Office for Nuclear Regulation

ONR GUIDE			
CRITICALITY SAFETY			
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1 INTRODUCTION

1.1. Criticality is an important nuclear safety hazard in plants where fissile material is manufactured, processed, handled or stored (but is also an important consideration during defuel/refuel operations on nuclear reactor plant). The potential consequences of a criticality accident can be considerable e.g. high/potentially lethal radiation doses to workers and potentially high radiation doses off-site, there is also a potential for the accident to damage plant and equipment, which can in turn provide further challenges to the safety of the workforce and the public. Hence it is of importance that Office for Nuclear Regulation (ONR) inspectors periodically satisfy themselves that the licensee has adequate arrangements in place, to protect the workforce and the public against the potential occurrence of accidental criticality events. Inspectors should use risk informed judgment in deciding upon the required periodicity of inspections in this area.

2 PURPOSE AND SCOPE

2.1 The purpose of this inspection guide is to provide assistance to ONR inspectors who are not criticality safety professionals, when conducting their duties in this area. However, the guidance should not be regarded as being mandatory and inspectors are expected to use their discretion in choosing topics from this guide to direct their inspection activities and/or in choosing specific questions for discussion with the licensee in a topic area, in obtaining the necessary confidence that the licensee has robust arrangements in place to control all its operations with fissile material.

2.2 Whilst the guidance contained in this document is comprehensive, it is envisaged that individual parts can be used by inspectors conducting routine compliance inspections against certain Licence Conditions in facilities where there is a significant criticality hazard. The guidance can also be used to inform System Based Inspections (SBI) in fissile material facilities. The conduct of more comprehensive criticality safety inspections, in contrast, will usually be conducted by specialist criticality safety inspectors.

2.3 The requirement to ensure criticality safety at nuclear sites is not addressed specifically in any of the Nuclear Site Licence Conditions, nor is it addressed explicitly in current legislation (although the requirement is implicit in the Health and Safety at Work etc. Act 1974, the Ionising Radiations Regulations 1999 and the Nuclear Installations Act of 1965 – as amended). However, various Nuclear Site Licence Conditions (LCs) do have legal requirements which directly impinge upon criticality safety.

2.4 The writing of this Technical Inspection Guide (TIG) has been informed by the recognised links to the LCs and accordingly the guidance to ONR inspectors is written in the form of a number of Appendices, one for each relevant LC, with a series of bullet points advising the inspector as to potential considerations when conducting criticality safety related inspections against this LC. The guide reflects ONR experience collated during criticality focused interventions on UK licensee sites and also takes account of feedback provided by the community of criticality professionals within ONR, as well as the UK nuclear industry as represented on the UK Industry Forum i.e. the Working Party on Criticality (WPC). A number of valuable improvements to the document have been made at the suggestion of the Defence Nuclear Safety Regulator (DNSR).

2.5 Whilst the questions in the Appendices of this document are generally aimed at plant applications, they can be adapted to inspections related to the transport of fissile material. However, question sets for criticality safety inspections, focused on transport, are already available as a part of the “Criticality Assessment Transport Permissioning Guide”, which can be found at:-

http://how2/Control/CtrlWebIsapi.dll/?__id=webDiagram.showFile&map=Library+Documents+-+Permissioning+Guides&dgm=0ECD9298ABB34A97A446DB120A1E0B29&rev=99&di=14&ai=0

2.6 ONR Transport is currently developing specific guidance for criticality safety inspections for transport packages, which will be published in due course and in the future ONR will seek to integrate this guidance with the information contained in this TIG..

3 REFERENCES

3.1 The References provided below link this TIG to other ONR guidance in the area of criticality safety (e.g. Technical Assessment Guides and ONR Safety Assessment Principles). However, in addition, for those inspectors wishing to enhance their knowledge of the subject, References have been provided to other reading which will provide the Inspector with a simple but more detailed description of the subject.

1. IAEA Safety Standards – Specific Safety Guide No. SSG-27 – "Criticality Safety in the Handling of Fissile Material," Vienna 2014

2. Safety Assessment Principles for Nuclear Facilities, 2014 Edition, Revision 0, November 2014. http://www.onr.org.uk/saps/saps2014.pdf

3. NS-TAST-GD-041 – "Criticality Safety," Revision 4, 2016,

4. NS-TAST-GD-018 – "Criticality Warning Systems," Revision 5, 2016

5. "Nuclear Physics. Principles and Applications," J Lilley, J Wiley and Sons Ltd

6. "Nuclear Criticality Safety – Theory and Practice," R A Knief

7. INL/EXT-06-01183 – "Criticality Safety Basics for INL FMHs and CSOs", Revision 1. http://inldigitallibrary.inl.gov/sti/5427214.pdf

8. LA-12808 – "Nuclear Criticality Safety Guide," N L Pruvost, H C Paxton, (LANL - Los Alamos National Laboratory), 1996. http://ncsc.llnl.gov/basic_ref/library/la_12808.shtml

9. LA 3366 – "Criticality Control in Operations with Fissile Material," H C Paxton, Los Alamos National Laboratories, Revision 1, 1972

10. LA-13638 – "A review of Criticality Accidents" 200 Revision (May 2000), Los Alamos National Laboratory. http://ncsc.llnl.gov/basic_ref/library/la_13638.shtml

4 APPENDICES

APPENDIX 1: CRITICALITY SAFETY CULTURE

During inspections, of the criticality safety arrangements put in place across a variety of UK licensees conducted over many years, ONR criticality professionals have formed a view on what evidences a good criticality safety culture within a licensee organisation. The following bullets describe some indicators the non-specialist ONR inspector may wish to look for when judging the ‘health’ of the criticality safety culture on a licensee’s site (the list is not intended to be exhaustive and the inspector may well identify other indicators that assist in forming judgements as to the adequacy of a licensee’s criticality safety arrangements). The bullets are not intended to be regulatory requirements, but instead provide indicators to a healthy criticality safety culture within a licensee’s organisation.

