**Radionuclide Observables for the Platte Underground Nuclear Explosive Test
on 14 April 1962**

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Abstract

Past nuclear weapon explosive tests provide invaluable information for understanding the radionuclide observables expected during an On-site Inspection (OSI) for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). These radioactive signatures are complex and subject to spatial and temporal variability. The Platte Underground Nuclear Explosive Test on 14 April 1962 provides extensive environmental monitoring data that can be modelled and used to calculate the maximum time available for detection of the OSI-relevant radionuclides. The 1.6 kT test is especially useful as it released the highest amounts of recorded activity during Operation Nougat at the Nevada Test Site – now known as the Nevada National Security Site (NNSS). It has been estimated that 0.36% of the activity was released, and dispersed in a northerly direction. The deposition ranged from 1×10^{-11} to 1×10^{-9} of the atmospheric release (per m^2), and has been used in this paper to evaluate an OSI and the OSI-relevant radionuclides at 1 week to 2 years post-detonation. Radioactive decay reduces the activity of the OSI-relevant radionuclides by 99.7% within 2 years of detonation, such that detection throughout the hypothesized inspection is only achievable close to the explosion where deposition was highest.

Keywords: Underground nuclear explosion, OSI, CTBT, Platte

1. Introduction

On 2 October 1992, the President of the United States signed into law the unilateral declaration to forego full-scale nuclear weapons testing. On 24 September 1996, the United States became the first country to sign the Comprehensive Nuclear-Test-Ban Treaty (CTBT). This effectively drew to a close the US nuclear explosive test program, which between 1945 to 1992 undertook 1,054 tests [1]. Of these, 215 were undertaken in the atmosphere, underwater or space and 839 underground [1-2]. Their purpose was to underpin the nuclear arsenal and assess weapon effects. From 1952 onwards, 928 tests took place at the Nevada Test Site - now known as the Nevada National Security Site (NNSS, Nevada, USA) of which 828 were underground [1]. During the period 31 October 1958 to 15 September 1961, the US observed a de facto nuclear explosion testing moratorium, although this ended following testing by the Soviet Union on 1 September 1961. The return to testing provides a useful case-study for assessing the radionuclide observables for a CTBT On-site Inspection (OSI). This is because it heralded a new era of underground tests (UGTs) that have become a technical focal point for CTBT verification and ratification.

The first UGT series was Operation Nougat (15 September 1961 to 30 June 1962), consisting of 44 low-yield (<67 kT) tests [1]. The impetus had been the growing concerns from radioactive fallout from earlier tests (although the Pacific Operation Dominic atmospheric tests would follow in 1962). The Operation Nougat series was performed at the NTS, in a combination of tunnels and wells design to minimize exposures to populated offsite areas [3]. Whilst one test deliberately vented as part of a cratering experiment (Danny Boy), only six released radioactivity detectable outside the NTS. Included in this number, was the 1.6 kT Platte test on 14 April 1962 [3-4]. The test was designed to test yield reproducibility, buried within a hillside (37.22203, -116.15744) at a depth of 170.7 m (see online video). The subsequent release of radioactivity was the highest detected during Operation Nougat. Platte remains especially useful for understanding radionuclide observables due to the comprehensive radiological

surveillance [3]. This provides useful data for modelling expected activity levels could be detected during an OSI for a similarly low-yield nuclear explosive test.

