UK Nuclear Industry Safety Case Forum Guide

Conservative Exposure Durations for Unmitigated Worker Doses in Design Basis Analysis

January 2014

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1 Purpose of a SCF Guide

1.1 Safety Case Forum Guides are produced by representatives of nuclear operators (nuclear site licensees and other companies with nuclear operations in the UK). Their purpose is *to provide guidance that is useful to a wide range of UK nuclear operators*. Such Guides do not set mandatory requirements on any nuclear operator, nor do they identify minimum standards. Guides provide a tool kit of methods and processes that nuclear operators can use if appropriate to their sites and facilities. The responsibility for justifying arguments in safety cases remains with nuclear operators.

1.2 The Safety Case Forum reports to the UK nuclear industry Safety Directors Forum. The companies represented at the Safety Case Forum include companies that cover:

- civil and defence activities
- design, operation and decommissioning of nuclear facilities
- low hazard and high hazard nuclear facilities

A full list of companies represented on the Safety Case Forum is given in Appendix A.

1.3 SCF Guides are written for suitably qualified and experienced safety case practitioners. Thus the basics of safety cases and safety assessment as they affect a particular SCF Guide are not necessarily explained in SCF Guides. Authors are expected to use their judgement in applying SCF Guides, taking account of company-specific, site-specific, building-specific and scenario-specific factors.

2 Introduction to the Topic, including Scope

2.1 Design Basis Analysis (DBA), also known as Design Basis Accident Analysis (DBAA), is a fundamental technique used to robustly demonstrate the fault tolerance of nuclear facilities and operations. It incorporates a conservative (pessimistic) approach, requiring the identification of an initiating event frequency and a conservative unmitigated radiation dose, in order to determine the safety measures needed to prevent or mitigate that dose. In overall ALARP terms, consideration needs to be given to any elimination, prevention or protection that is higher up the safety hierarchy than evacuation (which is an operational mitigating system and therefore at the bottom of the hierarchy), even if the unmitigated dose doesn't exceed any DBA threshold.

2.2 Within DBA, potential doses to workers in postulated accident scenarios are estimated. The *unmitigated* dose is the dose received when safety measures, e.g. evacuation in response to area gamma monitors, are assumed to have failed; no credit should be taken for evacuation due to any radiometric alarms operating for the unmitigated dose. Such evacuation should be treated as a safety measure that if successful gives a lower *mitigated* dose, but it does not have any effect on the size of the unmitigated dose.

2.3 The worker exposure duration is the period of time for which the worker is exposed to an external dose rate and/or for which the worker is breathing in airborne contamination. The exposure can usually be deemed to have finished:

- in the case of airborne contamination, when a worker leaves a room.
- in the case of external dose rate, when a worker is sufficiently far away or behind sufficient shielding (such that dose uptake falls below a consequence threshold).

2.4 The unmitigated dose is estimated based on a number of elements. For an inhalation dose to a worker, all the following elements are usually relevant:

- the inventory.
- the physical and chemical form of the material.
- the Release Fraction in the postulated accident.
- release chemical reactions and other removal mechanisms.
- the settling of particles of different sizes.
- the distance of the worker from the release point.
- the model assumed for expansion of the ‘cloud’ of airborne activity.
- the Decontamination Factors for passive, permanently available barriers.
- the breathing rate of the worker.
- the worker exposure duration.
- the model assumed for converting activity inhaled into dose to a worker.
- the Lung Class of the material.

For an external dose, the list would be shorter. The key point, whether for internal or external dose, is that this Guide only addresses one element (the worker exposure duration); none of the other elements are within the scope of this guide.

2.5 DBA requires that the estimated worker dose is demonstrably conservative overall. In most estimates of inhalation dose, many of the above elements will contain a degree of conservatism, giving an overall dose that is conservative. It is not necessary (or desirable) to make worst case assumptions for every single element, as that approach would multiply each of the worst cases, giving an unrealistically high overall dose. Thus the aim for a worker exposure duration is to identify ***a period of time which contains a suitable degree of conservatism***, thus contributing to an overall demonstrably conservative dose. If the analyst underestimates the unmitigated consequences, the whole process of DBA can be circumvented, i.e. the safety case will have insufficient extent and depth, leading potentially to safety measures of inadequate quality, or perhaps none at all.

2.6 This Guide does not attempt to provide guidance on workers who are unable to leave an area, for example because they are trapped in rubble, or because they have been made unconscious as part of an accident. Specialist advice, including Human Factors advice, should be sought in these cases.

2.7 The estimated worker exposure duration for unmitigated dose for DBA purposes is called ‘the conservative exposure duration’ in this Guide.

