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Regulatory approach to assessing health risks of toxic chemical releases following transportation accidents

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Abstract

Public health response to transportation accidents in which toxic chemicals are released into the environment require rapid data acquisition and review, health risk assessment, management decisions, and information dissemination. Following a train derailment that resulted in a massive spill of the herbicide metam sodium in the northern Sacramento River, the California Office of Environmental Health Hazard Assessment (OEHHA) was called upon to evaluate the health risks of the parent compound and its breakdown products, and to advise local health agencies in matters of public health concern. This paper describes the approach taken by OEHHA and the public health lessons learned during, and following, the accident.

1. Introduction

Transportation accidents involving hazardous materials might result in adverse public health and environmental impacts. Local, state, and federal agencies need to be prepared to respond rapidly when such accidents occur and coordinate efforts to avoid confusion and dissemination of contradictory information. Public health response to emergencies involving toxic chemical releases requires making appropriate decisions based on data that are often limited or inadequate. Health risk assessment is heavily relied upon by public health officials to evaluate the data and to determine the current and future health impacts of exposure to the accidental release of hazardous materials into the environment. This paper examines the approach to assessing health risks used by the Office of Environmental Health Hazard Assessment (OEHHA) while

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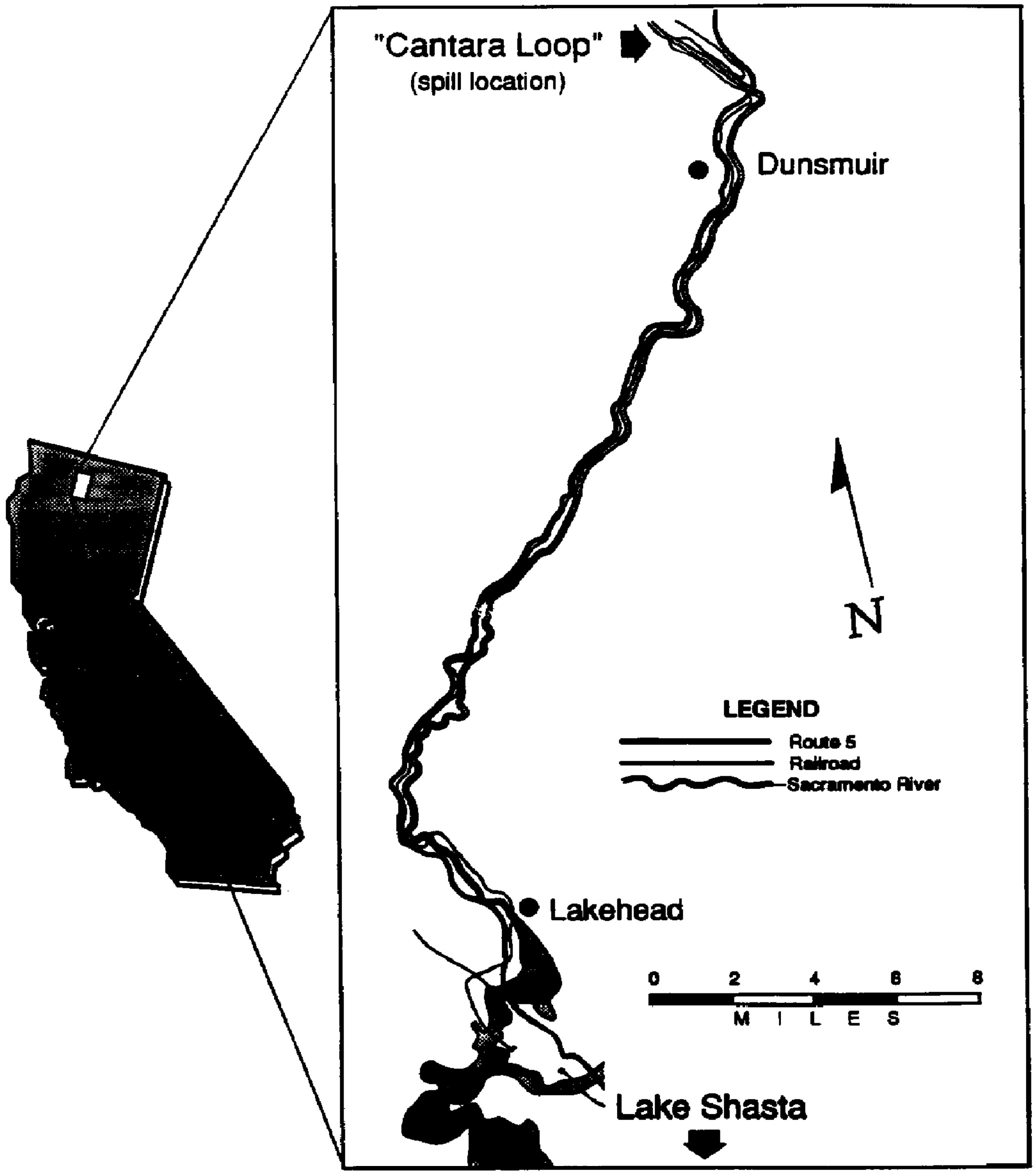

Fig. 1. Location of train derailment and metam spill.

responding to a massive chemical spill in California. OEHHA is a department in the California Environmental Protection Agency that specializes in health risk assessment and public health protection.

