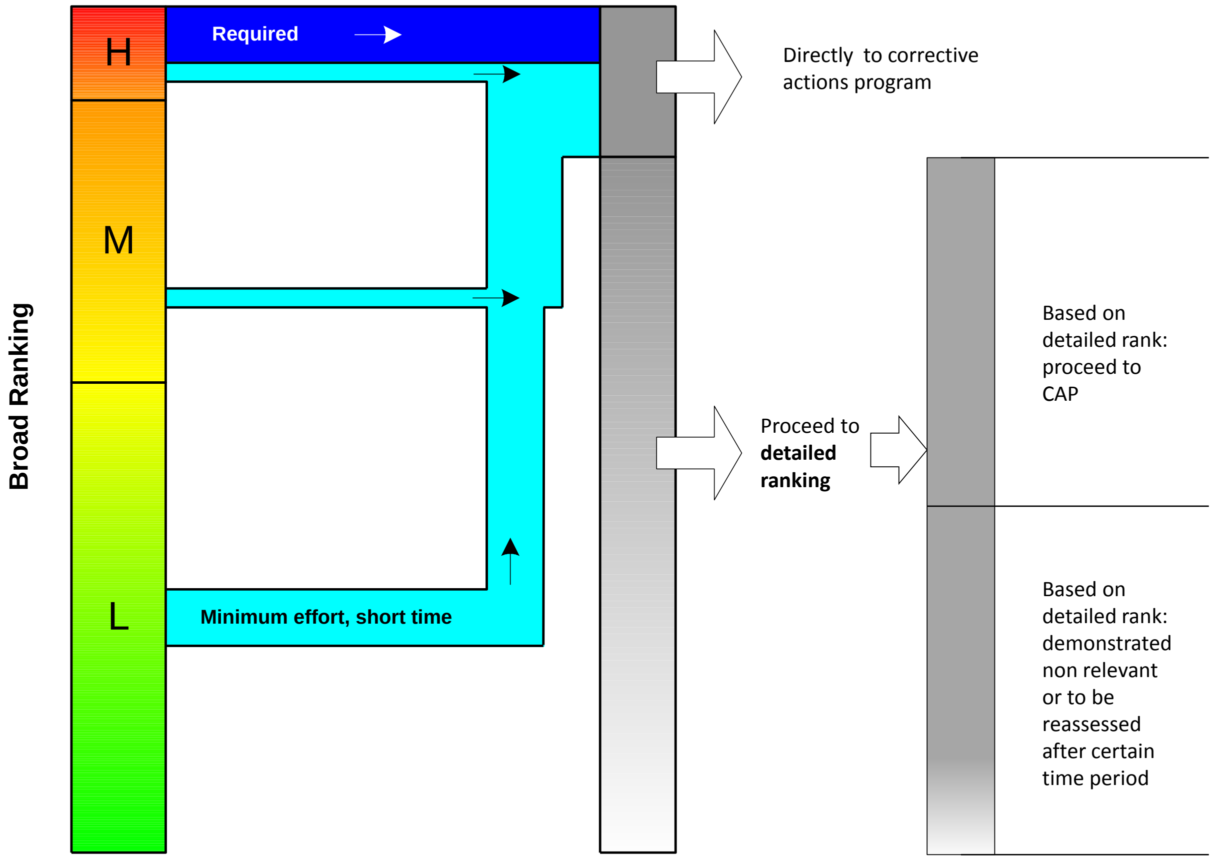

Figure 1: General Flow Chart for Issue Ranking

For resolution of any issue to be input, as a result of the detailed ranking process, into a CAP, particular corrective measure would be needed. Thus, in principle, each particular issue which will be, in the context of Figure 1, forwarded to CAP, can be associated with particular corrective measure. Thus, the issue ranking and corrective measures prioritization become single process. In this process the issue achieves its significance number through the evaluation defined by the path assigned to the issue "DS", "RS" or "SF". This significance number (final rank) would be generally achieved through consideration of issue against several layers of criteria.