2.8 The conservative exposure duration in any postulated accident scenario needs to be considered on an individual basis. However, **this Guide provides guidance on key aspects to be considered, and suggests some time periods as examples**. The quoted durations should not simply be used without considering the individual aspects of the postulated scenario.

2.9 In this Guide, it is assumed that nuclear workers are suitably qualified and experienced for the task they are doing, and are familiar with the key concepts of radiation and contamination.

2.10 This Guide focuses on accidents and workers inside rooms/buildings (though some limited advice is given on workers outside exposed to a revealed accident). Workers nearby are also included. Releases inside a building affecting workers outside the building are not included. Similarly, workers in adjacent buildings are not included - dose rates and/or airborne concentrations affecting these workers should in most cases be significantly smaller.

2.11 This Guide addresses unrevealed faults before clearly revealed faults, but no hierarchy is implied. If a fault is clearly revealed (as defined in Section 5), Section 4 is irrelevant.

3 Key Principles

3.1 The worker exposure duration is only one element of demonstrating an overall conservative dose, so worst-case assumptions (that would give an unrealistically high overall dose) would not be proportionate. The exposure duration for unmitigated DBA worker doses should be realistic, conservative and defendable.

3.2 For the *unmitigated* dose, no credit should be taken for evacuation due to any radiometric (or other) alarms operating.

3.3 The shorter the claimed conservative exposure duration, the more robust the justification needs to be. If the unmitigated dose is close to a DBA threshold, the conservative exposure duration should be justified to be suitably conservative with a very high degree of confidence. In addition, greater complexity in identifying a conservative exposure duration requires greater robustness in the justification.

3.4 The conservative exposure duration varies depending on whether the fault is clearly revealed or not, and on a number of other factors including those outlined below. Some typical durations have been suggested, but each scenario is different, and site-specific, facility-specific and scenario-specific factors need to be taken into account.

3.5 Where there is reasonable doubt that the fault will be clearly revealed, the advice for unrevealed faults should be followed.

4 Unrevealed Faults - Key Considerations for Conservative Exposure Durations

4.1 Although no credit should be taken for radiological alarms when assessing unmitigated DBA doses, an unrevealed fault would not in practice remain unrevealed for ever. The advice that follows mostly assumes that the worker is present where the accident occurs. If not, see the advice below on ***unrelated accidents***. Furthermore, most of the advice that follows is for a contamination event – see Paragraph 4.7 for advice on external dose rate events.

4.2 If the unrevealed fault may be terminated by the completion of the task, see the advice below on using ***task duration***. If not, the proposed concept for conservative exposure duration for unrevealed faults is a ***standard working period*** in the area where the worker would be exposed. This is typically less than half a shift ('shift' is taken to apply to 'working day' for day workers), given that workers can be relied on to take a meal break roughly in the middle of their shift, and usually have to pass through changerooms etc. in order to eat or to take a natural break. This would give typical exposure durations of approximately 3 to 4 hours (see Paragraph 2.8), but there are a number of caveats below.

4.3 If the fault can only occur while a worker is in an area requiring access beyond a further barrier, i.e. C3 area (or higher contamination classification), the conservative exposure duration is reduced due to the time needed for dressing and undressing in the sub-changeroom. This would give exposure durations of approximately 2 to 3 hours (see Paragraph 2.8), but there are a number of caveats below. There may be other considerations that reduce the conservative exposure duration, such as walking time from the changeroom to the work area in the facility.

4.4 The reasoning behind this concept is that workers will have had to pass through changerooms, carrying out monitoring on themselves as they pass into the clean (C1/C0) area. Even without any contamination being found, on return to the work area, workers are more wary of conditions on the facility, being more aware of their surroundings when returning fresh from a break. In many accident scenarios, plant-based parameters such as flow or pressure may be out of range; these would be investigated by control room operators on return to the work area, and investigation of these parameters would lead to discovery of the unrevealed accident. While it is possible that an unrevealed fault could remain unrevealed for longer than half a shift, this is considered too conservative for this one element of DBA. Contamination monitoring in changerooms becomes part of the safety

argument, but it may not need to be formally designated as a safety measure, since Local Rules made under the Ionising Radiations Regulations 1999 (Reference 1) will inevitably require it.

4.5 There should be no significant difference to worker exposure durations if lone working is allowed, for example the need for a work break still applies. However, lone working is more of an issue for clearly revealed faults – see Section 5.

