A UK Nuclear Industry Good Practice Guide:

Criticality Detection at UK Nuclear Licenced Sites

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Revision History

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It is recognised that – through the experience of using these Guides – there may be comments, questions and suggestions regarding its contents.

In the first instance, any such comments should be sent to the following:

The authors of this document via the Chair of the UK Working Party on Criticality (www.nuclearinst.com/WPC)

Foreword

This Good Practice Guide (GPG) has been produced following a review of the Criticality Incident Detection (CID) criterion historically used in the UK at nuclear licenced sites that handle fissile material. The historic detection criterion is based upon the requirement to detect the “minimum incident of concern”, which is dependent upon the system type (i.e. slow solution or fast metal) and operator proximity (i.e. close or non-close working operations).

Following consultation with some site licensees, a number of challenges were highlighted that are associated with installing or upgrading CID systems which have the requirement to detect the “minimum incident of concern”, as outlined above, due to inherent attenuation in the source or shielding between the incident and detectors. In particular, some licensees have found it difficult to justify modifications to existing plants that are potentially dose intensive, costly and time consuming to achieve. This guide hence presents an alternative detection criterion which can be used in those circumstances when the historic criterion is overly onerous, but which still leads to the important potential criticality incidents being detected.

The review also took into consideration the guidance, recommendations and standards relating to radiological protection and criticality incident detection provided by bodies including Public Health England, International Commission on Radiological Protection, International Organisation for Standardisation and American Nuclear Society. The information produced by the aforementioned bodies, in conjunction with the challenges identified by some site licensees, forms the basis for the alternative criticality incident detection criterion with the primary focus on avoiding serious deterministic effects.

Following the review, it is recommended that an alternative criticality incident detection criterion is defined based upon detecting incidents capable of producing serious deterministic effects, with the acceptability of the corresponding stochastic dose levels assessed on a case by case basis.

It is therefore recommended that an alternative design criterion for criticality incident detection and alarm systems (CIDAS) should be to detect an incident capable of delivering a deterministic (absorbed) dose of 125 mGy to the most exposed persons, taking account of plant specific conditions (e.g. operator distance, shielding). This dose limit is intentionally set somewhat below the 500 mGy dose threshold for deterministic effects and used for criticality emergency planning, as recommended by Public Health England.

The existing criterion based on the minimum incident of concern remains a valid alternative to this new dose based criterion.

Safety Directors Forum

In a sector where safety, security and the protection of the environment is, and must always be the number one priority, the Safety Directors' Forum (SDF) plays a crucial role in bringing together senior level nuclear executives to:

- Promote learning;
- Agree strategy on key issues facing the industry;
- Provide a network within the industry (including with government and regulators) and external to the industry;
- Provide an industry input to new developments in the industry; and,
- To ensure that the industry stays on its path of continual improvement.

It also looks to identify key strategic challenges facing the industry in the fields of environment, health, safety, quality, safeguards and security (EHSQ&S) and resolve them, often through working with the UK regulators and DECC, both of whom SDF meets twice yearly. The SDF members represent every part of the fuel cycle from fuel manufacture, through generation to reprocessing and waste treatment, including research, design, new build, decommissioning and care and maintenance. The Forum also has members who represent the Ministry of Defence nuclear operations, as well as "smaller licensees" such as universities and pharmaceutical companies. With over 25 members from every site licence company in the UK, every MoD authorised site and organisations which are planning to become site licensees the SDF represents a vast pool of knowledge and experience, which has made it a key consultee for Government and regulators on new legislation and regulation.

The Forum has a strong focus on improvement across the industry. It has in place a number of subject-specific sub-groups looking in detail at issues such as radiological protection, human performance, learning from experience and the implementation of the new regulatory framework for security (NORMS). Such sub groups have developed a number of Codes of Practice which have been adopted by the industry.

Sub-Group Description

This document is produced by the Working Party on Criticality (WPC), which is a sub-group of the Safety Directors' Forum. The WPC was established in the 1970s and brings together a wide range of representatives of nuclear operators, from all the Licensees and Authorisees across the United Kingdom, including:

- Civil, commercial and defence activities;
- Design, operation and decommissioning of nuclear facilities;
- Research facilities.

