Methodology to Assess Minimum Accident of Concern and Criticality Accident Alarm System Location

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ANS NCSD 2013 – Criticality Safety in the Modern Era: Raising the Bar
Wilmington, North Carolina
2013 Sept 29 – Oct 3

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Motivation

- Canadian Nuclear Safety Commission (CNSC) Regulatory and Guidance Documents on Nuclear Criticality Safety (RD-327 and GD-327) requirements:
  - Define the minimum criticality accident of concern
  - Identify possible criticality accident alarm system detector locations
  - Evaluate which detector locations are appropriate to detect the minimum accident of concern
- CRL's new approach complies with newly updated regulations

Minimum Accident of Concern (MAC) Definition

- As per CNSC RD-327, the MAC is defined as:

  "… the accident resulting in a dose to free air of 0.20Gy (20 rad) in the first minute, at a distance of 2 meter from the reacting material."

  (consistent with ANSI/ANS 8.3)

Notes:

– if significant shielding was present around the accident, the MAC will account for the additional shielding

Methodology

- Step 1: Define the Minimum Accident of Concern
- Step 2: Assess detector dose rate at each location

General Description

- Computer code used: MCNP5, version 1.40
  - Neutron and photon coupled mode (i.e., MODE N P) was used for all calculations
  - Criticality accident modeled as a criticality source using the KCODE card
    - Critical systems were defined such that the calculated k_{eff} was between 0.997 and 1.000
    - KCODE calculation was run until the tally results had < 1% relative uncertainty
  - The energy deposited in air was calculated using the F6 tally, which calculates the energy deposited, in MeV / g / source particle, averaged over a tallied volume

Step 1: Define the MAC

1 a) Identify the **type(s) of fissile materials** and postulate the **conceivable sequence of events** which would result in an inadvertent critical assembly

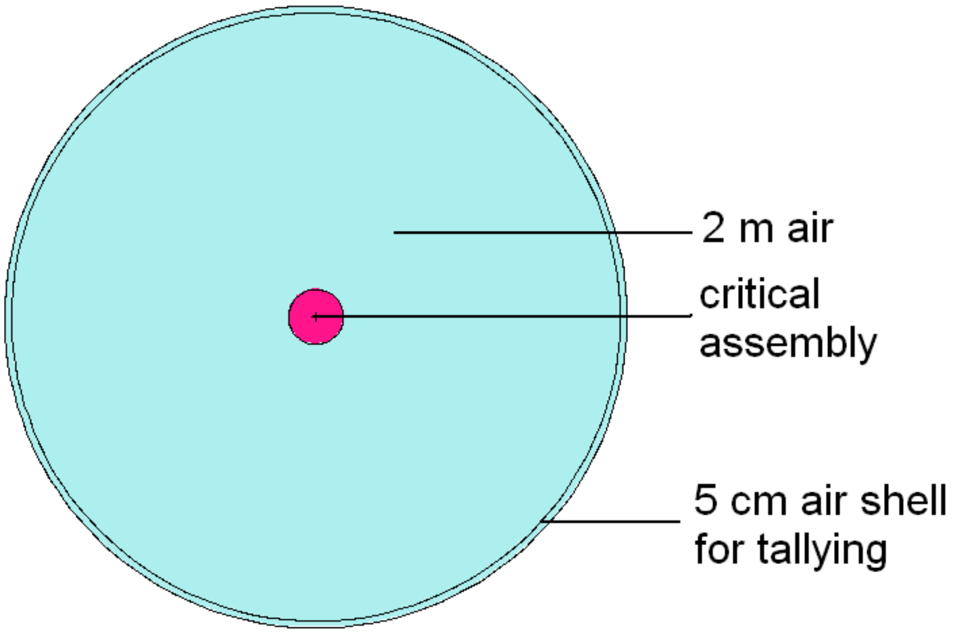
1 b) Perform a parametric study to estimate:

- The minimum critical mass – MCM for MAC
- The optimal conditions (i.e., optimal light-water moderation, most conservative geometry given available, engineering controls, etc.)