According to the above discussion, the first-layer criterion in each path would be related to DID impact. The "DS" and "RS" paths can be associated with DID impact in a rather straightforward manner: by deterministically considering the status of "lines of defense" (LOD) (e.g. evaluation of margins) or by risk assessment (quantification of risk which would reflect the status of the lines of defense), whichever is considered more appropriate. For the "SF" path, the relation to DID may not be so straightforward or direct and it can represent an assessment of issue on plant's "operational safety features" which in turn may indirectly or directly reflect on DID. All these terms are further characterized in the sections below. But, to conclude this part, it can be said that the first-layer criterion can be:

- For "DS" and "RS" path: significance with respect to "depth of defense" (DOD) impact or to risk impact;
- For "SF" path: significance with respect to operational safety features (OSF) impact.

The above criteria are used as means for primary ranking of safety issues. Finer sub-ranking can be achieved through the second-layer criteria. An example of a second-layer criterion may be:

- <u>Evidence from operating experience.</u>

  A criterion like this one can be applied to all three paths.

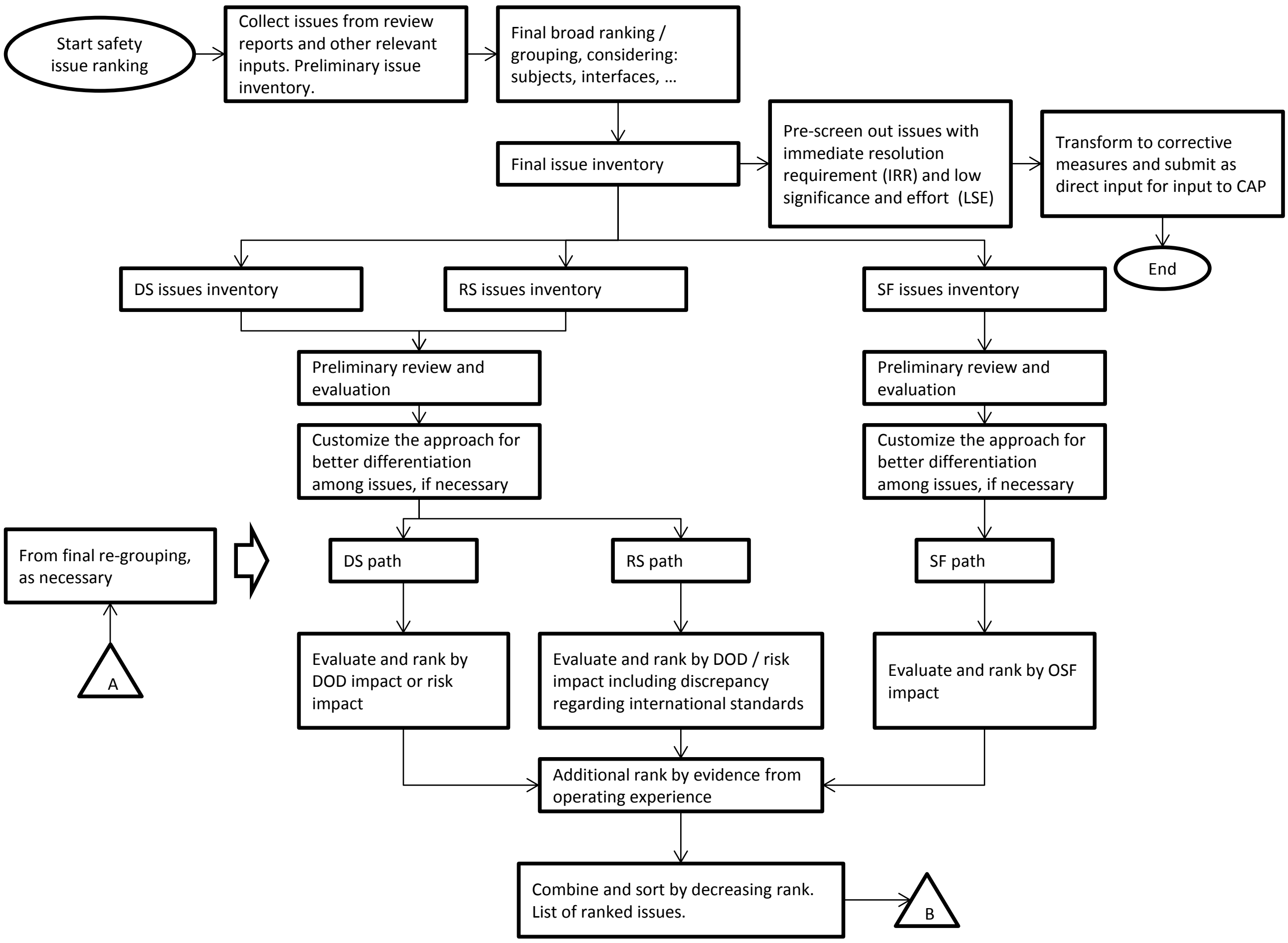

Figure 2: General Flow Chart for Detailed Issue Ranking (1/2)

Once the detailed ranking of safety issues is performed, the issues can be "translated" to corrective measures, as discussed above. This would be, as mentioned, a straightforward process in which for each identified issue a corrective measure is specified which would be necessary in order to remove the issue. These issues / corrective measures may then be further characterized through third-layer criterion, such as:

