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To Stay or to Go? Balancing the Risk of Reprocessing Plant Control Room Evacuation Following a Criticality Alarm

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Following a criticality alarm within the Magnox Separation Plant at Sellafield, there is a conflict of interest between the risks associated with complete evacuation versus continued manning of the control room. The historic emergency response policy would be to completely evacuate the control room upon a criticality alarm. If, however, the alarm was found to be false, the inevitable loss in control over the plant could have environmental, operational and radiological release consequences. Maintaining control room manning following a genuine alarm might, however, result in an avoidable high dose to an operator. Based upon the estimated dose equivalent to a control room operator for a range of criticality incident morphologies a risk analysis was undertaken. The results indicate that the differential risk between an operator who evacuates immediately and an operator who remains for a short time to complete diagnostic checks is very small. As a consequence a new emergency policy was therefore developed on plant which results in a relatively low risk to control room operators, but still allows control over the plant to be retained following a false criticality alarm.

KEYWORDS: Criticality Incident Detection and Alarm System, CIDAS, Operator Dose, Control Room Evacuation, Balancing Risk, Emergency Procedure

1. Introduction

The Magnox Separation Plant (MSP) at Sellafield reprocesses Magnox fuel using a solvent extraction process. It is a relatively old plant and relies heavily on operator intervention to control the process. Although the plant is intrinsically stable and not susceptible to rapid fluctuations from normal conditions, the risk of a criticality is such that it warrants the installation of a Criticality Incident Detection and Alarm System (CIDAS).

The purpose of this system is to alert operators to a criticality incident and to initiate a rapid evacuation of the affected area. The plant control room is located within the area that would be affected by a criticality incident. Historically, the control room has remained manned following alarms. If the plant is left unattended there could be a risk of an airborne release which would have the potential for a dose to the public, or there could be the risk of a criticality (either the first genuine incident if it had been a false alarm, or a further incident) or the risk of a contained incident which could require a clean up and subsequent plant outage. These risks must be considered against the review of the plant's emergency procedures which highlighted that continued manning of the control room may be exposing operators to undue risk.

The options of re-siting the control room, installing additional bulk shielding to the control room or constructing an additional remote control room have been dismissed due to the risks and the cost-benefit associated with such major modifications and the limited remaining lifetime of the plant. Therefore a detailed reassessment of the operator response to a CIDAS alarm was carried out based on estimated dose equivalent following a criticality incident. The analysis was aimed at achieving an optimised response that properly balances the risks between the different operator responses.

2. Magnox Separation Plant

Following dissolution of the Magnox fuel, within the MSP, plutonium (Pu) and uranium (U) are chemically separated from the fission products via a solvent extraction process within mixer settler vessels. Both the U stream and fission products are forward fed to different plants for further purification, however, the Pu stream is purified and finally concentrated by evaporation within the MSP.

Criticality safety is principally maintained by controlling the fissile concentration of the liquors and by the use of geometrically safe vessels. Operators continually monitor the plant both in the control room and on the plant, hence there is a wealth of operational experience, which has

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shown that the plant is intrinsically stable and not susceptible to rapid fluctuations from normal conditions. Indeed there have been very few transients which could be regarded as precursors to a criticality incident.

The main process vessels in the plant are located within shielded cells. The control room is remote from, and shielded from, most of the potential criticality sites. However, the shielding was not designed for criticality shielding, but rather was designed as a shield against gamma emissions from fission products and actinides.

The first part of this analysis was therefore to calculate the dose equivalent to an operator within the control room following a criticality incident. The dose was an estimation (taking into account the shielding present) following a criticality incident in the following cells:

- Low Active (LA) Cell
- Medium Active (MA) Cell
- Highly Active (HA) Cell
- Dissolver Cell

The other cell areas within the MSP were considered to give a negligible dose equivalent to control room operators due to their shielding and/or proximity from the control room or had a relatively low potential for criticality.

3. Operator Response to a CIDAS Alarm

The control room in the Magnox Separation Plant is equipped with instrumentation which allows continual monitoring of the plant. In the event of a CIDAS alarm some systems would also permit a rapid indication of whether a criticality truly had occurred or whether the alarm was false.

