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Editorial

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Sixty years ago the first nuclear accidents to cause serious radioactive contamination of the environment occurred at two military installations – one in the then USSR closely followed by a second in the UK. The quantities of radionuclides released during these accidents were large enough to require the implementation of countermeasures to limit the consequent doses received by members of the public.

At the Mayak nuclear complex in the Chelyabinsk Province of the Southern Urals of Russia, the cooling system in a highly radioactive liquid waste storage tank failed, which led to overheating of the tank contents. As a consequence, on 29 September 1957, a large chemical explosion occurred in the tank, forming an aerial plume of radioactive material that was blown to the northeast, contaminating an area stretching a substantial distance (~300 km, with a width ~50 km) beyond the Mayak site perimeter to create what became known as the East Urals Radioactive Trace (EURT) [1-8]. Radioactive contamination was sufficiently severe in the worst affected areas of the EURT to necessitate the eventual evacuation of 10,730 people,1154 within a fortnight of the accident because of high levels of environmental gamma radiation ("groundshine") from the deposition of relatively short-lived radionuclides (mainly ^{144}Ce+^{144}Pr and ^{95}Zr+^{95}Nb), and the remainder over the following two years because of the potential for unacceptable intakes of ^{90}Sr in locally sourced foodstuffs. This accident is usually referred to as the "Kyshtym Accident" because the town of Kyshtym is near Mayak, the establishment then being known cryptically as "Chelyabinsk-40" (and later "Chelyabinsk-65"). The primary purpose of Mayak was the extraction of weapons-grade plutonium from uranium fuel that had been irradiated in a nuclear reactor.

Then, less than a fortnight later, at Windscale Works, Sellafield, on the northwest coast of England, a low power annealing operation to release stored Wigner energy from the graphite moderator of an open-circuit air-cooled nuclear reactor (the "Windscale Pile No. 1") led to a fire in the core of the reactor, which came to be known as the "Windscale Fire" – the accident occurred almost exactly seven years after Windscale Pile No. 1 commenced operations. On 10-11 October 1957, substantial quantities of radioactive materials from the reactor fire were uncontrollably discharged to atmosphere through a 120 m high chimney. During the accident, radiation exposure of the public was assessed to be below the level that warranted the evacuation of communities in the vicinity of Sellafield, but the contamination of pasture by radioiodine was sufficient to require a hastily derived limit of ^{131}I ($t_{½}$ = 8 days) in milk of 0.1 μCi/L (3.7 kBq/L) to be established, with the objective of restricting doses to the thyroid glands of children to less than 20 rads

(200 mGy). The implementation of this limit resulted in a milk distribution ban eventually covering ~600 farms in an area ~500 km^2 around Sellafield, with the ban lasting six weeks for farms in the worst affected area [1, 9-12]. Like Mayak, the principal function of Windscale was the production of weapons-grade plutonium.

Arkadii Kruglov [13] describes the Kyshtym Accident thus:

> "Of the 20 MCi [740 PBq] of radionuclides contained in the tank, 18 MCi [666 PBq] were deposited within the limits of the [Mayak] production area, and 2 MCi [74 PBq] were dispersed over the area of the Chelyabinsk and Sverdlovsk Districts, known as the East Uralian fallout area of about 1000 km^2. An area of 200 km^2, including the East-Uralian State Reserve, was declared by a governmental decree as a protected zone. An area of 49.3 km^2 was allotted to the Experimental Research Test Station. The inspection conducted after the accident revealed that about 260,000 individuals residing in the contaminated area had received radiation doses exceeding the admissible yearly limit. More than 10,000 residents were moved from the most contaminated sites. More than 5,000 workers who were in the production area were subject to a one-shot exposure as high as 100 rem [1 Sv] within a few hours between the moment of explosion and the beginning of evacuation. In the course of remediation of the accident effects, in 1957-1959, nearly 30 thousand workers of the center, civil engineering builders, and military engineering troops received radiation doses above 25 rem [250 mSv]."

There can be no doubt from this description that the Kyshtym Accident at Mayak in 1957 was indeed serious, but the authorities in the USSR were keen to keep the existence of the accident secret and details only officially emerged from the USSR in 1989 [14]. During the intervening 32 years there was speculation in the West about the accident based on information from exiles and other unofficial sources. Some authors made a broadly correct assessment of the accident (e.g., Trabalka et al [15]), while others (e.g., Stratton et al [16]) were dismissive of the suggestion that a chemical explosion at Mayak had caused major radioactive contamination in the Southern Urals. In the summer of 1989, a detailed report of the accident appeared in a Russian-language open scientific journal [17] and the USSR formally communicated details of the Kyshtym Accident to the International Atomic Energy Agency (IAEA) [14]. The accident was the subject of a special session at an IAEA international symposium held in Vienna in November 1989, during which four papers covering various aspects of the accident were presented [2]. A description of the Kyshtym Accident was also provided in Annex B of the UNSCEAR 1993 Report [1].

