Technical guidelines for cleanup at the Union Carbide India Ltd (UCIL) site in Bhopal, Madhya Pradesh, India

Ruth Stringer & Paul Johnston

Greenpeace Research Laboratories
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Introduction

Subsequent to the catastrophic release of methyl isocyanate in the form of a toxic gas at the Union Carbide plant in Bhopal, India in December 1984, the factory was closed. The release killed thousands of people in the vicinity of the plant and left many more thousands suffering from permanent damage to their health. The cessation of operations at the plant, which was engaged in the production of a range of pesticides and intermediates was not followed by remediation of the site. The methyl isocyanate can be presumed to have been dispersed and degraded in the atmosphere following its release. The same, however, was demonstrably not the case for other chemicals in the site production and generated wastes portfolio. Moreover, there is also a legacy of pollution of the site with metals and organic contaminants both inside and outside the plant.

Within the factory walls the soil is contaminated, in some places very seriously, while some of the remaining buildings still house stockpiles of unwanted chemicals. Local people, including children, regularly enter the site, risking exposure to raw chemicals and those contaminating the soils. Some local residents even graze their cattle there, opening up the possibility of indirect exposure to contaminants that can be passed on via milk to humans.

The areas adjacent to the factory site, outside the perimeter fence, are also seriously contaminated. Solvents and other chemicals spilled or leaked into the soil have migrated into the groundwater. Many thousands of the local inhabitants depend upon the groundwater resources for cooking washing and drinking purposes. Further threats to groundwater resources are posed by the former solar evaporation ponds (SEPs) on the site. Union Carbide formerly discharged much of their liquid industrial effluent into these ponds situated towards the north of the factory perimeter as a primitive form of waste treatment. The ponds, containing the solid residues from evaporation were capped with plastic liners and soil in an attempt to prevent the pollutants being mobilised and moving offsite. The containment, however, has been breached in at least one location. Leaching of pollutants from them consequently poses an additional threat to the local population and the groundwater resources.

Accordingly, an urgent need exists to clean the site up and carry out a full post-production remediation. A site of the size and complexity of the Bhopal plant presents formidable challenges if remediation is to be carried out to acceptable standards in terms of final environmental quality achieved and the ongoing hazards posed to human and environmental health. The remediation process needs to be carried out the highest possible standards. This report, therefore, is designed to provide some insight into appropriate operational standards and acceptable methods and protocols to be applied in order to achieve these.

General Principles

i) Responsibility and financing

In 1989, Union Carbide paid some 470 million US$ to compensate people suffering gas-related injuries or who had lost relatives. Not all of this money was, however, distributed to the survivors; indeed there has been growing disquiet recently in relation to the fact that there have been persistent rumours that the money intended for compensation payments would be diverted to finance final chemical remediation of the site.

This is obviously a controversial issue since the original settlement was intended only as compensation for gas-related injuries and did not provide for the continuing healthcare costs of the survivors, nor the very considerable costs involved in a full site remediation. Under applicable US legislation, known as Superfund, liability for cleaning up contaminated sites rests with the polluter, a principle that should extend to international operations of multinational corporations. Indeed, Superfund does have limited extraterritorial provisions, subsequent to agreement between the US government and the government of the country in question.

At Superfund sites, site operators and owners are either required to carry out the remediation work themselves, or failing compliance the US government can reclaim from them the costs of the cleanup plus three times that amount in damages (see: Clay 1991). To date, the US government has reclaimed $18 billion from polluters, with the settlement in one case estimated at $1 billion (USEPA 2000). In the case of UCIL, the polluter, Union Carbide, became a wholly owned subsidiary of the Dow Chemical Company in February 2001 (Dow Chemical Company 2001), so the financial liability passes to Dow.