Criticality Safety Professionals

- Can the licensee provide evidence that its criticality assessment personnel are maintaining a focus on their continuing professional development in the criticality technical area?
- Do the licensee’s criticality safety professionals routinely and actively participate in the UK Working Party on Criticality (WPC) and its annual workshops?
- Does the licensee actively maintain an up-to-date database of criticality safety reference material e.g. text books, conference papers, papers from journals, American Nuclear Society -ANS publications, archives of its previous assessment work etc.?
- How does the licensee keep itself abreast of any relevant research in criticality safety or in the ongoing development of nuclear data-sets etc.?
- Is the licensee active in the production of its own Quality Assured (QA’d) internal documentation, to provide guidance on assessment of the fissile systems commonly encountered during its operations? ONR experience is that most licensee’s develop their own guidance notes and data which are often of a high quality and ensure that valuable previous work is not lost.
- How often do the licensee’s criticality safety professionals conduct inspections of operations on the site and are the findings from these both documented and acted upon? Is there evidence that such inspections are also used as an opportunity to engage with the workforce to try to ensure early identification of problems with implementation of criticality safety rules/working practices etc.?
- Is there clear evidence that the licensee is outward looking i.e. routinely interacts with other licensee bodies to ensure good practice is both sought and adopted where relevant? Close liaison might be expected where licensee are undertaking similar operations.
- For any cases where the licensee’s criticality safety assessment function is a centralised one, what provision has been made by the licensee to ensure some enhanced criticality safety expertise is present on the operating sites themselves (e.g. the role of a “Criticality Specialist” has been established by some licensees)? These personnel are trained to have a more detailed knowledge of criticality safety, without necessarily being trained as professional criticality assessors – the role is intended as a ‘first point of contact’ for the workforce on the site to raise any concerns with respect to criticality safety or to ask questions/seek clarification on matters pertaining to criticality safety on the site and to act as the liaison between the operating site and the more highly trained professional criticality assessors at the licensee’s Corporate Centre.
- Can the licensee demonstrate that it proactively learns from operational experience and makes suitable revisions to its assessments and practices?

The licensee should be able to provide evidence that its criticality safety analysis work is reviewed periodically and as new information becomes available i.e. to ensure that this new information (where relevant) is taken into account appropriately.

- What evidence exists that the licensee actively challenges the values applied to uncertainties (e.g. in modelling approximations, nuclear data etc.) in its criticality safety calculations? Good practice in this area is viewed by ONR as, for example, the licensee having an internal committee of peers, who will review and challenge the uncertainties being applied to criticality calculations. Alternatively, do the licensee's criticality safety professionals take expert advice from the code authors when applying uncertainties particularly to new or novel situations?
- Does evidence exist that the licensee actively challenges the k-effective criticality safety criterion it uses within its criticality safety analyses (e.g. by benchmarking against other licensees, consultation with the code authors etc.)?

Engineering and Shop Floor Staff

The inspector may wish to use the checklist at Appendix 4 ("Training of Other Persons on Site") when judging the focus the licensee applies to the criticality awareness training of its operators conducting work with fissile materials.

- During any walk-down inspection in licensee fissile material facilities the inspector may wish to engage with plant personnel (operators) to judge their knowledge of the key factors (e.g. engineering and/or administrative controls) maintaining criticality safety at their work-front. The inspector should seek to 'test' the operator's knowledge of the key requirements placed upon them by the relevant criticality clearance certificates.
- The inspector should make a judgement on licensee tolerance of degraded conditions with respect to criticality safety and this might be evidenced by, for example, standing alarms, overly cluttered gloveboxes, poor house-keeping in fissile material areas, accumulations of potentially flammable materials, gaps in and/or signatures missing from plant logs (e.g. of current plant moderator holdings etc.).
- When engaging with plant operators, personnel should be able to describe the actions required of them should a breach of a criticality clearance be suspected/occur, or if the criticality alarm were to sound. Are these requirements in accordance with relevant plant documentation?
- The inspector may also wish to question operating staff in fissile material areas as to their awareness of who to contact with questions regarding criticality safety.
- Do the plant operators have easy access to key criticality safety documentation e.g. the criticality clearance certificates?
- The inspector should seek to ascertain from operations staff that criticality safety professionals and/or Criticality Specialists (see above) visit the work fronts regularly and also seek to actively engage with staff to answer questions, identify problems/work-arounds at an early stage etc. What other management walk-downs are conducted with a focus on criticality safety?
- What supervisor checks, e.g. by a Duly Authorised Person – DAP, are conducted during the conduct of fissile operations and how are such checks evidenced (e.g. by counter-signatures on step-wise process instruction sheets)?
- Some licensee may choose to use computerised systems to oversee/control their movements of fissile material from one location to another. When using such systems it is ONR's expectation that the inputs into the computerised systems will be made by trained Nuclear Material Controllers and will also be

subjected to independent scrutiny by other trained Nuclear Material Controllers, who will confirm that the proposed move meets the requirements of the Criticality Clearance Certificate for the destination location, prior to the actual movement being conducted.

- The inspector may also wish to ascertain how the operators in fissile material areas would be briefed/trained on any change to a process, operations etc. Can the licensee provide evidence of such briefings/training being conducted e.g. log books that operators sign onto to signify that they have received and understood the training? Is their evidence of any grading in the training/briefing provided e.g. for very minor changes a short brief may be appropriate but for major/more fundamental changes a period of class-room training by criticality safety professionals may be more appropriate?

When reviewing the licensee's criticality safety culture, the ONR inspector could seek advice from ONR Human Factors specialists and advice from trained ONR criticality safety professionals is also recommended.

The inspector is reminded that good criticality safety culture is not solely indicated by the factors above, although these are good indicators, but also by strong performance by the licensee against some of the points raised later in this guide against other Licence Conditions.

APPENDIX 2: LICENCE CONDITION 7 – INCIDENTS ON THE SITE

- Does a criticality safety professional routinely examine all incident reports on the site, to look for any incidents both directly related to criticality safety and those which, although not necessarily directly criticality related, could impact upon criticality safety?
- How can the licensee evidence this ‘sifting’ of incidents by a criticality safety professional?
- What mechanisms exist within the licensee’s organisation for flagging concerns, identified from the ‘sifting’ of the incident/occurrence reports by the criticality safety professional, to the licensee’s management chain and for ensuring that learning is disseminated effectively through the licensee’s organisation (and where relevant, engineering or administrative improvements are made to improve criticality safety)?
- Can the licensee provide documentary evidence to show that its mechanisms for dissemination of learning through the organisation are being used effectively and where relevant is generating the implementation of improvements?
- Is the licensee able to demonstrate that the recommendations from any incident investigations are followed up in a timely manner and ultimately are satisfactorily closed out?
- Can the licensee demonstrate that the incident investigation recommendations are appropriately closed out i.e. via written records with close off being agreed at a suitable management level within the licensee’s organisation?
- Does the licensee have systems in place to routinely interrogate Operational Experience (OpEx) from elsewhere within its own organisation/the UK/internationally and how effectively is it using them?
- Can the licensee demonstrate a use of companywide/national/international OpEx in driving criticality safety improvements on the site?

A learning licensee should be able to demonstrate that where appropriate enhanced criticality safety measures, both engineered and/or administrative, are developed and introduced into plants as a result of plant experience and improvements.

It is anticipated that OpEx will cover a wide range of topics with a potential to impact upon criticality safety e.g. including false Criticality Incident Detection and Alarm System (CIDAS) alarms.

