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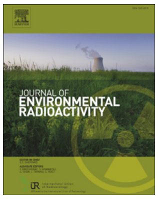

Long-term assessment of contaminated articles from the Chernobyl reactor

N. Alkhomashi [a, b, *], M.H.E. Monged [c]

[a] King Abdulaziz City for Science and Technology (KACST), P.O. Box 6086, Riyadh 11442, Saudi Arabia
[b] Department of Physics, University of Surrey, Guildford, GU2 7XH, UK
[c] RESTECH for Medical and Scientific Eqpt, Al-Khaleej Commercial Centre, Suites 140/141, P.O. BOX 484, Riyadh 11411, Saudi Arabia

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ABSTRACT

The Chernobyl accident caused a release of radioactive materials from the reactor into the environment. This event contaminated people, their surroundings and their personal property, especially in the zone around the reactor. Among the affected individuals were British students who were studying in Minsk and Kiev at the time of the Chernobyl accident. These students were exposed to external and internal radiation, and the individuals' articles of clothing were contaminated. The primary objective of this study was to analyze a sample of this contaminated clothing 20 years after the accident using three different detectors, namely, a BP4/4C scintillation detector, a Min-Con Geiger-Müller tube detector and a high-purity germanium (HPGe) detector. The clothing articles were initially assessed and found not to be significantly contaminated. However, there were several hot spots of contamination in various regions of the articles. The net count rates for these hot spots were in the range of 10.00 ± 3.16 c/s to 41.00 ± 6.40 c/s when the BP4/4C scintillation detector was used. The HPGe detector was used to identify the radionuclides present in the clothing, and the results indicated that the only active radionuclide was ^{137}Cs because of this isotope's long half-life.

1. Introduction

April 26, 2006, marked the 20th anniversary of the world's worst nuclear accident: the accident at the Chernobyl nuclear power station in Ukraine. This accident occurred in the fourth unit of the Chernobyl nuclear plant and destroyed the reactor core. Radioactive materials were released from the reactor and into the atmosphere for a duration of 10 days, and this release resulted in highly contaminated areas around the reactor, especially in the countries of Belarus, the Russian Federation and Ukraine (UNDP and UNICEF, 2002; IAEA, 2006a). In addition, large areas of Europe were also affected by various levels of contamination, depending on the direction of the winds and the levels of rain (IAEA, 2006a; Gould, 1990; Worley and Lewins, 1988).

The total release of radioactive substances was approximately 14 EBq (as of 26 April 1986), which included 1.8 EBq of ^{131}I, 0.085 EBq of ^{137}Cs and other cesium radioisotopes, 0.01 EBq of ^{90}Sr and 0.003 EBq of plutonium radioisotopes. Radioactive noble gases (mainly Kr and Xe) contributed approximately 50% of the total release of radioactivity (Worley and Lewins, 1988; IAEA, 2006a; UNSCEAR, 2000).

The major materials released included both fission-fragment radionuclides with short half-lives, such as ^{131}I, ^{95}Zr, ^{132}Te and ^{103}Ru, and fission-fragment radionuclides with long half-lives, such as ^{137}Cs and ^{90}Sr (Gould, 1990). In the short term, ^{131}I was the most dangerous radionuclide for the population because of this isotope's tendency to become concentrated in the thyroid gland. The major health impact of this radionuclide was thyroid cancer, which was observed predominantly among children (IAEA, 2006b; Kofler et al., 1986; Lynn et al., 1988; Rybakov et al., 2000). By contrast, ^{137}Cs, with a half-life of 30 years, was the most impactful radionuclide in the long term (NEA, 2002). Most of the strontium and plutonium radioisotopes were deposited close (less than 100 km) to the reactor because they were released as larger particles with limited mobility (IAEA, 2006b).

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* Corresponding author. King Abdulaziz University of Science and Technology (KACST), P.O. Box 6086, Riyadh 11442, Saudi Arabia. Tel.: +966 114814247; fax: +966 114814750.

E-mail addresses: khomashi@kacst.edu.sa (N. Alkhomashi), Monged79@gmail.com (M.H.E. Monged).

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The Chernobyl disaster also affected several British students near the exposed areas, predominantly in Minsk and Kiev. Consequently, the British Foreign and Commonwealth Office (FCO), after consultation with the National Radiological Protection Board (NRPB), decided to recall all British students. The initial monitoring of the students' thyroids and clothing was performed by the NRPB staff at Heathrow Airport, with the assistance of scientists from various universities (Holliday et al., 1986). A sample of the students' contaminated clothing was taken to the physics department at the University of Surrey for further analyses. The analysis results indicated that the clothing was not completely contaminated, but there were isolated hot spots in various regions of the selected articles of clothing (Jarvis, 1986).

The objective of this subsequent study was to investigate the contamination levels within the clothing 20 years after the Chernobyl accident. This task involved monitoring the clothing articles to locate hot spots, followed by further analysis of the hot spots using a high-purity germanium (HPGe) detector to identify the radionuclides present in the clothing and the radionuclides' activities. In addition, theoretical calculations of the radionuclide activities found in 1986 were also performed for comparison with the experimental results of the current study.

