Melting of 137 Cs and 60 Co sources in a steel plant: remediation and environmental monitoring

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The Accident

In early May 1997, two radioactive sources were accidentally melted in a steel factory located to the south-west of Brescia, Italy. The melting of the radioactive sources was discovered a few days after the incident, when a load of contaminated dust was tested for radioactivity at the industrial waste facility where the flue ashes were to be processed and disposed of. The load was rejected and sent back because of ^{137}Cs contamination. The steel company management submitted samples of dust for gamma-ray spectrometry analysis at the Department of Engineering of Milan University, where the event was confirmed (^{137}Cs concentrations of 144600 Bq/kg were found).

The local Health Authorities were alerted, and the first investigation of the steel plant, which has two melting lines equipped with electric furnaces each with a capacity of 70 tons of metal scrap, led to the discovery that only one production line was contaminated, but also that steel contaminated with ^{60}Co had been produced in the previous few days and some of it had already been sold. The two melting events probably occurred at the same time or within a few days of each other.

While the contamination with ^{137}Cs was certainly due to an incorrectly or unlawfully disposed of source, the contaminated steel could have derived either from a ^{60}Co source or from the melting of considerable amounts of contaminated steel scrap, for example 10 tons of scrap with a concentration of 10^5 Bq/kg.

An accurate radiation protection survey of all potentially contaminated workers was carried out by experts from the local Department of Medicine. The checks included Whole Body Counter measurements and radio-toxicological analyses, and it was concluded that none of the workers showed any signs of medical consequences.

Actions Taken by the Local Authorities

After notification of the accident, the following actions were taken because of the considerable amount of contaminated materials and the levels of radioactivity detected in the first samples analysed:

- A stop to the production of steel in the contaminated furnace and a stop to all processing of the steel produced.
- A stop to the sale of steel produced during the accident and in the next few days.
- Environmental monitoring of water, soil and vegetation in the area around the plant (see Table A).
- Collection of different types of samples inside the plant, including soil, water, mud, air, by-products, ingots, rods (see Table B).
- Immediate information to the workers and to the neighbouring residents about the incident and the actions taken to control and limit the consequences, followed by scheduled meetings during and after remediation.
- Recovery of the steel already sold and transported to other Italian regions, after evaluation of the risk connected with the transportation; fortunately, only the least contaminated steel had been sold.
- An urgent ordinance for remediation of the whole contaminated line, including the air filtering system. A committee of Local Authorities and experts approved the remediation plan proposed by a specialized company.

Environmental Monitoring

The population in the area surrounding the steel plant increased from the original 5,000 to 50,000 following approval of a new official town planning scheme in the 1970s. It was therefore essential that the level of possible spread of contamination be determined as soon as possible. The first action taken was an extended two-day monitoring campaign, which included hundreds of exposure rate measurements and the collection of a total of 32 samples of soil, vegetation and deposited dust. The collected samples are listed in Table A. Except for one of them, the levels of ^{137}Cs contamination were similar to those normally obtained in the same type of matrix due to the Chernobyl event, with values of the order of a few tens of Bq/kg. Based on the presence of measurable amounts of ^{134}Cs in four of them, the low level of ^{137}Cs concentration and the measured exposure rates, contamination outside the steel mill was ruled out. As expected, ^{60}Co was not found in any of the samples.

Table A - Samples collected for environmental monitoring

	No. of samples		
	Immediately after the accident	During remediation	After remediation
Vegetation and grass	9	15	9
Deposited dust, mud and soil	23	15	17

In the meantime, in order to evaluate the incident , to delimit the areas needing remediation and to protect the workers and their jobs (a rough estimation of the damage caused by the melting, as reported in reference 2, is summarized in the last paragraph), 224 samples were collected inside the plant. The area of the plant was divided into a grid of about 10m x 10m spacing, and exposure rate measurements were carried out in each grid square, at a height of 0.1 and 1m. As a result of the monitoring, the production of steel on the non-contaminated line was allowed to continue. The different types of samples are listed in Table B.

