Laboratori Nazionali di Frascati

LNF-73/15

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Health Phys. 24, 411 (1973).

Health Physics Pergamon Press 1973. Vol. 24 (April), pp. 411–415. Printed in Northern Ireland

MEASUREMENTS OF INDUCED RADIOACTIVITY IN DUST AROUND A 400 MeV LINAC

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(*Received* 19 *June* 1972; *in revised form* 9 *September* 1972)

Abstract—Some measurements of induced radioactivity in dust around a 400 MeV linear electron accelerator have been carried out.

The main radionuclides found in smear test samples concerning the final part of the accelerator are ^{39}Cl, ^{38}Cl and β^+ emitters with a short half-life; ^{54}Mn was also detected.

During a long maintenance work dust samples of about 10 g were collected and analysed. We found many radionuclides and particularly ^{54}Mn, ^{7}Be, ^{65}Zn and some cobalt isotopes.

Internal contamination problems around high energy accelerators do not seem particularly serious, but, at least for rather powerful accelerators, they should be given closer attention than that received up to now.

INTRODUCTION

RADIOPROTECTION problems related to the production of activated dusts around high energy accelerators, and consequent possible contamination, have never been thought particularly serious although sometimes they were considered.[1,2] Many radionuclides have recently been detected around a cyclotron[3] and a linear accelerator[4] though in very low concentration. Nevertheless, there is a feeling that these problems, or part of them at least, have been somehow neglected. We believe they should in fact be given more consideration, therefore we would like to present some of the most significant measurements effected around the 400 MeV linear accelerator of the Frascati National Laboratories.

RESULTS AND DISCUSSION

The results regard two different health physics operations, both carried out near the final part of the accelerator, between the pion targets and the electrons quench tanks.

This area includes a stainless steel guide, some steel structures placed near the beam line and the quench tanks. The floor, walls and ceiling are made of concrete. It should be noted that the area, obviously closed off during operations, is occasionally entered by radiation workers for emergency and upkeep actions in non-work conditions. It must be observed in any case that in this area the major radiation risks are those due to direct emission from activated materials, which are likely to cause high radiation levels such as a few hundreds of mR/hr and even a few R/hr.

The two health physics operations in the course of which various nuclides in the collected dusts were detected, respectively refer to smear-tests carried out in brief work interruptions and analysis of dusts collected in the area at the time of the line disassembling. In both cases, samples were analysed by means of a spectrometer provided with a 45 cm^3 Ge–Li detector and a 1024 multichannel analyzer.

FIRST OPERATION

In the first case, many smear-tests were carried out for a few days after the shutdown of the accelerator. Radionuclides were mostly detected in the samples within a few hours after the shutdown. This is chiefly due to the relatively short mean-life of the said radionuclides.

A typical example of the spectra obtained is shown in Fig. 1. In this case the smear-test concerned a metal surface of about 1000 cm^2, the accelerator having been operated for some hours at 320 MeV and a 50μA average current. Detected radionuclides are listed in Table 1, in the last column of which activities are shown as extrapolated at the moment of switching-off. Mean-life measurements were also effected in order to identify ^{38}Cl, ^{39}Cl and ^{24}Na. Obviously, activities do not turn out to be the same with

