NDA SYSTEMS USED BY EURATOM AT THE THORP FEED POND

P M Crossman & A S Chesterman
BNFL Instruments Ltd.
Pelham House, Calder Bridge, United Kingdom

P Schwalbach
Commission of the European Communities
Euratom Safeguards Directorate
Luxembourg

ABSTRACT

In the Feed Pond of the Thermal Oxide Reprocessing Plant at Sellafield (UK) fuel assemblies are automatically monitored by the Feed Pond Fuel Monitors using high resolution gamma spectrometry, and passive and active neutron counting techniques. The paper describes the co-operation between Euratom and BNFL in specifying the requirements for an instrument system to allow Euratom to independently obtain the irradiation, cooling time, initial and final enrichments of the fuel assemblies. It also describes the philosophy and design of the instrument system to meet those requirements.

1. INTRODUCTION

Euratom and BNFL worked closely together in defining the proposed way of safeguarding the different NDA stations within the THORP complex. This paper concentrates on one specific NDA station namely the Feed Pond Fuel Monitor. Before describing the philosophy that went into that design and the eventual production of the instrumentation systems for Euratom it is useful to have an overview of the BNFL THORP Feed Pond Fuel Monitors and their operation.

2. THE THORP FEED POND FUEL MONITORS

All fuel entering the Head End of THORP is required to be monitored to ensure that certain parameters conform with the THORP specification.

2.1 REQUIREMENTS

The measurement requirements of the instrument are to measure the :-

- Cooling time
- Irradiation
- Initial Enrichment
- Final Enrichment as % ^{235}U equivalent
- To provide a GO or NO GO signal depending on whether or not the above parameters fall within the limits of acceptable values. If all the parameters fall within the limits of acceptable values then a GO signal is generated. If any are outside the limits then a NO GO signal is generated.

2.2 FUEL PARAMETERS

- LWR fuel irradiation may be up to 40 GWD/Te(U), for which a cooling time of not less than 5 years is required.
- The corresponding figures for AGR fuel are 25 GWD/Te(U) and 3.8 years cooling.
- A (pre-irradiation) initial enrichment of not greater than 4% ^{235}U has been imposed for the THORP baseload fuels.

2.3 REASONS FOR THE MEASUREMENT

The measurements are required to ensure that fuel with parameters outside the THORP specification is not transferred to the Head End shear cave for the first stage of the chemical reprocessing cycle.
The limiting values for these parameters were set to :-

- to limit radiation exposure to the operators and public,
- to limit the magnitude of the fission product inventory and
- to ensure that that the amount of fissile material passing through the plant was within the THORP criticality design limits.

2.4 MONITORING STATIONS

The most suitable location in which to carry out the measurements was identified to be the west end of the Feed Pond, adjacent to the shear cave elevator. For operational requirements, to meet a throughput of 7 Te(U) per day, provision was made for the installation of two fuel handling machines and monitoring stations which can be operated independently and in parallel.

The locations of the monitor stations fulfil two important criteria :-

- they allow access for measurements to take place to individual fuel assemblies or slotted cans after removal from their respective containers, and
- after measurements, fuel assemblies can be returned to their original containers if the results of the measurement indicate that the fuel is outside the specified limits.

A monitoring system was therefore built for THORP to measure the irradiation, cooling time and initial and final enrichments and to communicate the results of these measurements to the Head End Control Computer, HECC. Additionally, a GO or NO GO signal is provided for the Fuel Removal Machine PLC, (FRM).

If a GO signal is generated for the FRM PLC then signals are also sent to the Head End Criticality Safety PLC informing it whether the irradiation and initial enrichments are above or below set limits. The fuel will then be taken to the shear cave elevator.

If a NO GO signal is generated by the FPFM and sent to the FRM PLC then the fuel will be returned to its original container to await further measurements and/or investigation.

