Upgrading an Active Neutron Interrogation System at NRS Dounreay - 25558

Antony C. N. Towner[1], Kevin J. Burke[1], M. R. Looman[1], John A. Mason[1], Henry R. Turner[1], Nick A. Troughton[1], Alan C. Lewis[1], Marco Sadgrove Di Giovanni[1], Matt J. Piotrowski[2], Charlie Graham[3], Paul Mullarkey[3], and Paul Tait[3]
[1]ANTECH, A. N. Technology Ltd., Unit 6, Thames Park, Wallingford, Oxfordshire, OX10 9TA, UK
[2]ANTECH Corporation, 7985 Vance Dr, Suite 307, Arvada, Colorado, 80003, USA
[3]Nuclear Restoration Services Dounreay, Dounreay, Thurso, Caithness, KW14 7TZ, UK

ABSTRACT

The NDA7 Active Neutron Interrogation System at NRS Dounreay is used to determine the mass of fissile material (Plutonium and Uranium) contained in several different size waste cans. The system was originally designed in the 1970s for both passive neutron and active neutron measurements of fissile material using a Philips neutron generator. It was upgraded to a Californium Shuffler in 1988. The measurement chamber incorporates 16 He-3 detector tubes surrounding the measurement position. The detectors are not evenly spaced to allow a location for the 'flight tube' through which the Cf-252 source is 'shuffled', during active measurements. Sample cans to be measured are raised using an electrical hoist from a 'hot cell/glove box', which is 5 meters below the measurement position. Sample cans are prepared for measurement by means of a master – slave manipulator (MSM) from outside of the 'hot cell/glove box' and then raised into the measurement position using the electrical hoist. The objective of the refurbishment upgrade was to remove electronic obsolescence issues, assure future maintainability and to enable future operational requirements to be met. The first phase of the refurbishment work was a design study using MCNP modelling techniques to assess replacing the decayed californium source with a neutron generator (a neutron emission module with a tritium target) and to optimise the design of the updated system. The neutron generator replaced the Cf-252 flight tube and shielded storage position adjacent to the existing sample measurement chamber. Implementing the design required a HAZOP assessment to be carried out to establish the radiation shielding and electrical safety measures required to ensure the safety of operational staff. The design also involved updating the system's mechanical and electrical hardware. A new programmable logic controller (PLC) was installed to control the hoist, and sample can location within the measurement position. The neutron counting electronics was replaced with an ANTECH N2000 Universal Neutron Counter (UNC) coupled to a modern computer running updated analysis software. A second modern computer at the operator workstation runs the user interface software that controls the overall measurement process. Major components of the original hardware were retained, including the original He-3 detector tubes, the hoist and charge sensitive amplifiers, minimising the cost of materials, waste disposal and disruption to the plant. Once the system had been refurbished, the return to service required the production of detailed calibration plans for passive and active calibrations, including a set of 12 waste containers and matrices to simulate expected waste streams and different size packages. MCNP modelling was used to develop the calibration procedures, and the design of the cans and matrices used for calibration. Inactive and active calibration using fissile sources was then carried out to ensure the performance of the system.

INTRODUCTION

The Californium shuffler, of which the initially upgraded NDA7 instrument is a good example, has its origins at the Los Alamos National Laboratory (LANL) and resulted from the work of G. R. Keepin, then director of the Los Alamos Safeguards Group [1]. Measurements of delayed neutron parameters by Keepin and others, led to the application of delayed neutrons measurements to assay uranium.

In the original concept, a Californium shuffler has a movable Cf-252 source that is used to induce fission in fissile nuclei such as U-235 and Pu-239. Following an irradiation period, the Cf-252 source is moved away from the irradiation position, which is in close proximity to the sample. After removal of the source, neutron counters measure the delayed neutrons induced by fission in the sample being assayed. A virtue of the shuffler technique is that the delayed neutron signal is proportional to the activity of the

Cf-252 source. However, at the same time the delayed neutron background is very low when delayed neutrons are counted, because the Cf-252 source is transferred rapidly away to a shielded external position. Although shufflers are used to measure waste containing both U and Pu, they are particularly suited to measure waste containing only U, where there is no spontaneous fission background as is the case when isotopes of Pu are present. If the Cf-252 interrogation source is not deployed, (passive measurement) then the instrument can be used to measure Pu by measuring spontaneous fission neutrons. This instrument is to be used to measure both U and Pu so the spontaneous fission neutron background will affect performance in measuring U.

When the Cf-252 shuffler was devised at LANL, consideration was also given to the use of other sources of neutrons, such as neutron generators. For example, delayed neutron measurements were made following irradiation by neutrons from D-T reactions in a Van de Graaff accelerator. Cf-252 sources had the advantage of being compact, intense sources with a reliable and predictable neutron emission rate. Also, the Cf-252 neutron energy is sufficiently low, so that (n,2n) reactions are not initiated. The main disadvantage was the necessity to shield the source, as unlike a neutron generator, it cannot be turned off. This also leads to more stringent health physics consideration and avoiding dose uptake to instrument operators. The cost of intense Cf-252 sources was not a limiting concern when shufflers were being developed.