The purpose of the WPC is to provide guidance that is useful to, and will benefit the widest possible range of UK nuclear operators.

Such guidance is not mandatory, nor does it seek to identify minimum standards. It aims to provide a tool kit of methods and processes that nuclear operators can use if appropriate to their sites and facilities.

These guides are intended to improve the standardisation of approach to the delivery of fit for purpose safety cases, while improving quality and reducing the cost of production. They are designed to cater for all stages of a facility's life cycle and for all processes within that life cycle. This includes any interim, continuous and periodic safety reviews, allowing for the safe and efficient operation of nuclear facilities.

When using the information contained within these guides, the role of the Intelligent Customer shall always remain with the individual nuclear operator, which shall retain responsibility for justifying the arguments in their respective Safety Cases. The Office for Nuclear Regulation is a consultative member of the Safety Case Forum.

The following companies and organisations are members of the WPC:

3T Safety Consultants (3TSC)	Office for Nuclear Regulation (ONR)
AWE	Radioactive Waste Management (RWM)
Dounreay Site Restoration Ltd (DSRL)	Rolls-Royce
EDF Energy	Sellafield Ltd
Enrichment Technology Company (ETC)	TÜV SÜD Nuclear Technologies
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Disclaimer

This UK Nuclear Industry Good Practice Guide has been prepared on behalf of the Safety Directors' Forum. Statements and technical information contained in this Guide are believed to be accurate at the time of writing. However, it may not be accurate, complete, up to date or applicable to the circumstances of any particular case. This Good Practice Guide is not a standard, specification or regulation, nor a Code of Practice and should not be read as such. We shall not be liable for any direct, indirect, special, punitive or consequential damages or loss whether in statute, contract, negligence or otherwise, arising out of or in connection with the use of information within this UK Nuclear Industry Good Practice Guide.

This Good Practice Guide is produced by the Nuclear Industry. It is not prescriptive but offers guidance and in some cases a toolbox of methods and techniques that can be used to demonstrate compliance with regulatory requirements and approaches.

Contents

Glossary

Term	Definition
ALARP	As Low As Reasonably Practicable
ANS	American Nuclear Society
CID	Criticality Incident Detection
CIDAS	Criticality Incident Detection and Alarm System
GPG	Good Practice Guide
ICRP	International Commission on Radiological Protection
IRR99	Ionising Radiations Regulations 1999
ISO	International Organisation for Standardisation
ONR	Office for Nuclear Regulation
PHE	Public Health England

1. Introduction

The current default position for UK nuclear facilities that handle fissile material is that they require a Criticality Incident Detection and Alarm System (CIDAS), unless a case can be made for the omission of such a system.

If an omission case cannot be made then a CID system is required with the detection criterion historically used in the UK being based upon the requirement to detect the "minimum incident of concern", which is dependent upon the system type (i.e. slow solution or fast metal) and operator proximity (i.e. close or non-close working operations).

This Good Practice Guide (GPG) has been produced following a review of the historic criticality incident detection criterion. Following consultation with some site licensees, a number of challenges were highlighted that are associated with installing or modifying CID systems which have the requirement to detect the "minimum incident of concern", as outlined above, due to inherent attenuation in the source or shielding between the incident and detectors. For example, it may be difficult to justify installing additional detector sets to meet this criterion if, in doing so, it leads to a disproportionate cost compared with the level of emergency planning dose saving. Additionally, modifications to existing plants to ensure the criterion is met could be dose intensive and time consuming and so potentially difficult to justify.

The review also took into consideration the guidance, recommendations and standards relating to radiological protection and criticality incident detection provided by bodies including Public Health England (PHE), International Commission on Radiological Protection (ICRP), International Organisation for Standardisation (ISO) and American Nuclear Society (ANS). The information produced by the aforementioned bodies, in conjunction with the challenges identified by some site licensees, forms the basis for the recommended definition of an alternative criticality incident detection criterion with the primary focus on avoiding serious deterministic effects.

