"RADIOIODINE REMOVAL FROM THE EXHAUST AIR SYSTEM OF THE OPEC 2 LABORATORY"

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Summary

The authorized discharge level of radioiodine in the area of the CSN Casaccia is very small, compared to the amount theoretically released in the hot cells of OPEC 2 Laboratory by a freshly irradiated fuel element.

In order to avoid a penalization of the operating capacity of the plant, i.e. restrictions on the nuclear fuel quantity allowed into the cells, a radioiodine removal installation has been located within the hot ventilation system.

The installation operates with charcoal filters: it is not normally in operation but is automatically inserted by a specific signal of the monitoring system, in case of high I 131 level detected in the exhaust air.

This paper describes the installed monitoring system used to control the gaseous effluent streams, and discuss the reliability of the radioiodine detection instruments.

A general presentation of the ventilation and filtration system is also given, with particular emphasis to the radioiodine removal circuit.

1. INTRODUCTION

A study on the environment receptivity of CSN Casaccia [1], the site where OPEC 2 Laboratory has been located, has led to determination of the maximum authorized discharge level of radioactive elements.

In case of gaseous or particulate radioelements released into the atmosphere, the amount of each nuclide can be calculated by the following expression:

$$\sum_{1}^{n}{}_{i} \frac{Q_i}{R_i} \leq 1 \qquad (1)$$

where Qi is expressed in Curies per year ;

Ri represents the environment receptivity for the i^{th} nuclide.

As shown in the expression (1), the total allowed release of Iodine can be reduced by a simultaneous release of other gases or particulates.

The value R of receptivity for 131I is 10 Curies per year in case of continuos release, with a limitation to 0.1 Curies per year in case of an instantaneous release.

Up to this date, the total amount of radioactivity released in the environment of CSN Casaccia, in the form of both gaseous or solid elements, has been much lower than the site authorized discharge level.

Licensing and operation of new plants on the same site will lower the level share assigned to every plant.

It is very likely that the maximum discharge level of OPEC 2 can be attained only by particulate or aerosols exhausted through the stack, downstream the absolute filters.

In order to avoid any restriction in the licensing of the Laboratory, but on the other hand, to extend its operating capabilities to freshly irradiated fuel elements, an absorption system for Iodine was conceived.

The amount of 131 I present in the fuel element taken as reference in the design of the plant (a mixed oxide, fast reactor fuel element, containing 91 rods and a total of 17,3 Kg of fissile materials, irradiated to a burn up 80.000 Mwd/t) is about 80.000 Curies at the time of the discharge from reactor, and about 1.200 Curies after 50 days of cooling time.

In OPEC 2 plant the Iodine quantity can be absorbed by a filtration system controlled by the 131 I monitoring equipment.

Such an absorption system is composed of two groups of 11 charcoal filters, inserted trough a by-pass in the active ventilation duct.

2. VENTILATION SYSTEM

As shown in table 1, the ventilation system yields, as it is usual in the hot laboratory practice, values of negative pressure and numbers of air changes proportional to the contamination risks existing in the different zones of the building.

TABLE 1

AREE	Air changes h	Pressure in mm of water
Green areas (offices cold change A rooms, etc.)	2 to 4	0
Yellow areas (operating areas, radio chemistry and special examination laboratories, assembling room, etc) B	5 to 8	-3 to -5
Red areas (hot storage, loading area, etc.)	8 to 10	-10 to -15
Red areas (hot cells, decontamination room) C	20 to 30	-25 to -40

A double regulation system, based on the air flow control at critical points, is foreseen in order to keep automatically the depression values.

Ventilation for the whole laboratory is provided by the following three indipendent systems:

A. Air conditioning system (flow rate 16.300 m^3/h)
B. Intermediate system (flow rate 44.500 m^3/h)
C. Hot areas system (flow rate 10.200 m^3/h)

The inlet air is supplied to the three systems by a group of two fans operating alternatively.

Indipendent filtration for each system by coarse filters and absolute filters is provided. In addition, the C. system is equipped with two batteries already mentioned of 11 charcoal filters: these batteries are normally in a stand-by position, but they can be automatically put in operation by the Iodine detecting device located in the exhaust pipe.