To minimise the potential dose to control room operators, complete evacuation of the control room would be necessary. However, such an evacuation of the control room following a false alarm would result in a loss in control over the plant. This may have environmental, operational and radiological release consequences. On the other hand if the alarm was genuine and operators remained in the control room, this might result in an avoidable high dose to the operator.

A possible compromise could be for just one operator to remain in the control room for a short period of time to carry out diagnostic check. If the alarm was confirmed to be genuine indicating a criticality incident had indeed occurred in the plant they would then evacuate. If the alarm was found to be false, they would remain and carry out the normal supervisory checks while awaiting returning support.

The analysis therefore considered the risks associated with the following operator responses:

(1) All control room operators evacuate immediately; or
(2) Most senior person remains to carry out quick confirmatory checks on whether the incident was genuine; or
(3) No evacuation of control room.

4. Criticality Incident Morphologies

Based on a review of historical incidents, three different types of criticality incident morphology are examined. Single spike, continuous and repeated spike incidents have previously been reported in criticality incidents/experiments which involve thermal liquid systems (i.e. those systems expected in the MSP). Based on a review of historic criticality incidents, it is assumed that the criticality incident will have one of the following broad characteristics, which are represented schematically in Figures 1 to 4.

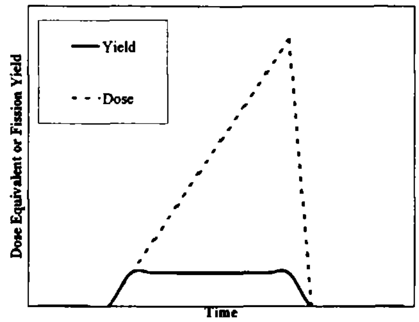

Fig. 1 Schematic of dose equivalent and fission yield for a plateau type criticality incident with the fissions occurring over a period of 1 hour at a constant rate (type 1 incident).

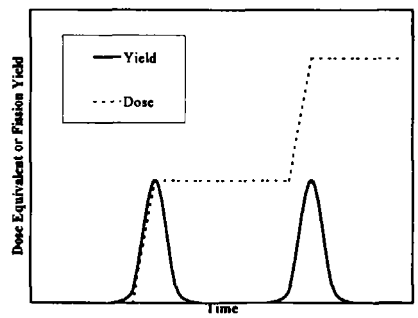

Fig. 2 Schematic of dose equivalent and fission yield for a twin spike type criticality incident with half the fissions occurring immediately and half the fissions occurring one hour later (Type 2 incident)

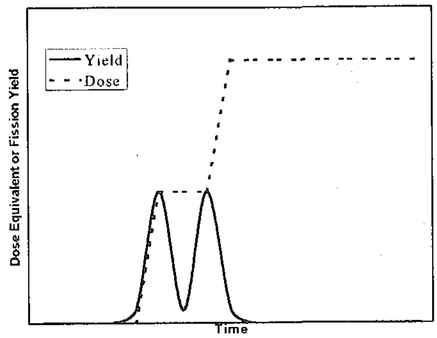

Fig. 3 Schematic of dose and fission yield for a twin spike type criticality incident with half the fissions occurring immediately and half the fissions occurring five minutes later (Type 3 incident).

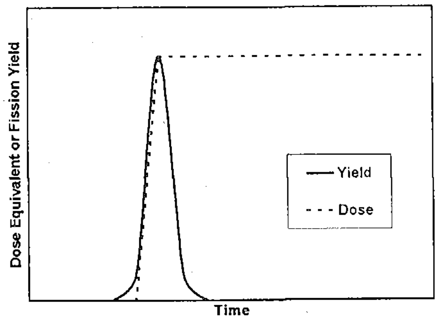

Fig. 4 Schematic of dose equivalent and fission yield for a single spike criticality incident with the vast majority of the fissions occurring before any action can be taken (Type 4 incident).

It is likely that any real incident will exhibit more complex behaviour, however, these characteristics are believed to be reasonably representative and they permit discrimination between the various evacuation strategies.