Step 1: Define the MAC

1 c) Model the postulated accident in MCNP to calculate the energy deposited in a 5 cm shell of air, located at 2 m away from the critical assembly

- The energy deposited includes both energy deposited by neutrons and gammas



Step 1: Define the MAC

1 d) Calculate the total fission rate for each postulated accident:

$$\text{fission rate}\left(\frac{\#\ \text{fissions}}{\text{min}}\right) = \frac{0.2\,\frac{\text{Gy}}{\text{min}}}{\text{Energy deposited}\left(\frac{\frac{\text{MeV}}{\text{g}}}{\text{neutron}}\right) \times \bar{\upsilon}\,\left(\frac{\text{neutrons}}{\text{fission}}\right)}$$

Energy deposited = the MCNP results obtained using the F6 tally, reported in MeV / g / source neutron

$\bar{\upsilon}$ = the average number of neutrons produced per fission, calculated using MCNP

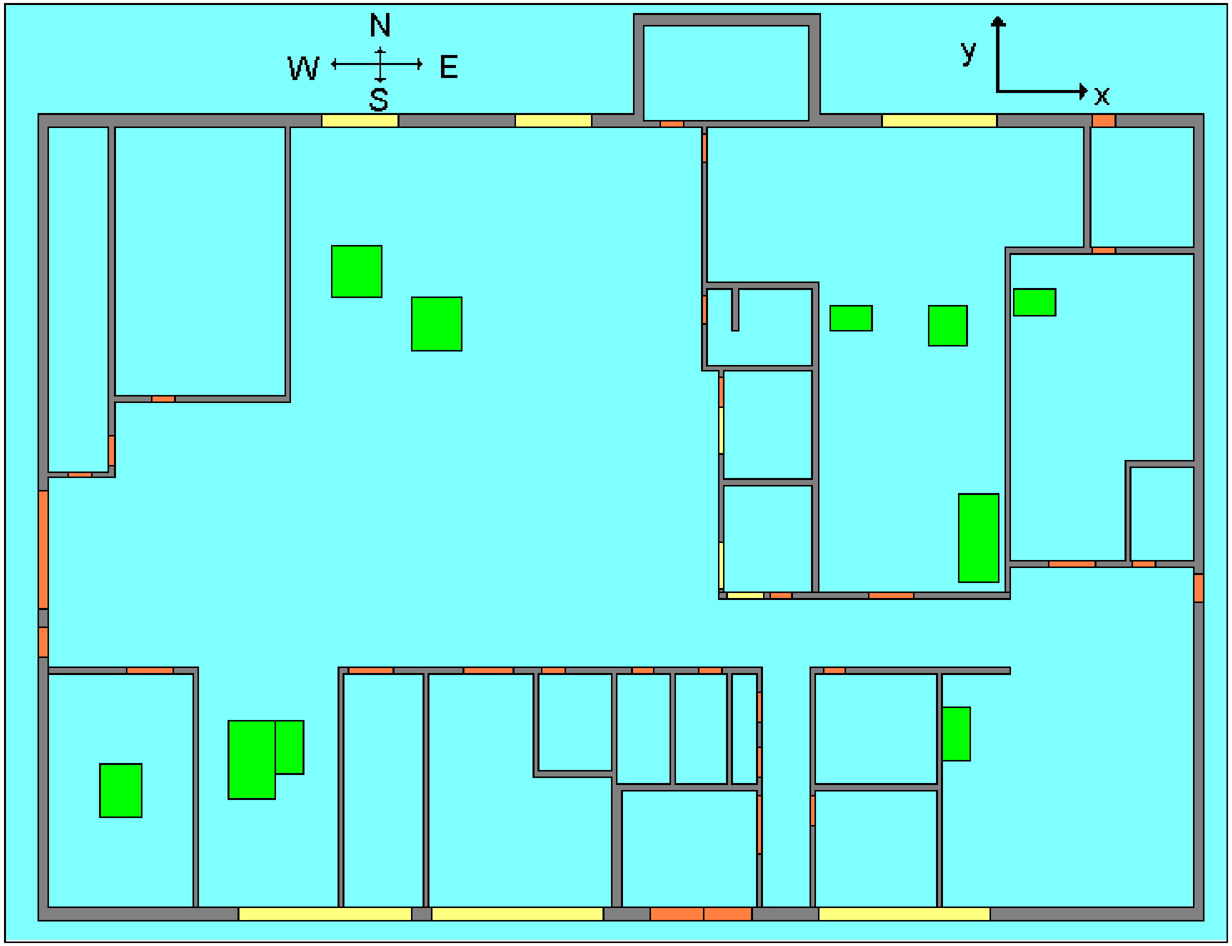
Step 1: Define the MAC

1 e) Identify the MAC as the accident resulting in the lowest fission yield

Postulated Accident Description	Estimated Fission Yield (# fissions / min)
Bare sphere, homogeneous HEU - water mixture	5.2×10^{15}
Reflected sphere, homogeneous HEU – water mixture	1.4×10^{16}

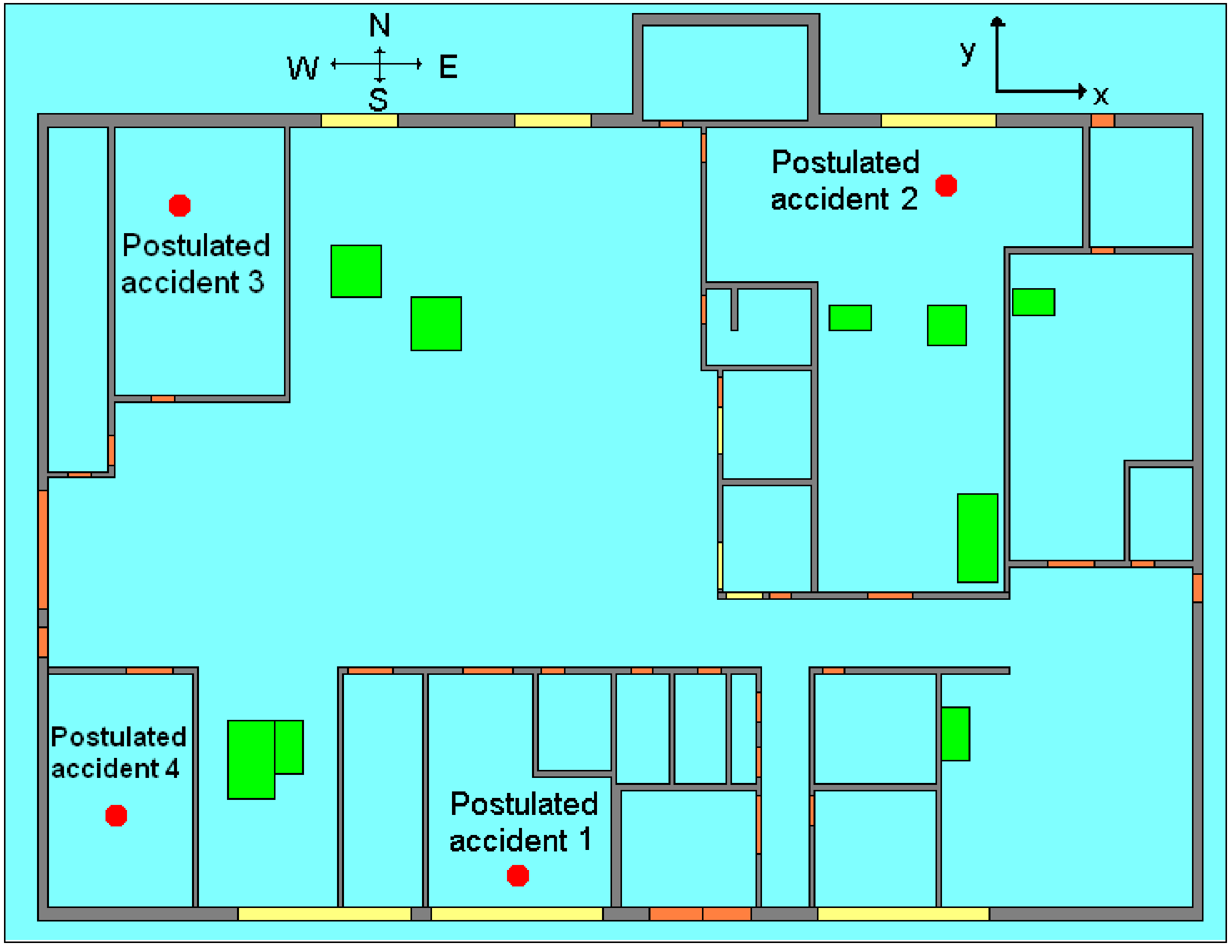
Step 2: Establish the location, type and # of detectors