An OSI is a key component of the CTBT verification regime and aims to clarify whether a nuclear explosion has been carried out in violation of the Treaty [5-7]. The objective of the OSI is to gather any facts that might assist in determining if a nuclear explosion took place and identifying any possible violator. This includes the measurement of “radionuclides of interest for OSI” including ^{95}Zr , ^{95}Nb , ^{99}Mo , $^{99\text{m}}\text{Tc}$, ^{103}Ru , ^{106}Rh , ^{132}Te , ^{131}I , ^{132}I , ^{134}Cs , ^{137}Cs , ^{140}Ba , ^{140}La , ^{141}Ce , ^{144}Ce , ^{144}Pr and ^{147}Nd . These 17 radionuclides are particulate in nature with half-lives ranging from 17.3 m to 30.1 y. Four gaseous “radionuclides of interest for OSI” also exist ($^{131\text{m}}\text{Xe}$, ^{133}Xe , $^{133\text{m}}\text{Xe}$, ^{37}Ar) with half-lives of 2.2 to 35 days. These radionuclides are produced from a nuclear explosion, either as fission or activation products, and allow discrimination of a nuclear explosive test from other radiation sources, such as reactor incidents or releases, nuclear waste and medical isotopes. This paper is intended to use data from a nuclear test to provide partial validation of the relevance of selected particulate radionuclides to OSI. The “radionuclides of interest for OSI” (hereafter referred to as “OSI-relevant radionuclides”) were chosen so as to encompass an OSI timeframe from one week to two years after an alleged nuclear explosion [8]. When used in combinations they can also provide timing information (e.g. $^{95}\text{Zr}/^{95}\text{Nb}$, $^{140}\text{La}/^{140}\text{Ba}$) or differentiation from reactor accidents ($^{137}\text{Cs}/^{134}\text{Cs}$). The concise list has been designed to avoid disclosure of information not related to the OSI.

This research examines the Platte test and the radionuclide observables produced. The work is underpinned by a model that incorporates radionuclide production, radioactive decay, venting, atmospheric dispersion and deposition, sampling and measurement [9].

2. Modelling

2.1. The Platte test

The Platte test was detonated at 1800 GMT on 14 April 1962. The test was located in a tunnel at a depth of 170.7 m within the weakly consolidated tuff of a hillside. Venting occurred within 1.5 seconds of detonation, through the tunnel portal, fissures and vent hole [10]. A persistent cloud was produced containing appreciable amounts of radionuclide particulates including $^{95}\text{Zr}/^{95}\text{Nb}$, ^{103}Ru , ^{105}Ru , ^{131}I , ^{133}I , ^{135}I , ^{132}Te , $^{140}\text{Ba}/^{140}\text{La}$, ^{141}Ce and ^{144}Ce . The estimated total release at 1 minute after detonation was 1.85×10^{18} Bq [10]. The released cloud obtained a height of 2438 m and drifted in a northerly direction at a bearing of 20 degrees [11]. At a distance of 60 km the airborne gross β -activity was 1.37×10^3 Bq m^{-3} and the maximum distance radiation was detected was up to 200 km [10]. The highest concentration of iodine isotopes was observed during Operation Nougat, with activities of 119 Bq m^{-3} (^{131}I), 651 Bq m^{-3} (^{133}I) and 703 Bq m^{-3} (^{135}I) at 2050 – 2340 on 14 April 1962 [3]. No further releases were noted during post-shot drilling or tunnel re-entry operations [10]. The device yield was later re-tested at the Des Moines test on 13 June 1962, which also vented [12-13].

2.2. Yield

An explosive yield of 1.6 kT was reported for the Platte test. This is a measure of explosive energy discharged from the test detonation measured in trinitrotoluene (TNT) equivalents. An initial value of 1.85 kT [11] was revised to assist seismological detection of underground tests [4]. As one kT is equivalent to 1.45×10^{23} fissions, and if the fission probability of a particular fission product is f , and its decay constant is $\lambda \text{ s}^{-1}$, its activity following a 1 kT nuclear explosion is $1.45 \times 10^{23} f\lambda$ Bq [14]. Using

fission product yield data [15] it is therefore possible to calculate the initial inventory for iodine isotopes and the OSI-relevant radionuclides for the 1.6 kT Platte test (Table 1).