- <u>Cost category.</u>

  For the purpose of issue ranking / measures prioritization process this kind of a criterion can be applied to all three paths and may be applied through a simple qualitative cost category estimate.

The process results with a final detailed rank or priority of each issue / corrective measure and is illustrated with generalized flow chart shown in Figure 2 and Figure 3.

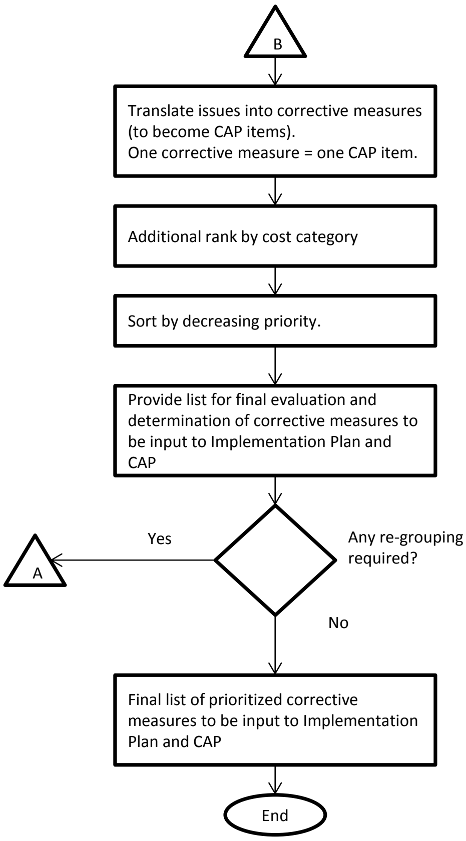

Figure 3: General Flow Chart for Detailed Issue Ranking (2/2)

Criteria for broad ranking and three-layer criteria for detailed ranking (as outlined above) are further illustrated and discussed in the sections which follow below.

3 BROAD RANKING CRITERIA

During the broad ranking process, particular safety issue from any review area (e.g. safety factor in [1]) needs to be viewed in the light of other issues (from the same or from different review areas / safety factors) which may be co-related. This can be done through the process of grouping of issues from different review areas / safety factors, with correlated subjects (considering, also, associated possible corrective measures). The process would, usually, involve expert engineering judgment to certain extent, which would be facilitated if a ranking analysts' team includes members with expertise and experience related to all review areas / safety factors. Figure 4 shows an example of a general flow chart for the interface impact assessment.