2 a) Create a computer model of the nuclear facility



Step 2: Establish the location, type and # of detectors

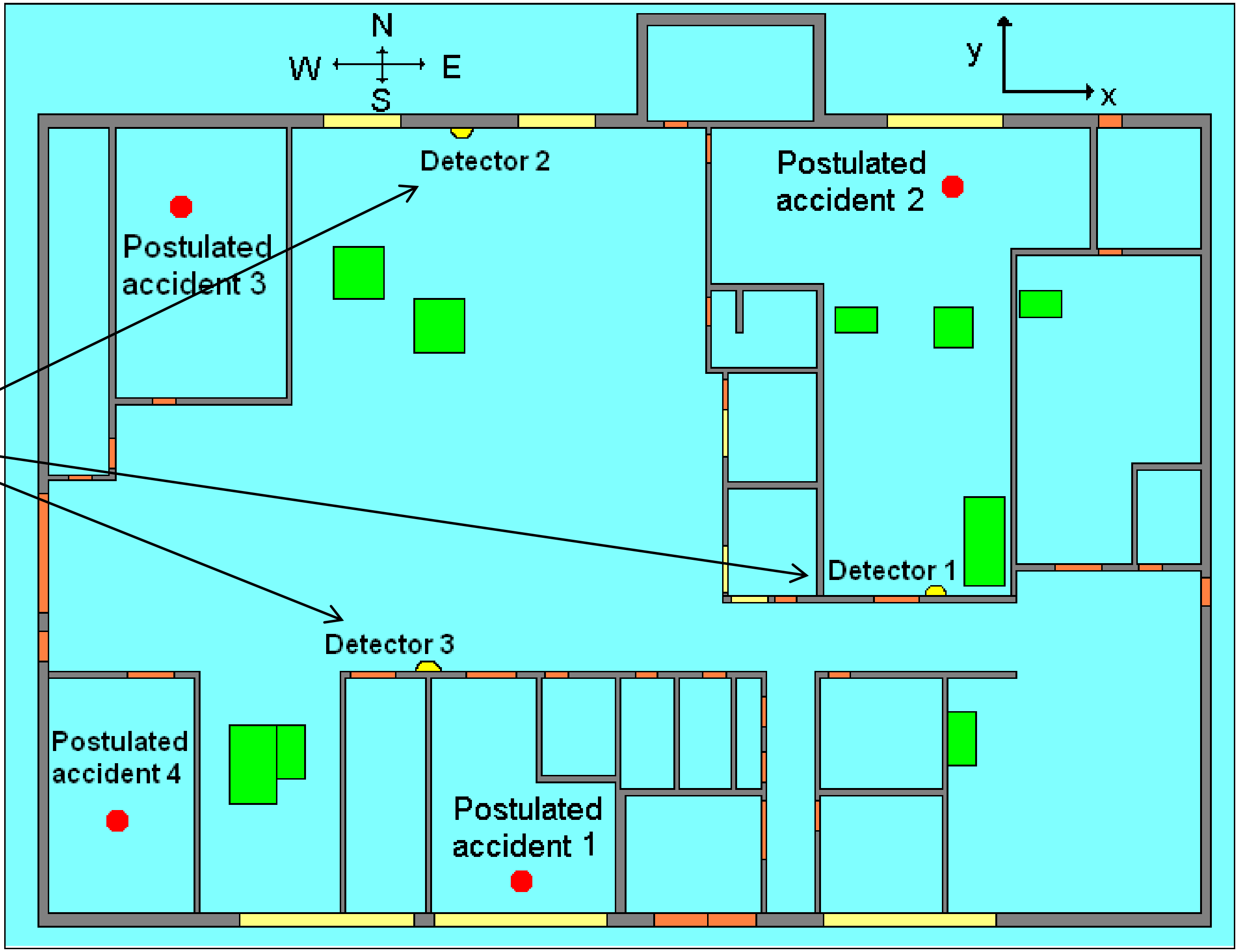
2 b) Identify the potential locations for the MAC defined in Step 1



Step 2: Establish the location, type and # of detectors

2 c) Select the location of potential detectors.