2.5 Measurement Technique

Three basic measurement techniques are used to determine the required fuel parameters of cooling time, irradiation and initial enrichments. These involve :-

- the use of High Resolution Gamma Spectroscopy, HRGS, to detect the gamma emission form the fuel,
- the detection of the inherent or 'passive' neutron emission, mainly from ^{244}Cm, and
- the 'active' neutron measurements from fissions induced in the fuel from an external ^{252}Cf neutron source.

Fuel contained in multi-element bottles (MEBs) or AGR containers are transported under water, in racks, to the Feed Pond from Receipt and Storage Pond.

Venting and flushing operations are carried out in the Preparation Area of the Feed Pond and, after positioning in the deep section of the Fuel Removal Pond with the lids removed, individual fuel assemblies or slotted cans are removed by one of the Fuel Removal Machines, FRM.

The FRM transports and 'handles' the fuel between MEBs/containers, the Feed Pond Fuel Monitor station, and the fuel carrier on the inclined elevator to the Shear Cave.

There are two Feed Pond Fuel Monitor stations, each serviced by its own FRM, these are referred to as the East and West stations respectively. Each FRM is controlled by its own PLC.
Each of the two Feed Pond Fuel Monitor stations is connected to a THORP Feed Pond Fuel Monitor, (instrumentation system).

To carryout measurements, the fuel is brought to the monitor station by a Fuel Removal Machine and centred on the vertical axis through the measurement position.

At each measurement height, up to 4, the fuel is continuously rotated back and forth through $\approx 400^o$ during the measurement cycle. During the central 360^o of the cycle, where the assembly is rotating at a constant speed, both neutron and gamma measurements are taken.

Following measurements at each selected height the local values of cooling time, irradiation, initial and final enrichments are calculated.

After completion of all measurements on the fuel assembly the weighted average cooling time, irradiation, initial and final enrichment values are calculated as well as a GO or NO GO signal.

2.6 Instrument System Description

Each THORP FPFM consists of a high purity LN_2 cooled germanium detector, and five fission chamber type neutron detectors.

The five neutron detectors are split into two different modules, one containing three detectors and the other containing two. The two modules are arranged such that they are at 90^o to each other.

A neutron source transfer system, controlled by the FPFM, is used to control the exposure of a ^{252}Cf source to enable active neutron counting measurements to be made when the source is exposed and passive neutron measurements when the source is retracted to its shielded position. The ^{252}Cf source is exposed in a position directly opposite the three detector module, as shown in Figure 1.

The separation of the three detector module and the source module as well as that of the two detector module and monitoring position is adjustable to allow the measurement of a range of fuel sizes.

A gamma standardisation source actuator, controlled by the FPFM, is used to control the exposure of a ^{137}Cs and ^{134}Cs source which is used for standardisation of the system at regular intervals.

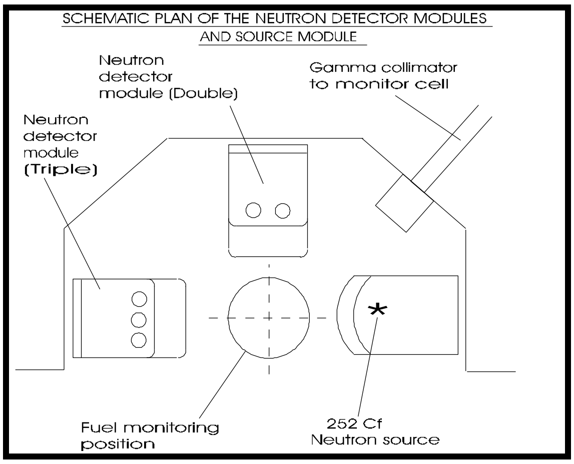


Figure 1

The germanium detector is connected to a set of front end electronics comprising of an EHT power supply, gated integrator amplifier, which amplifies and integrates the signal from the detector and sends the resulting signal to an analogue to digital converter, ADC. The digital signal from the ADC is then fed to a loss free counting module, LFC, for deadtime correction and then to a multi-channel analyser connected to the Ethernet.

Each of the fission chamber detectors is connected to an amplifier/discriminator. The output from these amplifiers is then converted to digital TTL pulses which are fed into counter and timer cards in a VME computer system.