APPENDIX 3: LICENCE CONDITION 8 – WARNING NOTICES

- Are appropriate notices displayed to clearly inform staff they are entering/leaving areas subject to criticality control?
- Are the boundaries of such criticality control areas clearly marked and are the signs delineating the boundary positioned in sensible locations?
- Are criticality evacuation routes clearly signed throughout the intended evacuation route i.e. both within and external to buildings?
- Are the posted signs in good condition and are they unambiguous?
- Are all signs, relating to criticality safety, standardised across the site?
- Are all the posted signs on a maintenance schedule and how frequently are they inspected and maintained (external signage particularly is prone to weather damage)?
- Are responsibilities clear for maintenance and inspection of signage?
- Is due cognisance taken of any required changes to the positioning of the signage in the event of changes on the site e.g. construction projects, re-routing of access ways etc. and how is this controlled?
- If criticality evacuation zones extend beyond the site boundary, is signage installed in these areas to clearly direct the actions to be taken e.g. on hearing the criticality alarms (noting that there may be access to such areas by untrained members of the public)? So far as is reasonably practicable the licensee should try to ensure that any access to such areas by members of the public would be unlikely and/or of a low duration. The licensee must be able to demonstrate it is cognisant of these areas and have arrangements in place to ensure they are promptly evacuated and secured against further access for the duration of the event.
- Are alternative visual warnings (e.g. flashing beacons) also installed in, for instance, high noise areas within buildings where fissile material operations are conducted?
- Are visual warnings installed, ideally triggered by the criticality alarm, at all entrances to fissile material facilities to warn workers to keep out of the building as a criticality event has occurred/is occurring?
- Are warnings present to prevent vehicles from approaching a building where a criticality event may have occurred/be occurring?
- In addition to the criticality alarm sounding in a building and the warning signs on building entrances etc. would there be other visual warnings to advise workers not to approach the building e.g. flashing beacons positioned high on each corner of the building?
- What routine tests are conducted to ensure that criticality alarms continue to be audible throughout facilities where they are installed (particularly in higher noise environments where alternative visual warnings have not been installed)?
- What signage is posted to advise workers of fire-fighting requirements in areas subject to criticality control and are these signs clear, the signs ideally should be large to ensure that mistakes do not occur ‘ in the heat of battle’ and are sensibly located?
- Is any signage present relating to moderator control in areas where fissile material is present and is the signage clear and sensibly located?

APPENDIX 4: LICENCE CONDITION 10 – TRAINING

There are two distinct main areas of training that the inspector may wish to focus attention on i.e.

- Training of criticality safety professionals on the site.
- Training of other persons on the site.

Training of Criticality Safety Professionals

- Is a structured training programme in place for criticality safety professionals on the site i.e. how can the Suitably Qualified and Experienced (SQEP) credentials of the licensee's criticality professionals be demonstrated?
- Is there clear evidence of continuing professional development for criticality assessors on the site? The licensee may be able to provide a demonstration that its criticality safety personnel are maintaining their professional qualifications with suitable bodies such as the Institute of Physics or the Society for Radiological Protection.
- For multi-plant/multi-process sites, is there a process for demonstrating the Suitably Qualified and Experienced Persons (SQEP) credentials of individual assessors to assess particular plants/processes?
- Is there a clear grading system for the licensee's assessors and is there a clear job description for each grade, to ensure that the checking/sign off of criticality assessment work is only permitted by the more experienced staff?
- In the case of an assessor not having worked on a plant/process for a length of time, is there a process for revalidating their awareness of that plant/process prior to them commencing criticality safety assessment work on that particular plant/process?
- Noting a need for overall balance and the requirement to allow individuals to develop evidence for SQEP accreditation, the licensee should be able to demonstrate that the balance of the overall team is SQEP i.e. key authors should be SQEP but can be supported by other workers who are not, thus allowing these non-SQEP individuals to work towards SQEP accreditation. In the case of smaller projects the use of SQEP 'checkers' and peer review can assist in allowing a lapsed SQEP to be revalidated.
- How have criticality assessor training programmes been developed e.g. has the licensee produced the training programme in isolation, or has reference been made to training material from other licensees, other licensee sites, international web based training material etc.?
- Has the licensee taken due cognisance of the Competence Framework for criticality assessors produced by the UK Working Party on Criticality?
  [The inspector may wish to refer the actual training material to a specialist ONR Assessor for comment on its quality and suitability].
- How is the progress of the licensee's criticality assessors measured against the training programme e.g. is there a formal assessment process in place?
- Is suitable mentoring available to trainee criticality assessors?
- Is the work load of the assessment group at a level where the mentoring functions can be delivered in a timely and efficient manner, or is there evidence that mentoring is slipping due to conflicting priorities?
- How has the licensee established a baseline for the number of personnel it requires in its criticality safety group and how often is this baseline reviewed?
- What succession planning does the licensee have in place for criticality safety professionals?
- In the case of the licensee's criticality safety professionals required to respond to events/emergencies, have these individuals received appropriate training to assist them in coping/performing in what are likely to be pressured situations?
- How much time on average do the criticality assessors actually spend on the plant(s) they are responsible for assessing? Are assessors seconded for periods of time to gain plant experience?

The inspector may wish to question a sample of the assessors to obtain their views on the quality and delivery of the overall criticality safety training.

The inspector may wish to sample the licensee's training records for its criticality assessors and/or any mentoring system they may have in place.

Training of Other Persons on Site

- Are all personnel on site, from the most junior to the most senior, subjected to an adequate level of criticality awareness training?
- How quickly does the awareness training have to be delivered after a person's arrival on the site? If the training is delayed for any reason, what interim arrangements are in place for supervision of untrained personnel, in fissile material control areas?
- How frequently do personnel on the site have to undertake criticality awareness refresher training?
- What records are kept of attendance of criticality awareness training and how is training prompted?
- Is more detailed training delivered to personnel who will have direct contact with fissile material operations?
- What sanctions (e.g. increased supervision etc.) are such personnel subjected to until they have successfully completed this more detailed training?
- How frequently is this more detailed training refreshed?
- How is refresher training prompted?
- For all criticality training material, how is the depth of understanding of personnel exposed to the training judged e.g. is there a test at the end of the training with a set pass-mark?
- If the training is tested then what are the arrangements for personnel who do not achieve the required pass mark?
- Is criticality training material standardised across the licensee's sites and if not why not?
- If the training material is not standardised, has the licensee benchmarked the material across their sites to ensure the training delivered is of a consistent quality?
- What use has been made of internationally available criticality training material in designing the licensee's criticality training courses?
- How often is criticality training material reviewed/updated to take account of UK and International Opex?
- What is the licensee's process for reviewing/updating criticality training material?
- If the licensee uses a third party to deliver criticality safety training to its personnel, how does the licensee discharge their Intelligent Customer requirement in this area?
- If the licensee does not have a dedicated criticality safety group on site, is a person(s) identified who has an enhanced level of criticality safety knowledge and to whom personnel can direct criticality related questions?
- How is this 'criticality expert' role publicised on the site?
- What training is provided for the 'expert' role and how is it evidenced that the person(s) has received and successfully assimilated the required degree of training? ONR's view of good practice in this area is that such individuals would receive detailed criticality safety training (probably over a number of days), as well as having to complete a 'mentor guide' on key criticality safety topics, tailored to that licensee's operations, within a certain timeframe prior to being subjected to interview by a senior and recognised criticality safety professional(s).