Table 1 shows an example of high level criteria for assigning low (L), medium (M) or high (H) safety significance to issues considered. As a part of the broad ranking, the issues would be grouped according to the three general attributes for detailed ranking, i.e. for each issue it would be defined which detailed ranking path ("DS", "RS" or "SF") will apply. As shown in Table 1, different assessment and criteria at broad ranking would be applied for general attributes "DS" / "RS" as compared to "SF". Broad ranking should involve subject matter experts for particular review area (e.g. safety factor in [1]).

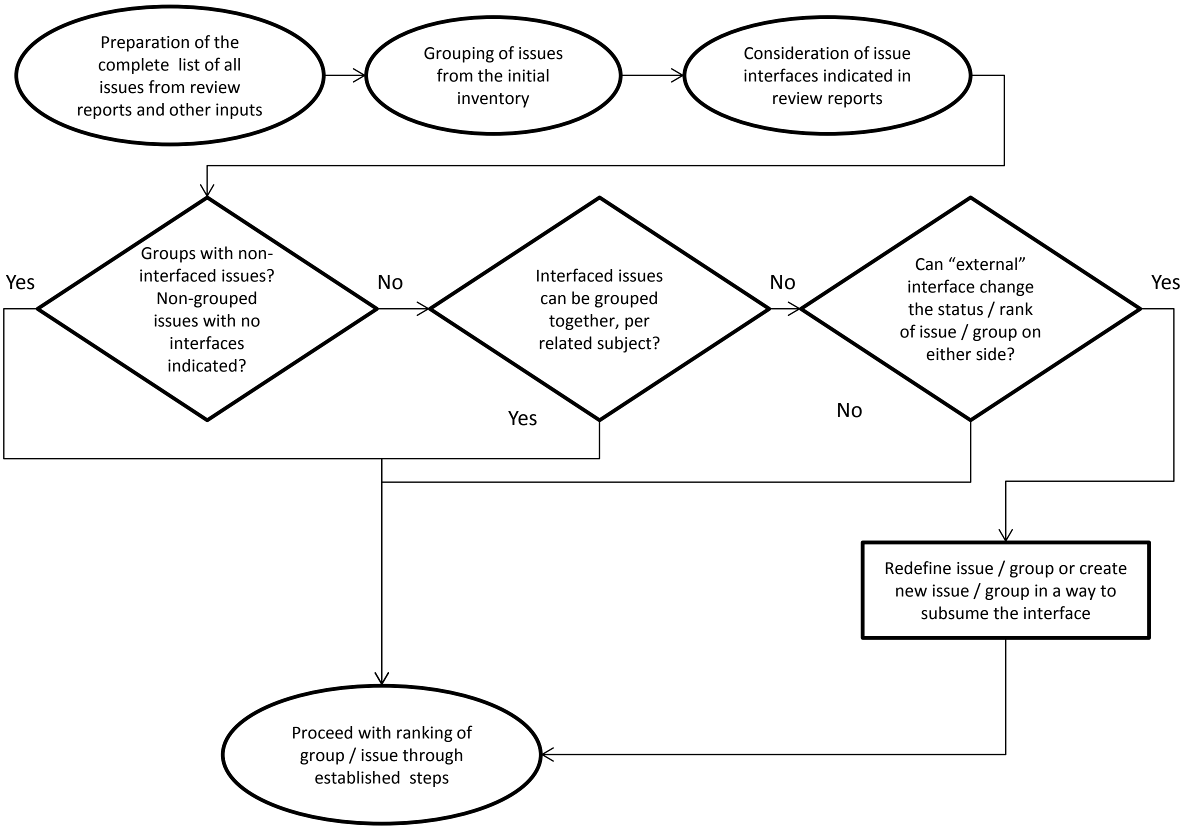

Figure 4: Example Flow Chart for Interface Impact Assessment

Table 1: Example of High Level Criteria for Broad Ranking

General Attribute (for Detailed)	**Description of assessment criteria**	**Safety significance**		
		Low (L)	**Medium (M)**	**High (H)**
DS or RS	Impact on plant risk of a new PIE or of increased frequency of a PIE	Small	Significant	Major
	Impact of issue on a physical barrier to the release of radioactivity	Affected	Degraded	Seriously degraded
	Impact of issue on one or more levels of defense	Affected	Significantly affected	Lost
SF	Level of staff training, operational performance and plant procedures	Warrants improvement	Inadequate	Unacceptable
	Level of safety culture or organizational safety or associated subjects	Warrants improvement	Inadequate	Unacceptable