That situation has changed today. The motivation for upgrading the NDA7 instrument was partly based on the significant cost of a replacement Cf-252 source. Also, health physics concerns are more prominent today and source transport and source handling have become more difficult and expensive.

Ironically, neutron generators were originally considered by the developers of the technology at LANL. In its earliest incarnation in the late 1970s, NDA7 employed a Philips neutron generator tube ‘neutron gun’. This was replaced in 1988 by a Cf-252 irradiation source converting NDA7 into a conventional Cf shuffler. The system was upgraded again in the early 2000s by Eurisys Mesures when the original shorter BF3 neutron detector tubes were replaced with the current He-3 detectors and the counting electronics was replaced and the current amplifiers were installed. The sample hoist motor and electronics were also replaced at that time.

Given the history of NDA7 and the original use of a neutron generator by the LANL developers, it seems an appropriate path for upgrading NDA7 to replace the Cf-252 source with a D-T neutron generator. Doing so brings significant cost savings and health physics advantages.

ANTECH (A. N. Technology Ltd.) have years of experience working with NRS Dounreay, supplying and supporting both gamma and neutron waste measuring instruments and systems. ANTECH previously supplied several active and passive can measurement systems [2] to Dounreay for measuring the site inventory of fissile materials including historic legacy un-irradiated fuels. With this experience, ANTECH was competitively selected to upgrade the NDA7 waste assay instrument located in the D2001 facility on the NRS Dounreay site.

The NDA7 active neutron interrogation waste assay system is used for the determination of the mass of fissile material (Pu and U) present in waste cans. Although the system has been upgraded to replace the californium source with a neutron generator, obsolescent component issues have also been addressed at the same time. These include the PLC, computer systems, some of the neutron counting electronics, instrument cabling and software. A new software suite has been supplied which is compatible for use with both the new and existing hardware.

Some of the existing equipment such as the measurement chamber, He-3 detectors tubes, neutron detector head amplifiers, positional sensors and indicators, sample hoist, and hoist motor have not been replaced. The associated cables, which are either an integral part of the installation or still in a serviceable condition, have also been retained. Significant additional cost has been avoided by not replacing the He-3 detector tubes and the existing head amplifiers. Additional spare amplifier components were supplied as part of the upgrade.

NDA7 WASTE CELL

The NDA7 active neutron interrogation waste assay system is located in the Waste Posting Cell (WPC) which is a part of the Waste Handling and Washing Cell of the D2001 waste facility at the NRS Dounreay site, formerly Dounreay Site Restoration Limited (DSRL) near Thurso in the north of Scotland. The site is now part of Nuclear Restoration Services (NRS), a subsidiary of the UK Nuclear Decommissioning Authority (NDA).

The NDA7 measurement chamber is built into the ceiling of the WPC. A hoist located on top of significant shielding above the cell is used to raise sample cans to be measured from the floor of the cell to an irradiation (measurement) position within a detector region built into the cell roof shielding. Originally, the source of neutrons for the irradiation measurement was supplied by a significant Cf-252 source of a nominal strength of 6.3×10^8 n/s (in 2006). The source was part of a Cf-252 shuffler system and was housed at the end of a large horizontal tube (flight tube) penetrating the WPC roof shielding and terminating at the sample measurement (irradiation) position.

The Waste Cell of which the WPC is a part is shown in an archive drawing as Figure 1. The WPC is the right-hand side of the overall cell. The original NDA7 assay system is labelled and includes the neutron detectors partially surrounding the irradiation position, the sample can hoist, the shielding above the measurement position and the 'neutron source shuffler system for NDA7'. Some of these key features are labelled in Figure 1, and a waste can, which is to be measured, is shown on the floor of the WPC.

