MEASUREMENT SYSTEMS FOR NUCLEAR FUEL CYCLE

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ABSTRACT

Measurement systems have to be implemented to monitor the radioactive inventory beginning with the construction and ending with the decommissioning of nuclear power plants. To limit the number of measurement systems presented in this paper, the in-core instrumentation of reactors is excluded.

NUKEM has developed several measurement systems (monitors), based on the experience, covering the full range of application and nearly every measurement (monitoring) task of the nuclear fuel cycle.

The monitors are designed to measure the emission of radiation as alpha, beta and gamma or the neutron particles. The intensity range begins with very low intensities like by free release of waste and ends with very high intensities as in the case of burned-up fuel elements. Therefore, the techniques for handling of radioactive material have to be taken into account by designing of the monitors.

INTRODUCTION

The radioactive inventory has to be controlled inside the plant, as well as the possible spreading outside the plant from the construction till the decommissioning of nuclear power plants. The goal is to start with a clean area and to end also with clean area with no restriction for further use.

The radioactive material entering the plant consists of only few Uranium isotopes like U-235 or U-238. During the plant operation additional isotopes are produced which have also to be observed (i.e., measured).

The radioactive material can be divided into different classes according to its activity, half-life time, spreading behaviour, danger for humans and biosphere etc. Because the focus of this paper are monitors, they are divided into intermediate and low activity waste monitors, very low waste and free release monitors and monitors for fuel elements.

At the beginning of the fuel cycle only the Uranium isotopes (i.e., mainly U-235 and U-238) are present. During the plant exploitation additional isotopes are appearing due to nuclear processes. Some of these isotopes emit high radioactivity because of short half-life. To cover all these intensities from very low to very high (like burn-up of nuclear fuel elements) the techniques in handling of radioactive material are an important aspect for designing of the monitors.

MONITORS

DRUM MONITORS FOR LOW AND INTERMEDIATE ACTIVE WASTE

Radioactive waste is usually collected in drums of 200-400 litre volume. The drums are stored in storages to wait until the radioactivity decreases below the limits as defined for free release. The drum surface dose rate is usually in the order of mSv/h and below.

Remark: The limits for activity classifications are not defined in this paper because the limits depend on government and/or local authorities and are subject of future changes.

The purpose of the drum measurement is to characterize the drum in respect to isotopic content and radioactivity. The measurement is performed by placing HPGe detectors (spectrometers) at the side of the drum during the drum rotation (Figure 1). The measured gamma spectra are analysed to identify the present isotopes. This analysis includes also the calculation of gamma absorption effects by the drum matrix material to correct the activity results.

The identification of present isotopes together with the actual activities is important to estimate the time until the activity is decayed, and the drum can be released.

All measured parameters together with information about the origin of drums, drum labels, their weight, activity and final storage place are stored in a data base. This allows a tracking of the radioactive content from the point of origin till storage.

FREE REALEASE MEASUREMENT SYSTEM FOR VERY LOW ACTIVE WASTE

Material which is contaminated with very-low activity can be measured for free release and stored at landfill areas outside the plant or can be reused. For example, after decommissioning of the nuclear installation and removing of the building, the areal can be measured for free release.

The monitors needed for such type of measurements are characterized by high sensitivity and large mass throughput.

One type of the monitor (Figure 2) is a lattice box system used typically for low density material. The box is after filling placed in a measurement housing equipped with large plastic scintillation panels for measurement from all sides. The panels are read out by photomultiplier with large cathode diameter. For the free release it is necessary to know the isotope vector inside the material. If necessary, the isotope vector is measured with HPGe detectors placed outside the housing.

Another monitor type, especially suitable for large amount of soil after demolition of plants is the conveyor belt system. The soil is crushed, homogenized, sieved and weighed in equal charges which are placed on the running conveyor belt. The charge is moved below a measurement housing in which HPGe detector array is mounted. During passing of the measurement housing the activity is measured for each charge and a decision is made according following criteria: free release, restricted release or no release. After the decision the material is guided by the belt to three different locations according to the measurement results. In real circumstances a throughput up-to 20 000kg per hour was realised. Figure 3 and Figure 4 show a conveyor belt monitor.

MONITORS FOR HIGH ACTIVE WASTE

High active waste includes waste with very high activities and with isotopes having long half -life times. Therefore, it is not economical to store this waste for long time in interim storages. This waste must be filled in a final repository with no further access.