The data processing electronics for each THORP FPFM consists of two processor systems. Preliminary data processing for the neutron counting system is performed by a VME computer system and the rest by a MicroVAX.

The MicroVAX receives instructions from the FRM PLC, through a parallel I/O interface, to start and stop measurements in phase with rotation of the fuel. This interface is also used for the communication of the GO/NO GO signal to the FRM PLC. The measurement results are communicated to the HECC over a serial data link.

The MicroVAX also communicates with three other systems; (i) the VME computer via a serial data link to control the acquisition of neutron pulses by that system, (ii) the MCA module via an Ethernet link to control the acquisition of gamma pulses and (iii) the HECC Criticality Safety PLC via a parallel I/O interface. The MicroVax also provides a data logging facility for both neutron and gamma data and an operator interface for maintenance operations.

2.7 Sequence of Operation

Prior to measurements on a fuel assembly the instrument system automatically STAND-ARDISES by exposing a $^{137}Cs/^{134}Cs$ source in front of the gamma detector and a ^{252}Cf source in front of the neutron detectors. The purpose of this phase of the measurement is to establish that the neutron and gamma detectors, and their associated electronics are functioning correctly and to allow a gamma energy calibration to take place. This phase of operation also checks that the positioning of the neutron detectors is correct for the type of fuel the monitor has been set up to handle and establishes that the counting channel efficiency is unchanged from the time of its reference determination. By retracting the sources a background spectrum can be acquired by the gamma detector and the neutron detector background countrates can be determined for use during the measurement phase.

The purpose of the MEASUREMENT phase is to determine the cooling time, irradiation, initial and final enrichments at a number of vertical positions along the fuel assembly. The number of vertical positions at which measurements are taken is determined by the fuel type code for which the monitor has been set up. Having calculated these parameters at each vertical position the assembly average values of the irradiation, cooling time and initial and final enrichments are calculated.

3. DESIGN CONSIDERATIONS

To provide safeguarding of the THORP Feed Pond it was essential that the design of the safeguards data logging facility, comprising the Euratom Feed Pond Fuel Monitors and the Euratom Neutron Logging System, adhered to a set of principles specified by Euratom. These are as outlined below :-

3.1 Installation

- **The raw data should be logged in the vicinity of the detector systems.**

A number of possible solutions to this principle were considered including the use of a second output from the THORP HRGS detectors. The final decision was to utilise the second set of outputs from the neutron amplifiers, for the fission chamber signals and for the THORP FPFM to transmit data files, containing the HRGS spectrum that it acquired, over the Ethernet to the Euratom FPFM.

- **Visual inspection of cables and other equipment should be possible, and**
- **Signal branching to take place in a visible, sealed, local distribution box.**

Both of these principles were adhered to in the installation of the cables from the THORP equipment and the Euratom equipment.

- **The position of neutron detectors and sources to be sealed so that the configuration remains unchanged after calibration.**

This principle was more difficult to adhere to as the position of the neutron detectors is variable and dependent upon the type/size of fuel assembly being measured. However the neutron and standardisation sources have been sealed in position by Euratom inspectors.

3.2 Functionality

- **The software should duplicate that used in the BNFL instrument.**

Whilst it is not 100% possible to use the same software in the Euratom FPFM as the THORP FPFM, since the THORP instrument interfaces with the plant, the principle was adopted in that the functions and procedures which carry out the calculations in the Euratom system are the same as those used by the THORP instrument.

- **Comparisons between the results produced by the BNFL instrument and those produced by the Euratom equipment should be possible.**

This principle has been adhered to by a number of methods. Firstly , as stated above, the same software algorithms are used for the calculations on both the Euratom and THORP FPFM systems. Secondly, maintenance mode facilities are provided on the Euratom system to allow inspectors to compare the BNFL declared results and the Euratom calculated results for a fuel assembly, any differences being automatically highlighted. Thirdly, the Euratom instrument receives the spectral data file including the calibration constants and other system constants used by the BNFL instrument. Inspectors can then compare the constants in use on both systems, any differences being automatically displayed on the screen.