All of the radionuclides shown in Table 1 are produced by fission with exception of ^{134}Cs and gaseous ^{37}Ar which are produced predominantly by neutron capture. Although a small amount of ^{134}Cs is produced during a nuclear explosion due to a low fission yield (0.0000279% per fission), its production is predominantly by neutron capture of ^{133}Cs ($^{133}\text{Cs}(n, \gamma)^{134}\text{Cs}$) which accumulates in a nuclear reactor [16]. Its addition to the OSI-relevant radionuclides list allows differentiation between nuclear explosions and reactor accidents, and is used in conjunction with ^{137}Cs to provide a ratio to ensure nuclear explosions occurring prior to the CTBT entry into force are not mistakenly identified as possible Treaty violations [17]. The ^{37}Ar is produced by the neutron activation of environmental calcium ($^{40}\text{Ca}(n, \alpha)^{37}\text{Ar}$) in the surrounding soils and rocks. Their activity can be derived by direct linear scaling of reported test values [18].

2.3. Containment

The reported Platte iodine release concentrations [3] provide the basis for estimating the extent of containment. This is a function of various parameters, including yield, burial depth and geological factors such as rock strength, porosity, water content, carbonate and iron content, and the ability of the compressed rock to form a containment cage around the cavity after detonation [13]. Visual observations during the Platte test indicated the formation of fissures through which radioactive material vented. Stemming measures which are intended to prevent the emplacement hole becoming a venting pathway were also not successful. Both are escape paths typical of an underground nuclear explosion (Fig. 1). A quantitative assessment of the containment can be made using the initial and reported iodine concentrations, once corrections for atmospheric dispersion and dilution have been undertaken.

2.4. Dispersion and deposition

After venting, radionuclide concentrations vary spatially and temporarily due to atmospheric mixing processes. Radioactive decay also acts to reduce radioactivity, with short-lived fission products disappearing quickly (although they may have longer-lived progeny). Deposition such as gravitational settling, diffusion and turbulent transport are also significant [20]. The extent of dispersion and deposition can be estimated using the HYbrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Table 2). This uses a combined Lagrangian and Eulerian approach, where advection and diffusion calculations are made in a moving frame of reference from their initial venting location, with radionuclide concentrations calculated on a fixed three-dimensional grid as a frame of reference [21,22]. The model uses the actual meteorological data corresponding to the event in April 1962.

3. Results and discussion

3.1. Release and Dispersion

The Platte device produced 7.28×10^{18} Bq of OSI-relevant particulate radionuclides. The amount released can be estimated using the iodine isotopes (^{131}I , ^{133}I , ^{135}I) measured at 2050 – 2340 on 14 April 1962. This requires an estimation of the dispersion due to atmospheric mixing that occurred prior to the measurement. This has been estimated using the HYSPLIT model (Fig. 2) and shows excellent agreement with reported observations. The cloud drifted north [10] at about 18 miles hour⁻¹ crossing Highway 25 (now numbered as Nevada State Route 375 and known as the Extraterrestrial Highway) near Queen City Summit [3]. It is at the summit where the highest iodine concentrations were recorded. According to the model, these would be diluted by a factor of 1×10^{-12} . Applying this factor and decay correcting from the mid-point of sample collection at 2215 GMT to the test detonation at 1800 GMT gives concentrations of

1.21 x 10¹⁴, 7.50 x 10¹⁴ and 1.10 x 10¹⁵ Bq m⁻³ for ¹³¹I, ¹³³I and ¹³⁵I. Comparing these concentrations to the initial inventory (Table 1), and correcting for ¹³¹Te, ¹³³Te and ¹³⁵Te decay and ¹³¹I, ¹³³I and ¹³⁵I ingrowth, gives release values of 0.75%, 0.43% and 0.31%. A ¹³²Te value is also reported near Queen City Summit of 100.27 Bq m⁻³ [3] which can be used to calculate a release of 0.34%.