4 DETAILED RANKING CRITERIA - FIRST LAYER

4.1 General Attributes (Ranking Paths) “DS” and “RS”

For “DS” and “RS” path first-layer criterion represents significance with respect to DOD impact or to risk impact. As an example, for DOD impact a limited set of qualitatively defined states can be defined such as:

- “D1”, Non Relevant or Awareness Needed;
- “D2”, Tolerable Long Term;
- “D3”, Tolerable Short Term
- “D4”, Not Tolerable.

The assessment (and respective criteria) for DOD impact can be based on the approaches such as counting “lines of defense” (LOD), e.g. [7] or [8]. In this context an LOD is defined as a system, barrier or human action (or combination of those) needed for providing protection against an initiating event. In principle, LODs exist at any or several of the levels of defense in depth.

If risk impact assessment is used, it can be based on the approaches such as Significance Determination Process, [10], [11] and [12], or industry approaches such as the lookup tables in [13].

Figure 5 below is an illustrative example of a set of criteria based on the DOD impact assessment, inspired by [7]. (“S” refers to a “strong” LOD while “W” refers to a “weak” LOD.) Criteria like these can be to DOD assessment under which a considered issue is imposed upon the existing LODs and the remaining LODs (accounting for the issue impact) are then identified. (It is noted that the figure is illustrative and without pretension to establish the actual criteria or definitions of “strong” and “weak”.)

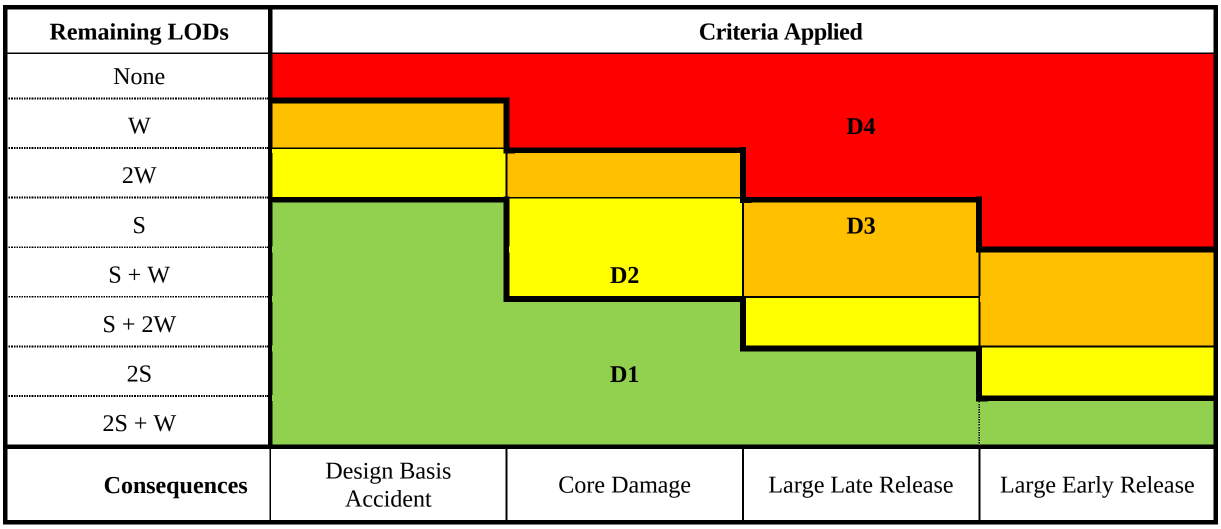

Figure 5: Illustration of Criteria for DOD Impact

A concept for counting of LODs is illustrated in Figure 6. There are six specific points in the accident progression “through” the LODs which are indicated in Figure 6:

- Point 1: Occurrence of an initiator. For some initiators (most of them, actually), one or more LODs already need to be broken for an initiator to occur.
- Point 2: Condition where, following an initiator, all but one design basis (DB) LODs have failed.