- **All logged data to be time and date stamped.**

This principle has been adhered to, all the MicroVAX spectral data files have a filename comprising of the time and date at which the acquisition of the data took place and secondly for the purposes of the neutron logging system the Rustrak data logger time dates stamps all of the incoming data.

- **The safeguards system should not interact with any plant control systems.**

This is very important, as it removes any potential conflicts between BNFL and Euratom equipment, and simplifies the design of the interfaces to the Euratom equipment. It also removes the potential for the Euratom equipment to impact detrimentally on the throughput of the plant.

3.3 Security issues

A number of features have been included within the Euratom instrument system and its design to provide the level of security required by Euratom for their instrument systems and the data they use.

Firstly, Euratom hold the source code used by the Euratom FPFM instrument system, this provides the potential for them to check all algorithms and software to ensure it has not been modified since commissioning.

Secondly the cubicles containing the Euratom FPFM and ENLS can be locked by Euratom hence ensuring their security.

As discussed previously the sources are sealed in position and the cabling runs are all visible both of which ensure that any tampering is obvious to the inspectors.

The password and in built security features of the VMS operating system in the case of the MicroVAX and OS-9 in the case of the VME computers are utilised to prevent unauthorised access to these computer systems.

3.4 Authentication

- **Measurement data and detector signals should be verifiable by the use of standard sources.**

- **Euratom should participate in instrument calibration, re-calibration and any software modifications.**

This principle has been adhered to by Euratom inspectors witnessing measurements on real fuel assemblies and participating in the calibrations of the THORP Feed Pond Fuel Monitors.

3.5 DETAILED FUNCTIONALITY

Consideration of the Euratom guidelines by BNFL resulted in a number of design proposals for the safeguards system. The functionality of this system was discussed extensively with Euratom and some important functional details were agreed.

- Actual signal/ data branch points for both the neutron and HRGS data.
- That results from the two systems would be comparable but not identical.
- The method of data storage and future off line recalculation of results.
- That only gross neutron counts required local direct logging.
- A journal of recent results giving the fuel assembly identification number and the calculated values of the irradiation, cooling time, initial and final enrichments would be maintained on the Euratom MicroVAX so that a summary report could be viewed or printed.
- A list of data sets to be sent from the THORP FPFMs to the Euratom FPFM was discussed and agreement reached on the following data sets :-

⇒ Up to four gamma spectra, one for each vertical measurement position.

⇒ Up to four sets of active and passive neutron countrate results, one set per vertical position. Each set comprising of five individual countrates, one per fission chamber detector.

⇒ The standardisation source gamma spectrum, background gamma spectrum and the five active and passive neutron countrates obtained prior to the fuel assembly measurement.

⇒ Fuel assembly identification data.

⇒ The BNFL calculated results for the cooling time, irradiation, initial and final enrichments for each vertical position and the assembly average results for these parameters.

⇒ The energy and full width at half maximum calibrations for the gamma system.

⇒ Additionally all maintainable constants on the THORP FPFM are sent to the Euratom FPFM.

Following agreement on these points a User Requirement Specification, URS, was written by BNFL Instruments Ltd. and the URS was then accepted by the customer.

4. THE EURATOM FEED POND FUEL MONITOR INSTRUMENTATION

This title is used to describe the two different instrument systems built for Euratom these are :-

- the Euratom Feed Pond Fuel Monitors, and
- the Euratom Neutron Logging System

The Euratom instrumentation is located in two separate rooms on THORP, one room is close to the east side of the feed pond and the other close to the west side. Each equipment room houses one Euratom Feed Pond Fuel Monitor and one Euratom Neutron Logging System. The Euratom equipment is deliberately separate from the THORP FPFMs to give the Euratom equipment maximum independence.

The two different types of instrument system are described below.