Whilst ¹³³I (0.43%), ¹³⁵I (0.31%) and ¹³²Te (0.34%) are in good agreement, the ¹³¹I is higher than expected. This may be attributable to the difference in gamma-energy of ¹³¹I (364.5 keV) compared to ¹³³I (529.9 keV) and ¹³⁵I (1260.4 keV). The lower energy can be problematic due to the effects of Compton scattering in samples containing a mixture of fission products. Other radionuclides, such as ¹³²Te/¹³²I and ¹⁴⁰Ba/¹⁴⁰La which were present (but not quantitatively reported) on the filter measured at Queen City Summit [3] emit multiple gamma-rays in cascade, causing significant elevation of the Compton continuum at lower energies. This has been shown to degrade ¹³¹I measurement, including in air filter samples collected after the 11 March 2011 Fukushima nuclear reactor incident in Japan [23]. A correction may also be required for ^{131m}Te interference at 364.5 keV (although gamma abundance is low at 1.2%). If ¹³¹I is anomalous, the average containment can be calculated from ¹³³I, ¹³⁵I and ¹³²Te as 0.36%. Assuming a 0.36% release and a dilution factor of 1 x 10⁻¹², this would result in a ^{131m}Te air concentration of approximately 4451 Bq m⁻³ at the sampling time.

The iodine and tellurium isotopes can be used to estimate containment as both are volatile [24] and are vaporized during the nuclear explosion. The presence of ¹³²Te indicates that the iodine isotopes (¹³¹I, ¹³³I and ¹³⁵I) were not separated from their tellurium isotope precursors (¹³¹Te, ¹³³Te and ¹³⁵Te). Whilst iodine fractionation has been observed for other NTS tests [25], the prompt release of the Platte test through the tunnel portal, fissures and vent hole [10] would have been initially unfractionated. The radioactive cloud was also noted to contain both gaseous and particulate material [3]. Using this assumption and a release of 0.36% allows the concentration of the particulate OSI-relevant radionuclides to be calculated at Queen City Summit during 2050 – 2340 on 14 April 1962 (see table insert of Fig. 2). These concentrations range

from 0.04 to 1110.7 Bq m⁻³ with the five main isotopes as ¹³²I (1110.7 Bq m⁻³), ^{99m}Tc (910.9 Bq m⁻³), ¹⁴⁰La (199.7 Bq m⁻³), ⁹⁹Mo (139.4 Bq m⁻³) and ¹³²Te (103.7 Bq m⁻³).

The concentration of OSI-relevant radionuclides provides a simplified scenario without considering the effects of fractionation. As iodine was detected in gamma-spectrometry measurements at Queen City Summit, it indicates a change from gaseous to solid phase most likely associated with attachment to aerosols [26]. In reality fractionation may alter the relative activities of refractory (R) and volatile (V) radionuclides in close proximity fallout by a factor of 3-4 compared with initial atmospheric concentrations [24, 27]. This occurs as the high-boiling point refractory radionuclides condense first at 1500 - 3000°C and deposit closer to the explosion due to their higher settling velocities [27]. In contrast, the volatile radionuclides only condense as the cloud cools further and approaches temperatures of ~ 50°C. Although the fractionation process is complex and not fully understood [27-31], the reduction in refractory OSI-relevant radionuclides (⁹⁵Zr, ⁹⁵Nb, ⁹⁹Mo, ^{99m}Tc, ¹⁴⁴Ce, ¹⁴⁴Pr, ¹⁴⁷Pr) could be estimated by a factor of 0.37 [24]. This reduction factor would be higher for non-prompt releases (e.g. late seeps) as the soil column acts to filter the more refractory radionuclides [28]. Notably, in both unfractionated and fractionated instances, the ⁹⁹Mo concentration exceeds the 10 µBq m⁻³ minimum detectable activity (MDA) requirement for radionuclide monitoring stations that are part of the CTBT International Monitoring System [32].

