IFRAT Risk Model: Purpose, Construction, and Results

The Cerro Grande Fire near Los Alamos, New Mexico, USA burned over 43,000 acres of mainly forested land in and around Los Alamos National Laboratory (LANL) and the town of Los Alamos. The fire destroyed vegetation in the area, which directly increases the potential for flooding in Los Alamos area canyons. These floods may transport legacy contamination and chemicals (including radionuclides) from burned areas to potential receptors down the watershed. The purpose of the risk assessment is to characterize potential risk to the public and to the environment associated with flooding. A secondary goal was to understand whether any identified risks are related to current or past operations at LAN L. The assessment focuses on evaluation of long term effects (years) of post-fire floods. Risks associated with chronic exposures would be higher than risks associated with short term exposure, so evaluation of chronic risk should reveal any pathway with a potential for risk from short-term exposure.

The risk assessment models potential risks to people using concentrations of chemicals and radionuclides measured in ash, sediment, groundwater, and surface water. Sampling and analysis of surface water (including storm water), groundwater, sediment, soils, crops, fish and wildlife in the areas that might be affected by floods was conducted from June 2000 to March 2001 by numerous agencies. Sampling is expected to continue over the next few years.

The IFRAT risk model is a spreadsheet-based analytical model that uses equations to calculate risk for various exposure scenarios. Exposure scenarios describe the media and pathways of exposure (for example, ingestion of well water). The model calculates potential risk values by analyte and exposure pathway for metals, organic chemicals, and radionuclides. Each pathway has an equation; the values for terms in the equation may change depending on whether the calculation is for a child, an adult, a maximally exposed person or a person with average exposure.

Residential, recreational, and irrigation exposure scenarios have been developed for post-fire exposure to soil, sediment, and water that contain elevated concentrations of metals, radionuclides, and organic chemicals. The scenarios, media (soil, sediment, water, plant, animal, and fish) and exposure pathways for each scenario are summarized in Table 1. The resident was located in Lower Los Alamos Canyon in the area directly downstream of possible post-fire effects. The Los Alamos Canyon watershed was also one of the most heavily impacted drainages by the Cerro Grande fire.

Table 1. Ex osure scenarios con i

Scenario	Medium	Pathway
Resident	Sediment (Lower Los Alamos Canyon)	Incidental ingestion
		Dermal contact
		External gamma
		Inhalation of dust
		Inhalation of vapors*
	Water (alluvial groundwater in Lower Los Alamos Canyon)	Drinking water
		Dermal contact
		External gamma*
		Inhalation
	Plants (predicted)	Ingestion of home grown produce
	Animals (predicted)	Ingestion of home raised livestock
Recreational	Water (Rio Grande/Cochiti Reservoir)	Dermal contact while swimming/wading
		Incidental ingestion while swimming/wading
		External gamma while swimming/wading*
	Fish (Cochiti Reservoir)	Ingestion of fish
Irrigation	Soil (predicted)	Incidental ingestion
		Dermal contact
		External gamma
		Inhalation of dust
		Inhalation of vapors*
	Plants (predicted)	Ingestion of home grown produce
	Animals (predicted)	Ingestion of home raised livestock

*Pathways not considered in this risk assessment

Where possible, actual measured values from the media were used in the risk assessment. However, the equations for concentrations of chemicals and radionuclides in plants and animals used predicted concentrations based on published ratios of soil to plant or meat concentrations. Concentrations in fish tissue were measured directly. For the irrigation scenario, a predicted soil concentration was calculated based on an estimated Rio Grande concentration. The estimated Rio Grande concentration was calculated based on the concentration of metals, organic chemicals, and radionuclides in storm water samples collected in side canyons near the Rio Grande. Concentrations in storm water in the canyons near the Rio Grande were adjusted by a mixing factor that represented the ratio of peak flow in the side drainage to the minimum flow in the Rio Grande. These predicted Rio Grande concentrations were used to provide a more complete list of analytes compared to the measured Rio Grande concentrations. The irrigation scenario was developed to assess possible adverse health effects on people using irrigation water containing elevated concentrations of metals, organic chemicals, and radionuclides from floods following the fire. For this scenario, it was assumed that the amount of each analyte was transferred from one foot of irrigation water to the soil and it remained there for 30 years; this assumption results in the model using concentrations as high as could possibly be expected to occur.