- Point 3: Condition where, following an initiator, all the DB LODs have failed. This still does not mean that reactor core damage would necessarily occur. For some initiators / accident sequences usually there are provisions in the Emergency Operating Procedures (EOP) which, although not part of the DB described in Safety Analysis Report, represent valid additional LODs.
- Point 4: Condition where, following an initiator, all the DB LODs and all additional LODs have failed. This condition leads to reactor core damage.
- Points 5 and 6: Condition where reactor core damage has developed into an event with early or late radioactivity release, respectively. These two conditions are considered mutually exclusive, what is, also, indicated in Figure 6: if early release has occurred, then any late release is not relevant anymore; if, on the other hand, the release is late, then early release has not occurred, by definition.

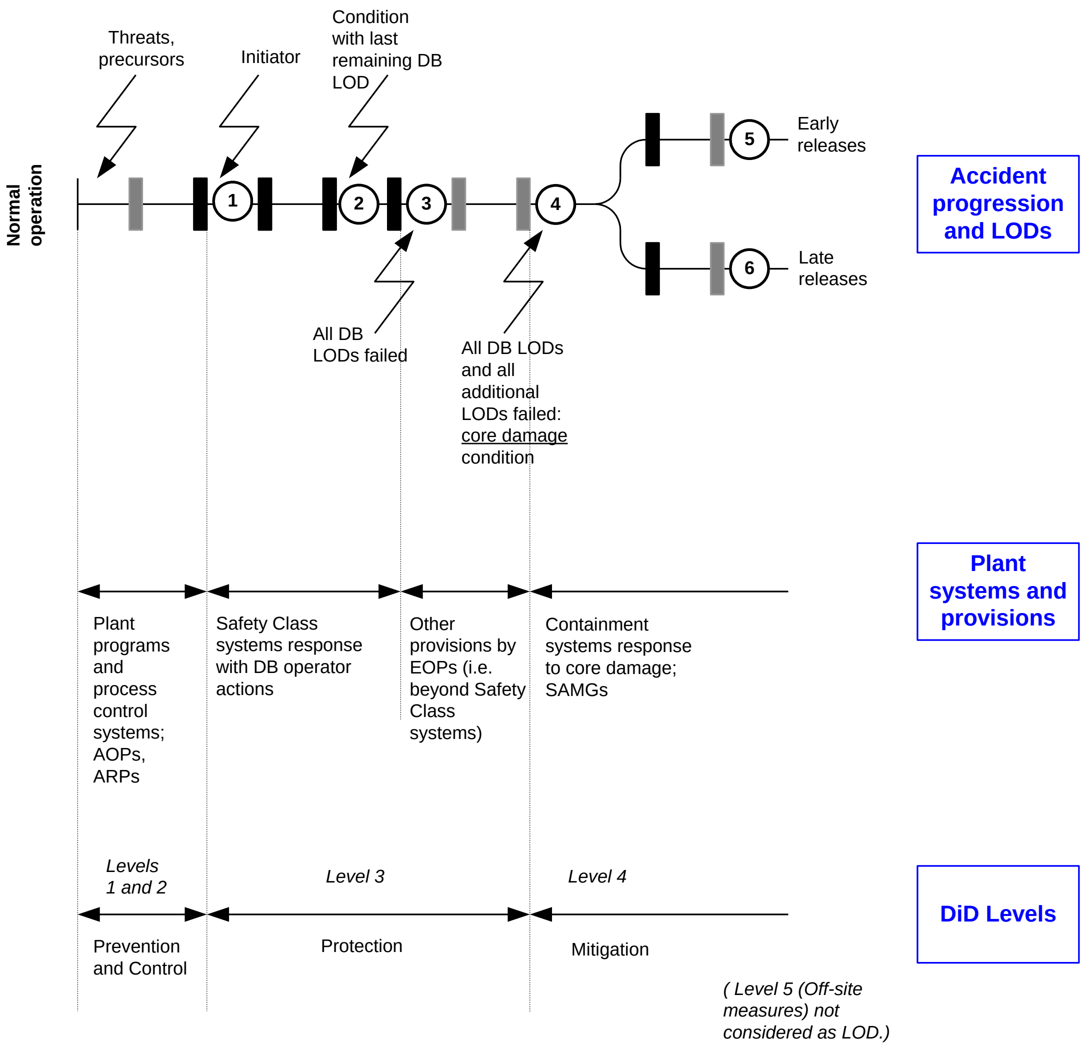

Figure 6: Concept for Counting of LODs

Once the DOD state (e.g. D2) is assessed for particular issue, it would be translated to significance number, as indicated by Figure 7. (The analogous would be done in the case that risk impact states were used, instead.) It is important to point out, though, that for the same state a significance number on the "RS" path would, in principle, be lower than on the "DS" path. For example, for the state D2 significance number on "RS" path would be lower than on "DS" path.

This is because in the case of “DS” an issue relates to the actual status of DOD (e.g. aging issue or environmental qualification issue) while in the case of “RS” an issue relates to potential or indicated status of DOD (which may not or may be confirmed when actual re-evaluation of safety basis is done).

DOD State	Functionality Impact	Significance Number
D4	-	xx
D3	-	xx
D2	-	xx
D1	D1.3 Affects safety system or feature involved in DB accident sequence	xx
	D1.2 Affects system or feature involved in BDB accident sequence	xx
	D1.1 Impact limited to non-safety system not involved in BDB accident sequence	xx

Decreasing

Figure 7: DOD States versus Significance Number (Rank) for Path “DS” or “RS”

4.2 General Attribute (Ranking Path) “SF”

