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# Harwell experiences with a Criticality Accident Dosimetry User Group

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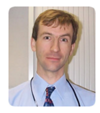
## Introduction

The poster provides a brief overview of (i) criticality accident dosimetry and (ii) some of the work carried out by the dosimetry services at Harwell (now incorporated within Nuvia) and the Criticality Accident Dosimetry User Group (CADUG). CADUG is the relevant expert peer group within the UK.



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## Criticality and associated dosimetry

What is a criticality accident?

An unplanned criticality excursion may lead to an acute (potentially fatal) exposure to radiation. Staff may be exposed to neutrons of a wide variety of energies (from fast to thermal) and to gamma-rays.

The neutron spectrum will consist of fast, thermal and epi-thermal energies.

Special dosemeters are used to assess neutron doses from such an accident. These contain gold, sulphur and indium components which are activated by neutrons.

Sulphur and indium are both threshold detectors. They have different energy thresholds above which the activation cross section significantly increases. The activity of gold and the two threshold detectors can be measured to assess the dose.

Additionally, semi-conductor diodes, whose internal properties are affected by fast neutrons, can also be used as part of the dosimetry system.

## Screening measurements

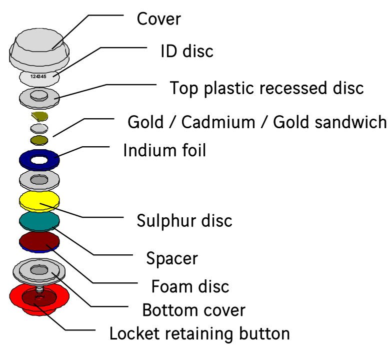
Screening measurements may be carried out on staff by assessing the induced sodium and chlorine body activity. This helps identify who has received the highest dose and where priorities need to be given.

A standard Health Physics hand-held instrument is held against the abdomen and the induced sodium and chlorine activity in the human body is assessed.

The use of indium strips located within dosemeters or passes may also be used by screening for the gamma emissions from the induced $^{116m}$In isotope. These measurements cannot be used to accurately assess dose, but can be used qualitatively as exposure indicators.

## Dosemeters currently in use

Mk III "Locket" with activation components

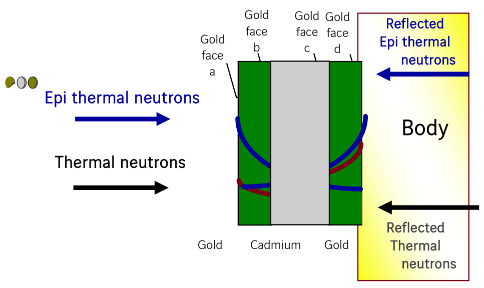



## Assessment of doses

The following can be used to measure fast neutron dose.

- The induced (beta) activity of the sulphur $^{32}$S(n,p)$^{32}$P is assessed using a GM counter. The activation of $^{32}$S has an energy threshold of 2.8 MeV.
- The induced (gamma) activity of the indium foil $^{115}$In(n,n')$^{115m}$In is assessed using a gamma spectrometer. The activation of $^{115}$In has an energy threshold of 1.2 MeV
- The changes to the resistance of the diode are used to assess fast dose; this effect has an energy threshold of about 0.2 MeV

The gold/cadmium/gold arrangement (energy threshold of about 5 eV) allows the thermal and epi-thermal doses to be assessed.




- The induced (beta) activity of the four gold faces $^{197}$Au(n,γ)$^{198}$Au is assessed using a GM counter.

The results of the different dosemeters can be combined to assess the doses from the neutrons of different energy.

Calculations of dose can be complex.

Gamma doses are assessed using standard gamma dosemeters, although choosing a gamma dosemeter with low sensitivity to neutrons greatly simplifies any corrections required for gamma dose. Electronic dosemeters are likely to be saturated by the extremely high dose rates involved and therefore are unlikely to give an accurate result.

## A background to Harwell and criticality dosimetry

Work in Criticality Accident Dosimetry was already advanced at Harwell in the 1950s and 1960s.

For instance the deceptively simple gold foil sandwich section of the dosemeter, used to evaluate the thermal and epi-thermal regions of the neutron spectrum, was proposed in a paper by N Adams and J A Dennis of Harwell in "A New method of using gold foils for the investigation of the leakage spectra form critical assemblies" published by the IAEA in "Neutron Dosimetry" in 1963. The same assembly had previously been put forward by Adams at a Harwell symposium in December 1962.

Another Harwell scientist (S J Boot) was looking at the activation of sulphur discs by fast neutrons, as shown in his 1963 paper "The effects of impurities on the fast neutron activation of Sulphur" (AERE M1244. V).

Criticality Accident Dosimetry is discussed in J A Dennis's paper "Dosimetry in criticality incidents" (AERE R4365) published in 1964. This report includes a picture of the complete CAD locket.

Fast forwarding on 20 years to the formation of CADUG in 1986 (as NADUG), the CAD lockets were in use throughout the UK. Papers continued to be published by scientists based at Harwell including three reports covering dose assessment (Nuclear Accident Dosimetry parts 1-3).

Harwell staff attended a number of intercomparisons which were described in Harwell reports. This gave the dosimetry system a chance for maturation, comparison and improvement.

## Operational considerations

Our reactor exercise highlighted a number of operational issues that need to be taken into consideration when contingency planning for a criticality accident.