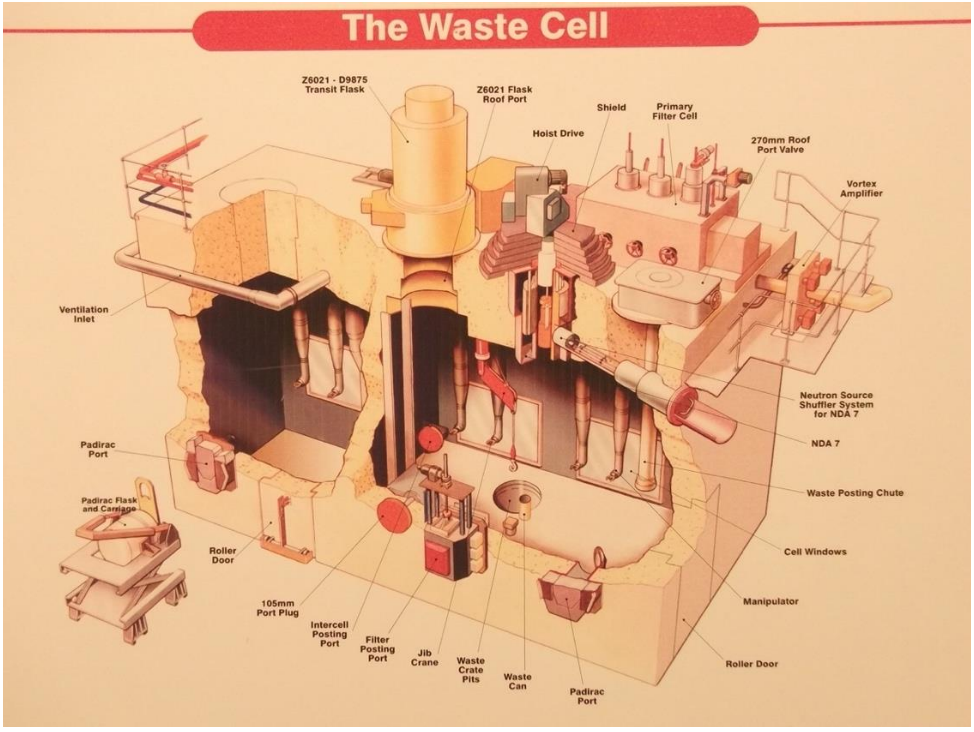

Figure 1. Archive drawing of the Waste Cell of which the Waste Posting Cell (WPC) on the right-hand side is a component. Also shown is the NDA7 Waste Assay System configured as a Cf-252 Shuffler (Active and Passive Neutron Interrogation Waste Assay System).

In its configuration as a Cf-252 shuffler, the Cf-252 source was stored in a shielded storage position near the outside end of the 'source tube' away from the measurement position. A 'teleflex' cable connected to a motor was used the move or 'shuffle' the source rapidly from the storage position to the irradiation or measurement position. Following a brief irradiation period, the source was 'shuffled' rapidly back to the storage position. This process allowed the delayed neutrons to be measured while the source was absent, and the measurement position radiation background was very low. Typically, this measurement sequence was repeated several times, with a suitable delay during which the delayed neutrons were counted. Repeating the measurement in this manner improved the measurement counting statistics.

The sample irradiation position is partially surrounded by 16 He-3 neutron detector tubes. If one views the detector tubes as arranged in a semi-circle about the centre of the sample can measurement position, then roughly a third of the circumference of the circle is not populated by He-3 tubes. The middle of this third is the point to which the flight tube housing the Cf-252 source points.

The 16 fast neutron detectors are XERAM Model 150 NH 100 He-3 tubes with a diameter of 25mm (1in). The tubes are imbedded in a polythene moderator and are also surrounded by a lead annular region which shields the He-3 tubes from the intense gamma ray dose arising from the sample cans. Each of the 16 detector tubes is connected to a single EURISYS MESURES model ACHNP97 charge sensitive amplifier by the existing coaxial cable arrangement.

MODELLING UPGRADED NDA7

The upgraded NDA7 instrument was extensively modelled using the MCNP Monte Carlo modelling code [3], developed at LANL. For much of the modelling an associated code, MCNP-PTA [4] was also employed. It is a modified version of MCNP for pulse train analysis. Figures 2 and 3 are images from the revised MCNP model showing a cross-section view of the measurement position in the roof of the WPC. A plan view from the MCNP model of the measurement position with the flight tube and neutron detector tubes is shown in Figure 4.

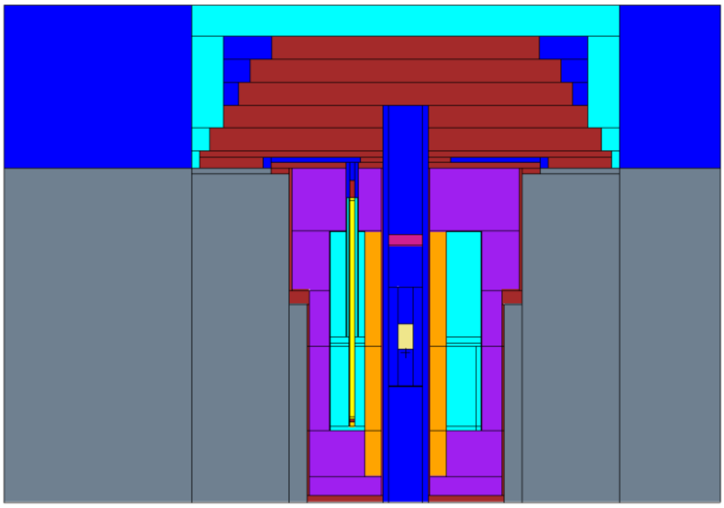

Figure 2. Cross-section view of the measurement position in the roof of the WPC with the stacked shielding above. The position of the He-3 tubes is shown in yellow as well as a sample can in yellow in the measurement position. The flight tube is not shown in this view.

The modelling was used to evaluate the design and eventually to generate calibrations for both active and passive operation. Many simulations were required to include both active and passive assay as well as encompassing several different waste-can sizes. The revised MCNP model of the upgraded NDA7 assay system was derived from a model generated by Eurisys Mesures of the original Cf-252 assay system in the WPC.