As mentioned above, for the “SF” path the first-layer criterion represents significance with respect to operational safety features (OSF) impact. For this purpose, many times the OSFs can be divided into a limited set of categories such as:

- Operating Organization;
- Normal Operating and Administrative Procedures;
- Safety Management Systems;
- Radiological Protection and Other Occupational Hazards.

For assessment of each of the categories there are a number of techniques which can be used, such as those based on the gap analysis, check lists, and others. Once the assessment of particular issue is done, the issue of concern would be assigned a significance number. An example of high level criteria for OSF is given in Figure 8. The range of the significance number values needs to be calibrated against the significance number values for “DS” and “RS” paths.

Significance number values “xx” in all three paths represent the “scores” which are assigned to considered issue with regard to the respective general attribute. They need to be calibrated for all three paths in a way that given “scores” can be put in the same scale of values and directly compared.

OSF Impact	Significance Number
Significant shortfall identified or major element missing	xx
Gaps or areas not fully addressed	xx
Minor areas to be impreoved in order to bring in line with best international practice	xx
Minor issue which does not influence safety-related SSC, plant security or workers safety	xx
Impact limited to operational excellence, external confidence or public image of the plant	xx

Decreasing

Figure 8: OSF States versus Significance Number (Rank), Path "SF"

5 DETAILED RANKING CRITERIA - SECOND LAYER

For all issues input into the detailed ranking and being assigned a rank with regard to the first-layer criteria finer sub-ranking can be achieved through the second-layer criteria. As discussed above, an example of a second-layer criterion may be:

- Evidence from operating experience.

The evaluation of evidence would consider problems encountered with respect to a particular safety issue identified in plant-specific experience, plants of similar design (e.g. vendor owner's group), or generic industry-wide sources.