The IFRAT risk model calculates intake through each exposure pathway separately and sums total intake to compare against information on toxicity. Exposure is calculated from estimates of the intake from contact with the media. For an example, the equation to calculate chemical exposure from plant ingestion is shown in Figure 1. Most of the values for parameters in the equation came from exposure factors developed by US EPA.

Figure 1. Plant Ingestion Equation

Intake (mg/kg-day) = **(C x TF x IR x FI x EF x ED x CF)**	**Exposure Values**			
AT				
	Child		**Adult**	
	CTE	**RME**	**CTE**	**RME**
C = Chemical concentration in soil (mg/kg)	Site-specific	Site-specific	Site-specific	Site specific
TF = plant - soil transfer factor or concentration ratio (mg/kg plant [fresh weight] per mg/kg soil)	Chemical -specific	Chemical -specific	Chemical -specific	Chemical -specific
IR = Plant ingestion rate (g-food/kg-body weight/day) Homegrown Fruits & Vegetables [as consumed]	1.2	13.6	1.2	13.6
FI = Fraction of plants ingested that are grown in contaminated area	1	1	1	1
EF = Exposure frequency (days/year)	350	350	350	350
ED = Exposure duration (years)	6	6	9	30
CF = units conversion factor	0.001	0.001	0.001	0.001
AT = Averaging time (period over which exposure is averaged - days)				
Noncarcinogenic effects	2190	2190	3285	10950
Carcinogenic effects	25550	25550	25550	25550

The IFRAT risk models were designed to be protective of public health. If a high chemical exposure causes an effect, it was assumed a low exposure also caused an effect. Because of the limited sample size, the maximum measured concentration was used. It was assumed that a resident is exposed all day, every day for 30 years, at the place where the maximum concentration of each metal, organic chemical, and radionuclide was measured.

Standard Environmental Protection Agency (EPA) default parameter values were used in the exposure scenarios, when available. These values are consistent with the objective of estimating risk under conditions of reasonable maximum exposure. Where EPA default parameters are not available, professional judgment has been used in selecting protective values from other publications or setting scenario-specific assumptions. Exposure parameters were selected to represent the reasonable maximum exposure (RME) and the central tendency exposure (CTE.). The RME represents the 90th to 95 h percentile and the CTE represents the average value. Risks were calculated to both adults and children. Exposure parameters used in the IFRAT risk model are given in Table 2.

Table 2. Exposure Parameters

Exposure Parameters	**Adult RME**	**Adult CTE**	**Child RME**	**Child CTE**
soil ingestion rate m. soil/da	200	50	400	100
	1	0.5	1	0.5
( )	5800	5000	4700	4300
(g)	0.2	0.07	0.2	0.07
y)	20	15.2	8.3	8.3
(Y)	3	2	1.5	0.74
g(	23000	20000	8450	7310
	0.75	0.17	0.75	0.17
homegrown fruit & veg ingestion rate /k bw/da	13.6	1.2	13.6	1.2
fraction plants from contaminated area		1	1	1
uptake rate of feed by animal k /da	50	25	50	25
uptake rate of soil by animal k /da	0.5	0.5	0.5	0.5
homegrown meat ingestion rate /k bw/da	3.4	0.6	3.4	0.6
fraction of meat from contaminated area		1	1	1
exposure fre•uenc da s/ ear	350	350	350	350
exposure duration ears	24	9	6	6
bod weit ht k.	70	70	15	15
Averaging time noncarcino ens da s	10950	3285	2190	2190
Averaging time (carcinogens) da s	25550	25550	25550	25550
exposure time swimmin /wadin hrs/event		1	3	1
y	24	9	14	14
(	64	32	24	12
	0.05	0.05	0.05	0.05
bod wei, ht for swimming k.	70	70	45	45
Averaging time s/w noncarcino ens	10950	3285	5110	5110
LANL s.ecific PEF m3/k.	1E+07	1 E 07	1E+07	1E+07
fish ingestion rate kg/ r	44.1	13.5	9.45	2.9