In a broader, moral sense, the pollution of the UCIL site is the responsibility of the United States of America specifically, and of the industrialised world in general. It is here that the chemicals, technologies and the associated manufacturing and operating procedures in use by Union Carbide at the Bhopal site originated. It was these that underpinned both the Bhopal gas tragedy and the continuing contamination of the site. Accordingly, any proposal to remediate the site to standards which fall below those that would be acceptable in the most highly industrialised countries can be considered both morally suspect and unjust. Equally, the disposal of polluted materials and residues arising from the cleanup cannot justifiably take place in India itself. Consequently, any materials that cannot be destroyed or otherwise treated to the highest possible standards with the technologies and facilities available within India should be transported to the USA or another appropriate OECD country.

ii) Consultation and transparency

The US Environmental Protection Agency (USEPA) report on the progress of Superfund over twenty years states that the public concern generated by the Bhopal disaster "*led to the passage of the first community right-to-know law under the 1986 Superfund Amendments*" (USEPA 2000). This key provision should be reflected in any proposed remediation plan. This should be devised as a fully open, consultative procedure for the cleanup of the UCIL site. Residents and other interested parties (stakeholders) should be consulted in the workup and finalisation of the cleanup plans and be kept fully informed of progress.

The remediation procedure will generate a large amount of data on the site based upon analytical campaigns to define the scale and extent of the overall problem. These data will comprise the baseline upon which any remediation plan is formulated. Hence, all analytical data (including sampling information), details of proposed cleanup procedures, safety protocols, disposal strategies and related material need to be made available without delay and free of charge to the stakeholder community. Further, these data should be made available in all appropriate local languages. At least one copy of each document should be available for public inspection at a library or other suitable location within Bhopal. To enable swift and efficient dissemination, data should be available directly from the offices of those responsible for the cleanup, by post and also on the internet. This latter provision will contribute markedly to an effective oversight of operations by interested parties not living in the immediate area.

iii) Protection of local environment and population

Action must be taken to protect residents from any possible exposure to substances mobilised through remediation operations. Possible exposure pathways of concern include dust generated as part of the operations and the mobilisation of volatile organic compounds (VOCs) to atmosphere through opening of the SEP containment. Appropriate measures should be taken to avoid the wider environmental mobilisation of hazardous components contained in the contaminated environmental media from the site (soils, dusts, groundwater etc.). Consequently, it could become necessary to relocate residents. In this case, they should be fully compensated and appropriately rehoused, whether on a temporary or permanent basis. Affected residents must be consulted in the planning and execution of any rehousing project and rehousing and other related costs should be considered part of the cleanup budget.

iv) Appropriate disposal technologies

The dominant hazardous waste disposal techniques have historically consisted largely of landfill and/or incineration. The former approach simply leaves the problem in semi-stasis for an unpredictable length of time with a possibility of unforeseen breach of containment. Indeed there have been numerous incidents globally where previously closed hazardous waste landfills have required later remediation, often at significant financial and human cost (see eg USEPA 2000, Stringer & Johnston 2001).

Incineration as a waste disposal technique has also been called into question (see eg Allsopp *et al.* 2001) because of the inevitable hazardous emissions and the potential for damage to the health of communities living in the vicinity. Moreover, it is probable that an incinerator used in the Bhopal remediation would be a transportable installation likely to be operating to relatively low standards. In any case, no hazardous waste incinerator in India is demonstrably capable of operating to the highest international standards – such as the EC standards, which dictate a maximum emission of 0.1 ng dioxin/furan ITEQ per cubic metre of gas (EC 2000), together with limits on other key polluting emissions. Moreover, incineration always generates residues in the form of ashes and scrubber wastes. These are often classified as hazardous wastes in themselves and these wastes generally require containment in secure landfill.

The above observations, coupled with the overall aim that the cleanup of the UCIL site should not result in the continued contamination of the Indian environment with materials derived from UCIL operations, dictate that landfill and incineration should not be used in the cleanup process. Pyrolysis and other high temperature waste disposal technologies exhibit many of the same problems as incineration and should also be excluded from the process.

