FEMOS - Advanced Neutron Monitor System for Waste Management

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ABSTRACT

FEMOS is a specially developed monitor to detect fissile materials for waste characterisation and it is also suitable to identify the main neutron emitters. The latest measuring prototype is in routine operation at FZK-HDB (Germany) for determining Plutonium content and alpha activity in 200l and 400l drums from the reprocessing plant Karlsruhe (WAK). Authorities license the measurement procedure. Routine measurements conducted over a period of about 6 years and the results show that all specified prerequisites are met with the required reliability.

INTRODUCTION

The former reprocessing plant Karlsruhe (WAK, Wiederaufarbeitungsanlage Karlsruhe) is since several years in the phase of decommissioning. The radioactive waste to be handled during decommissioning contains fissile material in addition to beta and gamma radioactivity. This material must be analysed and quantified before conditioning and transportation to interim and/or final storage. The drums with raw waste are transported from WAK to the waste treatment facility (HDB, Hauptabteilung Dekontaminationsbetriebe) of the research center Karlsruhe (FZK) for treatment, product control and analysis. A high gamma radiation field must be considered when performing the measurements. For the waste characterisation a sensitivity of 10 mg/Pu-eff. is required for 200 or 400 l drums filled with raw waste, containing up to 100g Pu. The expected gamma flux can be as high as 1 Sv/h at the drum surface. New measuring components were developed for the operation in such a high gamma field. The drum measuring device is an advanced application of the monitor system FEMOS which was developed in co-operation between FZK and RWE Nukem GmbH [1-3]. FEMOS is a specially developed monitor (Fig. 1) to detect fissile materials for waste characterisation and it is also suitable to identify the main neutron emitters.

Fig. 1. Monitor FEMOS

WASTE CHARACTERISATION BY FEMOS

The waste characterisation by monitor FEMOS is based on the alpha activity and spontaneous fission of fissile material.

The main uranium and transuranium elements (i.e. Pu,Cm) are alpha emitters.

The alpha particles are stopped in the package walls and therefore it is not possible to measure the alpha emission without opening the packages. The opening of packages helps only in limited way because the distribution inside the waste matrix is not homogenous and the self absorption in the matrix is very strong.

These problems are overcome by using the neutron emission of the waste. There are two origins of the neutrons: part of them come from spontaneous or induced fission process, which is restricted to the main alpha emitter. The other part of emitted neutrons originate from alpha,n processes at light elements (normally dominated by Oxygen).

Therefore the neutron emission is directly related to the existence of alpha emitters.

Measuring the neutron emission reduces the problem of total alpha activity content to the relationship between neutron emission and alpha activity.

There are different ways to determine this relationship:

- taking samples from the waste and measuring the ratio between neutrons and alpha activity
- using extended computer codes to calculate the ratio. These codes need the original isotope composition including the time, at which the composition was measured
- for waste from nuclear fuel elements the initial fuel composition is well defined. In this case burn up program codes can be used to find the isotope composition at a given time after the burn up process. The computing code must take into account the reactor type where the fuel was used.