4.6 The ***task duration*** is an alternative concept from the standard working period. It might be applicable for limiting some conservative exposure durations:

- The unrevealed fault may be resolved by the completion of the task, for example once a skip is in a transport flask, the dose rate is likely to be low (in safety case terms) even if the skip contains much more highly active material than expected. In this case, the task duration may well be the conservative exposure duration, but consideration should be given to the possibility that the task is not completed within expected times.
- If the unrevealed fault won't be resolved by completion of the task, and if this is less than the 'standard working period' concept above, it is certainly possible that the workers may stay in the same area (being exposed) because they have other tasks to do in the same area. If this can't be predicted in advance, task duration is not considered to be appropriate in this case.

4.7 For *external dose* scenarios that are unrevealed, there may be fewer arguments to support the 'standard working period' concept, as some of the reasoning above only applies to airborne contamination scenarios, so more case-by-case assessment may be required. But there are still ways of limiting conservative exposure durations:

- There may be a system for recording external dose that operates daily or even at the end of each working period. This system would have to be of a sufficiently high standard that it could be effectively 'guaranteed' just as the contamination monitoring in paragraph 4.4 is essentially 'guaranteed'. If credit is taken for an external dose recording system, then the requirement for operation of this system (from a safety case perspective) should be clearly communicated to facility managers.
- External radiation surveys may be frequent enough to be useful. There would have to be confidence that the survey would identify a problem (maybe not for localised dose rates), and it should be made clear to facility managers what arrangements are needed from a safety case perspective.
- Use of task duration may be appropriate – see previous paragraph.

4.8 If the job routinely involves a Health Physics (radiation protection) operative present during a task, it might be thought that the conservative exposure duration could be limited to a few minutes, but obtaining the services of a Health Physics (radiation protection) operative is in itself a safety measure, so the conservative exposure duration for unrevealed faults should be applied (see above). Similarly, the wearing of alarmed dosimeters is a safety measure, and no credit should be taken for these when assessing unmitigated dose.

4.9 In the case of ***unrelated accidents***, for example a high external dose rate appears in an area in which workers may be present, but the accident is not related to what the workers are doing, shorter conservative exposure durations may apply than those given above. In these cases, the affected area may have a low occupancy and more specifically may have a low maximum period that a worker may spend in that area, e.g. to change a filter paper on an air monitor. In this case, the low 'maximum period of occupancy' becomes the conservative exposure duration, as long as the accident is terminated before workers return to the area.

5 Clearly Revealed Faults - Key Considerations for Conservative Exposure Durations

5.1 ‘Evacuation’ in this section is ‘guaranteed evacuation’ that is bound to happen due to the clearly revealed nature of the fault, giving an *un*mitigated dose. It should be distinguished from evacuation as a result of radiometric alarms etc., which (if successful) is a safety measure giving a *mitigated* dose.

5.2 Paragraph 2.1 requires consideration of any elimination, prevention or protection that is higher up the safety hierarchy than evacuation (which is an operational mitigating system and therefore at the bottom of the hierarchy), even if the unmitigated dose doesn’t exceed any DBA threshold. Thus even guaranteed evacuation as a dose reduction measure should be considered after or alongside the search for other measures. Where guaranteed evacuation is claimed to support unmitigated doses, it must be recognised that it may take the fault out of a DBA region, compared to conservative exposure durations for unrevealed faults (see Section 4). Therefore, where guaranteed evacuation thus changes the DBA region, the level of confidence in the guaranteed evacuation (including a demonstration that the fault is clearly revealed) must be demonstrably equivalent to the level of confidence required in the substantiation of a typical DBA safety measure; this may require a significant depth of analysis that addresses all credible potential reasons why evacuation might not happen in the duration claimed.

5.3 A clearly revealed fault in this case means a fault that is obvious to operators by means other than radiometric alarms. Examples include: a container is dropped onto the floor and there is a visible break of containment; there is obvious release of material; fumes are detected; or a fire breaks out. In some cases a release of radioactive material might always be accompanied by a clear visible indication or other means of human detection. The senses of sight and hearing are the most likely ones to enable a fault to be clearly revealed. In such cases, conservative exposure durations that take credit for guaranteed evacuation can be justified.

5.4 Where there is reasonable doubt that the fault will be clearly revealed, the advice for unrevealed faults should be followed. It is worth remembering that what is obvious in ideal conditions may be less obvious to those in a noisy environment, wearing PPE, etc. In addition, in the early stages of an incident, there may be confusion as to what the accident actually is.

5.5 Consideration should be given to any counter-indications that could mean the worker does not evacuate despite apparently obvious evidence of the fault. For example, if there is a clear danger of airborne activity due to some loss of containment, but there is no alarm from the airborne activity monitor (or no alarm yet), this could cast doubt in the mind of the worker, and could delay evacuation believing that ‘no alarm’ equated to ‘no release’.