There are, however, innovative technologies that have the potential to treat many of the most recalcitrant waste streams to a more acceptable standard (see eg Costner *et al.* 1998, Picardi *et al.* 1991, UNEP 2000). Closed loop technologies that do not have the high rate of continuous mass emissions that are associated with technologies such as incineration should be used. The UCIL site will require the application of different techniques for the different sorts of contamination present in the various media. Any technology proposed for site remediation at Bhopal should be subject to rigorous evaluation and should be proven capable of addressing the waste stream in question.

v) Standards and monitoring

All aspects of the remediation operation needs to be carried out to the highest possible standards, and these should be at least equivalent to those that would be applied in the US, Europe and other similarly industrialised nations. International standards being developed under the global Stockholm Convention on Persistent Organic Pollutants should also be considered.

Cleanup should be aimed to remove all detectable contamination from the site wherever this is technologically feasible. Where this is not possible, final concentrations should be based on the highest standards applicable at the intergovernmental level (eg WHO limits for drinking water) or, where these do not exist, the most stringent limits applicable in the USA or other similarly industrialised countries.

Analyses in support of remediation operations should be carried out only by laboratories holding internationally recognised accreditation for those parameters that they will be required to measure in the media in question.

Handling, packaging and shipping of materials inside and outside India should be carried out to standards promulgated by the UN and IMO.

Provision should also be made to allow and facilitate independent monitoring of the cleanup as it progresses by experts appointed in agreement with the local residents and other interested parties.

Treatment of Chemical stockpiles at the site

There are documented stockpiles at several locations within the UCIL site. Moreover, laboratory chemicals remain in the abandoned laboratory building. Although it was the manufacturing of carbaryl (sevin) that required the MIC that was responsible for so many deaths, there are other pesticides associated with the site. Aldicarb (also known as Temik) and BHC are both reported to have been dumped on the site (Chouhan 2000). Aldicarb is an insecticide of the same “carbamate” chemical class as sevin, which acts by disrupting normal control of signals between the nerve cells. BHC is an insecticide which consists of one active ingredient, gamma-HCH (often known as lindane) and other HCH isomers and related organochlorines which are impurities resulting from the manufacturing process but which in fact make up around 85% of BHC (Stringer & Johnston 2001). Both BHC and lindane have been banned in many countries and international legislation has been designed to prevent countries importing BHC without prior agreement (Stringer & Johnston 2001). In addition, DDT isomers have been identified as contaminants in the soil of the site (Labunska *et al.* 1999) though there is no confirmation that it was among the products sold by UCIL and may therefore result from routine mosquito control in the vicinity of the plant.

All stockpiles should first be inventoried and analysed to confirm their content. Analyses should include quantitative analysis of metals (including mercury) and organics. Organics to be quantified should in the first instance include sevin, aldicarb, and the major components and impurities of BHC (alpha-HCH, beta-HCH, gamma-HCH, delta-HCH and chlorobenzenes). The laboratory conducting the quantitative analyses should hold internationally recognised accreditation for the specific assays they are to undertake. Quantitative analyses should be supplemented by GC/MS screening to identify other toxic components and pollutants identified in this way may need to be added to the list of chemicals for quantitation.

Toxic chemicals remaining in the laboratory should be inventoried. Containers that once held hazardous chemicals should be treated as hazardous and treated accordingly.

Once the constituents of the stockpiles have been established, they should be contained and labelled. Containment procedures need to be based on internationally acceptable standards. Personnel undertaking these operations should be fully trained and provided with comprehensive personal protection equipment and medical support.

As discussed above, destruction or other disposal should take place in the US or another OECD country. The United Nations (UN) has promulgated guidelines for the transport of hazardous chemicals. These have been incorporated into the national legislation of many countries as the basis of regulations on transportation and emergency response (see eg UKHSC 1999, NFPA 2002). The International Maritime Organisation (IMO) has produced guidance on how these materials should be carried by sea. These rules, the International Maritime Dangerous Goods (IMDG) codes, are closely related to the UN guidelines.