It should be noted that CID systems don't provide additional safety that can be claimed in the safety assessment (i.e. the criticality risk must be demonstrated to be As Low As Reasonably Practicable (ALARP) without them), rather they initiate action which is part of an emergency plan which may mitigate the consequences of a criticality accident. Such a plan must primarily focus on mitigating serious deterministic effects as they are the most significant potential consequences of an accident.

Following the review, and in line with guidance provided by the relevant bodies, it is recommended that an alternative criticality incident detection criterion is defined based upon detecting incidents capable of producing serious deterministic effects, with the acceptability of the associated stochastic dose considered on a case by case basis.

This Guide describes the basis and justification for defining an alternative criticality incident detection criterion for use in the UK and details the recommended detection criterion with a primary focus of detecting incidents capable of producing serious deterministic effects.

1.1. Scope

This Guide outlines an alternative assessment criterion for criticality incident detection and alarm systems installed or required to be installed at UK nuclear licensed sites that handle fissile material, with a primary focus of detecting incidents capable of producing serious deterministic effects.

It is not prescriptive and should not be read as a code of practice, it solely provides a reference that can be utilised by nuclear industry practitioners when reviewing the adequacy of existing CID systems and/or assessing the requirements for new CID systems. It gives an alternative criterion to use in those circumstances where the historic criterion is overly onerous as a consequence of significant source absorption or the presence of bulk radiation shielding.

1.2. Document Overview

Chapter 2 outlines the key purposes of CID systems along with the relevant health and safety legislation that has been considered throughout this document.

Chapter 3 discusses criticality emergency planning in context with the guidance provided by PHE on the protection of on-site personnel in the event of a radiation accident. This chapter also discusses the differences between the deterministic and stochastic exposure bands, including how emergency plans should focus on avoiding serious deterministic effects whilst decisions on protective measures for reducing stochastic exposures should be based on an evaluation of the relative levels of benefit and harm expected to result from different courses of action.

Chapter 4 describes the CIDAS omission criteria and criticality incident detection criteria used historically in the UK.

Chapter 5 details the further basis for an alternative criticality incident detection criterion with the primary focus of detecting incidents capable of producing serious deterministic effects. This chapter highlights the challenges identified by site licensees in justifying modifications to existing plants required to comply with the historic detection criterion, as well as consideration of the guidance, recommendations and standards provided by bodies including PHE, ICRP, ISO and ANS.

Chapter 6 details an alternative CIDAS omission criteria and criticality incident detection criterion, with the primary focus on detecting incidents capable of producing serious deterministic effects.

Chapter 7 provides a summary of the key points made in this document.

2. Criticality Incident Detection and Alarm Systems

2.1. Purposes

A CID system does not prevent a criticality incident from occurring. A CID system informs operators and other personnel that a criticality incident has occurred so that emergency procedures (such as prompt evacuation) can be instigated (i.e. dose reduction).

With some critical systems, further fission spikes may occur some seconds or minutes after the initial spike, and prompt evacuation will prevent exposure to these further spikes.

It is considered that that the key purposes of a CID system are as follows:

1. Avoid deterministic dose injuries as far as possible (via prompt evacuation as part of an emergency plan);

2. Protect personnel from residual dose and further criticality accidents;

3. Inform that a criticality incident has occurred (although for those situations in which the dose consequences of any potential accident can be shown to be below the deterministic threshold this can be achieved by alternative more appropriate means).

The consequences and subsequent further actions required by the licensee following a criticality incident are outside the scope of this guide and therefore are not discussed further in detail.

2.2. Legislative Requirements

This document has been generated with consideration of relevant health and safety legislation. Where appropriate legislation has been referenced, but the primary legislation that has influenced this document is:

- Ionising Radiations Regulations 1999 (IRR99)

Regulation 12 of IRR99 in [1] relates to the need to produce contingency plans for any reasonably foreseeable accidents which will restrict so far as is reasonably practicable the subsequent exposure to ionising radiation.

A CID system is designed to initiate action which is part of an emergency plan to mitigate the dose consequences of a criticality accident and so can be interpreted as a measure taken to ensure compliance with this regulation.

- Office for Nuclear Regulation (ONR)

The ONR has produced a Technical Assessment Guide (TAG) on criticality warning systems in [2].

- International Commission on Radiological Protection

ICRP recommendations on radiological protection are provided in [3] and [4].