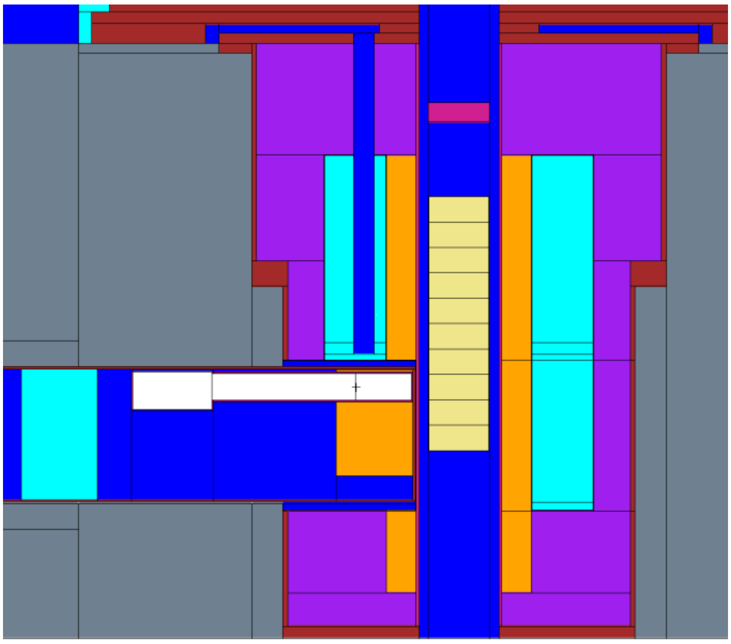

Figure 3. Expanded cross-section view of the measurement position in the roof of the WPC, but including the flight tube housing the neutron generator in white. Lead shielding surrounding the He-3 tubes and the lead neutron enhancer around the emission module is also shown in orange.

The use of MCNP modelling for upgraded NDA7 calibrations was a particularly significant aspect of the project. Obtaining appropriate Pu calibration sources was going to be extremely expensive and involve prohibitive procurement timescales. This problem was overcome through the use of MCNP to support the calibration process.

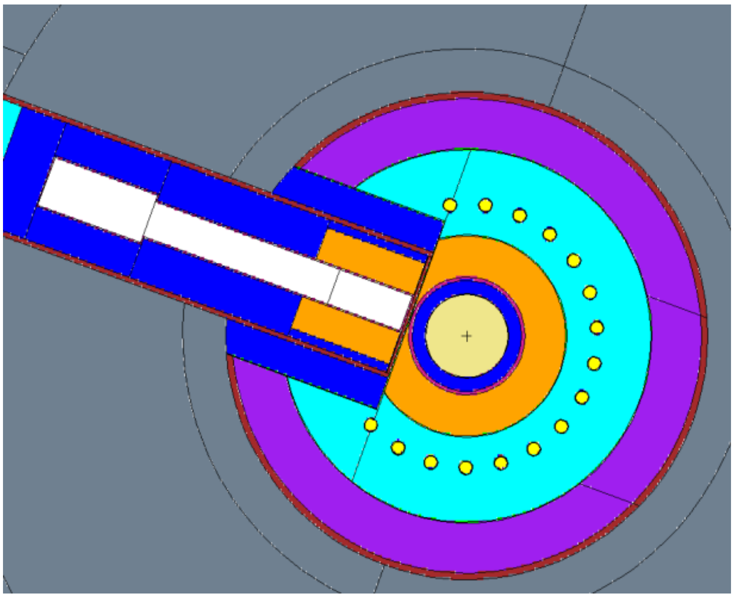

Figure 4. Plan view of the measurement chamber showing the flight tube with neutron generator (emitter), lead neutron enhancer (orange), the 16 He-3 detector tubes (yellow) and the lead shielding (orange) surrounding the sample can (yellow).

The positioning of the neutron generator in the flight tube has been made as close as possible to the previous position of the Cf-252 source to maximise the efficiency of the neutron irradiation. However, practical constraints, imposed by the physical dimensions of the neutron generator tube and mechanical requirements, meant that the vertical Z-axis position was offset by several centimetres from the original

Cf-252 irradiation source position. A neutron enhancer, (the lead cylinder surrounding the neutron generator target) is positioned towards the sample cavity, maximising the neutron flux inside the waste sample by contributing neutrons from (n,2n) reactions. Note that the lead placed around the cavity to shield the He-3 tubes from the gamma rays emitted by the waste also increments the neutron flux in the sample by (n,2n) reactions. A plan view of the measurement position with the flight tube and neutron detector tubes is shown in Figure 4.

As a part of assessing the performance of the neutron generator, a number of locations were studied for the position of the neutron flux monitor. A location, shown in Figure 6, was selected near the end of the middle section of the flight tube. In this position the neutron flux monitor has an approximately linear response with the generator output and the count rate is high enough to make the uncertainty due to counting statistics negligible.

The bulk of the modelling effort has been to consider both passive and active measurements of waste cans used in the D2001 facility and measured by the NDA7 assay system. The cans are 6” (15.24cm) in diameter and are available in 4 different lengths. The smallest can of 9” (22.86cm) is measured in a single measurement position, however the remaining longer cans of 18” (45.72cm), 21.75” (55.245cm) and 26” (66.04cm) are all measured in two positions (a double measurement). The can measurement positions and can sizes are shown in Figure 5. In practice, most measurements are made with 9” and 24” cans.

Simulations have been performed for a wide range of waste cans of different sizes and configurations. These include both passive measurements for plutonium bearing waste and active measurements for uranium bearing waste, considering a variety of matrices as well as different can double measurement positions. In order to evaluate the Pu contribution to active measurement results, the isotopic fingerprint is used to convert the U-235 effective mass into total masses of U and Pu. Isotopic fingerprints are automatically decay corrected to the date of the waste can measurement by the MCC software module, see below. Passive measurements are not used to correct the active measurements for the presence of Pu. A focus of the modelling has also been the hydrogen content in the waste matrix and its effect on the measurement result, particularly for active measurements.