4.1 EURATOM NEUTRON LOGGING SYSTEMS

The Euratom Neutron Logging System, ENLS, automatically logs the gross neutron counts so that an indication of the presence or absence of fuel at the monitoring station can be determined. There is no synchronisation of the neutron logging with fuel position or rotation, however the data acquired is time date stamped by a Rustrak Ranger data logger. This enables a quantitative comparison to be made between the data acquired from the Euratom FPFM (MicroVAX) and the Euratom Neutron Logging System. Sufficient data storage is provided to allow for 10 days of unattended operation.

The ENLS system utilises the second set of outputs from the THORP FPFM neutron amplifiers and feeds them to level converters which convert the neutron pulses from the amplifiers into TTL signals. These signals are then counted by a VME computer system which calculates the average gross neutron countrate, over the given sampling period, and converts the calculated countrate to a d.c output voltage using a Digital to Analogue Converter. The output from the DAC is fed to the Rustrak Ranger data logger. The choice of data logger was made by Euratom, as being an item of equipment with which they were familiar and which is compatible with other logging systems used by Euratom.

4.2 EURATOM FEED POND FUEL MONITORS

In contrast to the ENLS systems the EFPFMs operate on specific data files collected by the THORP FPFM during its standardisation, background and measurement phases.

The data for the Euratom Feed Pond Fuel Monitors is taken as early in the processing train as possible. The THORP FPFM transfers the raw spectral data including the neutron countrates and raw gamma spectrum in a file over the Ethernet link and places them in a specific directory on the Euratom FPFM MicroVAX hard disc. From there the files are automatically copied to two different directories. One copy of the files is placed in a 'BNFL' directory and the other in a 'WORKING' directory.

A 'MAIN_LOOP' process on the Euratom FPFM takes the files from the 'WORKING' directory and carries out the required calculations on them and saves the results back into the spectral data file. The type of calculation carried out on a file is determined by the filename prefix letter which dictates if the file is a background, standardisation or measurement file.

The file then has the first character of its filename changed to differentiate between the Euratom spectral data file and the BNFL spectral data file. The file is then saved to the 'EURATOM' directory on the hard disc.

From a diagnostics program on the Euratom FPFM it is possible to print out the results calculated by BNFL and held in the BNFL file and also the Euratom results held in the Euratom file. It is also possible to print out the differences (if any) between them.

As soon as a complete fuel assembly's files have been analysed the files relating to this assembly are removed from the MicroVAX hard disc and transferred onto a removable optical disc.

Additionally as the files for each assembly are processed a history file is appended detailing the fuel assembly serial number, time and date, irradiation, cooling time and enrichment.

The calculations carried out by the Euratom Feed Pond Fuel Monitor instrument are described in the following sections, the standardisation routine encompasses both background and standardisation source measurements.

4.3 STANDARDISATION ROUTINE

The purpose of the standardisation check phase on the THORP FPFM is to establish that the detectors, (gamma and neutron), and associated electronics are functioning correctly and to allow an energy calibration to take place. This phase also checks that the positioning of the neutron detectors is correct for the type of fuel the monitor has been set up to handle. It also establishes that the counting channel efficiency is unchanged from the time of its determination.

The purpose of this phase on the Euratom FPFM is to enable an energy calibration to take place and to calculate the Euratom results from the raw data held within the background and standardisation spectral data files. The calculations are carried out using the values of maintainable constants held on the Euratom FPFM.