The normal air duct is fit out with a motorized valve, controlled by the Iodine alarm circuit, wich deviate in the by-pass the whole air volume from the high-activity zones, to the charcoal filters (Fig. 1) (Fig. 2).

Some additional informations on the ventilation system are the followings. Downstream the batteries of absolute filters of zone C. three exhaust fans are installed: one for normal operation, the second as a stand-by for the first and the third fed by batteries.

Exhaust fans of the A. and B. zones are two for every system: both are able to ensure 100% performance on pressure drop and on air changes; both are connected to normal and emergency power supply.

The exhaust is discharged into the atmosphere trough a 30 meter high stack, hardened by antiseismic features.

Ancillary ducts for in cell operations under inert atmosphere are also provided to the hot celles ventilation C. system.

3. EXHAUST AIR MONITORING SYSTEM

The air fluxes from the various areas of the plant are collected into two separate ducts before being discharged through the stack.

The first duct collects the air from A. and B. zone systems, i.e. from areas with very week degree of possible contamination.

The following measurements are performed on the first duct:

- beta emitting particulate materials
- Iodine 131
- fission gases.

In the air duct from the hot areas (hot cells, isolation room, decontamination room), in addition to the above mentioned measurements, the detection of alpha particulate materials is also performed.

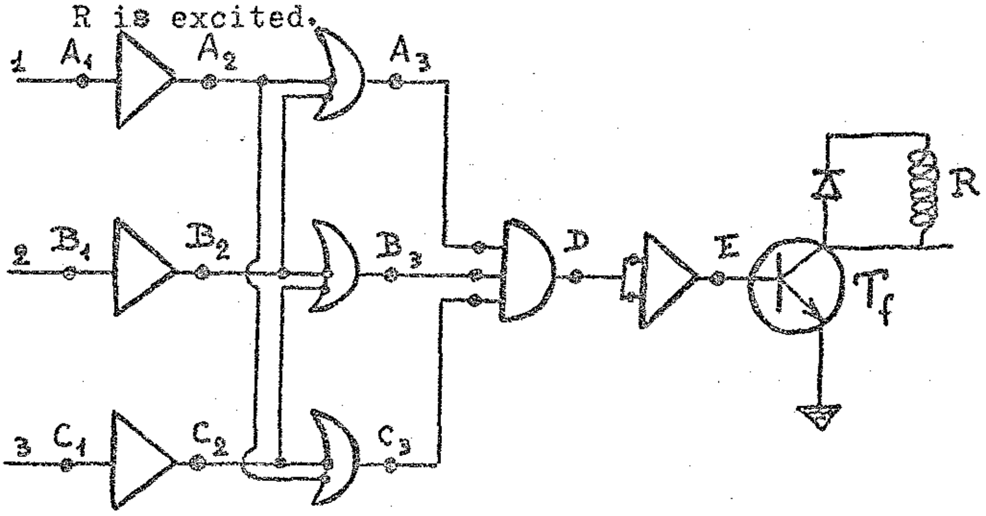
The whole monitoring system includes the following equipments, installed in the filter room.

- N°2 alpha radioactive particle detectors (1 is in stand-by) in ventilation duct C.
- N°3 Iodine 131 detectors in ventilation duct C. (in operation)
- N°1 (beta particulate; fission gas) detectors in ventilation duct C. (in operation)
- N°1 (beta particulate; Iodine; fission gas) detector in ventilation duct A. + B.) (in operation)
- N°1 (beta particulate; fission gas) detector connected to both ventilation ducts A.+B. and C. (acting as fail safe equipments).

Some general specifications of the installed monitors are the followings:

- beta particle detector :	sensitivity	10^{-9} Ci/m^3
	range up to	10^{-4} Ci/m^3
- alpha particle detector :	sensitivity	10^{-11} Ci/m^3
	range up to	10^{-6} Ci/m^3
- Iodine 131 detector :	sensitivity	10^{-8} Ci/m^3
	range up to	10^{-3} Ci/m^3
- gas activity detector :	sensitivity	10^{-6} Ci/m^3
	range up to	10^{0} Ci/m^3

The monitors are connected to a central console which includes a 12 track recorder, flux meters for gas sampling, switches to operate the stand by units, audible and visible alarms. The signals coming from the three Iodine detectors will be elaborated following a 2 over 3 logic and the output signal will be sent to the centralized console. It means that only if 2 out of 3 signals exceed the preset value an alarm for Iodine release will occur. In this case the servocontrolled valves in the ventilation system will be shut down to insert automatically the charcoal filter battery. A schematic block diagram of the alarm system is reported below. One can conclude that an alarm is given in case 3°) i.e. when the relay R is excited.