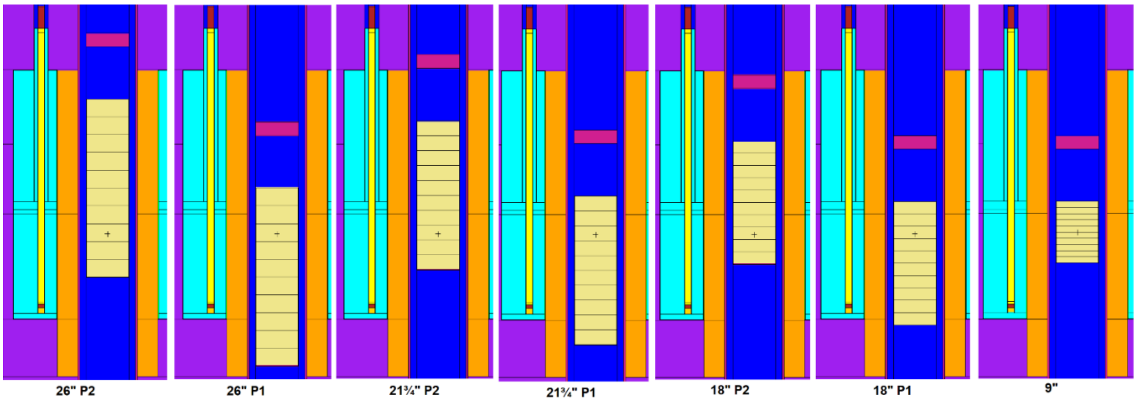

Figure 5. MCNP geometry plots (vertical section) for the various can sizes and assay positions (P1 and P2). The small cross inside each can is at the same height of the centre of the neutron generator. The cans are split in 10 vertical segments for MCNP tallying purposes.

As anticipated, the active modelling simulations have been more challenging due to physics considerations. Replacing the Cf-252 source with a D-T neutron generator not only has an impact on the hardness of the neutron spectrum but also on the location of the interrogating source, because of physical constraints of using the existing measurement position and neutron detectors. The mono-energetic 14 MeV neutron spectrum of the D-T generator is much harder than that of a Cf-252 source with an average energy of 2.13 MeV. Note, that the Cf-252 source spectrum has its peak around 0.8 MeV: a considerable number of neutrons are emitted at lower energies. These lower energy neutrons produce a larger fraction of thermal and epithermal neutrons entering the waste can (from collisions with the materials in the assay system). This leads to more induced fission and better counting statistics for active measurements.

HARDWARE STSTEM

Upgraded Flight Tube and Neutron Generator

The upgraded flight tube was manufactured in three sections: front, middle and rear, for practical reasons relating to the ease of installation and removal of the neutron generator. The pulse generator (proximity modulator or PROX MEN) unit is mounted behind the neutron emitter inside the bore of the front section of the flight tube. It enables pulsed mode operation of the neutron generator. The internal components of the flight tube are shown in Figure 6.

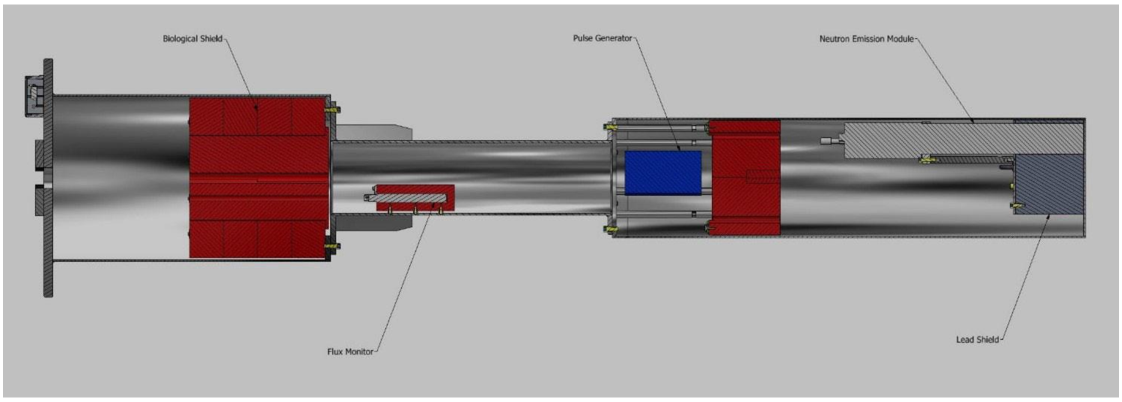

Figure 6. Drawing of the flight tube showing the neutron generator and flux monitor.

An He-3 detector for flux monitoring is housed inside a block of HDPE moderator located in the lower part of the middle section of the flight tube. The flux monitor is a Reuter Stokes (GE) model RS-P4-0806-110 He-3 detector with a gas pressure of 7.5 atmospheres, a length of 250mm (10in) and a diameter of 25mm (1in). It monitors the neutron flux produced during pulsed emission of the neutron generator. The flux monitor corrects for the fluctuation and decline in output of the generator over time and between calibrations.