The inspector may wish to request an ONR criticality specialist inspector to examine the quality of the criticality awareness training material and also may wish to sample the licensee's training records in the area of criticality safety 9with the guidance of an ONR criticality specialist if required).

APPENDIX 5: LICENCE CONDITION 11 – EMERGENCY ARRANGEMENTS

The following paragraphs are only intended to be applicable to those fissile material sites where criticality detection and alarm systems are installed and hence where there is a consequent requirement for criticality emergency evacuation arrangements to be in place. These paragraphs are not valid where the licensee has robust quality assured criticality incident detection and alarm system omission argument in place.

Evacuation

- Sample the training of the licensee's operators in fissile material control areas to ensure that they would evacuate immediately upon hearing the criticality alarm and whether they are aware of the marking of the evacuation routes. Prompt worker evacuation in a criticality can significantly reduce the radiation dose to which they are exposed.
- Ensure that there are routine plant/local exercises based upon a criticality event scenario.
- Has the licensee considered the make-up of its workforce and hence the ability of all its workers to evacuate promptly in the event of a criticality e.g. does the workforce contain any personnel who are hard of hearing and hence may not hear the alarm, does the workforce contain disabled members who may not easily be able to negotiate stairs etc.?
- Should the workforce contain members who due to disability may not be able to evacuate promptly in a criticality, what special arrangements has the licensee made for such personnel and do these arrangements appear practicable to the ONR inspector?
- Do the licensee's operations require workers to access remote areas, which may be within the potential criticality dose contours and from which prompt evacuation is also required, where the criticality alarm and/or visual indications of a criticality (e.g. flashing beacons) may not be audible/visible?
- Where workers may have to work in such remote areas, what arrangements has the licensee made to warn such workers of the occurrence of a criticality and hence for their prompt evacuation?
- Are the marked evacuation routes free from obvious conventional safety hazards e.g. are they well lit at night, are they free from obvious trip hazards, is anything present that could block the route, do workers have to cross busy roads etc.?
- Is evidence available to demonstrate the licensee routinely inspects the evacuation routes to ensure any emergent problems with the route are promptly dealt with?
- Do the marked evacuation routes generally serve to direct workers away from the potential seat of a criticality incident?
- Do the designated criticality evacuation routes make optimum use of any shielding that may be present along the routes?
- Are there any conflicts between evacuation routes for criticality and marked evacuation routes for other hazards (e.g. fire)?
- For criticality focused Exercises conducted by the licensee, is a criticality safety specialist involved in constructing the Exercise scenario i.e. to ensure it is both realistic and suitably challenging for the Exercise 'players'?

The inspector may wish to sample a criticality based exercise to see that workers evacuate promptly and are quickly and efficiently processed at the Evacuation Centre to ensure prompt identification of those worker who may have received a significant radiation dose from the criticality incident.

Criticality Dosimetry

- Are workers in fissile material areas equipped with criticality dosemeters or lockets? The inspector should sample that workers in fissile material facilities are wearing their dosemeters/lockets as required.

- Does the licensee have Health Physics Monitors and suitable instruments ready for prompt deployment to the Emergency Evacuation Centre to allow initial monitoring of worker's dosemeters, torsos if required (for Sodium-24 activation) etc. to allow prompt segregation of workers who may have received a significant radiation dose (and who hence may need medical intervention) from those who have received negligible doses?
- What arrangements does the licensee have with external organisations for monitoring of criticality lockets, blood samples etc. i.e. to give more definitive information on the magnitude of actual worker exposures and how quickly can results be obtained?
- Does the licensee have appropriate and viable arrangements in place with the local ambulance service to ensure that personnel exposed to high doses can be conveyed promptly to medical facilities where they can receive specialist assessment/treatment?
- Can the licensee produce documentary evidence to demonstrate they have looked at a full range of available options for the processing of criticality lockets, dosemeters, blood samples etc. to give the optimum turn-around of results?
- Does the layout of the Emergency Evacuation Centre lend itself to easy segregation of lower dose and potential higher dose personnel and does it allow for segregation of personnel from contact and non-contact areas?
- Is the welfare of the evacuating workers adequately catered for within the Emergency Evacuation Centre e.g. are there sufficient chairs, are toilet facilities available, could workers be given food and drinks if they had to spend an extended period in the Centre etc.?
- Can a roll-call easily be taken at the Emergency Evacuation Centre?

Criticality dosemeters/lockets would be assessed in the event of a criticality incident and the results used to estimate personnel exposures so that due prioritisation can be given by the medical services to the more highly exposed individuals.

<u>Incident Detection</u>

- Can the licensee demonstrate that an appropriate and robust assessment has been undertaken to inform the required number of Criticality Incident Detection and Alarm System (CIDAS) sensors that these have been placed in suitable locations and that each of the detectors will adequately respond to the minimum incident of concern?
- What mechanisms are in place to ensure that the location and performance of detectors would be re-evaluated should future modifications be made to the plant/plant layout?
- How has the licensee defined and justified the 'minimum incident of concern'?
- What provision has the licensee made to remotely access plant gamma monitors, CCTV etc. (to collate information to assist in the location of the criticality incident) within the Emergency Control Centre?
- Even though the licensee may have made a successful CIDAS Omission case, are other radiological instruments in place that would indicate that a criticality had occurred and are arrangements in place to ensure workers would evacuate the immediate area if such radiological instruments were to raise an alarm?

The inspector may wish to seek further advice from ONR specialists in this area.

<u>Specialist Criticality Support to Event Response</u>

- In the event of occurrence of a criticality, does the licensee have 'on-call' access to a trained criticality specialist and how quickly could this individual reach the Emergency Control Centre to commence the provision of specialist advice to the team responding to the incident? Does this timeframe appear reasonable to the ONR inspector and has it been justified by the licensee?
- Since criticality excursions have a potential to 'pulse' over protracted timeframes, does the licensee have suitable arrangements in place to ensure ongoing criticality safety support over any such extended timeframes?
- Does the specialist criticality assessor have key information already available at the Emergency Control Centre to assist him/her in the provision of advice to the team

responding to the incident e.g. some licensees have developed ‘grab packs’ containing key information/data which the criticality specialist can access, other licensees have developed such packs into quite sophisticated but easy to interpret ‘tool kits’?
- Is there evidence that the licensee is actively trying to improve the level of information made available at the Emergency Control Centre to its criticality specialist responder(s)?
- Is the licensee actively consulting with other licensees in order to seek improvements to its information provision to its criticality responders at the Emergency Control Centre?
- Have facilities been allocated in the Emergency Control Centre to allow the criticality responder(s) to work effectively e.g. a quiet area, access to computer databases, conference facilities for discussions with other responders etc.?
- What arrangements does the licensee have to bring in additional specialist criticality safety advice as required e.g. from elsewhere within its own organisation, other Sites, the Corporate Centre, from other licensee’s organisations etc. and are these arrangements exercised?
- The licensee should be able to provide unambiguous evidence that specialist criticality safety assessor advice is sought/obtained in all decisions concerning potential re-entry into the source building e.g. for event termination, casualty recovery etc..