Because the packaging condition for this waste are not finally defined, the waste is filled preferably into containers. The waste characterisation is performed by dose rate meters which can work in fields with high radioactivity. The use of HPGe detectors is mostly not practicable because the devices are paralysed by high count rates.

Because of radiation safety, the containers must be handled automatically. This includes the installation of emergency rescue equipment for the event of defects of the handling equipment.

BURN UP MONITORS FOR VERY HIGH ACTIVE MATERIAL

The nuclear fuel for power plants consists of Uranium with an enrichment of up to 5% of Uranium-235. If burned up, the fuel elements have to be replaced. The burned-up fuel is not a waste but a raw material, i.e. there is a possibility for its reprocessing. The burn-up monitors are designed to optimise the burn up process. They allow to measure the mean burn up as well as the burn up profile along the axial direction. If an asymmetric burn up has been observed, there is the possibility to change the burn up profile by changing the fuel position in the core.

The burn up measurement is based on the measurement of neutron emission along the fuel rods. The burned fuel elements have very high activity due to the fission process. Therefore, neutron detectors are required, which are not sensitive to gamma rays. The best choice are fission chambers which are cylindric proportional chambers with the inner side of the chamber coated with highly enriched Uranium-235. Incoming neutrons produce fission processes in the coating. The fission process releases heavy particles with high speed which ionizes the gas filled in the chamber.

Another method is the use of proportional chambers to directly measure gamma particles resulting from the burn up of the fuel rods. Special chambers are designed with low gamma sensitivity to avoid paralyzing of the device by the high activity of the fuel rod. A disadvantage of gamma detection is the effect, that constructive elements of the fuel assembly are made of steel which is activated by the neutron flux around the fuel element. It is very difficult to distinguish between gamma emission by burn up and gamma emission due to steel activation by neutrons.

The Figure 5 shows the burn-up monitor FAMOS developed by NUKEM, which is measuring the gamma emission as well as the neutron emission. The monitor is mounted under water in the fuel element storage pond. The fuel elements are guided through the central opening in vertical direction. The neutron emission as well as the gamma emission are measured by two counters each, grouped around the fuel element. Figure 6 shows such type of measurement. If the burn up is higher, the neutron emission is also higher. The ends of the fuel element show a reduced burn up because of suboptimal moderation of the nuclear flux. The measurement points for gammas were chosen in such a way, that spacer elements were in between the measurement points. At the lower end of the assembly (i.e. at the left side in the figure) the gammas show a higher level compared to the neutrons. This is caused by the activation of structural elements of the assembly at the lower end.

CONCLUSION

The paper has shown a variaty of monitors necessary to control the radioactive inventory inside and outside of nuclear plants. During the last years the monitors were improved in respect to sensitivity and operating characteristics. Aspecially the waste tracking and waste release measurments have made a big step forward.