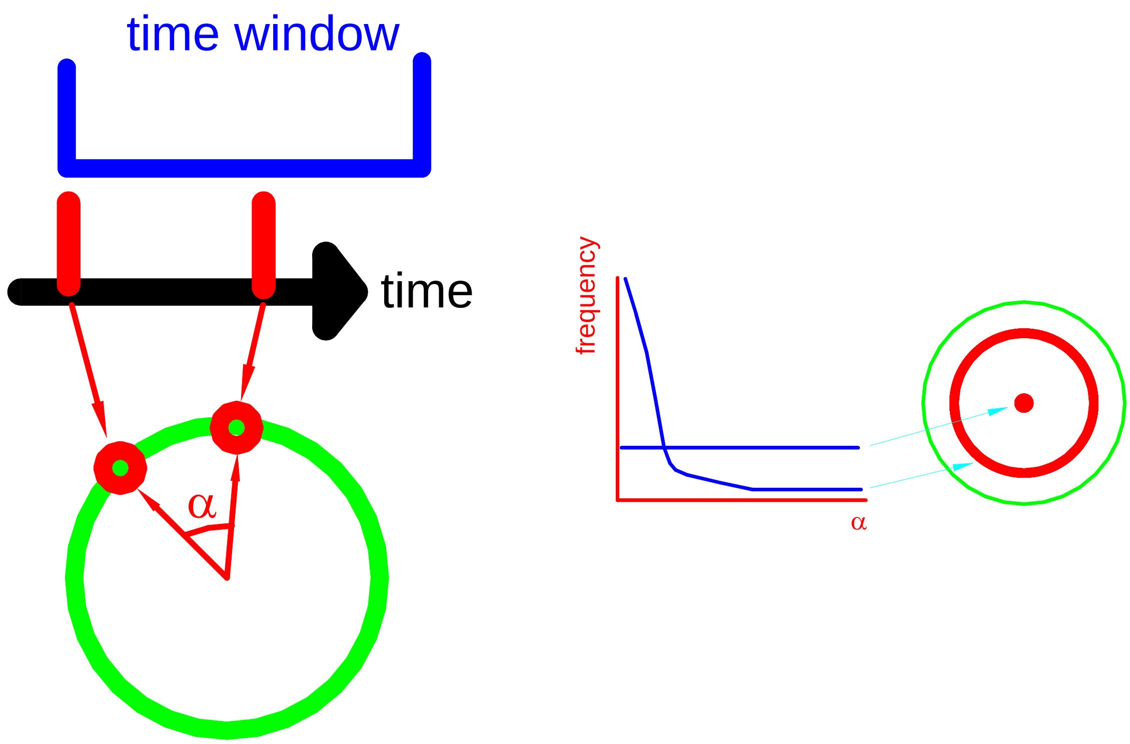
The FEMOS monitor was build to measure the emitted neutrons for alpha activity determination. The monitor itself is presented in the next chapters including a specific technique to identify some of the isotopes of interest.

MEASUREMENT METHOD

The method implemented in the FEMOS device is the so-called non-destructive assay (NDA). This measurement method is based on neutron monitoring by arrangement of neutron counter tubes around the drum filled with waste.

Additional information to the total count rate is gathered using a special data processing by the advanced TCA/LCA system (Time Correlation Analysis, Local Correlation Analysis). This system records the events as measured by the neutron counters together with the time of occurrence and the number of the counter tube and store these information on a hard disk.

For calculating the quantity of the fissile material from the measured total count rate a lot of additional information is required, i.e. the matrix composition, the distribution of the sources inside the drum, in addition to the composition of the neutron emitters. In general, this information is not available in detail when the system is working in a routine operation. The LCA is based on the correlation between the positions of the detectors, which have counted a neutron. The principle is presented in Fig. 2.



[1]Fig. 2. Principle of LCA

By applying the advanced LCA technique a higher accuracy can be yielded guaranteeing the required high sensitivity.

The TCA system is developed to analyse the process from which the neutrons are emitted. The neutrons from alpha,n processes are randomly distributed over the time. But neutrons from spontaneous fission processes are correlated, because there are in the average more than one neutron per reaction emitted. As a consequence of the slowing down of the neutrons inside the moderator material before they can be counted by the counting tubes, this original correlation is weaken and a high sophisticated analysis is required.