Table B – Samples collected inside the plant

	N. of samples		
	Immediately after the accident	During remediation	After remediation
Deposited dust, mud and soil	62	1	3
By-products and slag	13	-	5
Fumes	13	21	49
Atmospheric dust	18	179	82
Final products (ingots, rods)	62	-	7
Wipe tests on machinery, tools, etc.	56	55	-
TOTAL	224	256	146

The degree of contamination of the steel ranged from 1511 to 78830 Bq/kg of ^{60}Co, whereas in samples of dust and flue ashes collected in the filtering line concentrations of ^{137}Cs were as high as 862400 Bq/kg. The most contaminated part was the filtration system which, according to Regional authorization, enables a 99.9% abatement of the dust emitted by the stack. The slag showed low levels of ^{137}Cs contamination, and the survey performed with a portable spectrometer at the nearby landfill, followed by analysis of slag samples collected in the landfill body, confirmed this.

Remediation of the Contaminated Line

Because of their different chemical properties, the isotopes involved in the accident were distributed differently in the steel and in the by-products (see Table C).

Table C - Distribution of the contaminants during the melting process (maximal fractions)

	Ingot	Slag	Fumes
^{60}Co	1	1 x 10^{-2}	1 x 10^{-3}
^{137}Cs	1 x 10^{-3}	1 x 10^{-2}	1

The remediation plan centred on the filtering system, which was heavily contaminated by caesium. The contaminated steel (approximately 280 tons) was collected and segregated temporarily in a secluded area of the plant. The cleaning operation, started on 3 June and ended on 24 June 1997. Approximately 250 tons of dust were collected in large bags sealed in 42 concrete containers each with a capacity of 5.8 m^3 . The average concentration and the maximum exposure rate, measured at close distance (2 to 130 _Gy/h) and at 1m (0.5 to 38 _Gy/h), were determined for each container. The containers were stored away from the working areas while the company managers identified an appropriate area, within the perimeter of the plant, as the final destination of the contaminated waste and steel. The possibility of melting the contaminated steel under strict control while diluting it with other scrap was rejected by the local authorities, in consideration of recently issued Italian legislation. The option of sending all the materials to a controlled waste facility was precluded because no adequate national or regional waste disposal facilities exist in Italy.

A few of the workers in charge of routine maintenance of the steel plant collaborated with the company in charge of remediation. All workers wore adequate protective clothing. An integral dosimeter recorded the level of their external exposure, which was found to range from 30 to 70_Sv. During the entire clean-up operation the air was monitored in five positions of the contaminated area, in order to evaluate the dose deriving from internal contamination for the workers involved in the cleaning operations, for the other workers at the plant (as mentioned earlier, the other smelting line continued steel production), and for nearby residents. An analysis of the 179 samples gave the following results: <12x10^{-3} Bq/m^3 for ^{137}Cs and <10^{-4} Bq/m^3 for ^{60}Co. Since there was considerable concern that the remediation would increase the spread of radioactivity in the area , the residents were informed of the results of the air monitoring operation every 24 hours. During remediation, 30 samples of soil and vegetation were also collected outside the plant. Gamma-ray spectrometry gave results similar to those obtained in the first monitoring campaign. No significant presence of ^{137}Cs was observed outside the steel plant.

Re-start

After remediation and assessment of the report presented by the company, steel production was allowed to be resumed. During the first week, the samples listed in Tables A and B were collected. Continuous air monitoring systems were also positioned inside and outside the plant. Flue ashes were collected straight from the filtering system and analysed immediately. A small radioprotection laboratory equipped with a gamma-ray spectrometer was installed close to the clean-up area for this purpose.

A second modelling simulation, similar to the first one performed to guide the previous monitoring campaign, allowed the experts to determine where dust depositions could reach the highest levels. Despite thorough cleaning of the filtering system, small amounts of ^{137}Cs were expected to disperse through the stack. A description of the modelling simulations and the results are given in Appendix A.

Assessment of Doses

Dose evaluation was performed for several groups of individuals: steel plant workers, truck drivers and other workers, neighbouring residents, population living or working close to the transportation roads.

The following hypotheses were made about source geometry: point sources before the melting process and sources uniformly distributed in steel (for ^{60}Co) and in dust (for ^{137}Cs) afterwards.