3.2. Deposited activity

As the Platte cloud drifted from the test location, particulates would have been deposited. This would have included OSI-relevant radionuclides whose detection is used for identifying possible CTBT violations [5-7]. This surface footprint can be calculated using the HYSPLIT model (Fig. 3) and follows the plume dispersion towards Queen City Summit (Fig. 2). At this location the deposited activity ranged from 0.4 to 11107.4 Bq m⁻² (see table insert of Fig. 3) with the same five main OSI-relevant isotopes of

^{132}I (11107.4 Bq m⁻²), $^{99\text{m}}\text{Tc}$ (9109.2 Bq m⁻²), ^{140}La (1997.2 Bq m⁻²), ^{99}Mo (1393.9 Bq m⁻²) and ^{132}Te (1036.5 Bq m⁻²). Regrettably there was no routine soil and vegetation sampling undertaken during Operation Nougat [3] for comparison with the predicted deposition. Only ad hoc soil samples were taken at Queen City Summit that contained trace amounts of fission products. A qualitative grab sample of vegetation contained 0.48 Bq kg⁻¹ ^{133}I , 0.22 Bq kg⁻¹ ^{131}I and 0.15 Bq kg⁻¹ of ^{132}Te and a water sample (decay corrected to deposition time) contained 10539.3 Bq l⁻¹ ^{133}I and 4054.3 Bq l⁻¹ ^{132}Te . Both samples contained radionuclides in agreement with the released activity, and the water sample activity was consistent with deposition over a 2 – 4 m² area.

3.3. On-site Inspection

A 1000 km² area may be selected for an OSI of a suspected nuclear explosive test [6]. Two hypothetical inspection areas were selected for this paper at the location of the Platte test for assessment of the types of activities that might be present during an OSI. Area A is located close to the test location (and ignores sampling at the tunnel portal, fissures and vent hole) and includes the highest deposition rates of 1 x 10⁻⁹ (covering 10.2% of the area and ranging from 1 x 10⁻¹¹ to 1 x 10⁻⁹). Area B is located at Queen City Summit (63 km from the test location) and includes the lowest deposition rates of 1 x 10⁻¹¹ (covering 9.4% of the area). At both locations, the activity of deposited OSI-relevant radionuclides can be calculated during the inspection period occurring up to 2 years after the test (Fig. 4) using the initial inventory (Table 1), the estimated dispersion (Fig. 2) and deposition (Fig. 3). The effects of rainfall, resuspension, bioturbation and other site disturbances are not included for simplification purposes. Radionuclide activity differs by two orders of magnitude between the areas, with a changing composition with time as the shorter half-life radionuclides (e.g. $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$, $^{132}\text{Te}/^{132}\text{I}$, ^{131}I) decay and the longer half-life radionuclides (e.g. ^{137}Cs , $^{144}\text{Ce}/^{144}\text{Pr}$) persist. Over a period of one week to two years after the test, the total activity attributable to OSI-relevant radionuclides decreases by 99.7%.

To assess the detection probability for OSI Area A and B, the MDA for measurements during the CTBT Integrated Field Exercise 2014 (IFE14) in Jordan were used [33]. IFE14 was a major exercise that simulated the undertaking of an OSI for a fictitious nuclear explosion [5]. The MDA values were from soil samples collected using OSI surface-soil techniques [34] and measured using gamma-spectrometry for 50,000 – 60,000 seconds. At OSI Area A it is possible to detect OSI-relevant radionuclides throughout a 2 year period after the test. Four radionuclides remain detectable including ^{95}Nb , ^{106}Rh , ^{137}Cs and ^{144}Ce . Importantly ^{95}Nb can be used in conjunction with ^{95}Zr (detectable for much of the time period) for dating a nuclear event [35, 36]. This compares to OSI Area B where there would be no OSI-relevant radionuclides detectable after 316 days. The days available for measurement were also typically half of OSI Area A. At this location, the longer-lived ^{106}Rh , ^{137}Cs and $^{144}\text{Ce}/^{144}\text{Pr}$ were undetectable throughout a period of one week to two years after the test. Detection of the refractory radionuclides such as $^{95}\text{Zr}/^{95}\text{Nb}$, would be reduced further at Area B by fractionation effects which increase with distance [27].