The neutron generator consists of two components, the neutron emitter and the pulse generator. The SODERN MEN 16NG D-T neutron emitter is positioned at the front of the fight tube next to the outside edge of the measurement chamber liner. Lead is placed concentrically around the generator target to increase the neutron yield from (n,2n) reactions. The rear of the neutron emitter is shielded with HDPE to reduce or eliminate the stray neutron dose to personnel.

The rear section of the flight tube contains a large flange which secures it in position. The flux monitor amplifier box is mounted on the outside of this flange. As a results of the findings of the HAZOP assessment, additional shielding calculations were carried out, which resulted in the need to house several large blocks of HDPE shielding in the rear section to reduce or eliminate the stray neutron dose to personnel. Cables from the D-T neutron emitter, the pulse generator and the flux monitor pass through this shielding and exit the rear flange via a split gland plate. Figure 7 is a photograph of the flight tube during assembly.

Figure 7. Photograph of the flight tube during assembly. The rear flange is to the left of the photograph.

Sample Hoist and Can Handling System

The original hoist, which is controlled through the upgraded PLC, lifts a sample from the loading position in the WPC to the irradiation and measurement position in the ceiling, above. It maintains the sample in position during a measurement and lowers the sample at the end of a measurement. The hoist may be controlled from the Cave Face control switches or the upgraded MCC program Hoist Control Screen (see Upgraded Software, below). Power to the hoist is applied via raise and lower contactors supplying the power to the motor when triggered by the PLC. The position feedback for the hoist vertical motion is obtained from a single turn encoder, which has also been upgraded. The hoist and hoist drive (hoist motor housing) can be seen in Figure 1.

Implementing the overall design of NDA7 required a high integrity safety system which was designed to IEC 61508 SIL 1. This required the design of a safety circuit that incorporated new safety relays and contactors with the neutron generator safety interlocks, the hoist and emergency stop circuit loop. The safety circuit operates independent of the PLC.

The operator station at the cave face has a digital LCD readout that shows the positions for the sample can or canister being raised by the hoist. It also has two buttons to manually raise and lower the hoist. Manual hoist control is disabled by the MCC software during measurements. There is a local/remote key switch mounted on the front of the main enclosure which can be set to ‘local’ to override the MCC software. The extent of the hoist movement is limited by soft limits, and, in the event of a fault condition, by a series of hard limit switches.

Sample cans to be measured are posted into the WPC. Master-slave manipulators (MSM) are used by the operators to prepare the sample cans and load them for raising by the hoist from the load position in the WPC to the irradiation and measurement position in the roof of the WPC.

Upgraded Counting Electronics

The upgraded counting electronics consist of an ANTECH N2000 UNC (Universal Neutron Counter) which provides totals neutron counting for the active measurement and shift register coincidence counting for passive measurement. The N2000 utilises four BNC input channels, one for each of the measurement chamber amplifier outputs (ACHNP97 charge sensitive amplifiers – each connected to 4 He-3 tubes) and one LVDS (low voltage differential signal) input for the Flux Monitor amplifier output. An ANTECH A2000-15 LVDS input module connects to the N2000 and enables an additional 15 TTL counting channel inputs to the N2000. The Flux Monitor output is connected to the N2000 through the A2000-15.

High voltage (HV) to each of the measurement chamber He-3 detectors is provided by the N2000. The Flux Monitor is supplied from a separate HV supply as it is biased at a different voltage to the measurement chamber He-3 detectors. Initiation of the acquisition of pulsed/periodic active measurement data is based on instructions from the neutron generator instrument rack (the MEN 16 Neutron Emission Module). There is also a synchronising signal from the neutron generator to the N2000, used to synchronise the counting.

UPGRADED SOFTWARE SYSTEM

The upgraded system incorporates several software packages and associated software drivers and libraries, operating on three different hardware platforms. The full suite of software packages is listed below, along with the computer platforms on which they operate:

a) Workstation Computer
    i. Microsoft Windows 10™ Operating Platform
    ii. Master Control Computer (MCC) software with built-in Isotopic Module

b) Local Enclosure Embedded Computer
    i. Microsoft Windows 7™ Operating Platform
    ii. N2000-1 User Software
    iii. Passive Neutron Software (MPA)
    iv. Active Neutron Software (DNC)
    v. MMI Genie Control application for Genie16 Neutron Generator

c) Main Enclosure Allen-Bradley Programmable Logic Controller
    i. ANTECH PLC software.

The measurement process is controlled from Master Control Computer (MCC) software located on the Workstation Computer. Its functions and the functions of the programs it controls are listed below:

MCC software:

a) Controls the measurement process
b) Interfaces with the PLC and PLC software
c) Interfaces with Master Passive Active (MPA) and Delayed Neutron Counter (DNC) software
d) Enables and controls the hoist through the PLC
e) Functions as the user interface and displays the measurement results

MPA software:

a) Runs under instruction from the MCC software
b) Communicates with the N2000-1 software which controls the neutron counting process and acquires neutron counting data from the passive measurement
c) Makes passive neutron coincidence counting (PNCC) measurements (passive operation) to determine the Pu240 effective mass.