Given that a criticality would be expected to arise as a result of an 'unpredicted' fault there is no reason to assume that criticality incidents are more likely in one area. The probability of criticality incidents in the MSP is split between the LA, MA, HA and dissolver cells. It is also assumed that any criticality will result in a total of 10^{18} fissions. Considering the four types of incident and the three operator responses, the following assumptions are made:

- Staff who evacuate the control room immediately will be out of range of the incident within 5 minutes. They will receive the initial spike dose in a Type 2, 3 or 4 incident and 5 minutes worth of the continuous Type 1 incident dose.
- Staff who evacuate the control room following a quick diagnostic check will be out of range of the incident within 10 minutes. They will receive the initial spike dose in a Type 2, 3 or 4 incident, the second spike dose of a Type 3 incident and 10 minutes of Type 1.
- Staff who remain in the control room to monitor the plant will receive the entire dose from all 4 incidents (i.e. the dose due to the 10^{18} fissions regardless of the nature of the event).

5. Estimation of Dose Equivalent to B205 Control Room Operators

Based on a 10^{18} fission yield, the cell shielding and the distance of the cell from the control room, a estimate of the possible approximate dose equivalent to operators within the control room following a criticality within either of the four cell areas was obtained. This data is summarised in Table 1.

Table 1 Estimate of Dose Equivalent to a Control Room Operator following a Criticality Incident of 10^{18} Fissions in Various Cells of the Magnox Separation Plant

Cell	Dose Equivalent to a Control Room Operator (mSv)
Low Active	58
Medium Active	23
High Active	4
Dissolver	4

The dose equivalents to the control room operator were then specifically calculated for each type of criticality incident type. Given all four types of incident are considered to be equally probable, the mean dose equivalent to the operator was then determined. This data is summarised in Table 2 and the estimated dose equivalents for each type of criticality scenario are plotted for each type of operator response. This is shown schematically in Figures 5 to 7.

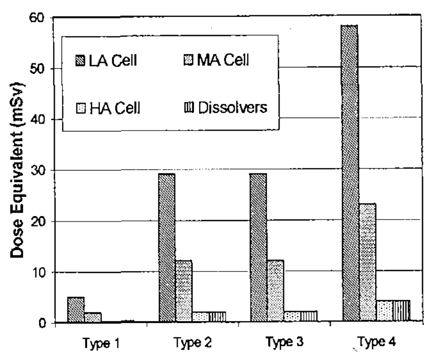

Fig. 5 Schematic of the dose equivalent to a control room operator following a prompt evacuation for each type of criticality incident

Table 2 Dose Equivalent to a Control Room Operator following each Type of Criticality Incident and Overall Mean Dose Equivalent for all Incident Types

Cell	Dose Equivalent to Operator who evacuates quickly (mSv)	Dose Equivalent to operator who remains for diagnostic checks then evacuates (mSv)	Dose Equivalent to operator who remains in control room (mSv)
Type 1 (Plateau) Criticality Incident			
Low Active	5	10	58
Medium Active	2	4	23
Highly Active	0.3	0.6	4
Dissolver	0.3	0.6	4
Mean	2	4	22.2
Type 2 (Second Spike after an Hour)			
Low Active	29	29	58
Medium Active	12	12	23
Highly Active	2	2	4
Dissolver	2	2	4
Mean	11.1	11.1	22.2
Type 3 (Second Spike after 5 minutes)			
Low Active	29	58	58
Medium Active	12	23	23
Highly Active	2	4	4
Dissolver	2	4	4
Mean	11.1	22.2	22.2
Type 4 (Single Spike)			
Low Active	58	58	58
Medium Active	23	23	23
Highly Active	4	4	4
Dissolver	4	4	4
Mean	22.2	22.2	22.2
Overall Mean for all 4 types of incident	11.6	14.9	22.2

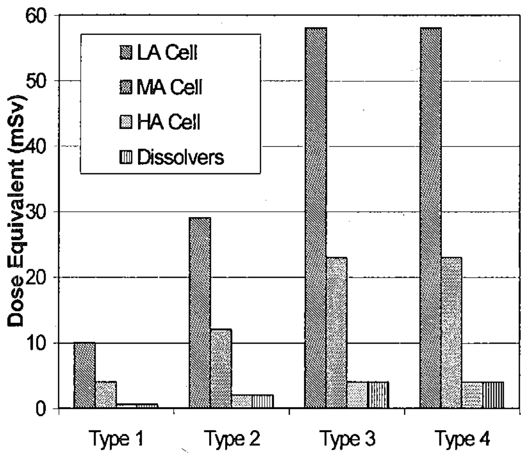

Fig. 6 Schematic of the dose equivalent to a control room operator following a delayed evacuation for each type of criticality incident