- Public Health England[1]

PHE have provided guidance on the protection of on-site personnel in the event of a radiation accident in [5] and [6].

[1] Formerly the Health Protection Agency (HPA) and before that the National Radiological Protection Board (NRPB).

3. Criticality Emergency Planning

PHE has provided guidance on the protection of on-site personnel in the event of a radiation accident [5]. This PHE guidance discusses that there are two key exposure bands relevant to emergency response plans: those where the doses (and dose rates) are sufficiently high to lead directly to serious deterministic injuries, and those lower doses (and dose rates) where serious deterministic injuries will not occur but the individual will have an increased risk of developing later health problems, in particular cancer (stochastic health effects).

Note that it is generally assumed that off-site personnel are unlikely to receive doses high enough to result in deterministic effects as a result of a criticality incident.

3.1. Deterministic Effects

Serious deterministic effects may be avoided by preventing doses from exceeding the relevant thresholds for these injuries. The dose thresholds used for emergency planning purposes are set at a level somewhat lower than those which would result in serious deterministic injuries. This is in order to ensure that no individual would be subject to serious deterministic injury if exposed to the threshold dose.

PHE recommend an emergency planning dose threshold of 0.5 Gy (500 mGy) whole body for acute exposure to neutrons and 1 Gy for low LET radiation (which includes gamma-rays and x-rays) [5].

The Office for Nuclear Regulation (ONR) Technical Assessment Guide (TAG) on criticality warning systems [2] states that the licensee should identify an appropriate dose contour for evacuation. Since the threshold for deterministic effects is generally assumed to occur at a whole body dose of 500 mGy, it is expected that a dose criterion no higher than this value is adopted for identification of the dose contour for evacuation to avoid deterministic effects.

3.2. Stochastic Effects

For exposures resulting in doses below deterministic thresholds it is generally assumed that the size of the stochastic radiation risk is directly proportional to the size of the dose, and that there is no threshold dose below which there is no risk.

PHE recommends that decisions on protective measures for reducing these exposures should be based on an evaluation of the relative levels of benefit and harm expected to result from different courses of action, in line with the standard principle of emergency planning.

The default criticality emergency plan currently consists of a full CIDAS or nothing and the system does not distinguish between dose levels capable of producing serious deterministic effects and those only capable of producing stochastic effects. Currently the evacuation dose contour is defined based upon the potential to receive 100 mSv from 10^{18} fissions.

Emergency planning for potential criticality events should focus on measures to avoid deterministic effects but needs also to include measures optimised to mitigate the stochastic effects that result from doses below the deterministic threshold.

A criticality detection and evacuation system that is designed to detect all potential incidents capable of producing serious deterministic effects achieves the first requirement but could leave smaller incidents undetected. These undetected incidents could result in potentially significant stochastic doses, which an optimisation process could require to be reduced (i.e. measures could be justified to reduce these stochastic doses which give a net benefit). An example measure would be to simply extend the detection system to also detect incidents capable of only producing high stochastic doses (e.g. approximately 200 mSv). It is judged by PHE in [6] that doses of approximately 200 mSv or greater should be considered to lead to high individual risk of stochastic effects. This would then ensure that all incidents capable of producing deterministic doses or high stochastic doses were detected.

However, such an approach which requires the CID to always detect incidents that are also capable of producing stochastic effects ignores the different nature of the deterministic and stochastic risk and it is recommended that such an approach is not blindly pursued. Instead it is recommended that the focus should indeed be on detecting incidents capable of producing deterministic effects by default with consideration on a case by case basis of extending detection into the stochastic region. Such an approach would properly consider the realistic benefit / harm balance associated with enhanced detection, which is sensitive to the plant specific physical conditions (e.g. levels of shielding between operators and potential incidents and realistic criticality characteristics such as locations and fission yields).

In summary, it is recommended that for the alternative approach being proposed in this document the CID system will focus on detecting incidents capable of producing serious deterministic effects. The potential undetected stochastic dose would then be assessed on a case by case basis taking into account specific plant conditions. If the stochastic dose is considered to be unacceptable then detection could be extended into the stochastic region following an evaluation of the relative levels of benefit and harm. Such an approach is recommended as benefit / harm considerations don’t really apply in the deterministic dose region [6] and so definite recommendations can be made independent of circumstances; this is not the case for the stochastic region.