Table 2 shows an example of the criteria and significance scale for the evidence from operating experience. The significance criteria / scale can be applied to issues from all ranking paths (i.e. "DS", "RS" and "SF").

Table 2: Illustration for Significance Scale for Evidence from Operating Experience

Evidence from Operating Experience	Significance Number
Issue identified as plant specific problem	3
Issue identified as vendor's group generic problem (no plant specific identification)	2
Issued identified as generic industry-wide problem exclusively	1

Expert judgment and consultation with plant subject matter experts (SME) can be utilized to determine the plant specific, vendor-specific, and generic industry-wide information sources for a given safety issue.

6 DETAILED RANKING CRITERIA - THIRD LAYER

Under the third layer, the issues can be "translated" to corrective measures, as already discussed above. This would be, as mentioned, a straightforward process in which for each identified issue a corrective measure is specified which would be necessary in order to remove the issue. These issues / corrective measures may then be further characterized through third-layer criterion, such as:

- Cost category.

Similarly to evidence from operating experience under the second layer, this kind of a criterion can be applied to all three paths and may be applied through a simple qualitative cost category estimate. An illustration is provided by Table 3. From the cost perspective, favorable are those measures which are cheaper.

Consideration of cost at third layer reflects the fact that safety concerns are given higher priority over the budgetary concern. Issues are always ranked by safety importance first.

Table 3: Illustration for Significance Scale for Qualitative Cost Evaluation

Qualitative Cost Evaluation	Significance Number
Less than X1 (EUR)	4
Between X1 (EUR) and X2 (EUR)	3
Between X2 (EUR) and X3 (EUR)	2
Greater than X3 (EUR)	1

7 CONCLUDING REMARKS

The above outlined process would result with each issue / corrective measure being assigned significance in the form "*p.s.t*" where:

- "*p*": significance number with regard to first-layer attribute (natural number, e.g. 1, 2, 3...);
- "*s*": significance number with regard to second-layer attribute (natural number);
- "*t*": significance number with regard to third-layer attribute (natural number).

All the issues can then be sorted in descending order: first by "*p*", then for a given "*p*" by "*s*", and then for given "*p.s*" by "*t*". The process would result with a list of safety issues which would be sorted according to their significance. The significance rank at second and third layer can be very important in the case of larger total number of safety issues: in those cases numbers of issues with same primary rank can also be considerable and second and third rank would then provide for their sorting in decreasing order.

Very important part of the process is defining the ranges of significance numbers for the three paths, "DS", RS" and "SF" in a calibrated manner, because the final order of the list may considerably depend on this. This may involve iteration or two in the process. Consistency checks may also help (e.g.: issue A is listed as more significant than issue B, and issue B as more significant than issue C; is issue A demonstrably much more significant than issue C?). This and some other parts would inevitably involve some expert judgement and discussions among the reviewers and subject matter experts.

It is very important to recognize that the ranking process as discussed in this paper is relative, i.e. the final result is a list of safety issues which are sorted by predefined significance. The results can be used to obtain an answer to the question: is issue X more than significant than issue Y or Z? However, no attempt was made in this paper to discuss the absolute importance, such as for example, at which place (item) can the sorted list be “cut off”. The answer to this particular question is not simple and it would ask for some kind of “global assessment” (e.g. [1]) which would consider joint impact of issues on lower side of “cut off” and implementation of the corrective measures for the issues on the upper side, as well as their time schedule (i.e. corrective actions implementation plan). This can be based on principles of risk assessment and / or deterministic principles such as those related to adequacy of safety margins and fault tolerance. Additionally, PSR [1] requires global assessment to provide safety justification for proposed long term operation [2] by evaluating the cumulative effects of both ageing and obsolescence on the safety and reflecting the combined effects of all safety factors (findings and proposed improvements).

In practice, a process like this was used, rather successfully, for the initial inventories with several hundreds of safety issues resulting from periodic safety reviews of nuclear power plants.

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