4. Conclusions

Environmental monitoring data from the US nuclear weapon explosive test program is useful for understanding the radionuclide observables and validating relevance for certain radionuclides for a CTBT OSI. This important legacy has been demonstrated with the Platte test of 14 April 1962 at the NTS. The 1.6 kT test produced 7.28×10^{18} Bq of particulate OSI-relevant radionuclides and it has been estimated that 0.36% of the inventory was released. The activity was dispersed in a northerly direction, which is in agreement with observations at Queen City Summit located 63 km from the explosion. The deposition ranged from 1×10^{-11} to 1×10^{-9} of the atmospheric release (per m^2) at two locations and this was used to calculate the maximum time available for detection of OSI-relevant radionuclides at 1 week to 2 years post-detonation. Detection of OSI-relevant radionuclides for a period of 2 years after the test was only possible close to the explosion, where deposition was highest and activity was above MDA. The composition of the deposition is dynamic and reduced by 99.7% due to radioactive decay over 2 years.

This analysis shows the value of using historical data to understand spatial and temporal limits during an OSI as well as validate the selection of the OSI-relevant radionuclides.

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Table captions

Table 1. Radionuclide inventory of the Platte test. Iodine isotopes are shown in addition to the 17 particulate and four gaseous OSI-relevant radionuclides. Each radionuclide is categorized as volatile (V), refractory (R) or intermediate (V-R). The activity of fission products has been calculated using fission product yields per 100 fissions for ^{239}Pu pooled fast neutron fission decay.

Table 2. HYSPLIT model parameters. The release top is the height the plume obtained [10].

Table 3. Maximum time available (days) for gamma-spectrometry measurements at OSI Area A and B. After these durations the deposited activity has decayed below the MDA. Radionuclides that are detectable throughout the 2 year period are denoted by (>) and undetectable by (--). The measurement of ^{134}Cs has not been included as it is mainly produced by neutron capture in a nuclear reactor.

Figure captions

Fig. 1. Escape paths of radioactive material to the surface (not to scale). Modified after [19].

Fig. 2. Predicted dispersion of the Platte Test release using the HYSPLIT model. The table gives modeled concentrations for OSI-relevant radionuclides at Queen City Summit during 2050 – 2340 on 14 April 1962. The shaded regions are fractional amounts of the initial release. Roads are shown by the grey lines.

Fig. 3. Predicted deposition of the Platte Test release using the HYSPLIT model. The area covered is approximately 337 km² and the shaded regions are fractional amounts of the initial atmospheric release. Two potential OSI inspection areas (A and B) are also indicated. The table gives predicted concentrations for OSI-relevant radionuclides at Queen City Summit during 2050 – 2340 on 14 April 1962.

388

389 Fig. 4. Predicted deposited activity of the Platte Test release at OSI Area A and B. The difference in
390 activity is two orders of magnitude and shown by the respective axis. The shorter half-life ^{95}Nb , ^{144}Pr ,
391 $^{99\text{m}}\text{Tc}$, ^{132}I and ^{140}La are not shown as they quickly attain equilibrium with their parent ^{95}Zr , ^{144}Ce , ^{99}Mo ,
392 ^{132}Te and ^{140}Ba .