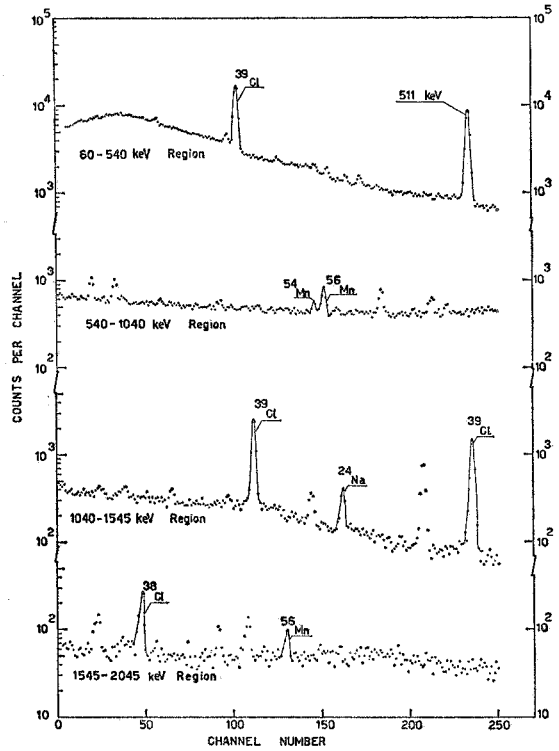

FIG. 1. Ge(Li) spectrum of a typical smear-test samples concerning a metal surface of about 1000 cm². Counting time = 50 min. The unmarked peaks are background ones. (The ^{60}Co peaks from a ^{60}Co source storeroom are also apparent.)

respect to all the measurements, depending upon the operating conditions as well as the sampling methodology, so values under Table 1 are merely meant to provide an order of magnitude.

As regards the origin of the various radionuclides, we believe it possible to assess that ^{38}Cl and ^{39}Cl derive from ^{40}A by virtue of (γ, np) and (γ, p) reactions respectively. The manganese isotopes certainly derive from the iron and the ^{24}Na ones from the concrete shielding of the accelerator. Scandium-47 was also found, although it does not appear so easy to account for its presence.

Table 1

Radionuclide	Energy (keV)	Half-life	Activity (μCi)
^{47}Sc	163	3.4 days	7×10^{-4}
^{39}Cl	246	55 min	8×10^{-2}
	1266		
	1520		
^{54}Mn	835	280 days	3×10^{-4}
^{56}Mn	845	2.58 hr	2.7×10^{-3}
	1810		
^{24}Na	1368	15 hr	2.4×10^{-3}
^{38}Cl	1640	37.3 min	2.1×10^{-2}

Figure 1 also shows a 511 keV line due to β^+ emitters, for the detection of which mean-life measurements were effected. An apparent half-life of the order of 10 min was at first observed, almost certainly due to the presence of ^{15}O ($T_{1/2} = 2.1$ min), ^{13}N ($T_{1/2} = 10.1$ min) and ^{11}C ($T_{1/2} = 20.5$ min). Later on β^+ emitters with a longer mean-life were found to be prevailing. After about 20 hr radionuclides with an over 4 hr half-life were still present, on whose nature we are not however able to make assumptions. The apparent activity of these emitters lowered from about 0.4 μCi 15 min after switching-off to about 2×10^{-4} μCi 22.5 hr later.

Regarding the health physics measures taken, it must be pointed out that this area, even in non-work conditions, is usually closed off on account of the presence of activated materials. Nevertheless it is sometimes necessary to carry out urgent maintenance operations, which are generally authorised only after 2 hr at least after switching-off. So far, since such operations have been occasional and short, it has not been thought necessary to adopt further precautions. It is however possible that in the future, especially in the case of longer operations, some protective clothing will be used and operators will be submitted to internal contamination checks.

SECOND OPERATION

The second operation was carried out during the beam-line disassembling which needed some important alterations. In the course of this work several samples were collected and analysed by means of the Ge–Li spectrometer.

The first set of measurements refers to sample dusts deposited on the floor in the area before the quench tanks. Figure 2 shows an example of the spectra obtained. This measurement, as well as the following ones, was effected about a month after the accelerator was stopped. Table 2 shows the results obtained by analysing this