When several cars of a Southern Pacific train derailed on July 14, 1991, a tank car containing the pesticide metam sodium fell from a 40 ft high bridge, and up to 19,000 gallons of the chemical spilled into the northern Sacramento River in California (Fig. 1). A plume of metam several miles long was carried down the 45-mile stretch of river, killing fish and other aquatic life, and injuring residents along the river. Metam sodium[1] (sodium methyldithiocarbamate) is primarily used in agriculture as a non-restricted pre-planting treatment to kill seeds, weeds, bacteria, nematodes, fungi, and insects in soil [1]. In the ensuing days, over 60 state, local, and federal agencies responded to the spill which became known as the "Cantara incident". The major events constituting the emergency response phase of the Cantara incident, and the activities of the state health agencies are presented in Table 1.

2. General approach

OEHHA first learned of the metam spill on July 15 at about 8:00 a.m., more than 10 h after the spill took place (Table 1). At that time, a medical officer and a toxicologist were dispatched to the site to conduct medical surveillance and to disseminate information to local health agencies and emergency responders. Medical surveillance was conducted in and around the affected areas by teams of physicians and other health professionals from OEHHA and the California Department of Health Services (CDHS) by visiting hospital emergency rooms and shelters. After one week of field activity, daily contacts were made by telephone with local emergency rooms to record the number of spill-related illnesses.

As of 9:00 a.m., on August 21, 1991, a total of 252 patient visits had been logged at Mercy Mt. Shasta Hospital with spill-related complaints [2]. Five were considered serious requiring hospitalization. Spill-related complaints included headache, eye and throat irritation, shortness of breath, dizziness, chest tightness, cough, nausea, vomiting, abdominal pain, diarrhea, and other symptoms that could reasonably be attributed to acute exposure to metam or its major breakdown products. Larger numbers of people (483) with less severe symptoms were seen at medical triage centers set up at the Dunsmuir evacuation center. Follow-up activities occurred in August when physicians investigated an outbreak of rashes among workers clearing dead fish from the contaminated portions of the Sacramento River [3].

In addition to the on-site staff, an internal workgroup consisting of toxicologists, physicians, epidemiologists, and other health professionals was convened in the home office to research the health hazards of metam and its breakdown products and to develop action levels to be used in formulating health advisories. These health advisories were used by public health officials during the emergency response phase of the accident to formulate strategies to protect the health of residents and workers in the affected areas.

OEHHA's approach for assessing the health risks from the metam spill may be described in the four distinct steps typically associated with health risk assessments [4]. These steps include: hazard identification, exposure assessment, toxicological and dose–response evaluation, and risk characterization. However, during an emergency, when risk assessors experience practical time constraints and management decisions

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[1] The word metam is used in this article rather than metam sodium since the counter ion could not be specified once the formulated product was diluted in the river water.

Table 1
Cantara incident event chronology: emergency response phase

Date and time	Event summary and state emergency response	Health agencies responding
July 14, 1991 9:50 PM	SP train derails about six miles north of Dunsmuir and about 45 miles north of Lake Shasta in northern California.	
July 14, 1991 10:50 PM	SP police arrive at the site and ascertain there is no hazardous material in the tank. CHP, DOT, OES, FRA and local emergency groups are notified of the accident.	
July 14, 1991 11:05 PM	DFG notified of accident, and attempts to identify contents of tank are hindered since no placard is attached to the car.	
July 15, 1991 12:30 AM	Siskiyou County establishes Incident Command Post.	
July 15, 1991 2:00 AM	SP notifies Mercy Mt. Shasta Hospital of accident. Sometime later, Siskiyou County Sheriff notifies University of California-Davis Poison Control Center of the accident and they characterize the primary risk of the spill as an environment hazard. Residents awaken from sleep due to fumes, odors and emergency personnel.	
July 15, 1991 4:30 AM	SP staff inspect site and estimate that 1000 gallons of material were spilled from the tank on the ground.	
July 15, 1991 5:37 AM	DFG reports tank contained metam sodium and 200 gallons were spilled in the Sacramento River.	
July 15, 1991 8:15 AM	Incident Command logs first report of exposure to noxious fumes.	OEHHA and DHS are notified of spill shortly after 8:00 AM
July 15, 1991 9:22 AM	First residential exposure call from Siskiyou County is received by UC-Davis Poison Control Center.	
July 15, 1991 10:00 AM	Incident Command receives report of an injured person in the spill area. Over the next 4 h, similar reports are logged.	
July 15, 1991 11:30 AM	OES activates the State Operations Center.	OEHHA (HIRAB) staff assemble available toxicology summaries on metam and MITC prepared by DPR, and continue to monitor situation.
July 15, 1991 11:59 AM		OEHHA is notified that spill is larger than first estimated. HIRAB Staff continue to collect information and estimate toxicity potential.
July 15, 1991 1:50 PM	Estimate is upgraded to 19,500 gallons spilled into the river. DFG closes river to recreational use. CHP closes 1-5 north of Lake Shasta to Mt. Shasta. Local officials announce voluntary evacuation in Dunsmuir.	HIRAB dispatches staff to site and determines that significant data gaps exist for metam. Office staff contact DPR and counties on health and toxicological issues and begin receiving media inquiries. Counties work on drinking water issues and await information from HIRAB on toxicity potential. Counties issue advisories to Dunsmuir residents to evacuate areas nearest the river.