The potential human health impacts are measured in several ways. Noncarcinogenic effects, such as kidney damage, are evaluated by a comparison of the concentration dose to the reference dose. The reference dose is the dose considered low enough to cause no effect. The dose predicted by the model is divided by the reference dose to generate a hazard quotient, which should be less than or equal to one. Chemical carcinogens and radionuclides are multiplied by a factor to produce an incremental cancer risk associated with the dose predicted by the model. Because the model predicts an increment of risk associated with each unit of carcinogen or radionuclide, US EPA has set a range of risk that it does not consider to be significant additional risk to an individual. *This risk range is* $10^{"6}$ *(1 in 1,000,000) to* 10^{-4} *(1 in 10,000). For brevity in the* results section we use scientific notation for risk values (1 E-06 = 1 in 1,000,000; 1 E-05 = 1 in 100,000; 1 E-04 = 1 in 10,000; 1 E-03= 1 in 1,000).

RESULTS

The risk results from the IFRAT risk model for the three scenarios are summarized in Table 3. The risk values for the resident and the irrigation scenarios are greater than 1 E-04 and all of the hazard quotients are greater than 1. However, the calculated risk and hazard values are generally not different from the relevant pre-fire values. Thus, there is no substantial change in potential adverse, chronic health effects as a result of the Cerro Grande fire. Tables were created to evaluate the analytes and pathways that contribute to these calculated risks.

Table 3. Summary of risk results for the IFRAT exposure scenarios

Scenario	**Radiological risk**		**Chemical risk**		**Chemical hazard (child)**	
	CTE	**RME**	**CTE**	**RME**	**CTE**	**RME**
Irrigation - background only	1E-04	6E-04	1E-04	3E-03	7	45
Irrigation	1 E-04	6E-04	1 E-04	3E-03	7	46
Resident[a] - background only	1 E-04	7E-04	2E-04	3E-03	12	58
Resident[a] - pre-fire	1 E-04	6E-04	2E-04	2E-03	10	46
Resident[a] - post-fire	1 E-04	7E-04	2E-04	3E-03	14	66
Recreational	1 E-07	5E-06	0[b]	0[b]	2	6

[a] resident equals 6 years' exposure as a child plus 24 years' adult exposure [b] *no chemical carcinogens were detected in Rio Grande water or Cochiti fish*

The following tables provide results for each receptor. These tables also give risk values for the average and maximally exposed resident (the resident is the sum of the child and adult risk for a scenario). These tables provide the values corresponding to the graphs in the presentation at the July 25, 2001 meeting, as well as additional information breaking down potential risk by pathway.

The table below shows that there is not a substantial change in overall radiological risk from background to post-fire conditions. Overall radiolo• ical risk values:

	resident RME	resident CTE
Background	6.9E-04	1.2E-04
Pre-Fire	6.2E-04	1.3E-04
Post-Fire	7.0E-04	1.4E-04

The radiological risk is dominated by the contribution from strontium-90, Thorium228, and cesium-137.

Radiological risk for three of the radionuclides (does not account for 100% of the total risk from radionuclides)

	adult RME	adul CTE	child RME	child , CIE	res RME'	es CTE
Cs-137	9.9E-05	1.7E-05	2.5E-05	1.1 E-05	1.2E-04	2.9E-05
Sr-90	1.9E-04	6.4E-06	4.7E-05	4.2E-06	2.4E-04	1.1 E-05
Pu-239	3.3E-06	2.8E-07	8.9E-07	1.8E-07	4.2E-06	4.6E-07

Radionuclide	Background	Pre-Fire	Post-Fire
Strontium-90	2.3E-04	1.3E-04	1.9E-04
Thorium-228	2.1 E-04	2.1 E-04	2.1 E-04
Cesium-137	3.9E-05	7.9E-05	9.9E-05
Uranium-238	1.2E-05	1.2E-05	1.4E-05
Plutonium-238	1.2E-08	9.9E-08	7.2E-08

Plant ingestion, meat ingestion, and external exposure are the dominant pathways for radiological risk both before and after the fire.

