Radiation Processing & High-Dose Dosimetry at ANSTO

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SUMMARY

The Radiation Technology group at ANSTO is part of the Physics Division and provides services and advice in the areas of gamma irradiation and high-dose dosimetry. ANSTO's irradiation facilities are designed for maximum dose uniformity and provide a precision irradiation service unique in Australia. Radiation Technology makes and sells reference and transfer standard dosimeters which are purchased by users and suppliers of commercial irradiation services in Australia and the Asia-Pacific region. A calibration service is also provided for dosimeters purchased from other suppliers.

1. Facilities

ANSTO maintains and operates a number of irradiation facilities. The pond facility consists of seven cobalt-60 sources configured in annular arrays with a range of activities and dose rates, stored under 5 m of deionised shielding water. Water-tight stainless steel canisters with capacities of up to 30 litres are lowered into the centre of the rigs for processing of goods.

The main irradiation facility is GATRI – the Gamma Technology Research Irradiator – a research and small scale batch irradiator commissioned in 1970. This facility consists of a concrete block-house with 1.5m thick walls over a 5m deep pond in which the cobalt-60 source is stored when not in use. The material for irradiation is sited manually in predetermined locations in the irradiation room or cell, the 12 tonne door is closed and the source is raised into the cell by means of an electric motor. The source is a cobalt-60 plaque approximately $1m^2$ with a maximum capacity of 3.7 PBq (100 kCi).

Radiation Technology is licensed by Australia's Therapeutic Goods Administration (TGA), the Australian Quarantine and Inspection Service (AQIS), and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). These licences require maintenance of a Quality System complying with the ISO 9000 series of standards, to which Physics Division is certified. The GATRI facility is also required to comply with the National Health and Medical Research Council's (NH&MRC) Code of Practice for the Design and Safe Operation of Non-medical Irradiation Facilities (1988).

2. Irradiation Services

Materials commonly irradiated at ANSTO include medical and other products requiring processing at sub-sterilising doses for manufacturers to comply with dose verification and other regulatory requirements, items requiring decontamination and disinfestation for quarantine purposes, frozen bone and tissue samples for transplant surgery, monomers and polymers for modification of properties, plant material and fruit, virus samples, and Queensland fruit fly pupae used in the Sterile Insect Technique. The GATRI facility has been loaded with cobalt-60 to provide the largest possible uniform radiation field, rather than for efficiency, so that the required doses can be provided as precisely as possible. Irradiations can be carried out at a range of dose rates and at frozen and elevated temperatures. During the recent past, client demand for target doses ranged from 10 Gy to 2 MGy, at temperatures from –196°C to 300°C.

It is generally the responsibility of the client to specify the minimum and maximum doses acceptable for the product to be irradiated. Before any materials can be submitted for routine irradiation, the parameters required to ensure the irradiation process produces acceptable results must be determined. This is known as process qualification. The outcome of process qualification is the loading pattern (the manner in which the materials will be loaded and handled within the irradiation facility) and processing parameters for the goods. The loading pattern and processing parameters are unique to a particular irradiation facility.

Once it has been determined how the goods will be loaded into the facility, dose mapping is carried out to determine the zones of maximum and minimum dose within the product and to assess the reproducibility of the process. Often, dummy material of equivalent bulk density is used to simulate the actual product. Dosimeters are located throughout the package in a 3-dimensional array and the set-up is irradiated in the pre-determined loading pattern. The dosimeters are then measured and a map of the dose distribution in the package is obtained. In particular, the maximum and minimum dose zones and the respective dose rates are determined.

During the dose map, positions on the external surface of the boxes are identified as locations to be used for reference dosimeters to be sited during routine processing. Dosimeter measurements made in these locations allow a mathematical relationship to be derived between the reference dosimeter reading and the maximum and minimum doses to the product. This procedure is normally repeated at least three times to demonstrate reproducibility and to allow statistical calculations to be made regarding the process. Reference standard dosimeters are used to establish all critical processing parameters.

3. Dosimetry Services

Dosimeters are usually divided into four basic classes according to their relative metrological quality and areas of application.

Primary standard dosimeters are usually established and maintained by national standards laboratories. The two most commonly used are calorimeters and ionisation chambers. The Australian Primary Standard for Absorbed Dose is held at the laboratories of ARPANSA in Melbourne.

Reference and transfer standard dosimeters are used to calibrate radiation sources and routine dosimeters, and in validation programs. Transfer standard dosimeters are used in establishing traceability chains. Routine dosimeters are used for process monitoring and for quality assurance in radiation processing facilities.

3.1 Dosimeters Used at ANSTO

ANSTO's dosimetry practices are based on the standards published by the American Society for Testing and Materials (ASTM), which have now been adopted as ISO standards. Dosimetry systems in use are Fricke, ceric-cerous sulfate, Harwell Red and Amber Perspex and alanine/ESR.

The Fricke dosimeter is used as a transfer standard to calibrate ANSTO's Underwater Calibration Facility with reference to the Secondary Standard Dosimetry Laboratory; for dose-mapping and calibration checks of self-shielded laboratory irradiators, such as blood irradiators; and to monitor irradiations for the Sterile Insect Technique and other low dose applications. The Fricke dosimeter as used by ANSTO is not suitable for mailing and is therefore not used for contract dosimetry, *ie* sold on a supply and measurement basis.