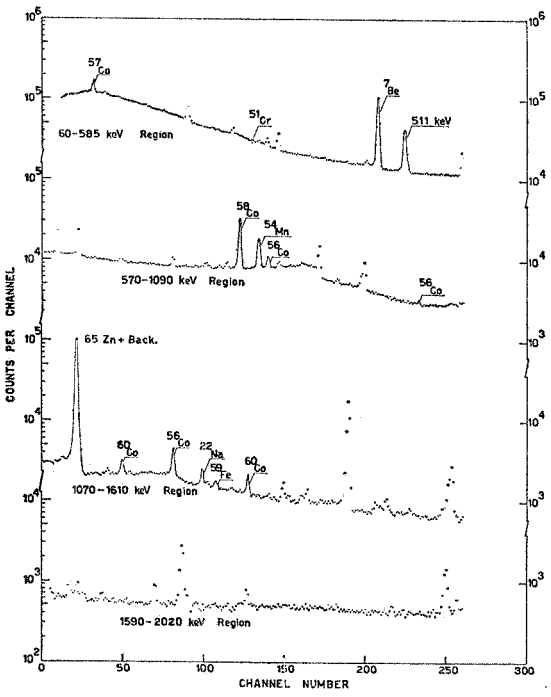

FIG. 2. Ge(Li) spectrum of a dust sample of about 9.5 g. This sample was collected about a month after beam shutdown and counted for 917 min. The unmarked peaks are background ones.

spectrum, together with the maximum permissible concentrations $(MPC)_a$ in inhaled air, deriving from an 168 hr/week exposure in insoluble form. Also we thought it useful to include in the last column a "relative hazard factor" equal to the ratio between specific activity and $(MPC)_a$, as normalized to the value of ^7Be appearing in all the samples.

In the sample considered, it can be observed that the nuclide potentially most dangerous is ^{65}Zn, which however, was not found in significant amounts in any of the other samples. The remaining measurements of this set provided results practically similar to those already shown apart from our remarks about ^{65}Zn. The number of detectable nuclides as well as their concentration lowered as distance grew from the hottest points (e.g. the quench tanks), while ^7Be and ^{54}Mn were still found in concentrations not smaller than 10^{-2} and 10^{-4} μCi/g respectively. In some samples ^{46}Sc was also found in concentrations of the order of $2 \div 3 \times 10^{-5}$ μCi/g.

Another set of measurements refers to dust samples of rust from some iron parts of the accelerators. Table 3 shows the detected radionuclides and their specific activity. Besides, as in the preceding table, the $(MPC)_a$ and the relative hazard factor are shown. In this case, as easily predictable, the radionuclide found in the greatest amount clearly was ^{54}Mn.

Lastly, some samples of mixed material collected from the floor after some parts of the accelerator had been sawn and unsoldered were analysed. This material contained, besides dust and mould, various deposits and metal shavings. The results of these measurements are summarised in Table 4. On account of the characteristics of the material forming the samples, a comparison in terms of danger based upon $(MPC)_a$ was not considered meaningful.

It should be noted that many of the detected radionuclides were found in every analysed dust sample, which is consistent with the fact, already noticed,[1] that the main nuclides found in dust around high energy accelerators are

Table 2

Radionuclide	Half-life	Specific activity (μCi/g)	$(MPC)_a$[5] (μCi/cm^3)	Relative hazard factor
^{57}Co	270 days	2.3×10^{-4}	6×10^{-8}	0.10
^{51}Cr	27.8 days	1.2×10^{-4}	8×10^{-7}	0.004
^{7}Be	53.6 days	1.5×10^{-2}	4×10^{-7}	1
^{58}Co	71 days	7.4×10^{-4}	2×10^{-8}	0.99
^{54}Mn	280 days	$\sim 2.5 \times 10^{-4}$	1×10^{-8}	0.67
^{56}Co	77 days	$\sim 1 \times 10^{-4}$	?	?
^{65}Zn	245 days	7.6×10^{-3}	2×10^{-8}	10
^{59}Fe	45 days	$\sim 1.4 \times 10^{-5}$	2×10^{-8}	0.02
^{60}Co	5.24 yr	$\sim 3.9 \times 10^{-5}$	3×10^{-9}	0.35
^{22}Na	2.58 yr	$\sim 2.8 \times 10^{-5}$	3×10^{-9}	0.25

Table 3

Radionuclide	Half-life (days)	Specific activity (μCi/g)	$(MPC)_a$[5] (μCi/cm^3)	Relative hazard factor
^{51}Cr	27.8	4.0×10^{-3}	8×10^{-7}	0.46
^{7}Be	53.6	4.3×10^{-3}	4×10^{-7}	1
^{54}Mn	280	1.9×10^{-2}	1×10^{-8}	180
^{46}Sc	84	2.3×10^{-4}	8×10^{-9}	2.7
^{52}Mn	5.7	$\sim 7 \times 10^{-5}$	5×10^{-8}	0.13
^{48}V	16	2.5×10^{-4}	2×10^{-8}	1.2
^{56}Co	77	2.3×10^{-4}	?	?

produced in the materials forming them. Moreover, in our case, the presence of rust in the dust deposited on the floor is highly probable.