July 15, 1991 2:20 PM	DFG reports massive fish kills. OES continues with the coordination of the State's emergency response.	OEHHA briefs OES on health issues and contacts HML, ARB and TSCP to initiate sampling activities.
July 15, 1991 6:00 PM	Siskiyou and Shasta Counties proclaim local emergencies. Spill observed to be migrating south in the form of a green-fluorescent plume (eventually it extends to about 10 miles). DFG estimates plume will reach Shasta Lake by midnight. ARB is monitoring air levels and SP contracts with a private lab for additional sampling and analysis. Hikers are evacuated from adjacent State parks. Second Incident Command post opens in Shasta County.	HIRAB continues to evaluate toxicology data and illness reports. OEHHA advises CHP to reopen 1-5 with checkpoints for passing motorists. ODW reports no public water systems are affected and develops a contingency plan. Counties update injury list to 13 reports and shelters are opened.
July 15, 1991 8:30 PM	Water samples collected by DFG and RWQCB are shipped to lab for analysis. US EPA arrives at the scene. 1-5 checkpoints are operating under CHP.	Shasta County prepares flyers for distribution to motorists on 1-5. Health advisories are issued to residents in both counties.
July 15, 1991 10:30 PM		HIRAB staff arrive at the scene.
July 16, 1991 8:00 AM	Remaining contents of damaged tank car are pumped to prepare tank for removal.	HIRAB assessment of health effects ongoing and staff at the scene make contact with both command posts, and local hospitals and shelters. DTSC staff are dispatched to the site to collect water and sediment samples.
July 16, 1991 1:00 PM	SP and State officials develop a safety plan for removing damaged tank. US EPA issues CERCLA clean-up and restoration order to SP. DPR takes water samples at Lake Shasta. A dye tracer is added to the water contaminant plume. The plume is estimated to reach Lake Shasta by 9 PM.	OEHHA (HIRAB) prepares interim drinking water action levels. Air standards are under development. Office staff continue to research the environmental fate and toxicology of metam and breakdown products. Staff on site report that 190 people were triaged, 30 with documentated illnesses, and advise residents to leave area if exhibiting symptoms or can detect odor. DHS dispatches staff to site to aid in medical surveillance.
July 16, 1991 6:00 PM	Latest estimate projects plume will reach Lake Shasta by early morning and then Shasta Dam in several days to two weeks. Tank car is removed from the river.	Draft OEHHA (HIRAB) interim drinking water action levels are released. Staff on site complete survey of area, continue medical surveillance, and assist Siskiyou County Environmental Health Director at a public meeting. ODW identifies two non-community water systems that draw water directly from the lake.
July 17, 1991 12:00 Noon	Plume reaches Shasta Lake early in the morning. Cal-OSHA recommends caution and prudence for workers, without restricting hours. CHP continues posts at off-ramps and reduces shifts to four hours. OES issues Incident Summary. State continues to take water samples. Air samples are taken by ARB and shipped to laboratories capable of analyzing MITC.	Some CHP officers report health symptoms of exposure. OEHHA and DHS issue joint advisory that workers should reduce time spent in affected areas, particularly CHP officers. Reports of illness in affected area continue to be received. HIRAB and DHS dispatch additional staff to the scene. Interim air, recreational exposure, odor threshold, and skin effects action levels are under preparation. Staff on site are working on medical, and questions and answers fact sheets, continuing with medical surveillance, and responding to numerous public and media inquiries. HML is working on developing methods to analyze air samples for MITC.

Table 1
Continued

Date and time	Event summary and state emergency response	Health agencies responding
July 17, 1991 10:00 PM	State continues to monitor plume in Lake Shasta, and air and water sampling continues. Biota samples are taken by DFG. Water samples that were taken on the first two days contained MITC at levels ranging from not detected to 97 ppm on 7/15 and 17 ppb to 18 ppm on 7/16. Residual levels of MITC in the river to the north are decreasing.	Staff on site continue to respond to numerous inquiries and health concerns from the public, media, and emergency response teams. Staff on site clarify the misconception that metam is a carbamate pesticide which started over an erroneous fact sheet that was circulated earlier. OEHHA prepares for a legislative hearing on the Cantara incident. HIRAB and DHS on-site staff meet with RWQCB to discuss sampling strategies and analyses. HML and AIHL to receive air and water samples but are awaiting MITC standard.
July 18, 1991 12:00 Noon	Removed from Incident Reports the fact sheet containing false information identifying metam as a carbamate pesticide.	HIRAB staff visit DPR to review metam and MITC toxicological database, assessment of health risks continues. Staff on site continue to respond to public and media inquiries and the public and medical fact sheets are in final draft stage. HIRAB and DHS on-site staff continue to examine case records at local hospitals. Compilation of sampling data ongoing and DHS staff have started a repository of sampling data at the scene. DHS staff on site are working with Cal-OSHA in resolving worker health and safety issues.
July 18, 1991 6:00 PM		Public and medical fact sheets are distributed. HIRAB holds staff meeting on site with local health officials to discuss reoccupation of homes, and other issues.
July 19, 1991 12:00 PM	SP proposal to aerate plume in Lake Shasta under review by State and federal agencies. Sampling and monitoring continue.	Staff on site investigating Cal-OSHA's report of methylamine being detected in the air near Dunsmuir. DHS plans a worker health survey while OEHHA receives update on metam toxicology from DPR. HIRAB and DHS on-site staff prepare for press conference on effectiveness and safety of aeration. On-site staff hold medical grand rounds at local hospitals. OEHHA (HIRAB) drinking water action levels are finalized for MITC and metam, and then issued. Interim air action levels are also issued.
July 19, 1991 6:00 PM	State continues sampling and monitoring while aeration is delayed due to concerns by ARB over projected air levels of MITC and other breakdown products. Checkpoints and leaflet distribution discontinues on 1-5.	Some on-site staff return home while remaining staff prepare for a public hearing. OEHHA, DHS and the local health departments issue joint health advisory recommending the reoccupation of residential areas but warning against the use of the river south of the spill to Lake Shasta for recreation purposes. Advisories also contain information on drinking water wells, livestock hazards and illness reports. OEHHA recommends discontinuing 1-5 checkpoints.