The inspector may wish to sample the information made readily available to the criticality specialist and may wish to seek advice from a specialist ONR criticality inspector as to the adequacy of the information available.

<u>Event Termination</u>

- The ONR inspector should question the licensee as to what consideration it has given in its emergency planning as to how it might realistically terminate a criticality event and what supplies – if required - (e.g. of neutron poisons) it has procured and stored on its site(s) to facilitate such shut-down operations?

<u>Exercising of Arrangements</u>

- With what frequency does the licensee conduct criticality focussed exercises to test its response arrangements and how are such exercises assessed?

APPENDIX 6: LICENCE CONDITION 22 – MODIFICATION OR EXPERIMENT ON EXISTING PLANT

- How does the licensee ensure that all proposed modifications to fissile material facilities/processes receive due scrutiny by a SQEP criticality safety expert and that the findings of such reviews are documented?
- How is it ensured that the advice provided by the criticality assessor has been incorporated in the plant modification, or that appropriate justification has been provided as to why the implementation of the advice is not practicable but how nonetheless criticality safety is maintained for the modification? In most cases the inspector should expect a fully quality assured criticality safety assessment to have been prepared to consider the modification, including consideration of both the normal operational intent and any potential deviations from normal operations (mal-operation conditions).
- Has the licensee adequately documented all modifications to a facility and does a safety submission support each such modification?
- Inspectors may wish to satisfy themselves that any modifications to the plant are accurately reflected in the extant plant drawings.
- Where necessary, the licensee should be able to demonstrate that a new criticality safety assessment has been performed and that any changes to plant operating limits etc. have been accurately translated into the extant plant documentation and adequate training has been delivered to the plant operators on the changes.
- If new criticality rules/operating conditions are introduced onto a plant or process, how does the licensee ensure that the new rules are being observed and that 'work arounds' are not developing?
- In any case where it is planned to restart a plant/process that contains fissile material, after a long period of lay-off/shut-down, how has the licensee satisfied itself as to the fissile material dispositions in the plant/process and has due consideration been given to the potential for fissile material to have migrated/settled? The licensee should be able to demonstrate that it has undertaken adequate checks/inspections of the plant conditions and can accurately account for the location of all residual fissile material.
- Has the licensee a robust process in place for reviewing all work requests to ensure that defects having a bearing on criticality safety are identified?
- What aspects of commissioning of a modification will demonstrate that the required criticality safety controls are being delivered and will a SQEP criticality assessor be involved in interrogating the data obtained from the commissioning i.e. to verify it does demonstrate that required criticality safety controls are in place and are functioning as required?
- Where any instrumentation/control device(s) are being modified on a plant, can the licensee demonstrate it has requested, received and acted upon expert advice to ensure that the modification cannot adversely impact upon claimed criticality control functions?

APPENDIX 7: LICENCE CONDITION 23 – OPERATING RULES

- How does the licensee ensure that the limits/conditions, derived from the criticality safety assessments conducted for their fissile material operations, are accurately translated into the plant operating instructions e.g. Criticality Clearance Certificates (CCCs)?
- Are the CCCs authored by a trained SQEP individual who is authorised to do so by the licensee (e.g. a Criticality Specialist on the licensee's station or part of the licensee's central criticality control function)?
- What quality assurance does the licensee give to its production of CCCs (the inspector should take a view as to how rigorous this process is)?
- What checks are made of accurate translation of limits and conditions?
- Are the potential end-users of the CCCs involved in the production of the CCCs?
- Does the licensee seek/obtain any feedback from the workforce on ease of interpretation of CCCs? The inspector should seek evidence of this process.
- What actions are taken if adverse feedback is obtained on ease of use/interpretation of CCCs?
- Is the CCC clearly authorised - ideally a CCC should be authorised by the licensee's senior criticality safety professional and be endorsed by a senior member of the management team e.g. the plant manager for whose plant the CCC applies, senior safety assessment professionals etc.?
- Can the limits and conditions on the CCC easily be complied with e.g. if the criticality control is the concentration of neutron poison in a vessel being above a set value, then how would an operator on the plant be able to ascertain that the poison is present at this required level?
- Has/does the licensee benchmark their CCCs against those produced by other licensees?
- Are the CCCs readily accessible to those persons controlling operations and ensuring the relevant limits and conditions are met? CCCs should normally be displayed in those areas to which they apply.
- Are CCCs displayed on plant suitably legible e.g. could operators with impaired vision still reasonably be expected to be able to read the CCC and are the CCCs protected from damage e.g. by being laminated, placed in protective frames etc.?
- Are the CCCs posted on the plant on a maintenance schedule with clearly defined responsibilities for inspection and maintenance of the CCCs if required?
- Are the licensee's CCCs constructed to a standard format across the licensee's site(s)?
- Do the CCCs have a clear expiry/review date on them and are all displayed CCCs in date?
- How are the expiry dates of CCCs tracked by the licensee and how is their process for CCC review triggered?
- What is the licensee's process for reviewing and re-issuing CCCs?
- What records are generated and retained for this review process?
- When a CCC is first implemented and if a CCC changes following review, then how are staff trained in the changes to the CCC and how is this training recorded?
- How is the staff's understanding of the requirements of the CCCs tested?
- Does the licensee generate/issue temporary CCCs and if so then how is this process controlled?
- What time limits are imposed on temporary CCCs? Ideally a temporary CCC should not be in force for of the order of more than circa 3 months.

- Is there any evidence of temporary CCCs being repeatedly extended (if repeated extensions have been necessary then why has the licensee not produced permanent CCCs)?
- Does the licensee keep a centralised log of all CCCs issued and posted on the plant, together with their actual locations?
- How is the physical boundary for the applicability of a CCC established on the plant e.g. are criticality station boundaries clearly marked out on the plant?
- Are the criticality station boundary markings regularly checked to ensure they have not been eroded e.g. by personnel passing to and fro over the markings?

The inspector should note that if the CCC has to be supported by other clarifying documentation, or by extensive notes on the CCC itself, then the CCC is generally deficient or incomplete. CCCs should be short, written in plain English and give clear and unambiguous instructions.

The inspector may wish to sample the licensee's records of inspection of the CCCs.

The inspector may wish to check that the criticality station boundaries are clearly marked and that the operators clearly understand the limits of applicability of the CCCs.

The inspector may wish to sample the current workload of the CCC review process i.e. can the licensee reasonably cope with the number of CCC renewals due?

The inspector should seek to interview a cross-section of workers on the plant to ensure that all can understand and comply with the CCCs.

