DEPENDENCE OF THE DETECTION LIMIT OF NUCLEAR MEASURING SYSTEMS ON THE GAMMA BACKGROUND

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Summary

Different detectors equipped with shielding were exposed to the rays let out through the horizontal channel of the Nuclear Training Reactor, Technical University, Budapest during the shut-down period. The spectral configuration of the rays approaches that of the radiation of possibly escaping fission wastes. The background intensities measured by the detectors were studied as function of the background dose rate, and a linear relationship was found in the range investigated. The minimum detectable activities were calculated from the background intensities. It has been evidenced experimentally that preparates exceeding in activity the calculated minimum detectable activity can really be detected, whereas activities lower than this can not.

The detection limit of a nuclear measuring system depends — under otherwise optimum conditions — on the intensity of background radiation. There may occur cases in practice where measurements are to be carried out at a background radiation exceeding the average laboratory level by two or three orders of magnitude. The question arises what will be the detection limit for a given isotope at the increased gamma background. In the present paper some results obtained with three different detector types (and shielding) will be reported. A relationship has been established between the dose rate of the gamma background and the detection limit of the measuring system.

Experimental

The increased gamma-background necessary in the measurements was provided by the gamma rays led through the horizontal channel of the nuclear reactor (Nuclear Training Reactor, Technical University, Budapest) during the shut-down period. The shielded detector was positioned in the axis of the rays.

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The dose rate (X) was measured at the surface of the lead shielding facing the rays.

In order to be able to study the background intensity (I_H) as function of the dose rate, a way had to be found to vary the latter. With the facilities available, two possibilities presented themselves for the variation of the dose rate: one was to alter the position of the detector, and the other to carry out measurements at the same place but at different points of time after shutting down the reactor. In the first case the spectral configuration of the radiation remains practically unchanged if the series of measurements is carried out within a relatively short time. In the second case the spectrum of the background radiation changes appreciably, but in a similar way as that of the radiation of fission products possibly escaping the reactor would change. As our intention was to study the correlation between background radiation of changing spectral configuration and the detection limit, the latter possibility seemed to be appropriate.

By the method outlined we wished to model a case where an area is contaminated with fission waste and to see whether a certain activity level can be detected or determined at the relatively high background prevailing, and, if so, what the relative standard deviation of the determination will be. The lead shielding enclosing the detectors were positioned at a distance of 90 cm from the exit of the horizontal channel using a hand-cart which could be moved in a direction perpendicular to that of the rays. This way the measuring systems studied could be placed in the right position in sequence. The scheme of the experimental set up with the section of the horizontal channel of the reactor is shown in Fig. 1.

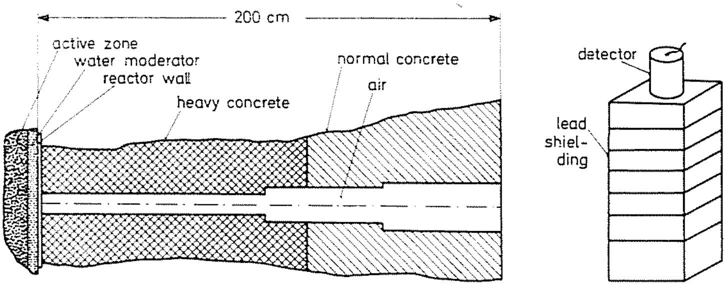

Fig. 1. Scheme of the experimental set-up with the section of the horizontal channel of the reactor

Measuring systems investigated

Detectors:

For measuring beta radiation

- a GM-GM anticoincidence detector (type ND-306 Gamma Works, Hungary) (Denoted Beta 1)
- a signal shape discriminating detector (type ND-304/E, Gamma Works, Hungary) (Denoted Beta 2)

For measuring gamma radiation

- an ND 302/E scintillation detector with a 7 S 115 06032 well type NaI/T1/scintillator (Gamma Works, Hungary)

Shielding Systems:

- Type NZ-305 (Gamma Works, Hungary), for beta detectors
- Type NZ-138 (Gamma Works, Hungary), for gamma detector

Other equipment

Counter: Detector signals were fed to an energy-selective counter (Type NK-225-B, KFKI, Hungary), which was connected to a printer (type VA-G-24). When beta detectors were used, the high-voltage and discriminator adjustment was the same for all isotopes studied.

With the gamma detectors the 364 keV ^{131}I (Gamma 1), the 662 keV ^{137}Cs (Gamma 2) and the 1112 keV ^{65}Zn (Gamma 3) full-energy peaks fell within the energy range located by the differential discriminator.

Measurement of the background spectrum.

Detector: HP Ge semiconductor crystal (Canberra, U. S. A.) with a volume of about 50 cm^3, with an energy resolution of 1.9 keV at 1332 keV and relative efficiency of 10%. Analyzer: A 8192 channel intelligent analyzer (type Canberra 80, U. S. A.).