In general, as can be observed from the results shown above, the radionuclides most frequently found and in the largest amounts may be grouped in three different categories related to their origin. Beryllium-7 can be produced by oxygen and other light elements by photodisintegration. Manganese-54, ^{48}V, ^{46}Sc, etc. are produced by photonuclear reactions presumably starting from iron isotopes. Chromium-51, ^{48}V, ^{56}Co, ^{58}Co, ^{59}Co may be produced in the same way starting from chrome and nickel present in stainless steel. It is more difficult to explain the presence of ^{65}Zn in one single sample and in a considerable amount; the most probable assumption is that a few small fragments of zinc or bronze were contained in the sample.

Separate attention should be paid to radionuclides not detectable in our measuring conditions, that is to say those having a relatively short mean-life and those emitting γ-rays not exceeding 70 keV. While leaving out the former ones as well as those which might be produced in negligible amounts compared to detected radionuclides, we will consider the case of ^{55}Fe. This may be produced by means of a (γ, n) reaction starting from ^{56}Fe, from which also ^{54}Mn is obtained by means of a (γ, np) reaction. Fortunately, while the production envisaged by the (γ, n) reaction is 25 times larger than that due to the (γ, np) reaction, the $(MPC)_a$ for ^{55}Fe is about 30 times higher than that related to ^{54}Mn. It is therefore quite clear that the relative hazard is about the same for both radioisotopes.

Table 4

Radionuclide	Half-life	Specific activity (μCi/g)
^{57}Co	270 days	1.8×10^{-4}
^{51}Cr	27.8 days	6.7×10^{-4}
^{7}Be	53.6 days	1.6×10^{-3}
^{58}Co	71 days	5.9×10^{-5}
^{54}Mn	280 days	5.2×10^{-4}
^{56}Co	77 days	3.3×10^{-5}
^{46}Sc	84 days	8.5×10^{-6}
^{48}V	16 days	5.2×10^{-6}
^{59}Fe	45 days	4.8×10^{-6}
^{124}Sb	60 days	1.4×10^{-6}
^{60}Co	5.24 yr	3.7×10^{-6}
^{22}Na	2.58 yr	3.7×10^{-6}

As regards radiation protection aspects, it must be pointed out that the activities found are sufficiently low so as not to give rise to any special problem. Nevertheless, the places where the samples were collected were cleaned out and some of the persons who had most often worked there were precautionally submitted to a whole body counter check-up. No sign of internal contamination was of course found.

CONCLUSIONS

Internal contamination problems for persons working around accelerators do not seem particularly serious. Nevertheless, at least in the case of rather powerful accelerators, such problems do exist and, in our opinion, should be given closer attention than that received up to now, both at the preventive stage and regarding dosimetric survey. It should be considered in fact that our measurements, although carried out in perhaps not ideal conditions concerning the construction material and lining of the place involved, nevertheless refer to an accelerator

which has so far been operated with mean beam power much lower than the highest one (about 40 kW). In fact only for a few months before our measurements the accelerator had been operated at about 16 kW for no longer than 1 or 2 days weekly, while formerly the maximum power had been 5–6 kW for the same weekly amount. In the remaining time it had been used at low power as an injector for the Adone storage ring.

Regarding preventive measures it does not appear excessive to recommend, for example, more care in selecting the construction material and the covering for the place where the accelerator is to be installed, in order to reduce the forming of activated dusts and chiefly to allow the premises involved to be easily cleaned out. Lastly, as regards dosimetric survey, it does not seem superfluous to submit exposed workers to periodical check-ups, if only in order to reveal possible unsuspected contaminations.

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