APPENDIX 8: LICENCE CONDITION 24 – OPERATING INSTRUCTIONS

- Are workers clear as to what actions they should take if a breach of CCC limits or conditions is identified? Ideally, if safe to do so, workers should 'walk away' from the affected operation, cease other operations in the immediate vicinity and inform management immediately. No immediate attempt should be made to recover from the breach.
- What Operating Instruction exists defining the actions to be taken by operators in the event of breach of a limit/condition on a CCC?
- If the CCC defines moderator or geometry restrictions for the plant, then how is compliance with these limits enforced and evidenced? How often are checks made and documented on compliance with such limits?
- How are quantities of moderator (solid and liquid) tracked on the plant e.g. what logs are kept and are these easy to interpret?
- Are there any obvious threats on the plant of ingress of liquid moderator e.g. leaks in the building fabric in the vicinity of fissile material, steam/liquid carrying lines passing over/through areas where fissile material is present etc.? What precautions has the licensee taken to limit the potential for contact of liquid moderator from any such sources with the fissile material?
- If the process subject to a CCC has fissile mass limits defined, then how are these masses tracked?
- Where required the licensee should have clear records of transfer of fissile material between areas subjected to criticality control and the records should show that the fissile mass limits at the various locations are being complied with.
- The plant records should also contain any other information required for fissile material control e.g. enrichment, chemical composition, container details etc.
- What systems does the licensee have in place for investigating any mass loss e.g. mass lost whilst conducting a process? Does the licensee have a system for assigning missing mass to that location and subsequently summing that mass with any other fissile mass entering the criticality station?
- What systems does the licensee have in place to prevent overbatching of fissile material in areas subject to mass control? Ideally any such systems should be engineered.
- Computerised systems for fissile mass tracking and control can be inherently complex and not amenable to traditional methods of reliability assessment. Accordingly, the inspector should be mindful that, particularly where many fissile moves are routinely made, then additional controls and checks may also be required. The inspector should seek guidance on relevant good practice from an appropriate ONR expert in this field.
- Is there a Nuclear Material Controller identified who confirms beforehand whether the movement of fissile material from one location to another meets the conditions of the Criticality Clearance Certificate?
- For the fissile mass accounting system, is there an "unaccounted for" mass limit at which operations would cease for investigatory purposes?
- For glovebox operations a cluttered glovebox may indicate a potential for the licensee to lose control of the mass of fissile material within the glovebox and the licensee should hence be challenged?
- If the CCC has defined enrichment limits, then how does the licensee control these i.e. how are the differing enrichments of various materials identified and recorded?
- Does the CCC have any concentration limits and if so then how are the concentrations measured?

- Are the concentration limits the plant must operate within clearly defined i.e. in the Operating Instructions and do the operators know what actions to take in the event that such limits are exceeded (these actions should be specified in the operating instructions)?
- Where criticality control relies upon concentration limits, has the licensee's safety case taken due account of the fact that precipitation of solids from fissile material solutions can occur?
- What methods does the licensee employ to look for potential precipitates e.g. in the base of sealed vessels?
- How would the licensee recover from unwanted precipitation of fissile bearing solids?
- Has the licensee's safety case identified any locations where solvent could accumulate in a system and progressively 'strip out' fissile material, if so then are appropriate and timely inspections of all such locations conducted and the findings recorded?
- Do the operators have clearly defined actions to take in the event that accumulations of solvent/fissile material are detected at such locations?
- Is the licensee adequately controlling fire loadings in fissile material areas i.e. preventing accumulations of flammable materials?
- Are fire extinguishers present as per the requirements of the licensee's criticality safety documentation?

The inspector may wish to conduct a spot check of moderator quantities against the moderator limits and against any on-plant logs of moderating materials.

The inspector may wish to examine any relevant Operating Instruction in this area to ensure that inspections are conducted well within the time that the safety case defines for any possible accumulations of concern to occur.

The inspector should sample the licensee's fissile mass records and material unaccounted for records to ensure these are clear and do not show continuing trends of 'missing' fissile material.

APPENDIX 9: LICENCE CONDITION 25 – OPERATIONAL RECORDS

Typical operational records, pertinent to criticality safety, which the inspector may wish to ensure the licensee is maintaining/retaining may include (but are not limited to):-

- Lists of all the licensee's extant criticality clearance certificates applicable to the licensed site, their review dates and posted locations on plant.
- Lists of any temporary criticality clearance certificates and their validity dates.
- Reports of the findings of criticality safety walk-downs, conducted by the licensee's criticality professionals and/or 'Criticality Specialists' (where relevant – see Appendix 1), senior managers etc.
- Evidence of closure of any actions emerging from criticality safety walk-downs/inspections etc. conducted by the licensee.
- Movement control records for all moves between criticality stations involving fissile materials.
- Moderator logs for criticality stations.
- Lists of criticality stations and drawings showing the location and extent of these stations.
- Copies of extant and historical criticality safety assessments for all fissile operations presently/previously conducted by the licensee.
- Copies of Peer Review/QA activities conducted on licensee's criticality safety assessments.
- Copies of any event reports relating to criticality safety, their investigation and findings.
- Logs of fissile material holdings for all of the licensee's declared criticality stations.
- Locations of criticality detectors and assessments demonstrating that the current positioning of criticality incident detection heads meets the requirement to be able to detect the licensee's defined 'minimum incident of concern'.
- Criticality awareness training records for both criticality professionals/SQEPs and for fissile plant operators.
- Training materials for plant operators.
- Drawings showing the location of all criticality related signage on/outside the licensee's plant(s) and maintenance/inspection records for this signage.

APPENDIX 10: LICENCE CONDITION 26 – CONTROL AND SUPERVISION OF OPERATIONS

- What is the licensee's mix of its in-house criticality safety assessors to contract labour and how has the licensee assessed and demonstrated its ability to adequately manage and supervise its contract criticality assessor workforce i.e. how does the licensee discharge its 'Intelligent Customer' requirements?
- Does there appear to be any over-reliance on the use of a contract assessor workforce and has the licensee any credible plans to address any such situation encountered?
- What quality assurance is applied to the work of contract criticality assessors i.e. does the work proceed through the licensee's own QA arrangements, or is the contractor tasked with applying the contractor organisation QA to the work undertaken by its staff?
- If contractor QA arrangements are used, then what scrutiny does the licensee exercise over the adequacy of the contractor's arrangements and how can the licensee demonstrate the application of this scrutiny?
- When choosing contract staff to execute criticality safety work on its behalf, how does the licensee assure itself that the staff it is hiring are Suitably Qualified and Experienced Persons (SQEP) for the particular task(s) they wish the individuals to undertake and how is this process documented?
- What supervision and monitoring of the operators on the plant is undertaken by the management?
- Is there a Nuclear Material Controller(s) identified and trained who confirm beforehand that the movement of fissile material from one location to another meets the requirements of the Criticality Clearance Certificate for the destination station?
- Does the safety culture on the plant enable workers to talk to their Supervisors regarding potential 'work-arounds' with respect to Operating Instructions and would the Supervisors in turn take these 'work-arounds' to criticality experts to see if they genuinely represent a better method of working?
- Are routine walk-down criticality safety audits undertaken by management/the licensee's criticality safety professionals?
- Are routine walk-downs conducted to a defined instruction and are the findings of the walk-down recorded?
- How are any adverse findings from a walk-down dealt with e.g. are appropriate Actions defined, assigned unambiguously and are these Actions then suitably closed out?
- Do Actions placed from criticality safety walk-downs have sufficient visibility with the licensee's senior management i.e. are management aware of the walk-down findings and can it be demonstrated that they actively track Action closure?
- Does the licensee encourage any external audit of their criticality arrangements e.g. by their internal regulator, by criticality safety personnel from other licensee sites/facilities etc.?
- How often are such audits undertaken and how are the findings/Actions etc. recorded?