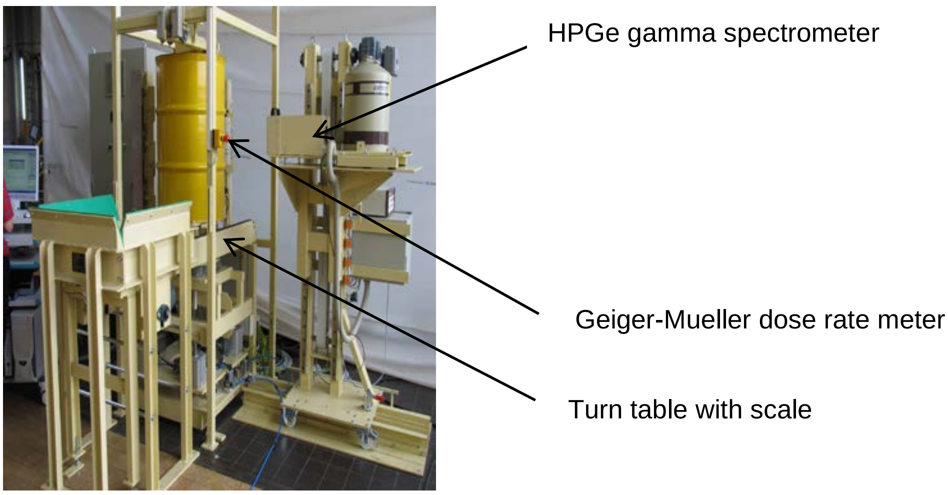

Figure 1: Drum monitor with HPGe spectrometer cooled by liquid Nitrogen

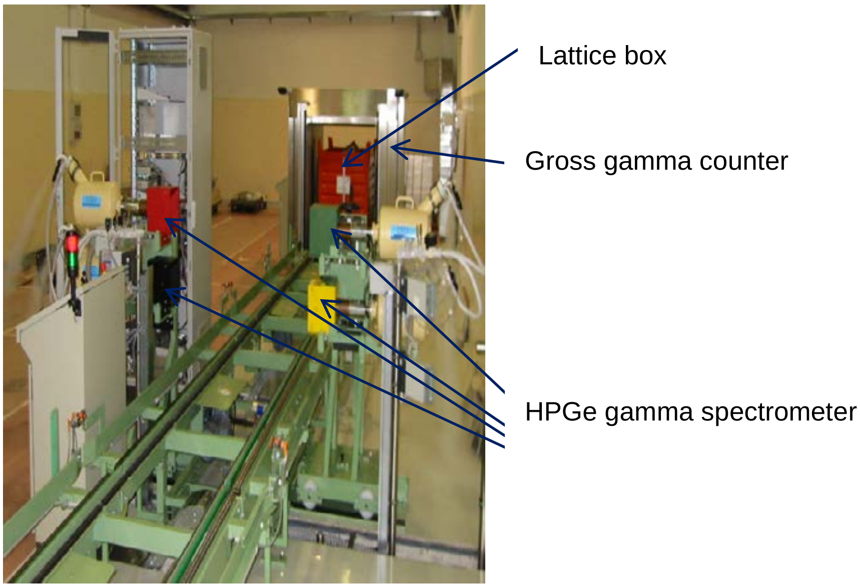

Figure 2: Lattice box monitor with gross gamma counters and HPGe gamma spectrometer area

Figure 3: Conveyor belt monitor for free release of large amount of soil

Figure 4: Measurement housing with array of electrical cooled HPGe spectrometer, mounted above the conveyor belt

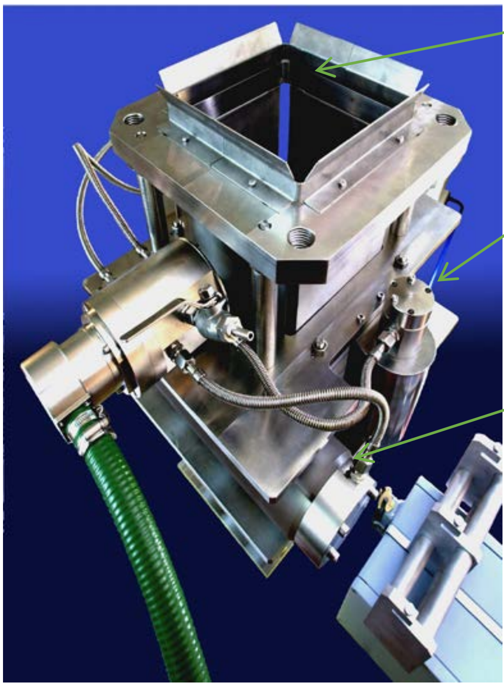

Figure 5: Fuel element burn up monitor FAMOS with neutron and gamma counters

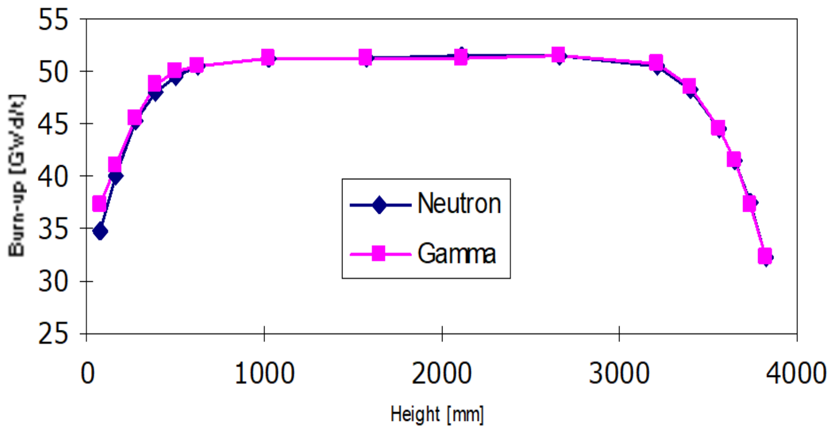

Figure 6: Burn up measurement with burn up monitor FAMOS