CASE 1°) : NORMAL CONDITION - Levels 1, 2, 3 are at 5V.
A_3= B_3= C_3= 0V; D= 5V; E=0V; T_f: STATE OFF

CASE 2°) : IODINE ALARM IN THE MONITOR 1: A_1=0V B_1=C_1= 5V,
A_3= 5V, B_3= 0, C_3=5V ; D=5 E=0 T_f: STATE OFF

CASE 3°) : IODINE ALARM IN TWO MONITORS 1 AND 2: A_1= B_1= 0V
C_1= 5V A_3= 5V ; B_3= 5V; C_3= 5V D=0V E= 5V
T_f: STATE ON ; RELAY R EXCITED.

An estimate of the radioactivity release rate from the plant has been carried out with the following two purposes:

1. to confirm the correct fitting of the sensitivity and range values of the installed detectors;
2. to compare the calculated release rate to the maximum authorized discharge level.

The release from the hot ventilation system C. has been calculated, due to operations of dismantling (10/year), transverse (500/year) and longitudinal cutting (20/year), puncturing (50/year), chemical dissolution (20/year) performed on 10 standard type fuel elements per year, after 150 days decay period [2] [3] .

The following release fraction to the cell atmosphere have been assumed [4] : 100% for 85 Kr, 133 Xe, 131 I, 137Cs
65% for Te
1% for all other non volatile nuclides that are supposed to be retained on the working surfaces or on local filtering devices.

As release values from the stack, the following figures have been taken into consideration:

0.1% for solid nuclides

1% for 131 I

100% for Xe and Kr isotopes.

Table II shows a syntesis of the results obtained. From data of TABLE II and from the exhaust flow rate the air concentration of total $\beta+\gamma$ activities due to destructive operations has been calculated.

Results are reported in table III, where the time of the single operation is also included: the reported concentration values compare well with sensitivity installed detectors.

TABLE III

OPERATIONS	DISMANTLING (time~8h)	LONGITUDINAL CUTTING (time ~ 2h)	TRAVERSE CUTTING (time~0,5h)	PUNCTURING (time~ $\frac{1\ h}{60}$)	CHEMICAL DISSOLUTION (time ~ 4h)
RELEASED ACTIVITY $\beta+\gamma$ (Ci/m^3)	$4{,}6 \cdot 10^{-9}$	$1{,}7 \cdot 10^{-6}$	$3{,}6 \cdot 10^{-8}$	$1{,}47 \cdot 10^{-2}$	$8{,}2 \cdot 10^{-8}$
RELEASED ACTIVITY α (Ci/m^3)		$8{,}9 \cdot 10^{-9}$	$1{,}9 \cdot 10^{-10}$		$4{,}6 \cdot 10^{-10}$

In table IV the site receptivities Ri of some relevant radionuclides are compared to the calculated activities released in the environment and to the amount "non recorded" by the monitor detectors in case of small continuous release.

TABELLA IV

NUCLIDES	R_i (Ci/year)	Activity released (Ci/year)	Activity "Non recorded" (Ci/year)
SR^{90}	5,5	2,3 10^{-3}	0,9
CS^{137}	45	0,41	0,9
RU^{106}	930	2,85 10^{-2}	0,9
CE^{144}	930	4,8 10^{-2}	0,9
$\beta + \gamma$ EMITTERS	1.800	0,36	0,9
I^{131}	10	2,1 10^{-4}	0,9
PU	0,34	1,6 10^{-4}	0,9 10^{-2}
α EMITTERS	0,93	3,6 10^{-7}	0,9 10^{-2}

The annual amount of "non recorded" activity, due to detector sensitivity, is lower than the receptivity values.

Even much lower than Ri are the calculated amount of radioelements released by the plant.

In the fuel element of the above described example, the Iodine content is very small, owing to the long decay period of 150 days compared to the half life of 131 I..

In effect in this case the charcoal filters could be kept in a stand-by position.