Measurement of the dose rate:

- X-ray-gamma dosimeter (type VA-J-15.2A, VEB, Vakutronik WIB Dresden, GDR)
- Dosimeter with semiconductor detector (type NS-115, Gamma Works, Hungary)

Results

At the beginning of a series of measurements the spectrum of the ray leaving the reactor channel was measured. The reactor operated for a period of 80 min at a power of 10 kW, 24 hours before the measurement. The dose rate was 220 μGy $\cdot$ h^{-1} at the exit of the completely open horizontal channel. The detector was set at a distance of 20 cm from the channel exit, into which was placed a 12 cm long lead collimator with a boring of 5 mm diameter. There were a great number of full-energy peaks in the spectrum: ^{140}La, ^{133}I, ^{132}I, ^{97}Zr, ^{95}Zr and ^{95}Nb as the predominating components (Fig. 2) [1].

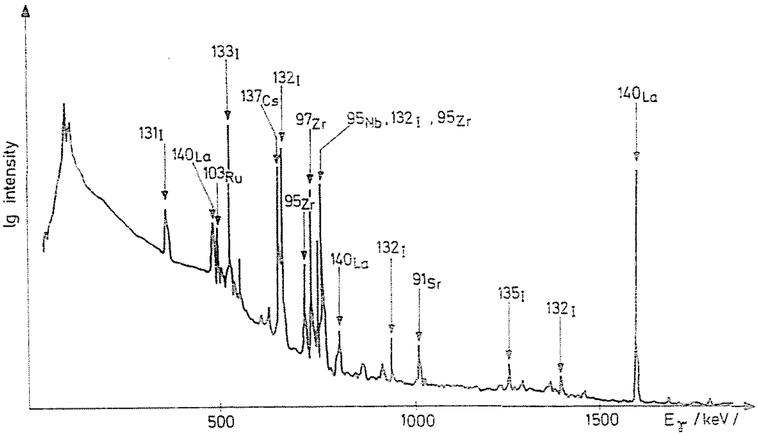

Fig. 2. Gamma-ray spectrum of the radiation leaving the horizontal channel at the beginning of the measurement

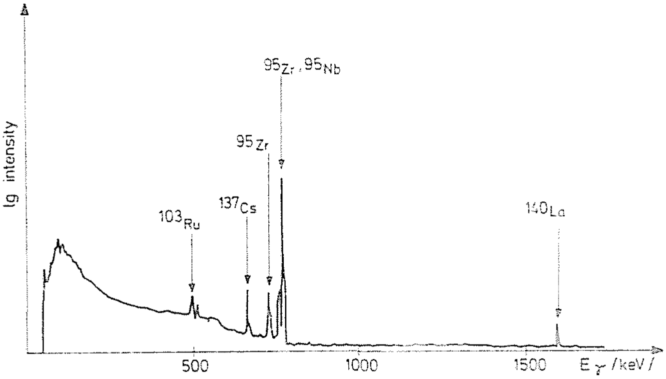

Fig. 3. Gamma-ray spectrum of the radiation leaving the horizontal channel at the end of the measurement

The background spectrum was measured again, 41 days after the reactor shut-down, when the whole series of measurements had been completed. The number of the peaks as well as the intensities decreased compared to the initial spectrum (Fig. 3). The components detected were ^{103}Ru, ^{137}Cs, ^{95}Zr, ^{95}Nb and ^{140}La. This means that the gamma background appears mainly in the 600—800 keV range, and this background remains rather high within a year, owing to the long half-lives of the radioactive components. In the high-energy range the 1596 keV ^{140}La peak is the most important component, the decay of which depends on the half-life of ^{140}Ba, its mother element (12,8 days), which means that this component is preserved fairly long.

In view of our objective — investigation of the possibilities of the selective measurement of radionuclides — the gamma background was measured

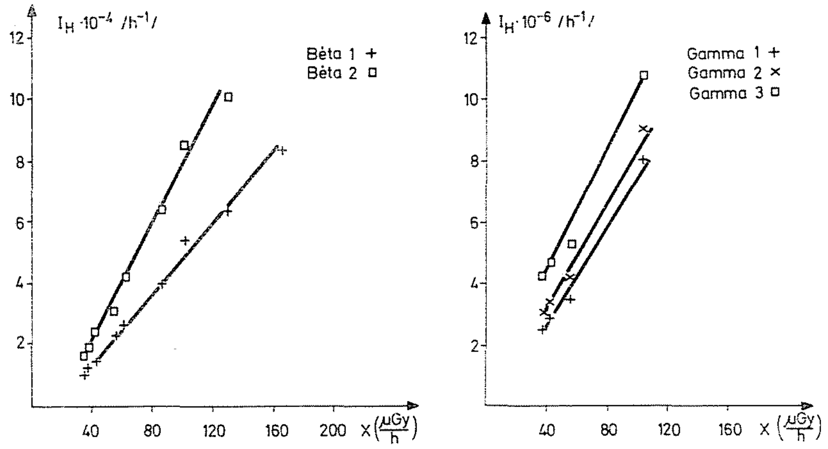

Fig. 4. Dependence of the background intensity on the background dose rate for different detectors