Organic chemicals should be destroyed using closed-loop non-incineration technology (see eg Costner *et al.* 1998). More than one technology may be appropriate depending upon the results of the analyses. For example, several technologies are designed to dechlorinate organohalogens (see eg UNEP 2000, Costner *et al.* 1998) whereas others may be able to destroy non-halogenated residues. Components of the stockpiles or residues thereof, for example, metallic components, which cannot be destroyed should be stabilised and placed in monitorable above-ground storage. Should facilities for the appropriate disposal technologies not be available immediately, the stockpiles should be returned to Dow in the USA for above-ground, monitorable storage until such time as they become available.

Treatment of buildings and other standing structures

Many of the buildings that used to make up the UCIL factory have been demolished and the rubble removed. A number, however, remain, notably those buildings housing the residual stockpiles, the structure in which sevin was produced, the MIC tower and other related manufacturing plant, the laboratory, the control room, administrative buildings and a number of concrete tank whose original function remains unclear.

All of these will need to be removed during the cleanup with due regard being paid to their known and possible contamination. Demonstrably uncontaminated material may be treated as ordinary building waste/scrap, though the degree of contamination of the site means that this is likely to be a relatively small component of the wastes generated. This suggests that a sequential cleanup will be necessary, with decontamination of structures taking place after removal of gross contamination.

Contaminated materials that will need to be removed and treated or disposed of can be expected to include:

- the concrete of floors in buildings where chemicals were handled during the lifetime of the UCIL plant or where stockpiles have been housed since;

- asbestos which may have been used in the construction or insulation of manufacturing plant and buildings.
- Mercury from equipment in the sevin structure
- sludges from the drains beneath process buildings and around the site. For example, the drain beneath the sevin structure was found to contain extremely high concentrations of mercury.
- sludges, process chemicals or wastes remaining in old storage tanks and similar structures

These materials will need to be analysed as described above. Subsequent to consideration of the nature of the material and its contaminants, they will need to be subjected to the same treatment regime as either the chemical stockpiles (described above) or contaminated soil (described below).

An exception to the above options is asbestos. Asbestos is a naturally occurring mineral extracted from mines at a number of locations, most notably in Canada and central Europe. It has been sold in a variety of forms, all of which are known human carcinogens according to the International Agency for Research on Cancer (IARC) and the US Department of Health and Human Service (USDHHS 2000). It is heavily regulated in the USA (USDHHS 2000) and sale within the European Union is almost totally banned (EC 1999). The most appropriate disposal method for asbestos is for it to be returned to an asbestos mine for permanent storage; the preferred location would be in the USA, but other OECD countries may be acceptable.

Treatment of Contaminated Soils

Previous investigations have clearly demonstrated the fact that there is extensive contamination within the UCIL site (Labunska *et al.* 1999). In many locations, there are piles of dumped materials, discarded barrels and similar items. The largest of these are found at the lime pit to the south of the site, where wastes were previously disposed of, and the Sevin structure, where a reaction vessel has split and spilled possibly up to several tonnes of materials onto the ground. Outside the walls, the solar evaporation ponds (SEPs) were found to contain high concentrations of organochlorine and other pollutants. Today the SEPs have been converted into a primitive landfill by covering them with a plastic membrane and a layer of soil. However, in at least one location, this membrane has become uncovered revealing the poor construction methods employed and raising the possibility of leaching of pollutants from the SEPs or more extensive and serious breaching of the containment. It is worth noting that the most extensive contamination of groundwater was found in a well between the UCIL site and the SEPs (Labunska *et al.* 1999) and the hypothesis that the SEPs were a factor in this finding cannot be discounted.