Applying the same discussion to a fresh fuel element entering the hot cell system after a decay period of 50 days, with the relevant content of 1.200 Curies of 131 I, only the intervention of the charcoal absorbers on the exhaust can reduce the fractional release to an acceptable level.

In this case, in fact, we have to consider a potential burst release originating from the different destructive operations carried out on the fuel element, to be compared with the istantaneous authorized level of 0,1 Curies.

Taking as example a longitudinal cutting, involving the highest amount of fissile material (52 g.), the in cell release of iodine will be 3,6 Curies.

The absorption on the charcoal filters will reduce the iodine release into the atmosphere to a value of 0,036 Ci, lower than the authorized level.

4. RELIABILITY OF THE RADIOIODINE DETECTION AND REMOVAL SYSTEM

A reliability analysis on the electronic detectors, on the relevant data processing and self control system, has led to the following values for both "detected" and "non detected" failure rates:

detected $= 1.1 \times 10^{-3}$ h^{-1}
non detected $= 0.2 \times 10^{-3}$ h^{-1}

The first figure for "detected failures" corrisponds to about 10 failures per year. Assuming that a single failure causes to cease operation for 50 hours, the unavailability for detected failures of the same detector will be:

$$\frac{50 \times 10}{8760} = 0.057$$

For non detected failures the probability Q(t) that a single detector goes out of operation at time t is:

$$Q(t) = 1 - \exp(-\lambda t)$$

If the electronic chain is checked every month [T (check electr) = 720 h] the probability that the monitor breaks down in the period between two subsequent checks of the electronic chain is:

$$Q(t=T \text{ check electronic}) = 1 - \exp(-0{,}2 \times 10^{-3} \times 720)$$

When the Q(t) trend is linearized the unvailability of a single detector in such a time period results equal to

$$\tfrac{1}{2}\, Q(t=720) = 0.0.652$$

The reliability R(t) of a single detector chain can be derived from the failure probability:

$$R(t) = 1 - Q(t)$$

Since the actual Iodine alarm monitor follows is connected with a 2 over 3 logic, the over all reliability of the system will be represented by the following expression:

$$R_{2/3}(t) = 3\ R(t)^2 - 2\ R(t)^3$$

In our case the reliability R(t) of the single detector chain is the same for the three detectors involved and the reliability of the equipment which select the inputs on a 2 over 3 logic is supposed to be equal to unity. Therefore:

$$R_{2/3}(t=T_{p\ \text{electr.}}) = 0.95$$

$$0.5\ Q_{2/3}(t=T_{p\ \text{electr.}}) = 0.025$$

Same discussion can be developed also on the mechanical and pneumatic systems activated by the Iodine alarm detector.

An analysis of the different mechanical and pneumatic components, assuming that all failures are of "non detected" type, and taking into account values of λ given in literature [5] [6] [7] [8] [9], has led to the following value of the total failure rate:

$$\lambda_{\text{mech.}} = 0.27 \times 10^{-3}\ h^{-1}$$

The probability of a mechanical failure, between two control checks made at a reasonable time interval of one week (168 hours) is given by:

$$Q(t=T_{p\ \text{mech}}) = 1 - \exp\ (- 0{,}2 \times 10^{-3} \times 720)$$

$$Q(t=T_{p\ \text{mech}}) = 0.044$$

The unavailability due to the mechanical and pneumatic system is therefore:

$$0.5\ Q(t=T_{p\cdot mech}) = 0.022$$

The total unavailability of the Jodine absorption system is given by the sum of the individual fractions for "detected" and "non detected" failures of the electronic, mechanical and pneumatic components:

$$0.057 + 0.025 + 0.022 = 0.104$$

Bearing in mind the above mentioned assuptions, a safety analysis of the plant operation must take into account this probability of about 10% unavailability of the Iodine removal system.

In case of a fresh fuel element, containing large quantities of 131 I, to be loaded into the cells, the assumpions can be changed in order to reduce the inoperative time probability.

The test time interval of electronic, mechanical or pneumatic chain, can be reduced for examples to 24 hours; recalculated values of unavailability (for non detected failure) are 3.4×10^{-5} and 3.2×10^{-3} in case of daily control test for electronic and mechanical systems respectively.

The first of the recalculated values, that is very low, is certainly acceptable from the point of view of the laboratory safety, since it assures an alarm signal from the exhaust monitoring in every case of Iodine release.