discriminated for selected peaks using gamma detectors. In the course of the measurements three discrimination ranges were studied, namely those of the 364 keV ^{131}I (Gamma 1), the 662 keV ^{137}Cs (Gamma 2) and the 1112 keV ^{65}Zn (Gamma 3) full-energy peaks so that pulses at the full-energy peak reached the detector.

The dependence of the background intensity on the background dose rate for different detectors is shown in Fig. 4. The experimental points lie on straight lines, which can be described as follows:

$$I_H = aX + b \tag{1}$$

The parameters of the equation are presented in Table 1.

Accordingly, in a given range the background intensity can be estimated if the dose rate is known, and from this the minimum detectable intensity can be determined. If, on the other hand, the counting efficiency is known, the minimum detectable activity of an isotope can be estimated, as well as the smallest amount that can be determined with a prescribed relative standard deviation. From the background intensities (I_H) the following values were calculated according to Currie [2]:

- Critical limiting intensity (I_C): the net intensity level above which an observed signal may be recognized as detected at a given probability level.
- Limiting detection intensity (I_D):
  the true net intensity level which may be a priori expected to lead to detection at a given probability level. I_D contains I_C and the net standard deviation of the expected net signal.

Table 1
Parameters of the background intensity
vs. dose rate function ($I_H = aX + b$) for different detectors

Detector	a	b	Range
	μGy^{-1}	h^{-1}	μGy · h^{-1}
Béta 1	$5.63 \cdot 10^2$	$-9.00 \cdot 10^3$	35–165
Béta 2	$9.32 \cdot 10^2$	$-1.64 \cdot 10^4$	35–130
Gamma 1	$8.52 \cdot 10^4$	$-8.84 \cdot 10^5$	35–104
Gamma 2	$9.23 \cdot 10^4$	$-6.95 \cdot 10^5$	35–104
Gamma 3	$9.98 \cdot 10^4$	$2.45 \cdot 10^5$	35–104

— Limiting determination intensity (I_Q):
the level at which the measurement precision is better than a prescribed value.

The limiting intensities defined above can be calculated using the following equations:

$$I_C = k \cdot \sigma_0 \tag{2}$$

$$I_D = \frac{k^2}{t_m} + 2k \cdot \sigma_0 \tag{3}$$

$$I_Q = \frac{1}{2t_m s^2}\left[1 + \sqrt{1 + (2\sigma_0 t_m s)^2}\right] \tag{4}$$

where

k is the abscissa of the standardized normal distribution corresponding to the chosen probability level
t_m is the sample counting time (s)
t_H is the background counting time (s)
s is the prescribed relative standard deviation
σ_0 is the standard deviation of the net signal with zero expected value.

$$\sigma_0 = \sqrt{\left(\frac{1}{t_m} + \frac{1}{t_H}\right) \cdot I_H} \tag{5}$$

In the present calculations a reliability level of 95% was chosen, for which $k = 1.64$ and I_Q is given for a relative standard deviation of 10% ($s = 0.1$). The minimum detectable activity can be calculated from the measured dose rate using equations 1, 3 and 5 as follows:

$$A_{\min} = \frac{1}{\eta}\left[\frac{k^2}{t_m} + 2k\sqrt{\left(\frac{1}{t_m} + \frac{1}{t_H}\right) \cdot \left(aX + b\right)}\right] \tag{6}$$

where

A_{min} is the minimum detectable activity, and

η the counting efficiency.

The counting efficiences for various isotopes of the measuring systems used in the present study are summarized in Table 2.

The minimum detectable activities were calculated for different dose rates; in each case the sample and background were measured for a period of 3000 s. The results are presented in Table 3. For comparison, the values referring to "normal" laboratory background are given in the first line of the table for all the isotopes investigated. The data in the table indicate that there is no appreciable difference in the detection limits obtained with the two beta detectors employed for the three isotopes studied: ^{131}I, ^{137}Cs and ^{90}Y. The detection limits are for ^{131}I and ^{137}Cs an order of magnitude, for ^{65}Zn two orders of magnitude higher when gamma activities are measured than in the case of measurement of beta activities. It should be noted that the counting efficiency (η) used in the calculations depends on the experimental conditions, such as the composition, layer thickness and geometry of the precipitate, hence the detection limits given in the table are not of general validity, but are valid under the conditions also presented in Table 2.