Steel plant workers, truck drivers and other workers - Evaluation of the exposure doses considered the measured exposure rates and the results of gamma-ray spectrometry performed on the samples, taking into account the distance of the work area and the time of exposure. Exposure was assumed to be uniform for the whole body. Internal doses derived from dust inhalation during melting and ingestion during metal refining for the steel plant workers, whereas it was considered negligible for truck drivers and other workers. A summary of the maximum estimated doses due to external and internal exposure is presented in Table D. The values were estimated using standard parameters for breathing rate, inhalable dust concentrations, etc., and the maximum determined values of radioisotope concentrations.

Table D - Maximum doses evaluated for external and internal exposure

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Maximum dose (_Sv)</td></tr>
<tr><td colspan="2">^{60}Co</td><td>^{137}Cs</td></tr>
<tr><td colspan="2">Driver(s) who transported the radioactive sources</td><td colspan="3">No dose assessment</td></tr>
<tr><td colspan="2">Drivers who transported mildly contaminated steel to various Italian regions</td><td colspan="2">0.5 - 15
(depending on the distance of the destination plant and steel contamination)</td><td>-</td></tr>
<tr><td colspan="2">Drivers who transported contaminated dust to disposal site</td><td colspan="2">-</td><td>7</td></tr>
<tr><td rowspan="10">Workers at</td><td>Scrapyard (10d exposure)</td><td colspan="2">140</td><td>650</td></tr>
<tr><td>Melting bay</td><td colspan="2">1 - 15</td><td>-</td></tr>
<tr><td>Metal refining</td><td colspan="2">0.5 - 2.5</td><td>-</td></tr>
<tr><td>Post-refining process</td><td colspan="2">0.05 - 1</td><td>-</td></tr>
<tr><td rowspan="2">Chemical laboratory</td><td>Body</td><td>0.005</td><td>-</td></tr>
<tr><td>Hands (_+_)</td><td>20</td><td>-</td></tr>
<tr><td>Rod storage area</td><td colspan="2">19 - 50</td><td>-</td></tr>
<tr><td rowspan="2">Final product storage area</td><td>Body</td><td>0.3 - 20</td><td rowspan="2">-</td></tr>
<tr><td>Hands (_+_)</td><td>5</td></tr>
<tr><td>Air filtering system</td><td colspan="2">-</td><td>40 to 80</td></tr>
<tr><td colspan="2">External maintenance workers</td><td colspan="2">< 12</td><td>-</td></tr>
<tr><td colspan="2">Workers at plants where contaminated steel was sold</td><td colspan="2">5 to 34</td><td>-</td></tr>
<tr><td colspan="2">Population living or working close to the transportation roads</td><td colspan="3">Negligible</td></tr>
</table>

Except for two cases in which it was possible to determine the doses to the workers' hands (laboratory personnel who performed the chemical analysis on the samples of steel and workers in the storage area), all doses referred to the whole body. No dose was evaluated for the driver(s) who transported the two sources responsible for the incident due to a lack of credible information regarding length of time and means of transportation.

Neighbouring population - The general population could have received doses from the dust deposited on the ground, by inhalation of the plume and by ingestion of contaminated vegetables. The concentrations measured in samples collected in the areas where the highest dust depositions were calculated ruled out the presence of ^{60}Co outside the plant. Therefore, only ^{137}Cs was taken into account in determining potential doses to the nearby residents. The results obtained from application of the dispersion model were used to determine the amounts of both isotopes emitted from the stack during the week of the melting event(s), and of ^{137}Cs during the re-start period. The results obtained for the week of the accident showed an amount of 1 kBq of ^{60}Co, which can be considered negligible, and a release of 150 MBq for ^{137}Cs. The evaluated doses are summarized in Table E.

Table E - Doses evaluated for the neighbouring population

	Committed Dose	External Dose
Children < 17 y	0.75 nSv	--
Adults > 17 y	0.3 nSv	1 nSv
Annual limit	10^{-3} Sv/y	

Final Considerations

The estimated activity of the sources was 7 GBq for ^{60}Co and 150 GBq for ^{137}Cs, as assessed from the contamination of steel and dust.