4. Historic Criticality Incident Detection Criteria

Although this document is focusing on defining an alternative criticality detection criterion, it is important to understand that there is a natural link between the detection criterion and the criteria used to determine whether a detection system is needed. This section therefore briefly describes both the historic CID omission criteria and detection criterion in preparation for proposing consistent alternatives to both. The alternatives are discussed further in section 6.

4.1. CIDAS Omission Criteria

Historically in the UK, CIDAS omission cases for facilities handling fissile material are generally based on one of the following two criteria [2]:

1. A CID system is not required where an assessment shows that the maximum dose to the most exposed individual from a maximum credible incident (outside a nuclear reactor) would not exceed the maximum acceptable emergency dose.

2. A CID system must be provided at all places where fissile material may be used or stored, unless it is confidently judged that in the event of the failure of any or all of those criticality controls which rely on human agency or on mechanical or electrical devices, criticality would not reasonably be expected having regard to the nature of the particular operations and facility concerned.

With regards to Criterion 1, the maximum credible incident is generally taken as $2x10^{19}$ fissions with the maximum acceptable emergency dose typically assumed to be 100 mSv. Therefore, for example, if a $2x10^{19}$ fission event results in the most exposed individual receiving a dose of 100 mSv or greater for a given plant then a CID system would be required and an omission case cannot be made.

Criterion 2 dates from the work of Aspinall and Daniels in the 1960s [7] and has been reiterated in the more recent work of Dellafield and Clifton in the 1980s [8]. In short, a CID omission case must demonstrate that an incident is not reasonably expected when all criticality controls have failed. Whereas, the criticality safety case should demonstrate safety from all reasonably foreseeable faults when all the controls are in place (with only a small probability of failure).

4.2. Criticality Detection Criteria

Where CIDAS is required, the UK detection criterion is historically based upon the requirement to detect the minimum incident of concern as follows [8]:

- For unshielded/lightly shielded systems and close working operations (< 2m), the minimum incident of concern is 10^{14} fissions over a period of between 1 ms and 0.5 s for fast systems or between 1 ms and 60 s for slow systems.

  For unshielded/lightly shielded systems and non-close working operations (> 2m), the minimum incident of concern is 10^{15} fissions over a period of between 1 ms and 5 s for fast systems or between 1 ms and 60 s for slow systems.

- For heavily shielded systems (i.e. where an incident of 10^{15} fissions would not be detected) the minimum incident of concern is that which could result in an operator receiving a maximum undetected dose of typically 100 mSv.

5. Basis for Defining an Alternative Criticality Incident Detection Criterion

This chapter details the principal guidance, recommendations and standards that have been taken into consideration and which form the basis for defining an alternative criticality incident detection criterion with the primary focus of detecting incidents capable of producing serious deterministic effects.

5.1. Public Health England Advice

The documents from PHE (NRPB at the time of publishing) were the first in the UK to bring standard emergency planning principles to the attention of the criticality community. This resulted in a sharper focus on avoiding serious deterministic injuries and the introduction of the concepts of justification and optimisation to criticality emergency planning. The alternative criteria being proposed here are in line with those principles i.e. prompt evacuation to avoid serious deterministic injuries followed by optimisation of further measures to reduce stochastic doses.

5.2. ICRP Recommendations

When justifying the basis for defining an alternative criticality incident detection criterion, the recommendations made within ICRP Publication 60 [3] (and ICRP Publication 103 [4]), were taken into account. These recommendations are upon which the Ionising Radiations Regulations 1999 (IRR99) [1] are based. ICRP 60 makes the following remarks:

“Dose limits do not apply directly to potential exposures (paragraph 129)”

“They are controlled by an assessment against risk limits (paragraph 246). Should they occur they will lead to an intervention the instigation of which should not be based on dose limits (paragraph 131) as that would result in measures that would be out of proportion to the benefit obtained and would conflict with the principle of justification”

“Nevertheless at some level of dose approaching that which would cause serious deterministic effects, some kind of intervention will become almost mandatory (paragraph 131)”

In relation to the statement made in paragraph 129 of ICRP 60, a criticality incident is not regular, extended or deliberate (outside of a nuclear reactor). A criticality incident is therefore a potential exposure (i.e. only has a small probability of occurrence) and consequently normal dose limits (such as 20 mSv) do not apply to them. Only at dose levels approaching those which result in serious deterministic effects (i.e. 500 mGy) would there be a mandatory requirement to take action.