The inspector may wish to see evidence that Actions placed from audits of the licensee's criticality safety arrangements are tracked and closed out appropriately.

The inspector may wish to sample the instructions for criticality safety walk-downs and examples of their findings, plus any Action tracking and closure process.

It is recommended that criticality management systems should be audited in detail at least every 5 years.

APPENDIX 11: LICENCE CONDITION 27 – SAFETY MECHANISMS DEVICES AND CIRCUITS

- Are fissile material containers of a geometrically favourable design i.e. assessed to be sub-critical for a range of plant conditions including faults that can occur without any modification to the geometry of the container and if so then what is the physical condition of such containers (note impacts/drops of such containers have the potential in the extreme to move them towards an unsafe geometry)?
- If additional containers of a geometrically favourable design have to be imported into a criticality station(s) then what procedures control their procurement and receipt to ensure that the new containers meet the relevant geometric constraints?
- What is the upper concentration for a safe by shape vessel and can it be reached? If it can what additional controls are in place to prevent this from happening?
- If a fissile solution were to leak, is the area where it would accumulate safe by shape or can criticality safety be guaranteed by other means?
- Where a criticality control on a process is provided by an engineered control e.g. instrument, device etc. then occasionally this has to be removed (e.g. for maintenance etc.). The safety case will often allow this control to be substituted for another control during the interim period. The inspector should examine the process controlling both the initial substitution and the return of the plant to its original condition, to ensure that these processes are robust and that plant personnel will, at all times, be completely clear as to what devices/systems are providing the criticality safety protection.
- There should be recognition of the physical/chemical environments within which neutron absorbing structures i.e. for criticality control purposes are sometimes present and that these environments could lead to a degradation of neutron absorbing structures with time, such that their neutron absorbing effectiveness decreases. In any such circumstances (more information can be supplied by ONR criticality experts), the inspector should expect to see routine Non-Destructive Assay (NDA) activities to ensure the required degree of neutron poisoning remains in place with time. Such NDA work should be designed/specified by the licensee in association with appropriate experts in the field. Records of each such inspection should be kept.
- When a neutron absorbing device, to be used for criticality safety control first arrives at a licensee's site from an external supplier/manufacturer, how does the licensee convince themselves that the device has been supplied as originally specified e.g. does the licensee conduct any testing on the device? Documentary evidence should be sought of any such testing claimed and advice should be sought from an ONR specialist as to the likely accuracy of the technique employed. Alternatively, does the licensee place a total reliance on the QA documentation shipped with the item? If reliance is placed on QA paperwork, then has the licensee independently inspected the manufacturer's facilities and obtained sufficient confidence in the QA controls applied by the manufacturer? What evidence can the licensee provide to confirm such audits have been conducted?
- If a plant item, containing neutron absorbing structures for criticality control purposes, is dismantled e.g. for inspection or maintenance, then what procedures does the licensee have in place to ensure that when the plant item is re-assembled then the neutron poisoning structures are re-introduced in the correct position and the proper orientation? What checking/sign off of disassembly/reassembly is conducted? What records are kept of the process?
- How are the disassembled neutron absorbing structures protected after removal from the plant/equipment?

- Are all plant items containing neutron absorbing structures for criticality control purposes clearly labelled?
- Is the area in which fissile material operations are taking place subject to a Criticality Incident Detection and Alarm System, CIDAS? If not the Inspector may wish to ask to see the licensee's documented CIDAS Omission argument.
- If the area is subject to a CIDAS coverage, then do the workers know what actions to take if the system's 'clip clop' warning tone were to cease? The inspector may wish to sample the worker's knowledge in this area.
- Where are the required responses laid down and how accessible are these to the operators/how well trained are the operators in the required responses?
- Can the licensee show the inspector where the required operator response to a failure in the CIDAS is laid down?
- For a site with multiple plants, the inspector may wish to check that the operator response to CIDAS failure is standardised across all plants.

If the CIDAS fails then the normal action expected of the operators would be to cease operations in the plant, especially those involving fissile material. However, if stopping a specific operation could increase the criticality risk (e.g. in nuclear chemical plants) then it may be reasonable for such operations to continue but with increased vigilance until the recovery plan is implemented.

The inspector may wish to examine the records of any disassembly/reassembly operations for neutron absorbing structures which provide a key criticality control function.

The inspector may wish to view the records of routine NDA inspections on neutron absorbing structures.

APPENDIX 12: LICENCE CONDITION 28 – EXAMINATION, INSPECTION, MAINTENANCE AND TESTING

- A number of different types of instruments are liable to be of importance in ensuring criticality safety e.g.
  - → Balances,
  - → Concentration meters,
  - → Moisture detectors,
  - → Neutron monitors,
  - → Level gauges and alarms,
  - → Enrichment monitors,
  - → Passive Neutron Coincidence Counters (PNCC),
  - → High Resolution Gamma Spectroscopy (HRGS),
  - → Criticality Incident Detection and Alarm Systems (CIDAS) – detectors, sound generators, amplifiers etc.
  - → Computer based systems for tracking fissile material moves.

The above list is not intended to be exhaustive.

The licensee's criticality safety case should clearly identify any claims being made on devices such as those listed above and what level of reliability is required from the device(s).

There are recognised standards for such systems and their maintenance, calibration etc. and the inspector should seek information from ONR assessors with appropriate expertise in this specialised field, to ensure that the claims made by the licensee in its criticality safety case are valid and substantiated.

Following maintenance on criticality safety mechanisms, devices and circuits (SMDC), particularly where these may have been deliberately suppressed and before they are brought back on line, are checks/tests conducted which verify the system operational safety functionality as a whole i.e. rather than for instance just a part or parts of it? Are the recommissioning procedures following maintenance adequate in bringing safety systems back on line?

For all such equipment, the inspector should ensure that it is on a suitable inspection, testing, calibration and maintenance regime and should endeavour to sample the licensee's records to ensure all such required testing/calibration/maintenance/inspection is up to date, with no defects being identified via the records. The inspector may also wish to seek the advice of other ONR experts to ensure that such calibration/maintenance/inspection regimes are appropriate.