Whenever at the same time of release, the mechanical system is out of operation (probability 6.4×10^{-3}) the alarm signal will permit to insert the absorption filters manually.

On the other hand the disposal of a relevant number of spare parts or detector components will eventually reduce the contribution of detected electronic failures to the total inoperative time fraction, thus increasing the general safety measures of the plant.

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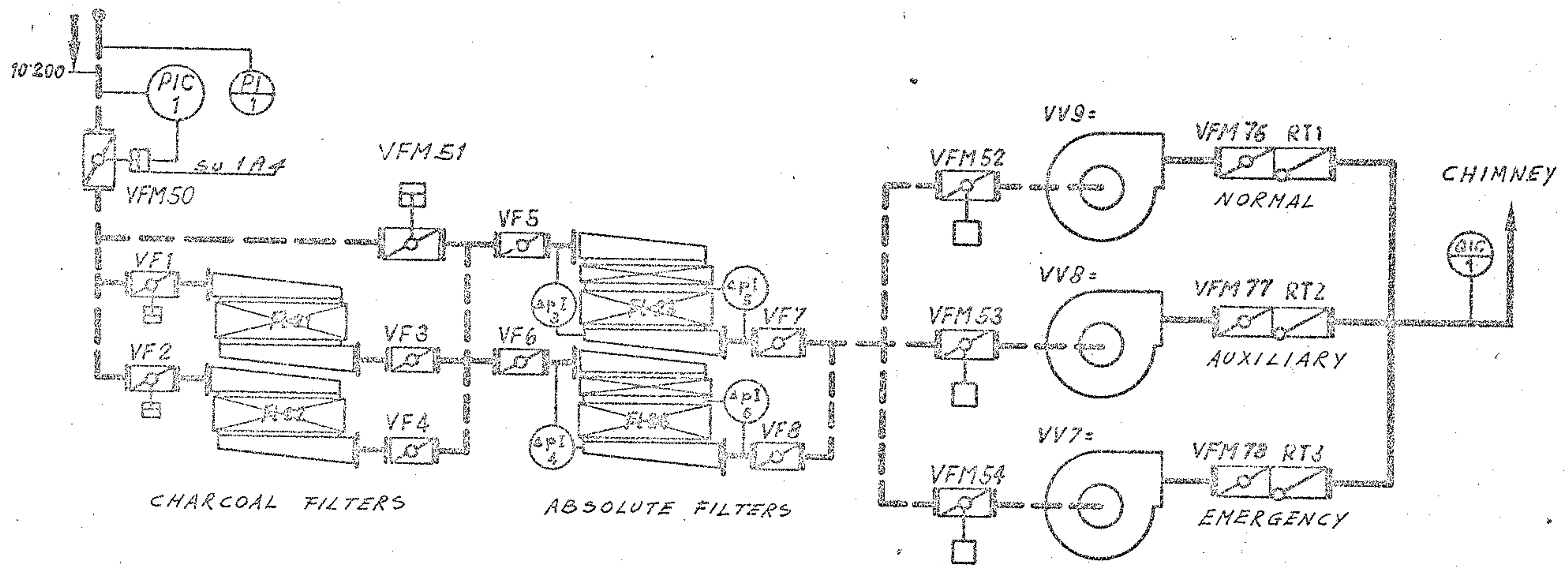