The evaluations performed and the results of the medical checks on the workers allowed the Local Health Authorities to rule out the possibility of deterministic effects for all of them. The same evaluations led to the conclusion that the permitted dose limits for the population had not been exceeded. Nevertheless, the accident had a strong impact on the city's residents and in the entire north of Italy, where the highest number of foundries, steel mills, aluminium refineries and scrap dealers is located. The cost of the accident, in terms of both economics and social consequences, as presented by the company (2), is summarized in Table F.

Table F - Economic implications

Shutdown of the factory activities	20 million euros
Clean-up operations and recovery of the plant (65 d)	> 5 million euros
Production of steel	- 50%
Loss of working time	50,000 hours
Number of jobless workers per day	200 units

After the accident, in compliance with a Regional Ordinance, a routine check of every incoming scrap load was started at every plant where scrap is recycled or collected. The Ordinance expired in June 1999, but the system implemented in the Region and elsewhere in Italy by the largest scrap recycling plants is still in operation. In our experience, the number of sources or contaminated objects found in scrap has decreased, although slowly.

APPENDIX A - Application of a Dispersion Model

Air quality modelling was used to determine the areas potentially contaminated with dust emitted from the stack during the incident and after re-start of production. A gaussian dispersion model, the short-term version of the US EPA ISC3 (5), was applied to obtain the maximum hourly and weekly average concentrations, and total deposition of particulate matter emitted during the 7 days of accidental release (6-12 May 1997) and for 7 days following re-start of production (11-17 July 1997).

The area under study is characterized by simple terrain and the meteorological data for both time periods, obtained from observations at the nearby Ghedi Air Force Base, showed calm winds for no more than 7% of the hours considered. The choice of a well-tested and widely used gaussian model such as ISC3 was therefore considered appropriate for the application. Conservative hypotheses, such as no terrain reflection for the deposition calculations, were introduced to ensure cautionary results from the model.

The calculated concentration levels were used to evaluate population exposure through inhalation of contaminated dust, and the deposition maps were used to select areas from which to collect soil samples for analysis, both following the incident and after production had been resumed.

Figures A.1 and A.2 show the maps of calculated total depositions (in units of mg/m_) for the two time periods. The position of the stack is shown with a red diamond. The size of the calculation grid (2800x2800 m_ for the week in May and 6400x6000 m_ for the week in July) was determined on the basis of the actual meteorological conditions so as to include the areas of maximum deposition and concentration. The 4x4 km_ background map shows the position of the steel plant, outlined in red, and the characteristics of the surrounding area. There are densely populated residential areas to the north, west, and south of the plant, and within a hundred meters of the boundary.