The entire factory site and the surrounding areas, including the "solar evaporation pond" areas where wastes have been landfilled, should be systematically sampled, using a grid pattern reinforced with extra samples at visibly contaminated locations. Samples should be collected from the surface and at regular depths to establish the extent of subsoil contamination. Samples should be analysed in the same way as for the chemical stockpiles: quantitation of organic pollutants known to be associated with the site (sevin, aldicarb and the major components and impurities of BHC (alpha-HCH, beta-HCH, gamma-HCH, delta-HCH and chlorinated benzenes). GC/MS screening should be used to identify further pollutants, which may need subsequently to be added to the list of quantitaive analyses. Analysis of metals including mercury should also be carried out for all samples.

Contaminated soil should be excavated for treatment. Samples of subsoil should then be collected to establish whether all contaminated soil has been removed.

Ideally the contaminants should be extracted from the soil using a technique such as carbon dioxide supercritical fluid extraction and then the extracted materials treated as described above for the chemical stockpiles, with a non-incineration technology tailored to the pollutant or pollutants they contain. If it is not possible to extract contaminated soil, it should be treated with a non-incineration technology appropriate to the type of contaminants it contains.

Wherever technologically possible, extraction and soil treatment processes employed should be capable of removing all detectable contamination. Where no process is capable of meeting this target, soil cleaning should meet the most stringent standards applicable. In the absence of international legislation on the subject, the highest standards at the national or regional level should be applied.

Once all contaminated soil has been removed the site then should be restored the cleaned soil covered with further clean soil from another location.

Treatment of Groundwater

Many thousands of people living close to the UCIL site are dependent for most if not all their water from wells tapping the groundwater resources. Samples from these wells exhibited extreme contamination, with maximum concentrations hundreds to thousands of times higher than the World Health Organisation (WHO) standards for drinking water. Contaminants are primarily chlorinated solvents (Labunska *et al.* 1999) known to be used by Union Carbide (Behl *et al.*1978) in the production processes at the site.

Clean water is one of the most basic human needs; it should be provided, free of charge, to people whose wells are found to be contaminated. Treatment via a "pump and treat" method will need to be continued until all contamination is removed; this can take years and the costs of suitable water supplies during this extended period must be part of the overall cleanup budget.

All wells and boreholes inside the UCIL site and within 2km of the boundary walls should be tested; if those furthest from the site show any signs of contamination, the testing area should be extended until no further contamination is detectable.

Quantitative analyses should be conducted for metals (including mercury) and organics to include sevin, aldicarb and chlorinated methanes, ethanes, benzenes and cyclohexanes. They should also be screened using GC/MS to identify other toxic chemicals that might be present. Chemicals identified by means of GC/MS may subsequently need to be quantitatively determined to identify a suitable remediation protocol.

While it may be appropriate to insert physical barriers to prevent further migration of contamination within the aquifer, this alone will not be sufficient. Water should be pumped from the wells and treated. Stripping or reverse osmosis, or a combination of the two, may be appropriate, depending upon the nature of the contamination. Wherever technologically possible, cleanup should be designed to remove all detectable contaminants from the water. Where methods to do this are not possible, the water must be treated to at least the drinking water quality guidelines promulgated by the World Health Organisation (WHO).

Solvent contamination of groundwater is frequently dealt with by simple air stripping which disperses the volatile pollutants into the air. This technique is unacceptable for two reasons; firstly that the thousands of people who live in close proximity to the wells would be at risk of continued exposure to whatever is extracted from the groundwater; and secondly the general principle that the cleanup should not lead to further contamination of the Indian environment.

Consequently, measures should be taken to prevent volatile materials that are present in the water/extracted from the water being released to the atmosphere. All substances extracted from the water should be treated in the same way as the chemical stockpiles described above; that is they should be destroyed using a closed loop non-incineration technology in the USA or other suitable OECD country.

Once cleaned, water may be used to recharge the aquifer or supplied to local residents.

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