MONITORED EXHAUST AIR FLOW DIAGRAM FIG. 1

DOUBLE BATTERY OF 11 CHARCOAL FILTERS FIG. 2

CALCULATED ACTIVITIES RELEASED IN THE ENVIRONMENT

TAB. II

ELEMENTI	Attivita' prodotti di fissione in una barretta (CURIES)	Attivita' prodotti di fissione riferita ad un g di combustib. (CURIES / g)	Attivita' del fissile+ +fertile riferita ad un g di combustib. (CURIES / g)	Attivita' riferita ad un g di polvere di AISI-316 M attivata (CURIES/g)	Fattori di rilascio nella atmosfera della cella per i diversi nuclidi	Fattori di rilascio complessivo dei filtri in cella e nella sala filtri	Attivita' rilasciata al camino nell'operazione di smantellamento del cluster [g 110 di AISI-316 M] (CURIES)	Attivita' rilasciata al camino nell'operazione di taglio longitudinale [9 g AISI 316 + 52 g combust] (CURIES)	Attivita' rilasciata al camino nell'operazioni di taglio trasversale [7·100 g AISI + +27/100 g di comb] (CURIES)	Attivita' rilasciata al camino nell' operazioni di punturazione (CURIES)	Attivita' rilasciata al camino nell' operazioni di dissoluzione [5,2 g di comb.] (CURIES)	Attivita' rilasciata al camino complessivamente in un anno (millicuries)
Ferro 58	—	—	—	0,333	10^{-2}	10^{-3}	$3,7 \cdot 10^{-4}$	$3 \cdot 10^{-5}$	$2,3 \cdot 10^{-7}$	—	—	4,3
Cobalto 59	—	—	—	$3,5 \cdot 10^{-3}$	10^{-2}	10^{-3}	$3,85 \cdot 10^{-6}$	$3,15 \cdot 10^{-7}$	$2,4 \cdot 10^{-9}$	—	—	$4,6 \cdot 10^{-2}$
Niobio 93	—	—	—	$1,66 \cdot 10^{-6}$	10^{-2}	10^{-3}	$1,9 \cdot 10^{-9}$	$1,5 \cdot 10^{-10}$	$1,2 \cdot 10^{-12}$	—	—	$2 \cdot 10^{-5}$
Zirconio 94	—	—	—	$1,2 \cdot 10^{-3}$	10^{-2}	10^{-3}	$1,3 \cdot 10^{-6}$	$1,1 \cdot 10^{-7}$	$8,4 \cdot 10^{-10}$	—	—	$1,56 \cdot 10^{-2}$
KR – 85	4,87	—	—	—	1	1	—	~ 2,5	~ 2,5	~ 2,5	$1,4 \cdot 10^{-1}$	$295 \cdot 10^{+3}$
SR – 89	161	0,86	—	—	10^{-2}	10^{-3}	—	$4,47 \cdot 10^{-4}$	$2,32 \cdot 10^{-6}$	—	$4,47 \cdot 10^{-5}$	11,0
Y – 89 m	161	0,86	—	—	10^{-2}	"	—	$4,47 \cdot 10^{-4}$	$2,32 \cdot 10^{-6}$	—	$4,47 \cdot 10^{-5}$	11,0
Y – 90	34,2	0,182	—	—	10^{-2}	"	—	$9,5 \cdot 10^{-5}$	$4,9 \cdot 10^{-7}$	—	$9,5 \cdot 10^{-6}$	2,34
SR – 90	34,2	0,182	—	—	10^{-2}	"	—	$9,5 \cdot 10^{-5}$	$4,9 \cdot 10^{-7}$	—	$9,5 \cdot 10^{-6}$	2,34
– 91	268	1,49	—	—	10^{-2}	"	—	$7,75 \cdot 10^{-4}$	$4 \cdot 10^{-6}$	—	$7,75 \cdot 10^{-5}$	19,0
NB – 93 m	100	0,53	—	—	10^{-2}	"	—	$2,76 \cdot 10^{-4}$	$1,43 \cdot 10^{-6}$	—	$2,76 \cdot 10^{-5}$	6,8
ZR – 95	450	2,4	—	—	10^{-2}	"	—	$1,25 \cdot 10^{-3}$	$0,65 \cdot 10^{-5}$	—	$1,25 \cdot 10^{-4}$	27,8