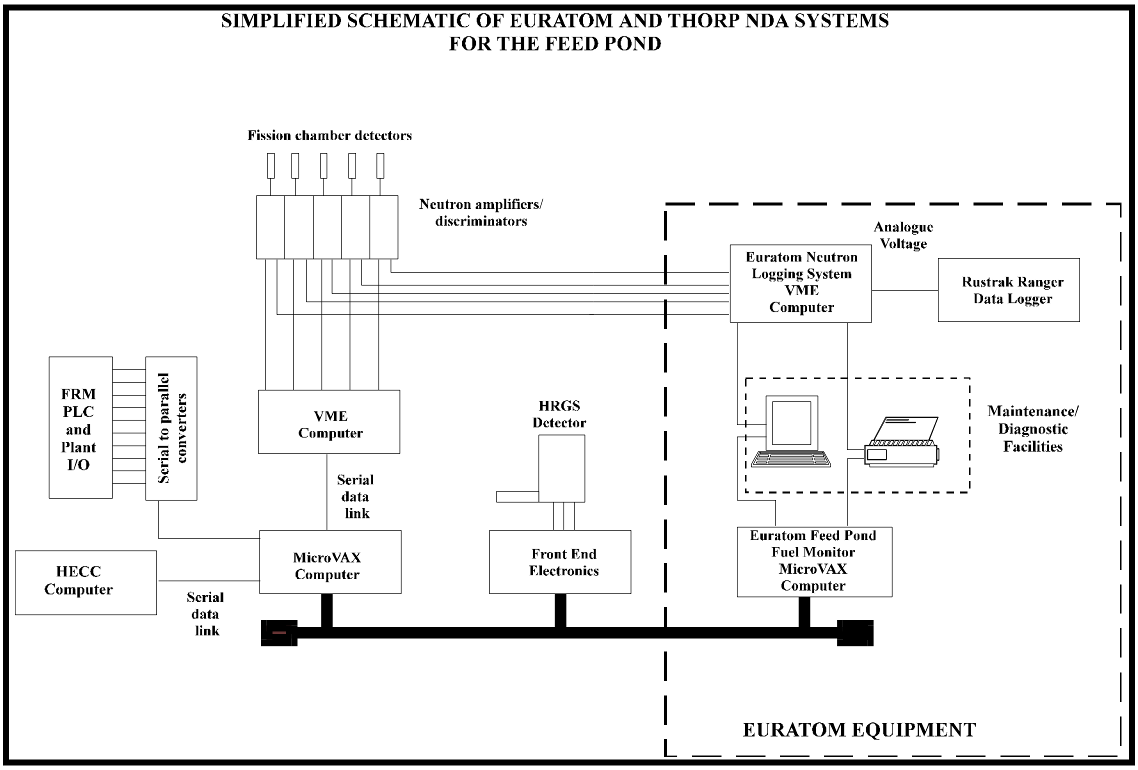
Entry to this phase occurs when the 'MAIN_LOOP' process has determined that it has all the spectral data files relating to the fuel assembly.

The standardisation and background spectral data files are opened.

The energy and FWHM calibrations are read from the standardisation spectral data file. (Note these are the BNFL energy calibrations and are used as a starting point for the Euratom calibration. This is done in order to prevent an amplifier change on THORP from affecting the Euratom processing.)

Both standardisation and background spectral data files are then peak searched. The nett peak areas are then determined by background correction of the standardisation source peaks. Any remaining peaks whose errors are greater than a reject threshold are deleted as being insignificant. The peak reject threshold is a maintainable constant on the Euratom FPFM. Any peaks other than the six required for the standardisation are also rejected.

If any of the six peaks required for standardisation are not found then the normal sequence of events is abandoned. If all of the six peaks are found then the background corrected nett peak countrates are decay corrected to account for the fact that the gamma standardisation source will have decayed since the determination of its reference value. (Note the gamma source installation time is read from the background spectral data file. This is the BNFL declared source installation time. This is done to prevent a change of gamma source from affecting the Euratom processing.) These decay corrected values are then checked to see if they are within the limits defined for each peak. These are the Euratom limits which are held as maintainable constants on the Euratom FPFM.



If any of the detected peaks do not pass this test then a Boolean alert flag is set.

An energy and FWHM calibration are then carried out. The resulting Chi² value is then tested against a reference limit. The reference limit is the Euratom value as held as a maintainable constant on the Euratom FPFM. If this test fails then a Boolean alert flag is set.

A test is then carried out on the FWHM of the ^{137}Cs 662 keV line by comparing it against a reference limit. The reference limit is the Euratom value as held as a maintainable constant on the Euratom FPFM. If this test fails then a Boolean alert flag is set.