DNC software:

a) Runs under instruction from the MCC software
b) Controls the neutron generator through the Sodern Genie Interface
c) Communicates with the N2000-1 software to acquire active measurement neutron counting data
d) Makes delayed neutron counting measurements (active operation) to determine the U-235 Effective mass.

MMI software:

a) Sodern MMI software controls the neutron generator for configuration and testing following initiation from the DNC software.

Under normal operating conditions, access to software packages other than MCC is not necessary. Access to N2000-1, MMI, MPA and DNC is only required to set up certain configurable parameters and for some diagnostics purposes. Software connectivity is achieved through the computing hardware in the following manner. The embedded computer, which incorporates Ethernet 10/100Mbps and TCP/IP connectivity, is connected by Ethernet to the workstation computer and the neutron generator NG16 instrument rack. It is connected by USB to the N2000 UNC (Universal Neutron Counter). The user programs DNC, MPA, N2000-1 and Genie NG16 MMI run on the embedded computer Microsoft Win 7™ platform.

RESULTS

In order to verify the validity of the MCNP modelling used for the design of the upgraded system in both passive and active mode, and subsequently the preparation of calibration samples and the calibration process, preliminary measurements were compared with MCNP simulations using the upgraded MCNP model. The results are described and presented below.

Passive measurements of a known Cf-252 source provided by NRS Dounreay were made at different positions to baseline the modelling. The results of this comparison of passive measurement and MCNP simulation are displayed in Figure 8. From the graph in Figure 8 it can be seen that good agreement is obtained between measurement and simulation.

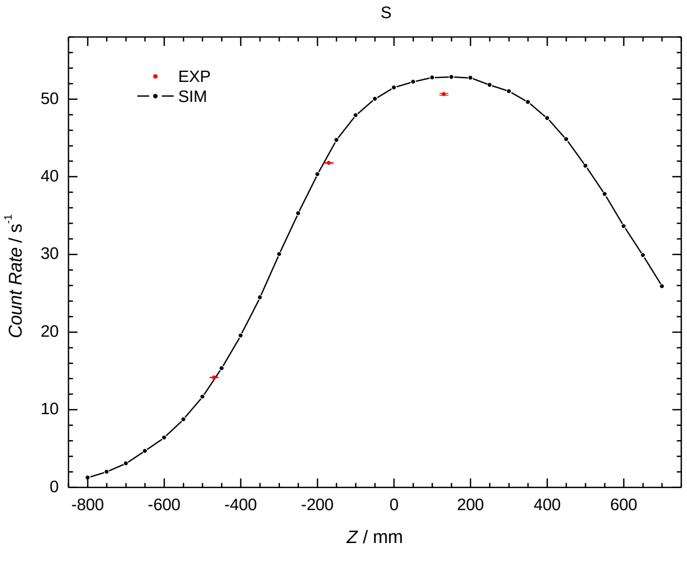

Figure 8. Singles count rate for the Cf-252 test source as a function of Z (vertical position) in the measurement chamber.

A series of active measurements were made of a known U sample provided by NRS Dounreay. The sample was placed within cylinders of differing mass, thickness and different material to verify the MCNP modelling for active mode. The sample was made of uranium oxide powder containing 5g of U-235. For the different measurements the sample was placed within cylinders of different neutron absorbing and moderating material within a sample can and measured. These samples had different hydrogen contents which is the most significant factor in the matrix response. The material composition and mass of the cylinders are listed in Table 1.

Table 1. The material composition and mass of the cylinders into which the uranium oxide sample was placed for the active delayed neutron measurements which are compared with MCNP simulations. The comparison results are displayed in Figure 9.

Cylinder	Material	Mass (g)
POM1	Polyoxymethylene	332
POM2	Polyoxymethylene	533
POM3	Polyoxymethylene	726
POM4	Polyoxymethylene	1201
POM5	Polyoxymethylene	1993
POM6	Polyoxymethylene	2579
PVC6	Polyvinyl chloride	2647
HDPE1	High density polyethylene	801

The comparison results of the active mode simulations and measurements are plotted in the graph in Figure 9.

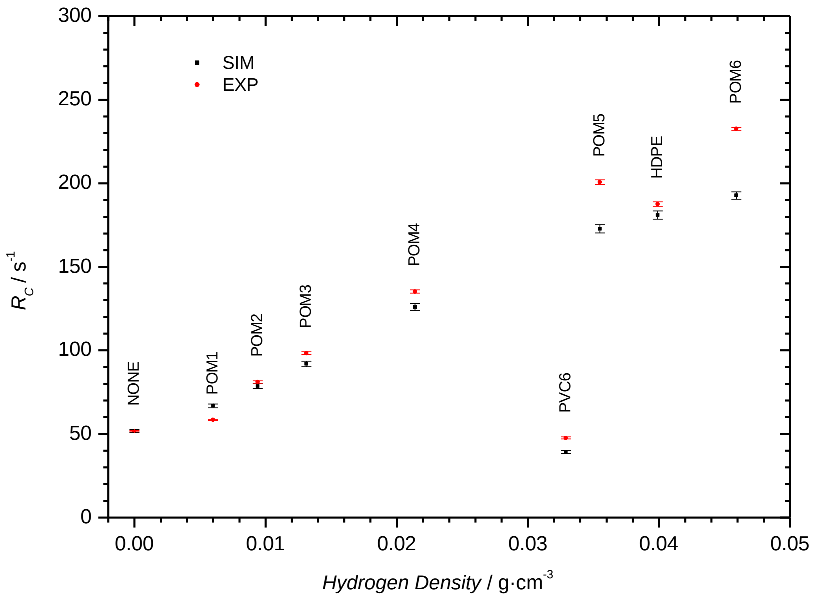

Figure 9. Simulation (SIM) and experimental (EXP) measurement results for an active measurement of a uranium sample for various plastic inserts with differing hydrogen content.