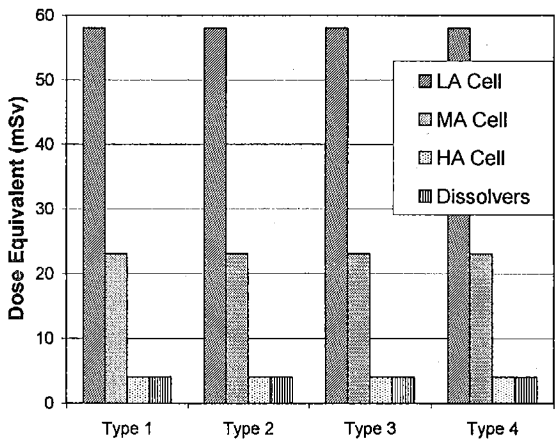

Fig. 7 Schematic of the dose equivalent to a control room operator following no evacuation after each type of criticality incident

6. Discussion and Conclusions

Subject to the assumptions of the analysis, it is apparent from Table 2 that the average detriment to an operator who remains in the control room to carry out diagnostic checks following a criticality event (Operator Response 2) is 3.3mSv when compared to an operator who evacuates immediately (Operator Response 1). This is a relatively small dose equivalent and carries a stochastic risk of 1.7×10^{-4} per criticality using a dose risk factor of 0.05Sv.[1] Given the expected low frequency of criticality incidents compared with false CIDAS alarms, this low risk supports a recommendation that a minimum level of staff remain in the control room following an alarm to carry out a quick deterministic check, provided there is a benefit in them doing so (see below) and provided the relevant staff are informed and give consent to the risk.

Subject to the assumptions of the analysis, it is also apparent from Table 2 that the average detriment to an operator who remains in the control room indefinitely following a criticality incident (Operator Response 3) is 11mSv compared to an operator who evacuates immediately (Operator Response 1). This is a more significant dose equivalent (although still recognised as being small under emergency conditions) and carries a stochastic risk of 5.5×10^{-4} per criticality, using a dose factor of 0.05/Sv.[1]

Before any additional risk can be sanctioned, it is necessary to demonstrate that there is a benefit to be gained from doing so (under the 'As Low As is Reasonably Practicable' or ALARP principle). In this case the benefit to be gained from not evacuating the control room, is that should the alarm prove to be false, control over the plant will have been retained. Loss of control may have other detriments associated with it such as potential environmental releases, increased risk of maloperations etc. Thus the competing issues of possible radioactive release into the pubic domain versus potential operator dose equivalent from a criticality incident must be considered. It should be noted that the majority of CIDAS alarm occurrences prove to be false.

Under BNFL policy it is considered that as the most rigorous precautions are taken to prevent a criticality incident, even an excursion of the size of the minimum incident of concern is symptomatic of a situation so abnormal and unpredictable that lives ought not to be staked against the chance that a sizeable incident will not follow. Thus in keeping with the existing standard emergency response, if the CIDAS alarm sounds and a quick diagnostic check reveals the incident to be genuine, then the area should be completely evacuated.

Balancing control room risks is complex and therefore this analysis has taken a pragmatic and simplified approach. With the assumptions already discussed, the results indicate that the differential risk between Operator Responses (1) and (2) is very small. As the detriment associated with abandoning the control room is genuine, this allowed a new policy to be adopted whereby:

- All but the most senior person present should evacuate the control room immediately upon hearing the CIDAS alarm.
- The remaining person carries out predetermined confirmatory checks. If these indicate definitely that the CIDAS alarm is false, he/she remains in the control room to carry out normal supervisory tasks.
- If it is not obvious from the confirmatory checks that the alarm is false, then the remaining person also evacuates the control room.

This policy has now been incorporated into emergency procedure adopted in the Magnox Separation Plant to be used in the event of a CIDAS alarm.

Acknowledgements

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References

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