July 20, 1991 AM	Sampling and monitoring continue. Agreement is reached to begin aeration of Lake Shasta.	HIRAB and DHS on-site staff testify at public hearing in Redding. Worker health questionnaire distributed by DHS. ODW issues its domestic water emergency response plan. Mecial surveillance continues.
July 20, 1991 PM	State park campgrounds reopen but visitors are warned to stay away from picnic areas near the river.	All initial DHS and HIRAB on-site staff return home.
July 21, 1991 AM	MITC levels declining to below action levels for air and water. Aeration project continues as planned while air and water levels continue to be monitored. OES announces that no problems are anticipated with drinking water supplies.	Replacement HIRAB staff are dispatched to scene to continue with technical assistance and to continue to monitor and help coordinate sampling activities. Medical surveillance continues.
July 22, 1991 AM	DFG to begin removing dead fish along river banks. Incident Command announces that health risks due to spill are now minimal and that restrictions will be lifted for sections of the river north of Lake Shasta	
July 22, 1991 PM	Emergency phase of the spill response declared over and the operation now moves into the recovery phase. By the end of the day, CHP discontinues ground patrol but continues air transport of environmental samples to labs. DFG closes river in affected areas to fishing for 120 days to allow for natural restocking. Lake Shasta remains open to fishing and only the upper arm where aeration is ongoing is closed to the public but restrictions to access river are lifted for sections north of Riverview. All park services are reopened. Rep. Boxer held briefing in Sacramento. The Department of Commerce is assisting OES in evaluating economic losses.	DHS medical surveillance continues with reportes that 300 + people have sought medical attention for complaints related to the spill and five were considered serious. HIRAB continues revising toxicological and health documents while providing assistance to the Siskiyou County Health Office regarding estimation of safe health levels and the use of Pesticide Illness reports. All shelters in both counties are closed and Siskiyou County health officials anticipate that emergency procedures would be over by the end of the day.

US EPA	U.S. Environmental Protection Agency	CHP	California Highway Patrol
OEHHA	(CA) Office of Environmental Health Hazard Assessment	Cal-OSHA	California Occupational Safety and Health Administration
OES	(CA) Office of Emergency Services	SP	Southern Pacific Railroad
DFG	(CA) Department of Fish and Game	HML	Hazardous Materials Laboratory (DHS)
ODW	(CA) Office of Drinking Water	AIHL	Air and Industrial Hygiene Laboratory (DHS)
ARB	(CA) Air Resources Board	DOT	Federal Department of Transportation
DPR	(CA) Department of Pesticide Regulation	FRA	Federal Railroad Administration
DTSC	(CA) Department of Toxic Substances Control	MITC	Methylisothiocyanate
DHS	(CA) Department of Health Services	RWQCB	Regional Water Quality Control Board
		HIRAB	Hazard Identification and Risk Assessment Branch (OEHHA)

are based on the available data, there will be no clear separation of these steps. It is only after the emergency is declared over that risk assessors may be able to better evaluate the existing data and more accurately report the results of a health risk assessment.

3. Hazard identification

When a chemical is released into the environment, the parent compound as well as breakdown products and other major ingredients in the original formulation must be identified. If the spill results from a transportation accident, a placard affixed to the vehicle would include information on the contents of the container. Metam was not specifically classified as a hazardous material under federal Department of Transportation criteria, and there was no placard [5]. As a result, there was a significant delay in identifying the contents of the tank since transportation log books had to be consulted.

During the hazard identification step, the relative hazard potential of the chemicals of concern should be determined. This will help identify those chemicals that represent the greatest short-term and long-term hazards. Evacuation plans are usually based on the need to reduce exposures to high concentrations of a chemical that are immediately dangerous to life and health. Longer-term health risks (e.g., cancer, reproductive toxicity) would need to be considered after the immediate threat is over.

Once the parent chemical is identified, information on the chemical and physical properties of this compound as well as for other ingredients in the formulation must be obtained. Literature searches using common on-line databases are invaluable during an emergency response to locate information in the published literature. Risk assessors should also consult available databases created by governmental agencies, chemical manufacturers, and other sources if available. For example, in California, a list of chemicals known to the state to cause cancer or reproductive harm is published under the Safe Drinking Water Act of 1986 (Proposition 65) [6]. For many new chemicals regulated under the Toxic Substances Control Act, the necessary health effects data may be classified as confidential business information, and will not be readily accessible by state and local agencies or the public [7].

Properties of the chemicals of concern in relation to storage, impurities, environmental influences, chemical–chemical interactions, and non-toxicological hazards (explosive, corrosive, flammable) should be obtained if available. For example, it was important to know that metam reacts with water to produce the active pesticide, methylisothiocyanate (MITC) as well as hydrogen sulfide, methylamine, and other breakdown products. Since eye irritation, headache, and respiratory effects were the most common complaints, it was likely that residents were exposed to the more volatile MITC and hydrogen sulfide than the parent compound metam [8].