The coefficients of the relative efficiency curve are then calculated from the ^{134}Cs photopeak countrates. The calculated coefficients are then used to check that the efficiency has not changed since the gamma detection system was set up manually during commissioning. This is done by comparison of a number of photopeak relative efficiencies against a set of reference values. The reference values are the Euratom values held as maintainable constants on the Euratom FPFM. If this test fails then a Boolean alert flag is set.

The raw passive and active neutron counts for each of the five fission chamber detectors are read from the background spectral data file.

The passive and active countrates and their associated errors are then calculated.

For each of the detectors the measured background countrate is checked against an upper countrate limit. The countrate limit is a Euratom value held as a maintainable constant on the Euratom FPFM.
If any of the countrates are greater than this limit then a Boolean alert flag is set.

The nett countrates are then decay corrected to account for the fact that the neutron source will have decayed since the determination of its reference value. (Note that the neutron source installation time is read from the background spectral data file. This is the BNFL declared source installation time. This is done to prevent a change of neutron source from affecting the Euratom processing.)

The nett decay corrected countrate for each fission chamber detector is then checked against its own reference limit for the fuel type in use.

If all the nett decay corrected countrates are greater than their corresponding reference limits then this could indicate that fuel may have been in the monitor during the standardisation. If this test fails then a Boolean alert flag is set.

If only one or more of the detectors nett decay corrected countrates are greater than the corresponding reference limits then this could indicate that there was a standardisation fault on that/those detectors. If this test fails then a Boolean alert flag is set.
Using a test fuel spectrum and associated neutron countrates and errors, derived during commissioning, the cooling time, irradiation initial and final enrichment values are calculated. The calculated values are then checked to see that they fall within an upper and lower limit. The upper and lower limits are the Euratom reference values as held as maintainable constants on the Euratom FPFM. If this test fails then a Boolean alert flag is set.

4.4 Measurement Routine

The purpose of the measurement phase is to determine the cooling time, irradiation initial and final enrichments of the fuel at a number of vertical positions along the fuel assembly. The number of vertical positions at which measurements are taken is determined by the fuel type code for which the monitor was set up.

The software sets the vertical position counter to 1.

The measurement spectral data file relating to the current vertical position counter is opened. The live time and real time are then read from the spectral data file, the deadtime calculated and tested against an upper limit held as a maintainable constant on the Euratom FPFM. If the deadtime exceeds this limit then a Boolean alert flag is set.

The local irradiation, cooling time, initial and final enrichments are calculated for the current vertical position, using the values for maintainable constants as held on the Euratom FPFM. This is detailed in Section 4.5.

The calculated results as well as the Euratom maintainable constants used are written to the measurement spectral data file.

The vertical position counter is incremented.

The above process is repeated for each of the vertical positions at which that the fuel assembly was monitored. These are referred to as the local results

The weighted mean cooling time and initial enrichment are determined from the local values.

The local irradiation values are then adjusted to the corresponding average assembly value, using the irradiation profile data stored as maintainable constants on the Euratom FPFM.

The assembly weighted average irradiation is then calculated.

The assembly average final enrichment is then determined from the assembly average irradiation and initial enrichment, using the values of maintainable constants held on the Euratom FPFM.

The mean irradiation, cooling time and initial enrichment are then checked against the respective limit of acceptable values, as held on the Euratom FPFM. If any of the limits are exceeded then a NO GO status is saved to the spectral data file else a GO status is saved.

The history file is then appended with the fuel assembly serial number, time and date, irradiation, cooling time and enrichment. If any of the Boolean alert flags were set during the analyses then an asterisk is placed alongside the results for that fuel assembly in the history file. This highlights to the Euratom inspectors that a fuel assembly has been analysed which should not have passed the BNFL declared measurement parameters.

4.5 Calculation of Local Results

The measurement spectral data file is peak searched and the nett peak areas and countrates are then determined by background correction of the measurement spectrum peaks by utilising the background data obtained at the last standardisation. Any remaining peaks whose countrates are insignificant after this background correction are rejected. Any peaks in the spectrum other then the 18 required for the measurement calculations are also rejected.