5.6 It is always possible that a worker may wish to retrieve a situation, or warn other workers, thereby increasing their exposure time. Adequate training should ensure evacuation in response to most accident situations. A judgement needs to be made on this and Human Factors guidance sought in case of any doubt. For example, where workers consider their own lives to be in danger, it can be confidently expected that evacuation will take place.

5.7 It has been standard practice within the UK civil nuclear reactor sector to design the reactor such that no human intervention should be necessary for approximately 30 minutes following the start of a requirement for protective action. Given that workers in a revealed fault scenario on plant are much more likely to take the simple protective action of evacuating to protect themselves than control room operators are to take potentially more complex protective action, it is considered that the worst case exposure duration for a clearly revealed fault is 30 minutes (see Paragraph 2.8). In some cases, this exposure duration may be overly-conservative. A worker exposure duration of less than 30 minutes for a clearly revealed fault should be justified, either specifically or generically for a particular type of scenario. This justification may need to take account of how obvious the fault is, and may need to consider generic Human Factors issues such as training, local environment, and other workplace, organisation and people issues.

5.8 There are some fault scenarios for which 30 minutes would clearly be too long to be realistic. For example, a fire is highly likely to cause evacuation in a short time, though consideration should be given to whether workers might attempt to extinguish the fire.

5.9 Whatever the scenario, short conservative exposure durations need to consider the following time periods:

- Time period to sense that there is something wrong, noting that the workers may not be looking in the 'right' direction all the time, though a flash or bang would draw their attention.
- Time period to decide that evacuation is the best course of action.
- Time period to effect the evacuation (see paragraph 2.3).

5.10 In most cases, assessment of the above time periods would conservatively add up to around 5 minutes, but see Paragraph 2.8. However, there may be situations in which the worker is facing extreme danger and/or extremely obvious danger, when shorter conservative exposure durations may be appropriate. Examples include:

- If a worker in an air-fed suit notices that the suit is deflating, the potential loss of breathing air may well be enough to strongly encourage evacuation conservatively within about a minute (see Paragraph 2.8) while using the breathing tube, though this would depend on evacuation distances etc.
- If a worker opens a door to enter a room, and observes an extremely obvious hazard inside such as a fire, the conservative exposure duration should be significantly less than 5 minutes (see Paragraph 2.8), noting that the action required to mitigate or prevent dose in this case is shutting the door, not evacuation, and this task can be completed more quickly than evacuation.

A conservative exposure duration of less than 1 minute (see Paragraph 2.8) should not normally be used for any scenarios, unless there is a robust justification that has involved relevant specialist disciplines, including Human Factors.

5.11 If there is lone working, a lone worker could be more likely to carry on with a task despite a revealed fault, and longer exposure durations may be appropriate. Thus, if there is a significant possibility that a facility might allow lone working, it should either be assessed for lone working (taking specific Human Factors advice), or if not, it should be made clear to facility managers that lone working is not allowed under the current safety case (or that no intrusive operations take place when lone working is allowed).

5.12 If there is historical evidence of exposure durations, this can be used directly for *expected* exposure durations, but the question still remains as to the *conservative* exposure duration to be used in the safety case, and the advice in the above paragraphs still applies, though it can be supplemented by historical evidence.

5.13 A fault that is clearly revealed to the workers involved may be totally unrevealed to other workers nearby, e.g. if they are behind a partition wall. Workers evacuating from a dangerous location can be relied on to inform their supervisor. If there are nearby rooms/areas that also need to be evacuated, evacuation should be effected within about 30 minutes (but see Paragraph 2.8). It is possible that these nearby workers would have a higher unmitigated dose, due to a longer exposure duration than the workers directly involved, and because they may be less well-protected than the workers directly involved. In order to support evacuation of nearby workers, it should be made clear to facility managers what arrangements are needed.

5.14 For a revealed accident outside a facility affecting a worker outside, the advice on conservative exposure durations is basically the same as for workers inside buildings. However, consideration needs to be given to other people outside, who may be further away but are unaware of an airborne release or a higher external dose rate, for whom the advice on *un*revealed faults would apply.

6 References

1 The Ionising Radiations Regulations 1999, UK Statutory Instrument No. 3232.

Appendix A: Companies and organisations represented at the Safety Case Forum

AWE plc
Babcock International Group plc
BAE Systems plc
Dounreay Site Restoration Limited
EDF Energy plc
GE Healthcare
Horizon Nuclear Power
Imperial College London
LLW Repository Ltd
Magnox Limited
Ministry of Defence
NDA Radioactive Waste Management Directorate
Research Sites Restoration Ltd
Rolls-Royce plc
Sellafield Ltd
Springfields Fuels Limited
Studsvik UK Ltd
United Kingdom Atomic Energy Authority
URENCO UK Limited