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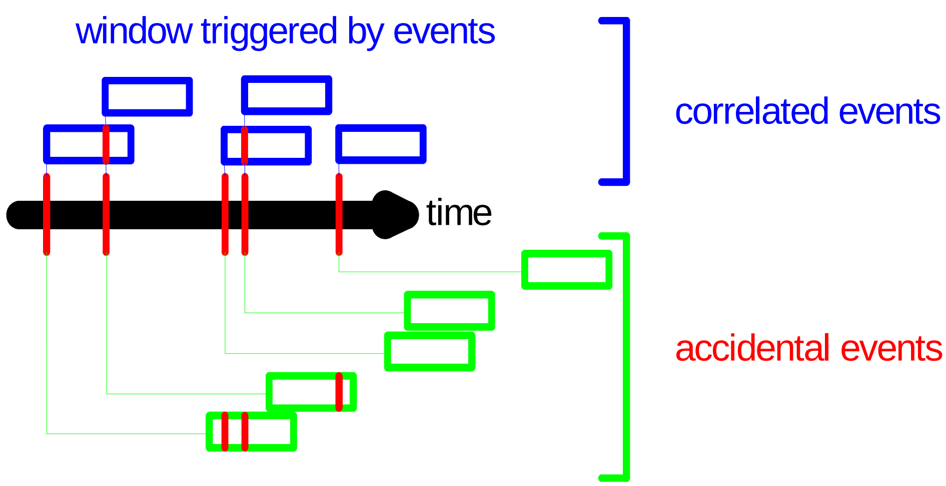
[1] If a counter counts an event, a time window is opened and the system waits for the next event. If this event is inside of the time window, the angle between the counter of the original event and the counter of the succeeding event is calculated. (left side)

For a source distribution in the middle of a drum and for a distribution which looks like a symmetric ring the counting frequency is shown as a function of the angle between the counters which have counted (right side). In the first case there is a constant value for the frequency as a function of the angle whereas in the second case there is a peak for small angles.

The principle of the correlation analysis based on the shift register method is presented in the Fig. 3.



[2]Fig .3Shift register method

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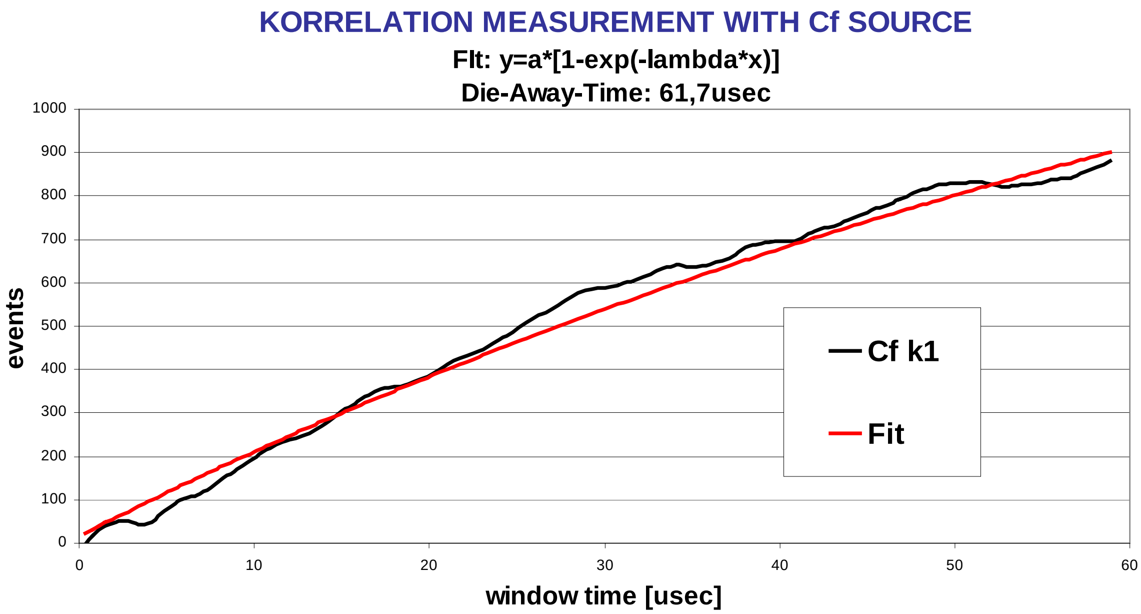
[2] In the shift register analysis a time window is opened if an event is counted. If during the life time of a time window another event appears, this event is counted as a correlated event. The accidental events which may also be counted as correlated events have to be subtracted at the end of the analysis. They are measured with windows randomly distributed in time or by shifting with a fixed time constant from the time of the starting event.