The Kyshtym Accident has been retrospectively rated as Level 6 ("Serious Accident") on the 1-7 International Nuclear and Radiological Event Scale (INES) [18], although the activities of the released radionuclides, as presented by

Nikipelov et al [14, 17] and in the UNSCEAR 1993 Report [1], strongly suggest that the accident, together with the Chernobyl and Fukushima accidents, should actually be rated as INES Level 7 ("Major Accident").

Doses received by certain non-human biota close to Mayak from shorter-lived radionuclides in the initial period after the accident were high, with the death of pine trees occurring after doses of a few 10 Gy [7], leading to "red forests". Soil invertebrates in the most contaminated areas received doses up to ~100 Gy, and a decrease in numbers of some species was observed [7]. A radioecological reservation within the EURT was established in 1958, and since then data have been gathered on the transport of radionuclides in the environment and the response of the ecosystem to the accident (e.g., see [19, 20]).

In comparison with the extensive epidemiological studies of the population affected by the severe contamination of the Techa River by routine and accidental discharges of highly radioactive liquids from Mayak during 1949-1956, the potential health effects of the Kyshtym Accident have so far been paid little attention in the English-language scientific literature [21]. Nonetheless, it is apparent from several papers published a few years after the Kyshtym Accident was officially acknowledged that investigations into its potential health effects had been conducted during the era of the USSR [22-27]. A cohort of residents from the most contaminated EURT settlements has now been established, and a report has recently been published of work to reconstruct intakes of radionuclides, principally ^{90}Sr, with the intention of calculating internal doses for use in epidemiological studies [28].

In this issue of *Journal of Radiological Protection*, Akleyev et al [29] comprehensively review the work that has been carried out to investigate the various aspects of the Kyshtym Accident: the causes of the accident and the subsequent EURT formation, radiological protection and monitoring, reconstruction of external and internal doses, the health status of the EURT population and their offspring, and studies of the excess risk of cancer mortality and incidence as a result of radiation exposure due to the accident. This is a timely review and demonstrates that much has already been done in Russia in studying the Kyshtym Accident and its effects, and that international collaborative work is underway to extend these studies, which have the potential to enhance our knowledge of, *inter alia*, radioecology and health effects arising from protracted exposure to radiation (in particular, exposure from internally deposited ^{90}Sr).

Although the description of the Kyshtym Accident by Kruglov [13] (see above) suggests that occupational exposures during the emergency and recovery operations were substantial, the findings of any epidemiological studies of workers involved in the accident and its aftermath have yet to be published.

In contrast to the 1957 accident at Mayak, that at Windscale was examined in detail in the open literature soon after it had occurred (see the literature cited in [1, 9-12]). However, the reporting of the accident was not without its problems. The weapons material ^{210}Po was released during the fire, but although this was reported in some papers published soon after the accident (e.g., [10]), it was not done so consistently in the open literature until the review of Crick and Linsley [12]. The discharge of the weapons material tritium during the accident was not mentioned at all in the open literature until the paper of Crick and Linsley [12], although this release was of minor radiological significance [12]. Substantial efforts were made for the 50th anniversary of the fire to ensure that the quantities and timing of the discharges of radionuclides during the accident, and their subsequent travels, were understood as accurately as possible (see the literature cited in [11]).

The Windscale accident has been retrospectively rated as INES Level 5 (“Accident with Wider Consequences”) [18]. However, in the light of recent revisions of the estimates of the activities of the radionuclides released [30, 31], it is likely that INES Level 6 (“Serious Accident”) is a more appropriate rating, especially if the release of ^{210}Po during the accident is taken into account, which it was not in the original assessment [18]. Any amendment of the INES rating does not, in itself, imply that doses received from the accidental discharge have to be revised upwards since these were largely based on environmental monitoring rather than release estimates [12].

In the immediate aftermath of the Windscale accident a closed inquiry by a committee under the chairmanship of Sir William Penney was established by the UK Atomic Energy Authority (UKAEA), which was responsible for operations at Windscale Works at that time. The Penney Inquiry reported to the Chairman of the UKAEA before the end of October 1957, a remarkably swift response to the accident earlier that month, and the UKAEA (and the UK Ministry of Defence) advised the UK Prime Minister, Harold Macmillan, that the Penny Report could be made public. However, the UK Government was then involved in sensitive negotiations with the US Government to re-establish nuclear cooperation between the two countries. Macmillan found the Penney Report “fascinating” and “prepared with scrupulous honesty and even ruthlessness” [9], but he was of the firm opinion that the report should not be published because its revelations of various shortcomings leading up to the accident could, in his view, jeopardise the prospect of a positive outcome to the UK-US negotiations [9], an outcome that was indeed achieved the following year.

As a consequence, the Penney Report was not made public at the time, but was selectively summarised in a White Paper (“Cmnd. 302”) published in November 1957 [32], which is often referred to, erroneously, as the “Penney Report”. The full report of the Penney Inquiry remained security classified (as “Secret Atomic”), and therefore unavailable to the public, until it was declassified and released in January 1988 (under the “30-year rule”) at the then Public Records Office (now

The National Archives) [33]. Sixty years on from the production of the original Penney Report, it is reproduced in the current issue of *Journal of Radiological Protection* as a document of historical interest [34].