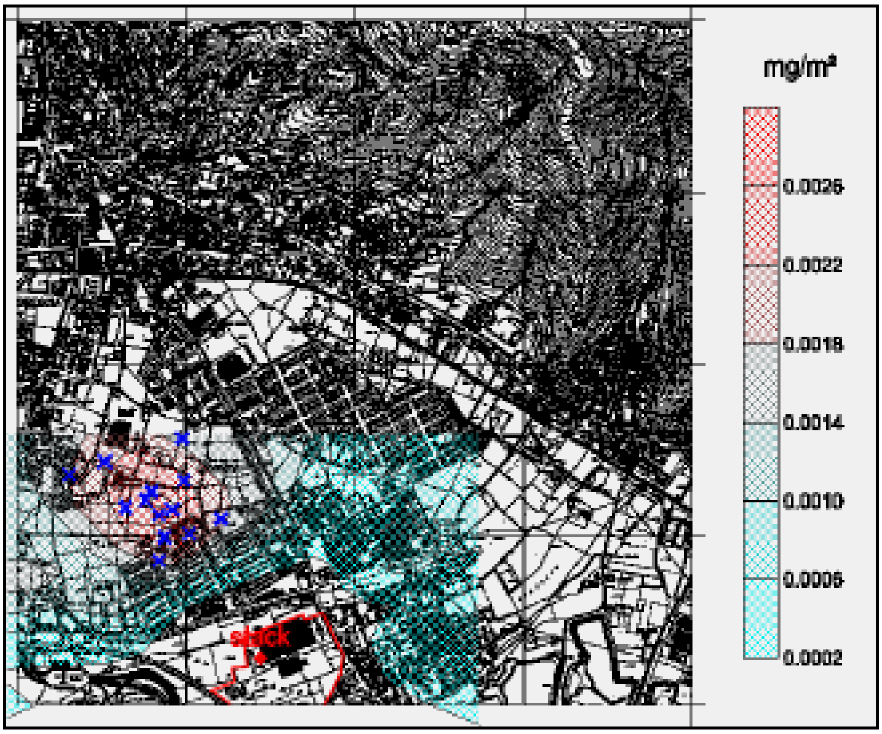

Figure A.1 – Deposition map for the period 6-12 May 1997. The background map shows a 4x4 km_ area surrounding the plant. The plant boundaries are shown in red.

For the week of the initial release, maximum average concentrations over the period were found to be negligible (a few hundredths of a µg/m_), and maximum total depositions amounted to 2-3 mg/m_ in an area about 1 km in the direction of prevailing winds, to the north-west of the plant. Maximum average weekly concentrations for the week following re-start of production were estimated at about 30 ng/m_. Total depositions also gave very low maximum values of 4-6 mg/m_ concentrated in two areas at a distance of about 1 km to the north-north-west and to the east-south-east of the plant.

As mentioned earlier, the deposition maps allowed identification of the areas of potential maximum contamination and thus selection of the soil sampling areas. The sampling sites are marked by blue crosses in the maps in Figures A.1 and A.2.

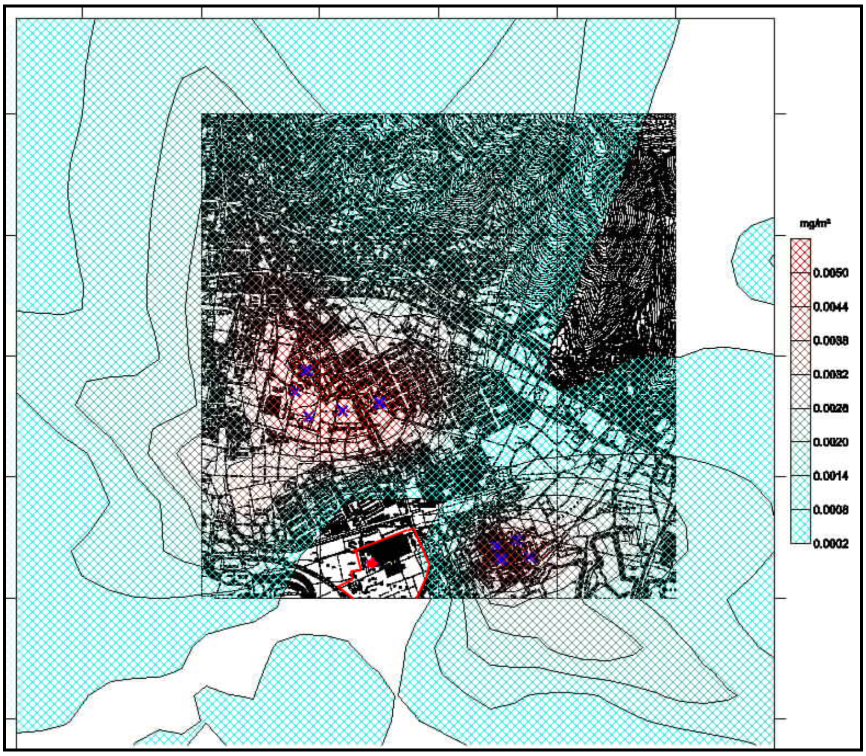

Figure A.2 – Deposition map for the period 11-17 July 1997.

References

1. Proceedings of a Conference organised by the Italian Radiation Protection Association, Brescia 11-12 May 1995, Italy, (S.Risica and P.Di Ciaccio eds.) Rapporti ISTISAN 96/24. 116 p. (ISS, Rome) (1996).
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4. EPA, 1995, User’s Guide for the Industrial Source Complex (ISC3) Dispersion Models, EPA-454/B-95-003a, b. US EPA, Research Triangle Park, NC.