5.3. International Standards

The international standards for criticality detection that have been used for comparison against those historically used in the UK are outlined below:

- International Organisation for Standardisation “Nuclear Energy - Performance and testing requirements for criticality detection and alarm systems”, ISO 7753 [9]:

"Criticality alarm systems shall be designed to detect promptly the minimum accident of concern. For this purpose, in typical unshielded process areas, the minimum accident of concern may be assumed to deliver an absorbed neutron and gamma dose in free air of 0.2 Gy at a distance of 2 m from the reacting material within 60 s."

- American Nuclear Society "Criticality Accident Alarm System – an American National Standard", ANSI/ANS-8.3-1997 [10]:

"Criticality alarm systems shall be designed to respond immediately to the minimum accident of concern. For this purpose, in areas where material is handled or processed with only nominal shielding, the minimum accident may be assumed to deliver the equivalent of an absorbed dose rate in free air of 0.2 Gy/ min ~20 rad/ min at 2 meters from the reacting material. The basis for a different minimum accident of concern shall be documented."

Both of the above international standards for criticality detection criteria are based upon detecting a dose of 0.2 Gy (i.e. 200 mGy) at a distance of 2 m from the *minimum incident of concern*. These criteria are consistent with the historic UK detection criterion, in that they are based upon detection of a minimum incident of concern which although it is defined in a different manner (by dose and not incident size) represents essentially the same sized incident. However it is perhaps re-assuring that the dose values used in these standards are close to the accepted threshold for serious deterministic injuries (500 mGy) and so any alternative criterion based around this threshold could be made consistent with the standards without compromising the guiding principles outlined above (Section 5.1). The alternative criterion will therefore remain consistent with these standards that may be viewed as good practice.

6. Alternative Criticality Incident Detection Criteria

Taking into account the guidance, recommendations and standards relating to criticality incident detection and emergency planning, it is judged that it would be reasonable to define alternative CIDAS omission and incident detection criteria as described in this chapter.

6.1. CIDAS Omission Criteria

Acknowledging that the primary purpose of a CID is to avoid serious deterministic effects leads to the proposed alternative CID omission criterion (i.e. Omission Criterion 1, see Chapter 4.1) being based upon the deterministic dose threshold of 500 mGy. However, a lower dose may be justified on a case by case basis, or to introduce a margin for uncertainty. Criterion 2 for CID omission should remain the same (see Chapter 4.1).

In order to assess whether 500 mGy can be received (and hence whether a CID omission case can be made or not), a fission yield of 2×10^{19} should be used in the absence of any other information. However, if appropriate, a larger or smaller fission yield could be used based upon plant specific conditions and information. Appendix A provides information regarding the justification of increasing or lowering the fission yield used to determine whether a CID omission case can be made on a plant specific basis.

This combination of incident size and dose could also be used to define appropriate default evacuation contours.

There is no implied necessity for licensees to use this alternative approach, but it gives the possibility of providing a more focused emergency plan that targets the important need to avoid serious deterministic injuries. Having said that, this alternative dose based criterion changes the status of the 'omission case' i.e. it can no longer be viewed as the boundary between having an emergency plan and not having one. In particular, although it is unlikely that a bespoke criticality detection and alarm system will be required for incidents which are not capable of producing deterministic doses other less costly measures (e.g. utilising standard radiological instruments or simpler systems to instigate controlled evacuation) may be needed to reduce high stochastic doses (in the range 100-200mSv).

6.2. Criticality Detection Criterion

Although ICRP 60 recommends that dose limits should not be applied to potential exposures (such as criticality incidents), it also states that intervention will be required at some dose level approaching that which would cause serious deterministic injuries. This forms the basis for defining an alternative detection criterion based upon detecting a dose of ≤ 500 mGy in order to avoid serious deterministic effects.