2. Experiment and methods

The initial monitoring of the contaminated clothing at the University of Surrey was performed on May 16, 1986, using an RM-25/BP7 combination detector. There were two major aspects of the analysis of the contaminated clothing: the monitoring of the clothing articles to locate hot spots and the use of gamma-ray spectroscopy to identify the radionuclides that were present and their activities.

The RM-25/BP7 apparatus is a large-area scintillation beta probe combined with an anthracene phosphor for the general-purpose monitoring of low-, medium- and high-energy beta radiation, with a 50 cm^2 window angled at 45° to the probe axis. It can also be calibrated using any beta source, and its efficiency for $^{90}Sr/^{90}Y$ beta surface emission is 41% (Thermo-scientific, 2006).

The hot spots within the clothing were located using a portable RM-25/BP4 combination detector, which indicated that there were several hot spots in various regions of the articles of clothing, with count rates in the range of 50 c/s to 500 c/s (Jarvis, 1986). It was also found that articles of clothing worn near the ground, such as socks and shoes, were the most contaminated items. In addition, high count rates were also observed in articles of clothing that were commonly in contact with outdoor objects, such as seats and walls. The main examples of such articles were the seats of trousers and the sleeves of jumpers (sweaters).

Among the students' clothing, approximately 1000 items were monitored using portable BP7 probes. These probes had been calibrated using a ^{90}Sr source such that 5 c/s corresponded to 1 Bq cm^{-2}. According to the published NRPB information, the acceptable level of contamination was defined to be 30 Bq cm^{-2}, equivalent to a count rate of 150 c/s from ^{90}Sr (Holliday et al., 1986). However, the acceptable count rate was intentionally restricted to 100 (c/s) because of uncertainties regarding the composition of the mixture of fission products.

The identification of the isotopes present in the contaminated clothing and their activities was performed using Ge (Li) detector gamma-ray spectroscopy. However, a hot spot within a white sport sock was the only region analyzed in that project.

In the current study, the number of monitored articles of clothing was 14. These articles were as follows: 1- a holdall (fabric bag), 2- a jumper (sweater), 3- a pair of trousers, 4- two pairs of socks and 5- three pairs of shoes. These articles were wrapped and stored in plastic bags until they were analyzed in 2006. The contamination survey was predominantly performed using two radiation monitors: a BP4/4C scintillation detector and a Mini-Con survey meter. The BP4/4C apparatus is a scintillation beta probe with high sensitivity to low-, medium- and high-energy beta radiation. The BP4 family of detectors offers the highest available efficiency for ^{14}C. Extra window protection can be obtained by increasing the window/grill spacing. This probe can be matched with any of Thermo's portable survey meters, such as the Electra or RM-25. The BP4 probe has a circular radiation window that suits 5 cm filter paper wipes. It can be calibrated using any beta source, and its efficiency for $^{90}Sr/^{90}Y$ beta surface emission is 27% (Thermo-scientific, 2006). The Mini-Con survey meter (Thermo-scientific, 2006) is a Geiger-Müller tube detector with a movable mica shield, which was closed to detect only gamma rays. In addition, an Electra contamination meter (Thermo-scientific, 2006) was utilized in a survey check before clothing monitoring was begun to provide initial estimates of the contamination levels.

The initial step was to record the background count rate in the working area using the contamination monitors: the BP4/4C detector and the Mini-Con survey meter. The contamination monitors were then calibrated to relate the count rate to the activity. Subsequently, the monitoring procedures were performed by dividing each of the articles of clothing into different regions and measuring the activity in each region. For example, each shoe was divided into upper and sole regions. The sole was further divided into three regions: toe, middle and heel. When using the BP4/4C detector, an appropriate jig was used to fix the probe position and to set a fixed distance between the probe and the clothing surface (approximately 1 cm).

For the identification of the radionuclides that were present and the quantification of their activities, a low-background high-purity germanium (HPGe) detector was used to analyze the gamma-ray spectra of the contaminated clothing and to identify the radionuclides present within the hot spots. The radionuclide activities within the articles of clothing were also determined, and the results were compared with the calculated data from 1986. The procedure was begun by recording the background spectrum and identifying all radionuclides and their count rates. The contaminated articles of clothing were then placed a suitable distance from the detector, and the spectrum for each article was acquired with a counting time of 24 h.

In this experiment, a coaxial HPGe detector with a crystal diameter of 48 mm and an operation voltage of +3000 V was used. The relative efficiency of this detector was 9.2% relative to a 3 × 3 NaI (Th) detector at 1332.5 keV for ^{60}Co. The energy calibration for HPGe detector gamma spectroscopy was performed using a ^{152}Eu source to cover energies in the range of 121.7 keV–1407.9 keV.

3. Results and discussion

3.1. Review of the 1986 data

3.1.1. Monitoring of students from Minsk and Kiev after the Chernobyl accident

The primary purpose of the monitoring was to provide reassurance to the students, as it was expected that the degree of contamination would be found to be at a level that would give no cause for concern. Thus, it was explained to the students that their thyroids would be checked for radioiodine and that their clothing would be monitored for radioactive contamination.

The levels of radioiodine in the students' thyroids were measured using a portable radiation monitor. The committed dose equivalents in the thyroid were calculated to be in the range of 4 mSv–14 mSv, or from 8% to 28% of the annual dose limit to the