Potential Detector Locations



Step 2: Establish the location, type and # of detectors

2 d) Calculate neutron and gamma doses for each detector location:

$$\text{Dose rate}\left(\frac{\text{Gy}}{\text{h}}\right) = \text{Energy deposited}\left(\frac{\frac{\text{MeV}}{\text{g}}}{\text{neutron}}\right) \times \bar{\upsilon}\left(\frac{\text{neutron}}{\text{fission}}\right) \times \text{MAC fission rate}\left(\frac{\text{\# fissions}}{\text{min}}\right)$$

dose rate	= calculated neutron or gamma dose rate at the detector location
Energy deposited	= the MCNP results obtained using the F6 tally, in MeV/g/source neutron
MAC fission rate	= the term calculated in Step 1 d)
$\bar{\upsilon}$	= the average number of neutrons produced per fission

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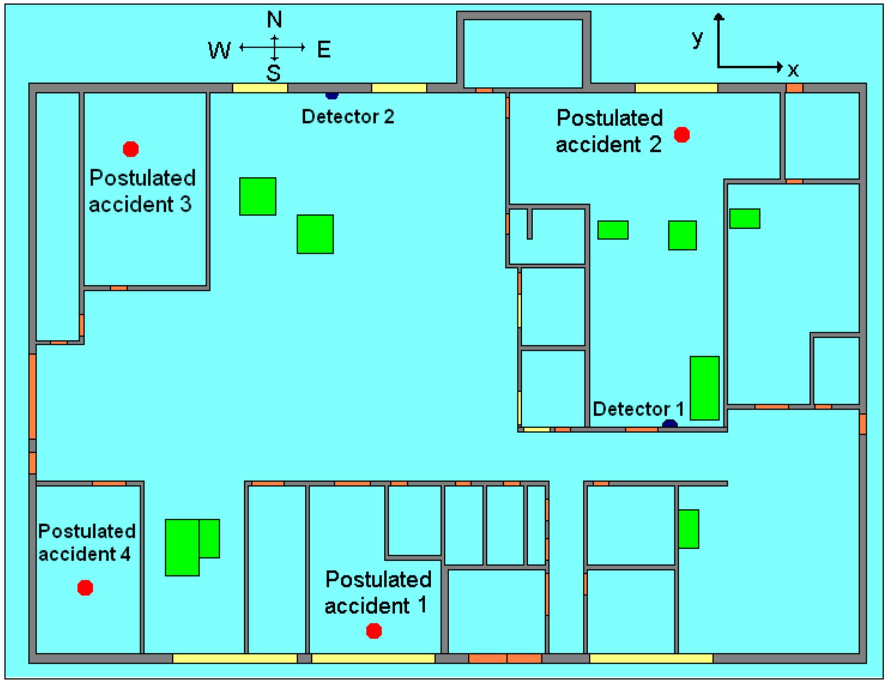
Step 2: Establish the location, type and # of detectors

2 e) Compare dose rate to detector trip point and establish which identified locations provide sufficient coverage for the MAC

- Analysis showed that detector locations 1 and 2 were sufficient to provide coverage for the four MAC locations
- Calculated gamma doses were bounding; hence, using gamma CAAS detectors was appropriate
- Implementing at least a 2-out-of-3 logic at each detector location is recommended to reduce the rate of false alarms



Concluding Remarks

- First step in complying with CNSC regulatory requirements for criticality accident alarm system and in establishing the system parameters and design requirements
- Implemented a step-by-step process to establish the minimum accident of concern and identify criticality accident alarm detector location, type and number
- The results provide the basis for the acquisition, installation and/or upgrade of criticality accident alarm systems in facilities where a criticality accident may lead to an excessive radiation dose

Acknowledgements

The authors gratefully acknowledge the help and assistance provided by fellow staff at AECL, including Fred Adams, John Allen, Laura Blomeley, Lloyd Dunn, Darren Radford, Bruce Wilkin, and Ross Webster.

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