4. Exposure assessment

Assessing exposure to emergency chemical releases involves characterizing the source and location of the hazard, the pathways of human exposure, and the population at risk. For risk management, it is necessary to evaluate exposures immediately after the chemical release, and predict exposures until the source is eliminated. Therefore, the origin of the release must be located and the time of the accident confirmed. It is also important to know if the source of the exposure has been stopped. In most cases, public health officials will need to rely on the first responders to emergencies for this information since it is likely that they will be denied access to the original scene of the accident.

Once the spill source has been characterized, potential pathways of human exposure need to be identified. For massive air releases of a chemical from explosions or fires, inhaling contaminated air would be an obvious source of exposure. However, the exposure pathways of most concern may not always be apparent. For example, metam itself is relatively non-volatile, yet following the metam spill, inhaling contaminated air was the most significant source of exposure. This was the result of the rapid conversion in the river of metam to its volatile and more toxic breakdown product, MITC [9]. Also following the metam spill, skin and eye contact with contaminated water, drinking contaminated water, consuming contaminated fruits and vegetables, inhaling smoke from burning contaminated leaves, and consuming contaminated fish were identified as potential pathways for human exposure. Because of the severe time constraints, the exposure pathways posing the greatest public health concern should be ranked in order of priority. In addition to inhalation of contaminated air following the metam spill, public health officials were most concerned over the potential ingestion of, and contact with, contaminated water.

In order to better characterize potential exposure pathways, it is useful to map the geographical region of the spill and identify features such as terrain, weather, and proximity of residential areas that may affect exposure potential. Public health officials may be asked to advise local first responders of placement of emergency shelters. Therefore, the geographical features that would result in less exposure to the chemical should also be identified. For example, if the spill occurs in a valley, exposures to individuals in higher elevations and upwind away from the source would be reduced. If possible, shelters and emergency response teams should be located away from the spill and not in locations directly influenced by the airborne contaminants.

If a computerized Geographical Information Systems (GIS) is available, much of the necessary information may be obtained by accessing the appropriate files. However, GIS are expensive and complicated to use and it is unlikely that during the confusion that follows an emergency that access to this system will be readily at hand. Public health officials must improvise by obtaining topographical maps and road maps, interviewing local residents and other emergency personnel, and contacting the state or federal offices of emergency response. Information may also be obtained from the news media, but care must be taken to confirm factual information.

The population at risk should be identified by determining who would be exposed to the identified pathways of concern. If possible, accurate demographics of the affected areas should be obtained. If the emergency occurs in a residential or business community, individuals living or working near the origin of the release would be an obvious population at risk. Emergency responders, including public health officials, are also a population at risk. If the source of exposure is contained (i.e., not displaying uncontrolled migration away from the origin), the population at risk can usually be accurately identified, and risk management may involve evacuation procedures as well as protective clothing and respirators as the best means to reduce exposures in those individuals. If the source of exposure is not contained, risk management procedures will depend more on the speed and direction of chemical migration, the pathways of exposure, the fate of the chemical in the environment, and the health risks to the exposed population.

In the situation in which the population at risk may increase, such as in the case of a dynamic exposure source, environmental monitoring is essential. Environmental samples should be collected immediately after the release and analyzed according to good laboratory practices. For example, during the emergency response phase of the Cantara incident, residents and workers were exposed to MITC and possibly other breakdown products [10]. Environmental monitoring was conducted by state, local, and federal agencies beginning on July 15, 1991, when water, sediment, and soil samples were taken (Table 1). However, useful air samples were not obtained until July 17, three days after the spill. This delay was largely the result of a lack of known monitoring and laboratory methods for MITC in air. Vegetation and biota samples were also taken when the monitoring effort was expanded a few days after the spill.

Environmental monitoring must be carefully coordinated to avoid excessive duplication of effort, or more importantly, to avoid the possibility that essential samples are not being taken or properly analyzed. The California Environmental Protection Agency was the state agency responsible for coordinating the environmental sampling effort during the emergency phase. The results of the sampling are documented [10].

Since inhalation exposures for the first three days following the metam spill were not directly measured, OEHHA estimated potential human doses by combining the available air monitoring data with geographical and atmospheric information. It is estimated that transient MITC inhalation exposures a few hours after the spill may have been as high as 1600 ppb as the plume passed by, depending on an individual's proximity to the river [11].

5. Toxicological and dose–response evaluation

Several toxicological endpoints of concern for metam and MITC were identified from the available information which consisted of the pesticide registration database, the published literature, and unpublished documents (Table 2). For a pesticide, data in US EPA's pesticide registration database may be considered confidential by manufacturers, and legal permission to access the data might be required. In California, the Department of Pesticide Regulation (DPR) maintains an extensive library of information related to pesticide registration, including the test data required by DPR and US EPA. Since OEHHA is allowed access to these data, a complete review of the toxicological database was conducted following the spill.

Acute toxicity tests in animals demonstrated that metam and MITC at high doses cause irritation of skin, throat, and airways, sensitization, general malaise, and at high

Table 2
Metam sodium and MITC: toxicological endpoints of concern

Metam and MITC acute exposures
Weak clastogenicity (metam)
Eye irritation (MITC)
Irritation of skin, throat, and airways
General malaise
Lethality
Salivation and lacrimation (MITC)
Sensitization
Metam and MITC subchronic exposures
Change in blood chemistry and organ weights
Developmental toxicity:
embryolethality (metam)
increased preimplantation loss (metam)
reduced fetal weight and size (MITC)
Gastric lesions (MITC)
Kidney effects
Neural tube defects (metam)
Urinary bladder lesions (metam)
MITC chronic exposures
Gonadal effects
Growth inhibition
Liver toxicity

enough doses, lethality [12, 13]. MITC was also shown to cause eye irritation, salivation, and lacrimation [14].