The good agreement between these preliminary measurements and the modelling results for both passive and active modes of operation demonstrate the effectiveness of the modelling and supports the validity of the calibrations subsequently developed using the MCNP model.

MCNP modelling has been used to establish calibration factors for the four types of sample cans and all of the associated measurement positions. This has been done for both passive and active measurements. These include a set of 12 waste containers and matrices to simulate expected waste streams and different size packages. The scope encompasses the range from hard waste (metal) to soft waste and highly moderated waste. MCNP modelling has also been used to design cans and matrices, including fissile sources that were then deployed in the calibration measurements to test and validate the performance of the system.

Table 2. There are four waste matrix types from hard waste - metal M01 (unmoderated) to high plastic content M04 (highly moderated) which are included in the Table.

Matrix	Moderator Content (Hydrogen Density in g/cm^3)	Description
M01	0.0000	Mostly Metal, more than 80% by volume
M02	0.0065	Less than 10% plastic, rest is a mix of paper/wood/metal (under 80% metal by volume)
M03	0.0135	Low plastic (More than 10% but less than 25% of can by volume)
M04	0.0235	High plastic (More than 25% of can by volume)

As a result of this extensive testing, supported by MCNP modelling, the following performance results and characteristics for the upgraded NDA7 Active Neutron Interrogation System at NRS Dounreay were achieved:

- Detection limit Pu-240 effective (g): Hard waste: >0. 031
  Highly moderated waste: > 0.034
  Soft waste: >0.032

- Detection limit U-235 (g): Hard waste: >0.076
  Highly moderated waste: > 0.035
  Soft waste: >0.058

- Measurement range: Total Pu240 effective: 35mg to 20g
  Total Pu (‘O’ Grade) :180mg to 100g
  Uranium-235: 40mg to 20g

The Total Measurement Uncertainty (including the most challenging wastes) for passive measurements is 42.7% and for active measurements, 45.9%. Specific 2 sigma TMU values are listed below:

Passive 9” can (1 position)	34.3%
Passive longer can (2 position)	42.7%
Active 9” can (1 position)	37.7%
Active longer can (2 position)	45.9%

Typical measurement time for a single measurement cycle consisting of a passive and an active measurement is 30 to 50 minutes.

CONCLUSIONS

This project has demonstrated the successful upgrading of a traditional Cf-252 based shuffler system for measuring fissile material, using delayed neutron measurements, to active operation using a D-T neutron generator. A very successful aspect, saving significant procurement time and exceptional cost, was the use of MCNP modelling of the calibration process which avoided the acquisition of new Pu calibration sources.

The upgrade process has, however, experienced some challenges. The main challenge was to obtain from the generator a high enough interrogation flux that was necessary to meet the active measurement time required to achieve the specified measurement uncertainties and MDAs.

With the harder neutron spectrum resulting from employing the D-T generator used to supply the interrogating neutron flux, it was appropriate to deploy a neutron enhancer in the form of a lead annulus surrounding the neutron generator target. The neutron enhancer maximises the neutron flux inside the waste sample by contributing neutrons from (n,2n) reactions. The neutron enhancement was also assisted by the lead which shields the He-3 tubes from the intense gamma rays emitted by the waste. The lead shield also increments the neutron flux in the sample by (n,2n) reactions.

A disadvantage of a harder neutron spectrum resulting from using the D-T generator, as opposed to Cf-252, is that it makes the active assay strongly dependent on the amount of hydrogen (coming from plastics, paper, swipes, etc.) inside the can. To avoid systematic errors larger than 30 %, a minimum of four calibrations is required to cover the entire range of hydrogen densities that may be present in the waste. Another disadvantage is that the sensitivity of the active assay is quite low for hard matrices. This fact when combined with the high background rate of 35 s^{-1} results in larger MDA values. Longer active assay times are necessary using the neutron generator to meet the required minimum MDA levels.

A harder spectrum has also some advantages in that it keeps the response of active assay counts linear with the total fissile (U-235 and Pu) mass. Moreover, it reduces the difference between the signal obtained with the fissile material concentrated in lumps as compared to a relatively homogenously spread over the volume of the can. Another advantage of using a neutron generator is that it can be operated at short intervals, and by interleaving short irradiation and active count intervals, the number of measured delayed neutrons can be increased by a factor of 2.5 with respect to the analysis settings used with a Cf-252 source.

The upgrade retained several major components of the hardware, minimising the cost of materials, waste disposal and disruption to the plant. The refurbishment and upgrade removed electronic obsolescence issues and assured future maintainability. Ultimately, the original system performance was restored enabling the future operational requirements to be met.

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