393

394 Video caption

395

396 The Platte underground nuclear explosive test on 14 April 1962.

397

TABLE 1

Nuclide	Half-life (Days)	Energy (keV)	Abundance (%)	Ind. Yield	Cum. Yield	Volatile or Refractory	Activity (Bq)
¹³¹ I	8.02	364.5	81.7	2.01×10^{-2}	3.88	V	9.00×10^{15}
¹³³ I	0.87	529.9	86.3	1.30	6.91	V	1.48×10^{17}
¹³⁵ I	0.27	1260.4	28.9	3.92	6.08	V	4.13×10^{17}
⁹⁵ Zr	64.03	756.7	54.4	9.30×10^{-2}	4.67	R	1.36×10^{15}
⁹⁵ Nb	34.99	765.8	99.8	1.92×10^{-4}	4.67	R	2.48×10^{15}
⁹⁹ Mo	2.75	739.5	12.1	1.31×10^{-2}	5.98	R	4.05×10^{16}
^{99m} Tc	0.25	140.5	89.1	1.49×10^{-6}	5.26	R	3.91×10^{17}
¹⁰³ Ru	39.26	497.1	91.0	1.29×10^{-3}	6.83	V	3.24×10^{15}
¹⁰⁶ Rh	373.61	621.9	9.9	3.85×10^{-1}	4.36	V	2.18×10^{14}
¹³¹ I	8.02	364.5	81.7	2.01×10^{-2}	3.88	V	9.00×10^{15}
¹³² Te	3.20	228.2	88.0	3.00	5.15	V	2.99×10^{16}
¹³² I	0.10	667.7	98.7	1.74×10^{-1}	5.33	V	1.04×10^{18}
¹³⁴ Cs	754.17	604.7	97.6	Activation	Activation	V	9.78×10^{11}
¹³⁷ Cs	10972.22	661.7	85.1	1.00	6.58	V	1.11×10^{13}
¹⁴⁰ Ba	12.75	537.3	24.4	9.17×10^{-1}	5.32	V-R	7.76×10^{15}
¹⁴⁰ La	1.68	1596.2	95.4	9.87×10^{-3}	5.33	V-R	5.91×10^{16}
¹⁴¹ Ce	32.51	145.4	48.3	2.46×10^{-4}	5.15	V-R	2.95×10^{15}
¹⁴⁴ Ce	284.95	133.5	11.1	1.64×10^{-1}	3.67	R	2.40×10^{14}
¹⁴⁴ Pr	0.01	696.5	1.3	5.10×10^{-5}	3.67	R	5.69×10^{18}
¹⁴⁷ Nd	10.98	91.1	27.9	1.72×10^{-3}	1.99	R	3.37×10^{15}
³⁷ Ar	35.01	-	-	Activation	Activation	V	4.89×10^{12}
^{131m} Xe	11.8	-	-	2.67×10^{-5}	5.43×10^{-2}	V	8.54×10^{13}
¹³³ Xe	5.2	-	-	1.58×10^{-2}	6.97	V	2.47×10^{16}
^{133m} Xe	2.2	-	-	4.65×10^{-2}	2.40×10^{-1}	V	2.03×10^{15}

TABLE 2

Parameter	Value	Comments
Release top	524 m	Top height of the pollutant source
Release bottom	0 m	Bottom height of the pollutant source
Release duration	10 min	Duration of venting
Runtime duration	3 hours	Duration of model calculation
Meteorology	REANALYSIS	NCEP/NCAR Reanalysis Project
Dry deposition velocity	0.001 ms ⁻¹	

TABLE 3

Nuclide	MDA (Bq m ⁻²)	Days	
		A	B
⁹⁵ Zr	4.7	642	217
⁹⁵ Nb	3.5	>	316
⁹⁹ Mo	26.5	35	16
^{99m} Tc	9.9	38	20
¹⁰³ Ru	3.0	468	208
¹⁰⁶ Rh	24.9	>	--
¹³¹ I	3.6	106	53
¹³² Te	4.3	47	26
¹³² I	3.2	49	28
¹³⁷ Cs	3.3	>	--
¹⁴⁰ Ba	11.4	144	59
¹⁴⁰ La	2.6	174	89
¹⁴¹ Ce	7.2	343	127
¹⁴⁴ Ce	31.9	>	--
¹⁴⁴ Pr	189.6	623	--
¹⁴⁷ Nd	17.5	104	31

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4