- Calibration/operability checks should be conducted as per the manufacturer's advice.
- Is the calibration sufficiently accurate to ensure that significant differences in fissile material mass can be distinguished?
- Is all calibration and maintenance undertaken by SQEP personnel and how can the licensee demonstrate this?

The inspector may wish to understand how the licensee convinces themselves as to the operability and accuracy of the equipment before commencement of each operation involving fissile material.

Inspectors should note that other items of plant (i.e. not only instruments) may also require consideration as EIMT items. For example, where cranes and other lifting equipment are used to move either fuel, or transport containers loaded with fuel, criticality safety cases may take credit for the reliability of those items, including any interlocks and safety trips. Similarly, other items of fuel handling equipment may provide “active engineered” functions that are important to criticality safety. The licensee should be able to demonstrate that all such items, assumed to provide an important function within the criticality safety case, have suitable and sufficient maintenance/inspection/testing routines in place and should be able to provide robust evidence that these routines are being adhered to.

- The licensee should be able to demonstrate that they have adequately considered and documented all possible locations in the process where fissile material could adventitiously accumulate e.g. in ventilation ducting, filters, drains, machines and generally in inaccessible areas – this list is not intended to be exhaustive.
- The inspector should seek evidence that the licensee is routinely inspecting/surveying all identified areas where the licensee has deemed fissile material has a potential to accumulate. Records should be available of the findings of all such inspections/accumulations. The inspector should take a view (in consultation with ONR criticality specialists if required) as to whether such surveys/inspections are being conducted with an adequate frequency.
- Are the licensee’s criticality safety professionals involved in interrogation of data from surveys to look for potential fissile material accumulations?
- The inspector should ask to see a representative sample of the licensee’s records of surveys/inspections and should look to see that there is no evidence in the records of accumulation increasing with time.
- The inspector may choose to walk the process to obtain assurance that the licensee has comprehensively identified all likely locations for fissile material accumulations.
- Is there evidence that the licensee routinely reviews its schedule of locations of potential fissile material accumulation (does the licensee take account of any national/international Operational Experience, Opex, in the review?
- If a fissile solution were to leak slowly and the solution evaporate to leave an accumulation of solid fissile material, then what visual inspections does the licensee undertake and how often to check for any such leaks?
- Does the Licensee keep a record of all visual inspections for leaking fissile material?
- Are there any inaccessible locations in the process through which fissile material passes and where there is a potential, e.g. if a pipe were to leak, for fissile material to slowly accumulate over time – what efforts is the licensee taking to obtain evidence that no such accumulations are occurring or have occurred?

The Inspector may wish to question the licensee as to whether any instrumented means of detecting slow fissile material leaks has been considered.

APPENDIX 13: KEY PHYSICAL FACTORS AFFECTING CRITICALITY SAFETY

The factors which are important for criticality safety include type of nuclide, mass of nuclide, enrichment, density/concentration, shape, moderation, reflection, neutron absorbers and interaction. These factors are briefly discussed in the following.

Type of nuclide

The most important fissile nuclides are those of uranium and plutonium, in particular U-235 and Pu-239. Some other uranium and plutonium nuclides are non-fissile, for example U-238 and Pu-240.

Mass

The mass of fissile material is an important factor. For each nuclide there is a mass below which a criticality is not possible in any system. Where facilities process or store inventories of fissile material in excess of the critical mass, criticality must be prevented by controlling other factors i.e. as discussed below.

Enrichment

Reducing the relative proportion of fissile nuclides in a fissile material will reduce its reactivity and increase its critical mass.

Enrichments vary considerably e.g. natural uranium contains circa 0.7 % of the fissile isotope Uranium-235 (U-235), whereas the level of U-235 in civil reactor fuels can be up to about 5% and the U-235 level can be > 90 % for specialised systems.

Moderation

This is the slowing down of the high energy neutrons produced in fission by collisions with atoms of the moderator. This process is important because the probability of a neutron causing fission is appreciably greater for thermal neutrons (< 0.1 eV) than for fast neutrons (>100 keV). Optimising the amount of a moderator will therefore maximize both neutron production and reactivity.

The most effective moderators are those with a low atomic weight e.g. water, heavy water, polythene, plastic containers, graphite and people. Hydrogen has the same mass as a neutron hence ensuring maximum energy exchange when a neutron collides with a hydrogen atom. Hydrogen moderation can hence lead to compact fissile systems. However, it should be noted that hydrogen also absorbs some thermal neutrons i.e. it also acts to slightly reduce the reactivity of the fissile system.

In contrast, graphite is much less efficient than hydrogen at slowing neutrons down and hence large masses and volumes of graphite are required to act as an efficient neutron moderator. However, graphite does not absorb thermal neutrons and hence if large enough quantities of graphite are present, then it can still pose a potential threat to criticality safety.

Density/concentration

The density or concentration of fissile material in a moderated system is an important factor which determines whether or not criticality is possible. Because moderators can also absorb neutrons, very dilute arrangements of fissile material in moderator will not be able to achieve criticality.

Shape

The reactivity of any given mass of fissile material is very dependent on its shape. In general, compact shapes with low surface areas reduce neutron leakage and increase reactivity. The most reactive shape is a sphere because this has the lowest surface area for any given volume. Increasing the surface area/volume ratio decreases reactivity and can be used to prevent criticality via the creation of inherently safe vessel shapes e.g. such as slab tanks.

Reflection

This is the process in which neutrons escaping from fissile material are reflected back into it. This reduces net leakage and increases reactivity. Commonly encountered reflectors are concrete, water, steel, graphite, aluminium and beryllium, although virtually any material will act as a reflector to some extent.

Neutron absorbers

Neutron absorbers are substances which have a high neutron absorption cross section, i.e. a high probability of absorbing/capturing neutrons, thus making these neutrons unavailable to cause fission. Neutron poisons are generally considered to be neutron absorbing materials intentionally added to a fissile system (i.e. they are present solely and intentionally to absorb neutrons and hence to reduce the reactivity of the fissile system to which they have been added). Neutron absorbing material, in contrast, refers to everything else that may cause an effect upon the fissile material system, but which has not been added intentionally.

Examples of materials with a high neutron absorption cross section (i.e. a high probability of absorbing neutrons) include boron (rich in the B-10 isotope), cadmium, gadolinium and hafnium.

Interaction

If two systems e.g. waste drums containing fissile material, each of which is subcritical in isolation, are placed close together, neutrons from one system can reach the other system and will increase the likelihood of the overall system to go critical. Hence the spacing between adjacent systems containing fissile material is important. Also, when a person steps between such systems he/she could unwittingly introduce additional moderation.

Heterogeneity

This is not a straightforward nor necessarily intuitive topic e.g. for uranium enrichments of less than 10%, an optimised heterogeneous arrangement of fuel and moderator is more reactive than a homogeneous arrangement. This effect can also apply to Mixed Oxide (MOX) fuel. For higher uranium enrichments, an optimised homogeneous arrangement of fuel and moderator can be more reactive than any practical heterogeneous arrangement.