It is judged to be good practice for the detection criterion be revised to 125 mGy (i.e. somewhat lower than the 500 mGy deterministic dose threshold for emergency planning). The choice of 125 mGy is significantly below the 500 mGy threshold and provides some safety margin for repeat undetected incidents (i.e. it would take four repeat incidents giving a dose of 125 mGy to approach the 500 mGy threshold).

7. Summary of Key Points

A summary of the key points made within this document is provided below:

- An alternative criticality incident detection criterion is defined based upon avoiding dose which could result in serious deterministic effects, with the acceptability of the associated stochastic dose considered on a case by case basis;

- Reducing high stochastic doses should be considered on a case by case basis but should not detract from the primary aim of a bespoke CID system (i.e. to avoid deterministic effects). Stochastic dose protection may be achieved by extending the detection into stochastic region or via a separate system but should be based on an evaluation of the relative levels of benefit and harm expected to result from different courses of action;

- To be consistent with the alternative detection criterion an alternative CIDAS omission dose criterion should be defined based upon the deterministic dose threshold of 500 mGy (i.e. emergency planning dose threshold recommended by PHE) as opposed to the current maximum acceptable emergency (stochastic) dose of 100 mSv.

  The maximum credible incident should be to $2x10^{19}$ fissions based upon information gathered from past incidents and used for both CIDAS omission arguments and evacuation contours, unless it is appropriate to use an alternative fission yield (see Appendix A for further information);

  This alternative omission criterion no longer represents the boundary between an emergency plan and no plan, but the boundary which defines when a plan to avoid serious deterministic injuries is required. It therefore in practice defines when a bespoke criticality detection and alarm system is likely to be necessary.

- The CID system must detect ≤ 500 mGy to avoid serious deterministic effects. As such, a detection criterion of 125 mGy is proposed, which provides some safety margin against repeat incidents;

- The alternative detection criterion as described above, is consistent with ICRP recommendations (ICRP 60 and ICRP 103) and advice from PHE.

8. References

1. Statutory Instruments, “The Ionising Radiations Regulations 1999”, 1999 No. 3232.

2. Office for Nuclear Regulation, ONR Guide - Criticality Warning Systems, NS-TAST-GD-018 Revision 5, May 2016.

3. International Commission on Radiological Protection, “1990 Recommendations of the International Commission on Radiological Protection”, ICRP Publication 60, 1991.

4. International Commission on Radiological Protection, “The 2007 Recommendations of the International Commission on Radiological Protection”, ICRP Publication 103, 2007.

5. National Radiological Protection Board (Public Health England), “Protection of On-site Personnel in the Event of a Radiation Accident”, Volume 16 No.1 2005.

6. Health Protection Agency Radiation Protection Division, “Further Guidance on Protection of on-Site Personnel in the Event of a Radiation Accident”, RPD-EA-9-2007, September 2007.

7. K. J. Aspinall, J. T. Daniels, “Review of UKAEA Criticality Detection and Alarm Systems 1963/64 Part 1: Provisions and Design Principles”, 1965.

8. H. J. Delafield, J. J. Clifton, “Design Criteria and Principles for Criticality Detection and Alarm Systems”, SRD R309, 1984.

9. International Organisation for Standardisation, “Nuclear Energy - Performance and testing requirements for criticality detection and alarm systems”, ISO 7753: 1987 (E), 1987.

10. American Nuclear Society “Criticality Accident Alarm System – an American National Standard”, ANSI/ANS-8.3-1997.

Appendix A – Guidance for Justifying Appropriate Plant Specific Fission Yields for Criticality Emergency Planning.

There is a long history in the UK nuclear industry of assuming that the maximum fission yield for a criticality incident, excluding reactors and critical assemblies is $2x10^{19}$ fissions e.g. [A1]. This assumption has been reviewed over the intervening years and shown to be still appropriate e.g. [A2]. The assumption is also consistent with international standards e.g.[A3], which also specifically recommends its use for CID omission purposes. All three references base their assumption on the historic record of real incidents. [A3] states that a different yield can be employed if it is documented; implying that $2\ x10^{19}$ fissions is the default position but can be reduced based on suitable evidence. This appendix will briefly discuss the issues associated with justifying plant specific fission yields which are different to the accepted maximum value.