The ceric-cerous dosimeter is used by ANSTO during product dose mapping studies for critical process parameter determination; during sterilisation dose determination for product qualification studies; and for routine process control where a high degree of accuracy is required. These dosimeters are sold on a supply and measurement basis to users and suppliers of commercial irradiation services in Australia and the Asia-Pacific region wishing to verify the response of their routine dosimetry systems or confirm the dose delivered to their products. The dosimeters are also used as a transfer standard during the in-plant calibration of the routine dosimetry system used by Australia's only commercial irradiation company. ANSTO produces ceric-cerous dosimeters for use in two dose ranges, 1 to 12 kGy and 10 to 35 kGy.

Harwell Red 4034 and Amber 3042 dyed perspex dosimeters, manufactured in the UK, are used by ANSTO during dose mapping studies for relative dose determinations and for process control for routine irradiations.

ANSTO has a Bruker EMS104 ESR analyser and is in the process of developing protocols for the use and calibration of alanine dosimeters using this instrument for inclusion in our Quality System. The alanine/ESR system is not yet ready for use as a contract dosimeter by ANSTO, but it is anticipated that it will be used as a transfer and reference standard, hopefully at doses from 10 Gy to 100 kGy.

3.2 Calibration

All dosimetry calibrations performed at ANSTO either for internal use or for external clients are carried out in the known radiation field of the Underwater Calibration Facility (UCF). The UCF consists of 12 cobalt-60 pencils in an annular arrangement, stored in ANSTO's pond facility.

All items for irradiation are loaded into a water-tight stainless steel canister which is in series with a continuous stainless steel roller chain driven by an electric motor which lowers it reproducibly into the centre of the source. The dosimeters for calibration are mounted onto a turntable fitted with a polyethylene holder with locations for up to 12 dosimeters. The turntable is sited in a fixed position

within the irradiation canister and the dosimeters are continuously rotated to ensure an even dose. The facility is controlled by a computer which provides for independent confirmation of irradiation time, irradiation temperature and rotation of the turntable. Temperature is monitored using a thermocouple.

Each batch of dosimeters is calibrated by irradiating several samples to known absorbed doses. A calibration curve relating dosimeter response values to absorbed dose is generated giving a dose response equation for that batch. Doses are routinely expressed in terms of the dose absorbed in water.

At ANSTO, measurement traceability to the national standard is obtained by the following approach. The Australian Standard for Absorbed Dose consists basically of a cobalt gamma source whose dose rate at a fixed point is measured using a graphite calorimeter. This primary standard is then disseminated by the Secondary Standard Dosimetry Laboratory or SSDL. The SSDL ionisation chamber is calibrated against the primary standard and this chamber is then used to calibrate a collimated beam from a teletherapy gamma source. ANSTO's Fricke dosimeters are then irradiated in this calibrated beam to a range of doses so that the response of this solution is well characterised. This dosimeter solution is then used to determine the dose rate in a fixed geometry on the turntable in the Underwater Calibration Facility. Routine and transfer standard dosimeters are then calibrated as required in the UCF, with the dose rate calculated according to the decay of the cobalt-60 source.

In conjunction with this calibration process, ANSTO has confirmed the dose rate in the UCF through irradiation of dosimeters supplied and measured by the National Physical Laboratories in the UK and via the IAEA's International Dose Assurance Scheme (IDAS).

The dose rate measured in these instances agrees within 1% with ANSTO's calibrated dose rate.

In principle ANSTO follows the guidelines set out in ISO's 1993 "Guide to the Expression of Uncertainty in Measurement" and ISO/ASTM 51707. Components of uncertainty are classified as Type A or Type B and are given as the percent standard deviation. Components of uncertainty are combined in their simplest form, that is, they are assumed to be uncorrelated and are added in quadrature by type before a combined uncertainty is obtained. The reported expanded uncertainties are based on standard uncertainties multiplied by a coverage factor of $k = 2$, providing a level of confidence of approximately 95%. When adequate care is taken in the calibration, analysis and use of ANSTO ceric-cerous dosimeters, the overall uncertainty of absorbed dose measurement by a single dosimeter is calculated to be $\pm$ 3.5% at the 95% confidence level.

4. Conclusion

ANSTO's facilities are unique in Australia in their capacity to provide precision irradiation services. Dose uniformity ratios, URs, (ratio of maximum dose/minimum dose) required during dose verification experiments for medical device manufacturers are better than 1.22. In a typical commercial irradiation plant, URs of 1.5 to 2 would be expected. At ANSTO, we are able to meet the stringent UR requirements of the Sterile Insect Technique of better than 1.07, for quantities of live pupae of up to 20 million per day.

In addition, ANSTO is the only body in Australasia with dosimeters for radiation processing able to cover dose ranges from 40 Gy to 50 kGy. Demand for these services has been steadily increasing, with GATRI now routinely booked up to 3 – 4 months in advance.