At lower doses and subchronic exposures, metam and MITC caused changes in blood chemistry and organ weights, kidney effects, and developmental toxicity [embryolethality and increased preimplantation loss (metam), and reduced fetal weight and size (MITC)] in experimental animals [12, 13]. At doses of 100 mg/(kg day) in rabbits and 120 mg/(kg day) in rats, metam caused neural tube defects, a serious structural birth defect [15]. No teratogenic effects were reported for MITC, although there is some debate among state and federal scientists as to whether MITC was adequately tested for this effect.

Metam and MITC exposure resulted in growth inhibition and liver toxicity following long-term dosing in experimental animals [12]. MITC did not produce treatment-related carcinogenicity in rats or mice although chronic exposure to MITC resulted in changes in gonadal weight and histology [13]. Of relative importance was the discovery of several data gaps (including carcinogenicity) in the toxicological database for metam, whereas OEHHA found the majority of required studies for MITC were satisfactory for risk assessment purposes, with the exception of the reproductive/developmental toxicity studies.

From these data, experimental toxicity thresholds for non-cancer endpoints, or cancer potency from positive cancer bioassay results are obtained. Extensive literature exists for the derivation of cancer potencies using a variety of statistical methods [16]. Since the available data on metam and MITC were insufficient to classify either as a carcinogen, no cancer potencies were derived for these two chemicals.

For non-cancer endpoints in which mechanistic evidence suggests a threshold for toxicity, an experimental no-observed or lowest-observed-(adverse)-effect-level [NO(A)EL or LO(A)EL] for the most sensitive or most serious toxic effects is identified. These experimental thresholds may be estimated by evaluating the statistical significance of the data, or by plotting dose–response relationships and extrapolating to a predetermined benchmark dose. In each case, the risk assessor must relate toxic dose levels in animal experiments to equivalent dose levels for humans usually on a body weight or surface area basis. Other methodologies for estimating toxicity thresholds have been proposed and applied under some circumstances for regulatory actions [17].

6. Risk characterization

The risk characterization phase allows the risk assessor to identify the greatest individual risks of adverse health outcomes, and promulgate emergency response action levels to protect individuals from further exposure, or to prevent immediate or long-term injury. Following an accidental release of a chemical into the environment, public health officials should be concerned about immediate dangers to exposed individuals as well as delayed adverse effects. Following a short-term exposure (up to two weeks), risk assessments can be made of potential delayed effects such as cancer based on the inherent toxicity of the compound, the exposure level, and the dose–response evaluation. For most carcinogens, however, a short-term exposure would most likely lead to a negligible cancer risk. Therefore, short-term immediate impacts on health as well as delayed effects such as birth defects or other outcomes of reproductive toxicity present more of a concern immediately following an emergency release. Nevertheless, if an emergency chemical release may result in chronic environmental or occupational exposures to relatively low levels of the contaminant, it would be appropriate to estimate cancer risk for a carcinogen or other long-term effects to aid in the determination of the necessary mitigation steps.

In California, reference exposure levels (RELs) are defined as threshold exposure levels (in mg/(kg day) at which no adverse non-cancer health effects are anticipated. These reference levels are comparable to US EPA's reference doses (RfDs). However, RfDs are typically based on chronic or lifetime exposures and RELs may be developed for exposures of any duration. Emergency response action levels are based on RELs and modified to account for exposure-specific parameters (e.g., amount of water used per day, differences in human body weight and skin surface area, variable breathing rates).

For emergency response or emergency planning, short-term exposures must be evaluated. As with RfDs, RELs are derived by identifying and dividing the NO(A)EL [or LO(A)EL] by uncertainty factors (usually factors of 10) to account for inadequacies in the database, incomplete scientific knowledge, and for protection of more

Table 3
Examples of uncertainty factors that may be used in deriving reference exposure levels

Parameter accounted for	Uncertainty factor
Extrapolation from acute to chronic	100
Extrapolation from subchronic to chronic	10
Human variability	10
Animal to human variability	10
LOAEL to NOAEL	10
Evidence for genotoxicity	10
LOEL to NOAEL	5
Reported NOAEL may be a LOAEL	5
Extrapolation from subchronic to acute	1
Extrapolation from chronic to subchronic	1
Structure activity relationships	varies
Inadequate experimental design	varies
Pharmacokinetic corrections	varies

sensitive individuals (Table 3). The application of uncertainty factors offers a margin of safety for risk managers to consider when plotting a course of action. These uncertainty factors are considered to be default values when adequate physiological or toxicological information does not exist to provide a more precise estimate of uncertainty. Documented differences in physiology and toxicology between species may be used to modify RELs to better reflect the human exposure and predicted response to the chemical.

The concept of ensuring a margin of safety between exposure and toxicity should still apply, however, even when a more precise estimate of uncertainty can be made. In particular, some subpopulations (e.g., pregnant women, children, the elderly, individuals with pre-existing medical conditions, individuals taking medication) may be more sensitive or susceptible to a chemical exposure. It is very difficult to predict with accuracy the effects of a chemical exposure to such an individual compared to the average, healthy adult in the population. Frequently gender, race, or other genetic traits may also affect an individual's sensitivity. Therefore, in emergency response situations, the risk assessor should take a health-protective approach when developing RELs.