The minimum requirement to indicate that a fuel assembly is present is that the ^{137}Cs 662keV line should be found. A test is carried out to see if the 662keV limit is above a certain threshold. If it isn't then a Boolean alert flag is set.

A test is then carried out to determine if the ^{134}Cs photopeak at 1365keV is present. If it isn't then default values are used for the coefficients of the efficiency curve. If the line is present then they are calculated from the ^{134}Cs photopeaks.

The relative activities of all the isotopes of interest are then determined.

The cooling time is then calculated from the $^{134}Cs/^{154}Eu$ activity ratio.

A test is then carried out to see if there is significant ^{106}Ru activity.
If there isn't then only the $^{134}Cs/^{154}Eu$ values are used to determine the cooling time. Otherwise a second cooling time is calculated from the $^{106}Ru/^{137}Cs$ activity ratio and the weighted average of the two are used for that measurement position.

If there is an absence of measurable quantities of both ^{106}Ru and ^{134}Cs then a default cooling time is used, provisionally set to 15 years.

The zero cooled value of the ^{137}Cs photopeak countrate is then determined. The irradiation is then calculated from the zero-cooled ^{137}Cs isotope's countrate. The passive neutron countrate is also adjusted to its zero cooled value.

The initial enrichment is then set to a default value appropriate to the fuel type in use and the following calculations iterated twice :-

The irradiation is determined from the passive neutron measurements.

If there is not significant ^{106}Ru activity as tested for previously then the irradiation is calculated from the ^{137}Cs and the passive neutron results. Otherwise a further irradiation is calculated from the $(^{106}Ru * {}^{137}Cs)/(^{134}Cs)^2$ activity ratio and the weighted mean irradiation is then calculated from all three of the above techniques.

The percentage ^{235}U equivalent final enrichment is then calculated from the neutron multiplication via the active neutron measurements and the measured irradiation.

The initial enrichment is subsequently calculated from the final enrichment and irradiation in conjunction with a FISPIN* relationship between fissile material burnup and irradiation.

* FISPIN is a computer code used to provide isotopic inventory data as a function of reactor type and irradiation history.

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7. SUMMARY

The control and safety of operations in BNFL's THORP plant at Sellafield has been ensured by the installation of a comprehensive array of instrumentation, much of which has been specifically developed to achieve the required accuracy and specificity. At specific measurement points, Euratom have worked closely with BNFL Instruments Ltd, the designers of the special instrumentation, to provide a measurement capability compatible with the needs and standards of the safeguards authority.

In the Feed Pond area, fuel assemblies are automatically monitored for operational purposes as well as for safeguards reasons. High resolution gamma spectroscopy, passive and active neutron counting techniques are applied. These techniques allow the cooling time, irradiation and initial and final enrichment to be calculated. Dependent on whether or not these parameters fall within operationally acceptable limits, a GO/NO GO signal is generated. This signal is used to determine if the fuel assembly should pass to the next stage of reprocessing i.e. the shear cave, or be returned to its original container in the pond to await further measurements and investigation.

Euratom and BNFL worked together in defining the specification for the Euratom Feed Pond Fuel Monitor, (FPFM). The paper describes the design of an instrument system for safeguards purposes. The system allows Euratom to independently determine the parameters of cooling time, irradiation, initial and final enrichments from the raw data. The system automatically also logs the BNFL raw data and the results calculated by the operator's FPFM. Any differences between the Euratom and BNFL results are automatically flagged in the log report produced by the Euratom FPFM. When Euratom inspectors examine the log report they can select any fuel assembly's raw data files, reanalyse them and determine the source of any discrepancy between the BNFL measured results and the results obtained by the Euratom FPFM.

A second Euratom Instrument system using a second set of outputs from the neutron amplifiers automatically logs the average neutron count rate from the five neutron detectors which form part of the BNFL FPFM. This instrument allows the Euratom inspectors to detect all fuel assemblies which are presented to the FPFM and allows a check of the consistency of recorded measurements with activities in the Feed Pond.