It might be thought that the Penney Report was withheld from public gaze partly because of what it said about the health consequences of exposure to the released radioactive materials. In fact, the report states (§100c) [33, 34]: “There has been no immediate damage to the health of any of the public or of the workers at Windscale, and it is most unlikely that any harmful effects will develop.” This conclusion was strongly endorsed by a subsequent report of the UK Medical Research Council, which was included in Cmnd. 302 [32]. As the understanding of the risks of radiation exposure has evolved, this position changed somewhat, such that in 1990 Roger Clarke tentatively suggested [35] that the releases during the fire may eventually cause ~100 fatal cancers (largely lung cancers due to inhalation of ^{210}Po) and ~100 non-fatal stochastic effects (~90 of which would be non-fatal cancers, mainly thyroid cancers resulting from intakes of ^{131}I); these predicted effects would occur throughout England over many years [12, 35].

It is to a high degree unlikely that such numbers of excess adverse health effects potentially arising in the general population as a result of the Windscale Fire could be discerned statistically against fluctuations in background disease levels, but if any effect is to be detected then the most likely candidate is an excess risk of thyroid cancer among those exposed to ^{131}I at a young age. The 1986 Chernobyl accident released ~1000 times more ^{131}I than the Windscale accident, and there is a clear excess risk of thyroid cancer among those living near Chernobyl who as young children received high thyroid doses (>1 Gy) as a result of drinking milk heavily contaminated with radioiodine [36]. However, the substantially lower level of discharge of ^{131}I at Windscale together with the local milk distribution ban led to much smaller thyroid doses as a consequence of the fire than those experienced by children around Chernobyl [12]. A preliminary investigation of thyroid cancer in northwest England found unusual temporal and geographical patterns of incidence, but the nature of these patterns imply that they are most unlikely to be attributable to the Windscale Fire and that other factors are responsible [37]. The UK Committee on Medical Aspects of Radiation in the Environment (COMARE) has recommended further investigations of thyroid cancer among those born in Cumbria during the 1950s to examine incidence in the group predicted to have the highest risk of thyroid cancer from the accident [38].

Mortality and cancer incidence among the 471 Sellafield workers known to be involved in fighting the fire or in clean-up operations have been studied [39]. The relatively small number of Windscale Fire workers together with the low mean recorded external dose of 6 mSv received during October 1957 compared to the mean lifetime recorded occupational dose from external sources for these workers of 320 mSv leads to low statistical power to detect any effect of the accident, although it should be borne in mind that other doses (e.g., from intakes of radionuclides) will have been received as a result of the fire. The study did not find evidence of an influence of the fire upon the health of those workers involved in the accident. For example, the rate of cancer mortality (based on 83 deaths) experienced by the Windscale Fire workers in the 50 years following the accident was statistically non-significantly less than that (based on 150 deaths) of 2926 workers employed at the Sellafield complex in October 1957 but not directly involved in fighting the fire or in recovery operations. The study shows that any effect of the accident at Windscale upon the health of the workers involved is not discernible.

That the first two nuclear accidents having serious off-site consequences happened within two weeks of each other seems a rather remarkable coincidence, particularly when the next such accident – the Chernobyl accident in 1986 – occurred nearly 30 years later. Is this just a fluke or does the closeness in time of these two accidents point to some underlying commonality? Recall that the accidents took place at the first weapons plutonium production installations in the former USSR and the UK, that there was substantial governmental pressure to produce plutonium quickly to build up the nuclear weapons arsenals of these two countries, and that the constituent plants of the two sites had been hastily constructed and were being operated approximately in parallel under conditions that would not be acceptable today [40]. Undoubtedly, in these circumstances, it is not surprising that major problems arose at an early stage in operations at the installations, and continued to do so. Matters were made worse when plants that had fulfilled their original objectives continued to be run for longer than was prudent, and accidents were just waiting to happen [9, 13]. Perhaps it is not too surprising that the two serious accidents occurred ten years after construction of the installations began and when operations had been underway for more than half a decade, by which time luck was running out. Nonetheless, the coincidence of two serious accidents within a fortnight is still pretty extraordinary. Certainly, the operational and regulatory structure of the nuclear industry in the UK changed substantially in the wake of the Windscale Fire [9], and it would seem that safety at nuclear installations in the former USSR improved in the late-1950s [13], presumably at least partly due to the Kyshtym Accident. Unfortunately, the lessons learnt from these early accidents have not prevented major nuclear accidents in later years, the Chernobyl and Fukushima accidents being notable examples [41], illustrating the need for constant vigilance to counter the beguiling influence of familiarity and consequent complacency about safety. As George Santayana wisely noted, “Those who cannot remember the past are condemned to repeat it.” [42].

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