Table 2
Counting efficiencies of different detectors
for various isotopes

Isotope	Efficiency		
	GM-GM anticoincidence detector	Signal-shape discriminating detector	NaI (Tl) Scintillation detector
^{137}Cs	0.130	0.135	0.12
^{131}I	0.095	0.095	0.11
^{90}Y	0.185	0.200	–
^{65}Zn	–	–	0.005

Beta measurement:
^{90}Y in Y_2O_3 precipitate, layer thickness 13 mg cm^{-2}
^{131}I in AgI precipitate, layer thickness 23 mg cm^{-2}
^{137}Cs in Cs_2PtCl_6 precipitate, layer thickness 40 mg cm^{-2}
Distance of the precipitate from the detector surface: 3.8 mm.

To test the calculation method, radioactive preparates with different activities were prepared from several isotopes, and studied at various background intensities. Some results obtained with use of a GM-GM anticoincidence detector are presented in Table 4, and those provided by a signal shape discriminating detector in Table 5. (In both tables A values mean the true activity of the preparates.)

Table 3
Minimum detectable activity (*Bq*),
as function of the background dose rate, for different detectors
and isotopes

Isotope	Dose rate	Detectable activity		
		Beta 1	Beta 2	Gamma
	$\mu Gy \cdot h^{-1}$	*Bq*	*Bq*	*Bq*
^{137}Cs	0.43	0.19	0.21	1.5
	35	1.2	1.3	18.7
	61	1.7	2.1	26.2
	87	2.2	2.7	31.9
	104	2.5	3.0	35.3
	130	2.8	3.4	–
	165	3.2	–	–
^{131}I	0.43	0.26	0.30	2.0
	35	1.6	1.9	18.5
	61	2.3	2.9	26.6
	87	2.9	3.8	32.8
	104	3.4	4.2	36.4
	130	3.8	4.8	–
	165	4.3	–	–
^{90}Y	0.43	0.14	0.14	–
	35	0.8	0.9	–
	61	1.2	1.4	–
	87	1.5	1.8	–
	104	1.7	2.0	–
	130	1.9	2.3	–
	165	2.2	–	–
^{65}Zn	0.43	–	–	32
	35	–	–	545
	61	–	–	710
	87	–	–	840
	104	–	–	920

Summing up, it can be concluded that if $I_D > A \cdot \eta$, then — as expected — $I_{\text{measured}} < I_C$, that is, no useful signal can be detected. On the other hand, if $I_D < A \cdot \eta$, then, in every case $I_{\text{measured}} > I_C$, that is, a useful signal is detected. For cases where $I_Q < A \cdot \eta$, the deviation of I_{measured} from $A \cdot \eta$ is generally within 10% of the true value. The fact that in some cases a greater deviation was found, can be ascribed to the errors in the values of A and η. When the GM-GM anticoincidence detector was used, the intensities measured for the No. 2. ^{137}Cs preparate were always lower than expected, and the deviation was greater for higher and smaller for lower background intensities. This might be connected with the behaviour of the detector system.

Table 4

Data measured with a GM-GM anticoincidence detector and calculated detection limits

Dose rate	I_H	Sample	t_m	t_H	I_C	I_D	I_Q	I_{meas}	$A \cdot \eta$
μGy · h^{-1}	s^{-1}		s	s	s^{-1}	s^{-1}	s^{-1}	s^{-1}	s^{-1}
220	25.8	1. ^{137}Cs	1200	1200	0.34	0.68	2.12	<0	0.38
220	25.8	1. ^{90}Y	1200	1200	0.34	0.68	2.12	<0	0.30
165	23.0	2. ^{137}Cs	3000	4000	0.19	0.38	1.18	4.28	5.05
165	23.0	2. ^{131}I	3000	4000	0.19	0.38	1.18	0.45	0.74
104	15.0	1. ^{137}Cs	3000	3000	0.16	0.33	1.02	0.21	0.38
61	7.2	2. ^{137}Cs	1200	4000	0.14	0.29	0.93	4.76	5.05

Table 5

Data measured with a signal-shape discriminating detector and calculated detection limits

Dose rate	I_H	Sample	t_m	t_H	I_C	I_D	I_Q	I_{meas}	$A \cdot \eta$
μGy · h^{-1}	s^{-1}		s	s	s^{-1}	s^{-1}	s^{-1}	s^{-1}	s^{-1}
104	23.6	1. ^{137}Cs	3000	1200	0.27	0.55	1.68	0.06	0.40
35	4.5	3. ^{90}Y	3000	3000	0.09	0.18	0.56	2.56	2.60
35	4.4	3. ^{131}I	3000	3000	0.09	0.18	0.56	1.48	1.41

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