NB – 95	450	2,4	—	—	10^{-2}	"	—	$1,25 \cdot 10^{-3}$	$0,65 \cdot 10^{-5}$	—	$1,25 \cdot 10^{-4}$	27,8
RU – 103	132	0,705	—	—	10^{-2}	"	—	$3,7 \cdot 10^{-4}$	$1,92 \cdot 10^{-6}$	—	$3,7 \cdot 10^{-5}$	9,1
RH – 103 m	132	0,705	—	—	10^{-2}	"	—	$3,7 \cdot 10^{-4}$	$1,92 \cdot 10^{-6}$	—	$3,7 \cdot 10^{-5}$	9,1
RH – 106	418	2,23	—	—	10^{-2}	"	—	$1,16 \cdot 10^{-3}$	$0,6 \cdot 10^{-5}$	—	$1,16 \cdot 10^{-4}$	28,5
RU – 106	418	2,23	—	—	10^{-2}	"	—	$1,16 \cdot 10^{-3}$	$0,6 \cdot 10^{-5}$	—	$1,16 \cdot 10^{-4}$	28,5
SB – 125	14,2	$7,6 \; 10^{-2}$	—	—	10^{-2}	"	—	$3,95 \cdot 10^{-5}$	$2,05 \cdot 10^{-7}$	—	$3,95 \cdot 10^{-6}$	0,97
TE – 127 m	31,8	0,17	—	—	0,65	"	—	$5,8 \cdot 10^{-3}$	$3 \cdot 10^{-5}$	—	$5,8 \cdot 10^{-4}$	142,6
TE – 129	8,6	$4,6 \cdot 10^{-2}$	—	—	0,65	"	—	$3 \cdot 10^{-5}$	$1,55 \cdot 10^{-7}$	—	$3 \cdot 10^{-6}$	0,74
I – 131	$3,3 \cdot 10^{-3}$	$1,7 \cdot 10^{-5}$	—	—	1	10^{-2}	—	$0,88 \cdot 10^{-5}$	$0,46 \cdot 10^{-7}$	—	$0,88 \cdot 10^{-6}$	0,21
CS – 137	59,2	0,317	—	—	1	10^{-3}	—	$1,65 \cdot 10^{-2}$	$0,86 \cdot 10^{-4}$	—	$1,65 \cdot 10^{-3}$	406
BA – 137 m	59,2	0,317	—	—	10^{-2}	"	—	$1,65 \cdot 10^{-4}$	$0,86 \cdot 10^{-6}$	—	$1,65 \cdot 10^{-5}$	406
BA – 140	0,612	$3,27 \cdot 10^{-3}$	—	—	10^{-2}	"	—	$1,7 \cdot 10^{-6}$	$0,88 \cdot 10^{-8}$	—	$1,7 \cdot 10^{-7}$	$4,18 \cdot 10^{-2}$
LA – 140	0,612	$3,27 \cdot 10^{-3}$	—	—	10^{-2}	"	—	$1,7 \cdot 10^{-6}$	$0,88 \cdot 10^{-8}$	—	$1,7 \cdot 10^{-7}$	$4,18 \cdot 10^{-2}$
CE – 141	81	0,433	—	—	10^{-2}	"	—	$2,25 \cdot 10^{-4}$	$1,17 \cdot 10^{-6}$	—	$2,25 \cdot 10^{-5}$	5,53
CE – 143	85,9	0,460	—	—	10^{-2}	"	—	$2,40 \cdot 10^{-4}$	$1,25 \cdot 10^{-6}$	—	$2,40 \cdot 10^{-5}$	5,9
CE – 144	703	3,76	—	—	10^{-2}	"	—	$1,95 \cdot 10^{-3}$	$1 \cdot 10^{-5}$	—	$1,95 \cdot 10^{-4}$	47,9
PR – 144	703	3,76	—	—	10^{-2}	"	—	$1,95 \cdot 10^{-3}$	$1 \cdot 10^{-5}$	—	$1,95 \cdot 10^{-4}$	47,9
Uranio (234+235+238)	—	—	$1,7 \cdot 10^{-5}$	—	10^{-2}	"	—	$1,53 \cdot 10^{-8}$	$4,6 \cdot 10^{-11}$	—	$1,53 \cdot 10^{-10}$	$3,6 \cdot 10^{-4}$
Plutonio 239	—	—	$7,67 \cdot 10^{-3}$	—	10^{-2}	"	—	$4 \cdot 10^{-6}$	$2,07 \cdot 10^{-8}$	—	$4 \cdot 10^{-7}$	$9,8 \cdot 10^{-2}$
Plutonio 240	—	—	$4,75 \cdot 10^{-3}$	—	10^{-2}	"	—	$2,47 \cdot 10^{-6}$	$1,28 \cdot 10^{-8}$	—	$2,47 \cdot 10^{-7}$	$6,1 \cdot 10^{-2}$
Plutonio 241	—	—	0,336	—	10^{-2}	"	—	$1,75 \cdot 10^{-4}$	$9,1 \cdot 10^{-7}$	—	$1,75 \cdot 10^{-5}$	4,3