In the first step of the analysis, the neutrons from (alpha, n) processes are separated from the neutrons of spontaneous fission. In the next step, the number of neutrons per fission is evaluated to distinguish between Plutonium and Curium which are the main neutron emitters.

The die away time, which can be directly measured by the correlation technique as shown in Fig. 4, is a device constant, which describes how long a neutron is captured by the moderator material before it can escape. When the die away time is longer, the detection efficiency for the neutron is higher. But, a very long die away time makes the time correlation measurement worse because the number of accidental coincidences is enhanced. Therefore the FEMOS device is designed to optimise both effects: to have a high efficiency for neutron detection and a good correlation resolution.

The shift registration method is used as a measuring technique[4] to make a separation between neutrons from (alpha, n) and from spontaneous fission processes. For waste containing combustible material, approximations are based on described standard measurement methods and the techniques are proven to be sufficient. However, for waste drums filled with conditioned waste, heterogeneities of neutron emitters and higher uncertainties must be considered. Due to this situation, it is extremely important to exactly locate the source since the system responds rather sensitively to the dislocation of the source. The problem is more relevant when the matrix density increases.

To localise the source position, the variation in the counting rates of the detectors is used. However, this method of neutron radiography cannot be applied when the source is symmetrically distributed in respect to the drum axis. With the so-called LCA system different symmetric distributions can be distinguished especially when the source is located in the centre of the drum and/or homogenously distributed. This system combines the time correlation of the events and the multiplicity coincidence determination.



[3]Fig. 4. Die-Away-Time measurement by correlation analysis

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[3] The diagram shows the number of events as a function of the windows length as explained in Fig. 3 The value ln(2)/lambda is the so called the Die-Away-Time. The value characterizes the time of neutron moving inside the moderator until it is detected by the neutron counting tubes.

Summarising, the TCA/LCA measuring device has the following features and application possibilities:

Basic Features

* equivalent efficiency of each channel (counter)
* variable threshold adjustment
* discrimination of burst effects
* location of the probe; no restriction with respect to the source position
* neutron die-away-time in only one measurement
* variable triggering in coincident measurement
* TCA (time correlation analysis) for each spot

Applications

* waste package characterization
* fissile balance
* coincidence measurement
* multiplett analysis
* time correlation analysis (TCA)

DESIGN OF THE MONITORING SYSTEM

The detector head consists of a polyethylene cylinder in which the neutron detectors are embedded. To achieve a high sensitivity in a short measurement time, 60 He-3 tubes are integrated in the device as neutron detectors. High efficiency is necessary to fulfil the requirements for location and time correlation analysis.

Special He-3 tubes are used as neutron detectors including special adapted electronics. The measurement demonstrates that the neutron count rate can be detected in the presence of a gamma field up to 1 Sv/h at the drum surface, guaranteeing a measuring sensitivity of 10 mg Pu-eff.

Each detector has its own electronics and data evaluation system. The surveillance is controlled by PC. The count rates of each measuring channel are separately entered into the LCA data evaluation system.

The complex measuring technique is based on industrial standard equipment consisting of drum handling system, drum transport system and neutron measuring system. The waste drum is operated by a crane. The drum size of 200l or 400l is automatically confined by light barriers.

The drum handling system is controlled by a PLC. The commands for PLC are coming from the PC, where the operators program is running.

After data acquisition and analysis all results are stored into a data base.

Offline data analysis is possible, i.e. to check different waste matrices etc.

A protocol print out of the measurement and the results can be perfotmed on demand.

CONCLUSION

The latest measuring prototype is in routine operation at FZK-HDB for determining Plutonium content and alpha activity in 200l and 400l drums from the reprocessing plant Karlsruhe (WAK). The measurement procedure is licensed by the authorities. Routine measurements conducted over a period of about 6 years and the results show that all specified prerequisites are met with the required reliability.

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