Once human exposures are estimated and non-carcinogen RELs developed, risk of non-cancer health effects can be determined. Traditionally, this is accomplished by calculating the hazard index which is the ratio of human exposure to the REL. If the hazard index is equal to or less than one, an adequate margin of safety exists. If the hazard index is greater than one, the estimated exposure is greater than the REL and further examination of the public health implications is required. Fig. 2 presents a summary of experimental doses and human benchmarks for MITC exposure from inhalation. These comparisons were found to be useful when estimating the potential for adverse health effects during emergency response efforts.

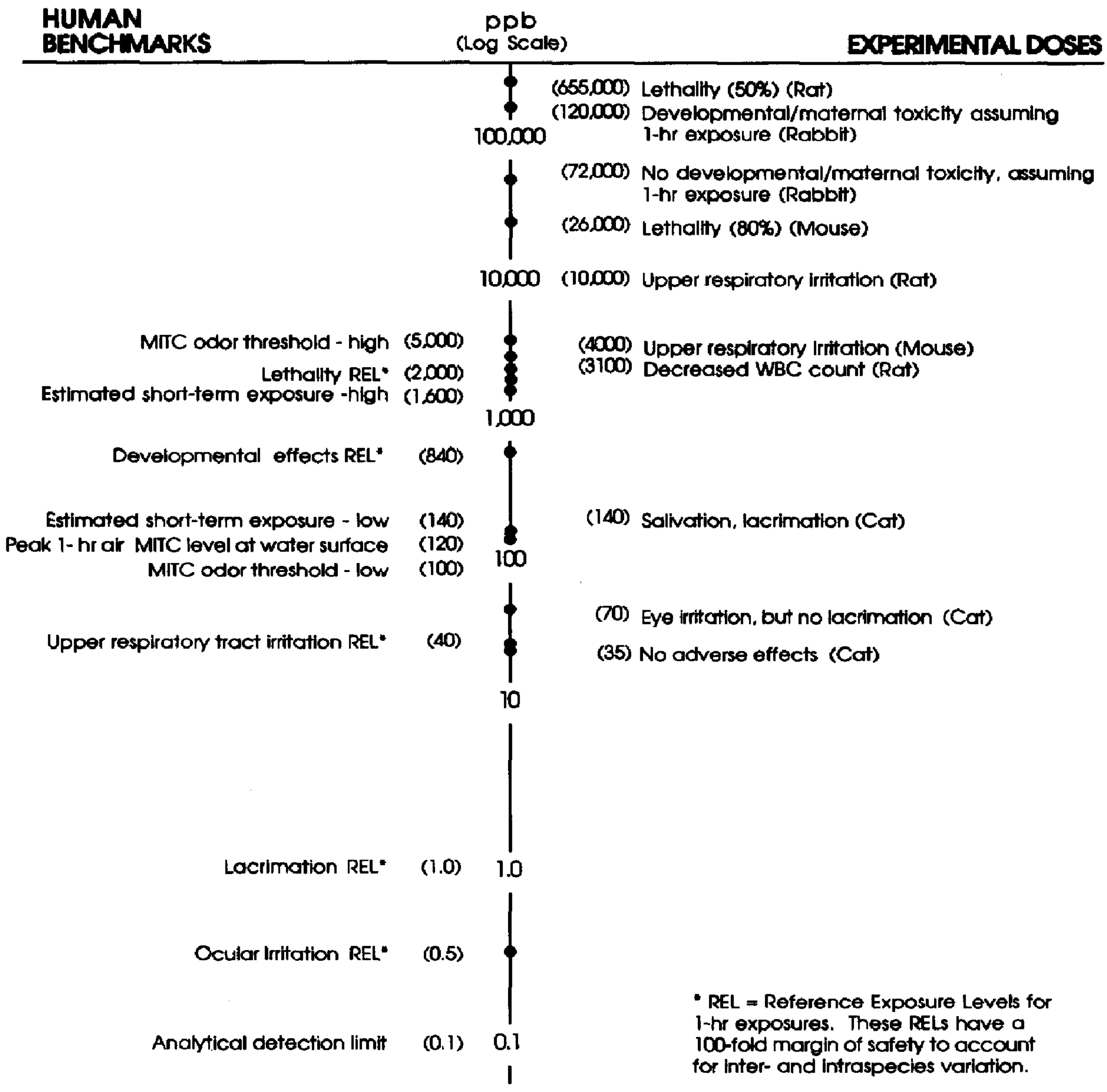

Fig. 2. Short-term inhalation toxicity of MITC for comparison to environmental concentrations during emergency response.

7. Risk management decisions during an emergency

Risk assessment results, when available, will likely form the basis for most risk management decisions following an emergency. Of importance for risk managers would be to determine whether environmental pathways and exposure routes identified in exposure assessment are still of concern. For example, public and worker exposures to MITC in air remained a source of concern for a week following the spill.

On the other hand, the California Office of Drinking Water determined that no community drinking water supplies originated directly from the affected section of the Sacramento River, and there were only a few private supplies feeding directly from Lake Shasta [18]. Nevertheless, OEHHA developed drinking water action levels to use as a reference clean-up level. MITC levels in the river water decreased to below action levels during the first week after the spill.