- Contamination issues: what impact on both the monitoring of the abdomen and the handling of the dosemeters?
- Consideration must be given to staff welfare when carrying out the initial monitoring. It would seem sensible that staff are segregated prior to carrying out this measurement and that nothing be done which could cause unnecessary distress. Can instrumentation be set to "silent" mode to reduce any psychological trauma?
- How will staff be counselled if elevated readings are detected?
- How will activated dosemeters be handled?

## Future work

The Approved Dosimetry Service at Harwell has now ceased to provide a criticality accident dosimetry service, and research and development on criticality accident dosimetry ceased some time ago.

The baton for continued work in this area has been passed on to other sites where the hazards will be present for a long time into the future. In addition, the funding of CADUG has also changed. Up to 2008, members paid a subscription which covered annual costs and the running of exercises. Recently, the membership subscription was stopped and members now directly fund any work which is to be carried out.

The UK Criticality Accident Dosimetry Locket has been in existence in the region of 50 years. Its function is based on sound, well understood physics.

However, it is believed that, with better data on neutron reaction cross sections and more powerful Monte Carlo computer models, improvements can be made on dose assessment techniques, dosemeter characterisation and function testing.

Function tests without the need for activated locket components would reduce costs and doses.

Other methods of dosimetry not involving neutron activation could also be developed (such as the silicon diode currently in use).

## Criticality Accident Dosimetry User Group (CADUG)

In the 1980s CADUG (originally called NADUG) was established by staff at Harwell. Group members co-operated by pooling resources and funding development work and intercomparisons.

Early Timeline and some key reports (including pre-CADUG work)

- Dose Assessment in Criticality Accidents (Provisional data), (1961 Smith and Peirson)
- Nuclear Accident Dosimetry parts 1 to 3, (Delafield, Dennis and Gibson 1973)
- Proposal for formation of Nuclear Accident Dosimetry User Group (NADUG) (Harrison, Delafield and Gibson 1986)
- First NADUG report Nov 1986
- Nuclear Accident Dosimetry- evaluation of the use of PVC belts as an exposure and orientation indicator for personnel irradiated in a criticality accident NADUG(87)P7 (Perks 1987)
- Changed name to CADUG in 1990
- The response of some radiological protection monitoring instruments to Sodium-24 and chlorine-38 activities in a BOMAB Man-phantom. NADUG(90)P28 (Delafield, Gallacher, Smith* and MacKechnie* 1990) *AWE staff
- Use of silicon diode (Harshaw DN-156) for Criticality Accident Dosimetry including NPL calibration with $^{252}$Cf neutrons CADUG (91) P34 (Delafield and Gallacher 1991).
- Intercalibration of detectors for the measurement of 115mIn activity in indium foils from criticality dosemeters CADUG(93)P52 (Spencer and Adsley 1993)
- Dose Assessment Procedures Based on Sodium Activation CADUG(93)P56 (Delafield 1993)
- CRISIS, A knowledge-based system for criticality accident dosimetry CADUG(94)P64 (Baker 1994)
- Criticality Accident Dosimetry Manual CADUG(95)P68 Issue of first parts of the Criticality Accident Dosimetry Manual (Delafield, Spencer, Gallacher and Baker 1995)
- The intercalibration of the CADUG sulphur and gold counters CADUG(98)P80 (Gallacher and Spencer 1998)

## Training courses

It is essential to maintain a group of skilled dose assessors within each of the Approved Dosimetry Services in the UK for CAD. Therefore Nuvia staff have developed and provided dose assessment training in the form of a two day course.

## CADUG – continued development of CAD

The developments of dose assessment tools
Staff from Harwell irradiated a number of diodes and assessed the fading properties. Work from this was used to derive the relationship between voltage and dose.

Dosimetry manual
The techniques described both in past papers and during recent work were incorporated into a Group manual. This was designed to be user friendly and to assist with any dose assessments.
The manual was issued in both paper and electronic format.

Supporting CRISIS software
The criticality expert assistant software (CRISIS) was developed to enable a Health Physicist, who is not necessarily an expert in criticality accident dosimetry, to arrive at best estimates of dose to individuals within a short time of a criticality incident.

CRISIS takes data in the form of personnel dosemeter information and dosimetry measurements, which are provided by keyboard entry or as data files.

It produces, initially, a list of persons ranked by radiation dose, followed by estimates of their doses which are progressively updated as more dosimetry information becomes available.

Gold and sulphur intercalibration of counting equipment

GM counters are used by CADUG members to assess the induced activity of the gold and sulphur components. The counters are "intercalibrated" to provide traceability to NPL.

- Gold and sulphur locket components irradiated at reactor. Thin gold foils and thioacetamide tablets irradiated at reactor.
- All components delivered to Harwell where they were counted on ADS counters and a "reference" counter as appropriate
- Thin gold foils and thioacetamide tablets sent to NPL for absolute assessment.
- Gold and sulphur locket components sent to CADUG members for counting in all equipment.
- Traceability provided as such

NLP assessment of thin gold foils and thioacetamide tablets ↔ Harwell assessment of all components ↔ Member assessment of components

Handheld instrument intercalibration
A BOMAB phantom was filled with water with dissolved sodium salts to simulate blood. Dosemeters were attached to the phantom.

The phantom and dosemeters were irradiated in a reactor (estimated dose ~ 2 grays).

The phantom was removed from the reactor and the dosemeters were separated from the phantom.

A variety of instruments were used to assess the induced activities of phantom and dosemeters as time progressed.