First of all it is important to note that plant specific estimates are difficult to justify as they must consider the characteristics of an incident that is likely to be unforeseen. It is for this reason that [A2] recommends that the historic record of past incidents is a much better basis of estimating representative fission yields on which to base emergency planning. The historic record, although limited in the number of data points ([A2] considered 33 incidents that covered a range of systems appropriate to potential future incidents) was shown to be surprisingly robust e.g. the different systems included (process accidents (solutions), critical experiments (solutions), bare and reflected metal systems, moderated metal and oxide systems, miscellaneous systems) followed similar trends and when more data became available [A4] it too was broadly consistent with the original [A2] record. So moving away from the default assumption, shouldn't be done lightly and only for situations where confidence can be gained that the physical characteristics of a potential criticality can be adequately described. If this is the case e.g. the critical volume is constrained by vessel size, the reactivity insertion rate by gravity, and the fissile materials by the nature of the process then it is possible to use a range of prediction techniques to derive more appropriate (less pessimistic) fission yields that could form a better basis for emergency planning.

Potential fission yield estimation tools

[A5] uses the results from various experimental programmes (the CRAC, Silene and KEWB series of experiments from France) to determine limiting first spike yields in liquor systems (10^{15} fissions per litre) and the subsequent total yields. These empirical methods are shown to be consistent with the historic record discussed above and can be viewed essentially as a means of limiting the upper bound yield ($2x10^{19}$ fissions) as a consequence of a limited critical volume. [A5] considers liquor systems only as there is a '*seemingly negligible accident rate in non-solution media'* and so liquor systems are by far the biggest concern. The limiting yields appear constant across a range of liquor chemistry (and fissile nuclides) and are applicable to reactivity insertion rates that are unlikely to be exceeded accidently.

Beyond these simple empirical methods are more detailed computer codes that can model the physical processes that occur during a criticality incident (e.g. a reactivity calculation coupled with neutron kinetics and thermal feed-back mechanisms) and hence predict the time evolution of the incident including its final shutdown and total yield. An example of such a code is FETCH [A6]. The use of such methods to predict plant specific yields is limited by the difficulty in defining the initial conditions and validation of the results. Nevertheless the codes continue to improve their physical modelling capabilities and may have a role to play in estimating plant specific yields in those circumstances that initial (accident) conditions can be adequately bounded and appropriate validation is available (e.g. from modelling of experimental arrangements).

Appendix A References

A1 H. J. Delafield, J. J. Clifton, "Design Criteria and Principles for Criticality Detection and Alarm Systems", SRD R309, 1984

A2 SCN-91 Rev 1, The characteristics of Criticality Excursions- A Review for Criticality Safety considerations, T B Austin, January 1994

A3 ANS8.3-1997, Reaffirmed 2012, Criticality Alarm System.

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A5 Process Criticality Accident Likelihoods, Magnitudes and Emergency Planning- A Focus on Solution Accidents, Thomas McLaughlin, JAERI Conf 2003-019

A6 CC Pain et al, Transient Criticality in Fissile Solutions- Compressibility Effects, Nucl Sci Eng 138, p78-95 (2001)

List of SDF Publications

Codes of Practice

Best Available Techniques for the Management of the Generation and Disposal of Radioactive Wastes
Changeroom Design, Operation and Maintenance
Clearance and Radiological Sentencing
Management of Change and the Nuclear Baseline

Good Practice Guides

Independent Oversight – A Nuclear Industry Good Practice Guide
Personnel Dosimetry Management
The Application of ALARP to Radiological Risk
The Selection of Alarm Levels for Personnel Exit Monitors

Other Guidance

An Aid to the Design of Ventilation of Radioactive Areas
Best Practice on Peer Review Case Submissions
Conservative Exposure Durations for Unmitigated Worker Doses in Design Basis Analysis
Key Attributes of an Excellent Nuclear Security Culture
Right First Time Safety Cases: How to Write a Usable Safety Case
Conservative Exposure Durations for Unmitigated Worker Doses in Design Basis Analysis