Emergency response action levels may be used to advise or even require evacuations following a chemical spill. During the emergency phase of the Cantara incident, it was concluded that signs of acute toxicity from MITC exposure may have occurred before odor was detected and OEHHA, CDHS, and the local health authorities issued an advisory that individuals should leave the area if they were experiencing symptoms, even if they did not detect an odor. Although human inhalation exposures were generally below the action level for developmental toxicity of MITC (720 ppb), based on the worst-case exposure estimates, and the teratogenic potential of metam, an advisory for pregnant women living in the affected areas to seek medical consultation and be administered the alpha-fetoprotein test was also issued.

On the other hand, it was determined that the already existing health risks from breathing smoke from burning vegetation were not significantly increased by burning MITC-contaminated vegetation at the measured levels in dried leaves [19]. Predicted MITC doses from eating contaminated berries were below drinking water action levels and residents were told not to harvest and eat dead fish. Residents were also warned to stay out of the river for the week following the spill.

8. Discussion

Although the Cantara incident may be considered by some to be the worst inland environmental disaster in California's history, as public health officials, we learned valuable lessons that have helped shape a plan to better prepare ourselves for emergency chemical releases in California. Public health input, rapid and complete data acquisition, proven and readily available analytical methods, pre-determined action levels, and adequate personnel training are all necessary in planning for emergency chemical releases. Assigning duty officers to be available on-call in case of an emergency is important. However, forming a technical team to obtain, review, interpret, and assess the toxicological and exposure information during the emergency proved to be essential for making risk management determinations during the Cantara incident.

The Cantara incident emphasized the need for input from agencies that have expertise in assessing health risks and promoting public health since health advisories and environmental clean-up levels were based on the results of OEHHA's risk assessment. Therefore, in any command and control structure implemented during a crisis, particularly when human health may be impacted, it is essential that health scientists and medical officers be formally included in the chain of command. Following the Cantara incident, the California emergency response command and control structure was modified to include formal public health input [20].

Since the results of health risk assessments are used by public health officials in making decisions with regard to public and worker safety, it is important to evaluate the validity of the methods. The level of uncertainty in a risk assessment is dependent on the quality of the data and the level of detail incorporated to derive risk values. The level of health protection afforded by a risk assessment is dependent on how the risk assessor addresses uncertainty in the analysis. Traditional uncertainty factors allow risk assessors to account for sources of uncertainty by lowering action levels accordingly. In emergency response situations, there is no time to complete a detailed analysis of risk, and therefore the adequate application of uncertainty factors is important. For inhalation exposures to MITC from the metam spill, OEHHA applied uncertainty factors using standard assumptions of human and animal variability. Although the resultant advisory levels were considered to be health protective, residents still complained of symptoms after air MITC levels fell below the "safe" level. The lesson learned is that risk managers must not underestimate the importance of good public health practice when basing decisions on risk assessment.

The approach taken by OEHHA in assessing health risks during the Cantara incident was comparable to the approach taken in non-emergency situations. However, office staff needed to adapt to the severe time constraints in order that timely decisions could be made in the field. Therefore, the ability to access complete chemical, analytical, and toxicological data is crucial in conducting a risk assessment under emergency conditions. For many existing chemicals, health effects data for short-term high level exposures (from accidental releases) and long-term lower level exposures are not readily available. For emergency planning, complete toxicological and health effects data on manufactured chemicals are necessary to review existing standards, and develop levels for the most commonly used and transported chemicals. Although the toxicological data for pesticides are generally far better than for other chemicals, information in confidential databases for toxic chemicals in commercial use needs to be more readily accessible and identifiable by state and local government. Caution should be used when simple or generic fact sheets are relied upon for health effects information. For example, a material safety data sheet (MSDS) for a chemical, which is often relied upon in emergencies, may not contain adequate or accurate health effects information.

We were unable to estimate the potential harm in the initial stages of the metam spill until analytical results became available. Reliable sampling and test methods for identifying and analyzing chemical contaminants in a variety of environmental media need to be developed and made available before new chemicals enter commerce, or for existing chemicals most commonly transported. To aid in monitoring efforts during an emergency response, environmental fate data should also be required for new and existing chemicals, and test methods need to be developed for the major breakdown products, since compounds of higher toxicity may be formed when the original chemical is released into the environment. However, the starting chemical should be analyzed, even if it is thought to break down completely in the environment. Ready access to analytical equipment and sampling devices as well as computer modeling equipment, to gather preliminary information and speed the process for assessing health risks, should be planned.

Resources should be made available for conducting risk assessments on transported materials and for developing action levels for emergency response. There are no generally accepted pre-determined action levels for acute chemical exposure resulting from accidental releases of most chemicals in commercial use. Existing acute exposure guidelines are usually not developed for the special cases of public exposure to accidentally released toxicants. As a result, OEHHA has developed general guidelines for determining "emergency planning levels", or levels of a chemical in air to be used as a benchmark for emergency response for acute exposure [21].

Finally, we learned it is important to train health professionals in responding to emergencies. Staff responding to emergencies need to anticipate that the working conditions and the information available will be worse than expected. In an emergency response setting, it is often difficult for office staff to provide information to field staff because communication resources are lacking or inaccessible. Plans for communicating with local and state emergency responders are essential for coordinating emergency response efforts. In addition, training in communicating with the news media and the public is needed since dissemination of health effects information is of paramount importance during an emergency.

Immediately following the accident, the impact of the metam spill on wildlife, residents and the local economy was dramatic, and individuals living in the area are still reporting lingering health effects [22]. Substantial state and local resources were used to mitigate the incident. We have documented the health impacts and the lessons learned from this accident so that others who share some of our concerns regarding safe transportation of hazardous materials and emergency preparedness may learn from our experience.

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