Post-Fire Radiological risk by pathway

Plant	2.1E-04	7.0E-06	5.3E-05	4.6E-06	2.7E-04	1.2E-05
Meat	3.2E-05	1.1 E-06	7.9E-06	7.3E-07	4.0E-05	1.8E-06
External	2.9E-04	7.1E-05	7.3E-05	4.8E-05	3.7E-04	1.2E-04

Non-radiological risk is at similar levels pre-fire and post-fire.

Non-radiolo• ical risk

	adult RME	adult CT	child RME	child CTE	res RME	res CTE
Background	2.3E-03	1.1 E-04	6.6E-04	1.0E-04	3.0E-03	2.1 E-04
Pre-Fire	1.8E-03	9.9E-05	5.1E-04	9.3E-05	2.3E-03	1.9E-04
Post-Fire	2.5E-03	1.3E-04	7.1 E-04	1.1 E-04	3.2E-03	2.4E-04

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Non-radiological risk is due primarily to arsenic, which is found at similar levels before and after the fire. Dioxins also contribute to the post-fire non-radiological risk, but dioxin concentrations were not measured at this site before the fire.

Non-radiological RME risk by chemical

	Background	Pre-Fire	Post-Fire
arsenic	2.3E-03	1.8E-03	2.5E-03
TCDD equivalents	No analysis	No analysis	4.2E-05
chromium (VI)	1.1E-06	1.5E-05	2.1 E-05
beryllium	1.0E-07	1.0E-07	9.5E-08

risk total 2.3E-03 1.8E-03 2.5E-03

The plant ingestion pathway makes up most of the non-radiological cancer risk.

Non-radiological risk by pathway

	adult, RME dult	TE child	RME child	CIE
Soil	0%	0%	2%	2%
Dust	1%	5%	1%	9%
Plant	89%	58%	79%	43%
Meat	3%	2%	2%	2%
Drinking Water	7%	34%	14%	43%
Skin	0%	1%	1%	2%

The hazard index (the sum of the individual hazard quotients) changes substantially from pre-fire to post-fire conditions.

Non-radiological Hazard Index

	adult RME	adult CTE-child	RME child	CTE
Background	41	9	58	12
Pre-Fire	32	7	46	10
Post-Fire	47	10	66	14

Manganese and arsenic account for most of the non-radiological, noncancer hazard. The potential hazard from manganese changes substantially from prefire to post-fire conditions, but the potential hazard from arsenic is similar before and after the fire.

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Non-radiological Hazard Quotient by chemical

Analyte	Background	Pre-Fire	Post-Fire
manganese	21	16	32
arsenic	17	13	16
iron	3	2	3
copper	1	1	3
cadmium	4	4	2
zinc	1	1	2
mercury compounds	4	3	2
antimony	0	2	1
selenium	1	1	1
barium	1	1	1

Again, the plant ingestion pathway accounts for most of the potential hazard.

Percent of Non-radiological Hazard Index by Pathway

	adult -RME	adult CTE	child RME=	child- CTE
Soil	0%	0%	3%	2%
Dust	4%	17%	6%	31%
Plant	75%	40%	67%	28%
Meat	5%	4%	5%	3%
Drinking Water	4%	18%	9%	21%
Skin	0%	0%	0%	0%

In summary, the chemical and radionuclides of potential concern following the fire were similar to the levels seen in the Los Alamos surrounding area prior to the fire. The chemicals of potential concern are arsenic, manganese, mercury, cadmium, chromium and dioxin. However, arsenic and manganese appear to be the main risk drivers for the risk assessment. The primary pathway of exposure for arsenic and manganese is from plant ingestion. Both of these chemicals increased in concentration after the fire. Both arsenic and manganese are also naturally occurring in the State of New Mexico.

The radionuclides of potential concern are strontium-90, cesium-137 and thorium-228. Of the radionuclides of potential concern for the radionuclides, cesium-137 is the only one that has increased in concentration since the fire. The primary pathways for radionuclides are plant and meat ingestion for strontium-90, external radiation for cesium-137 and thorium-228.

There were changes in the concentrations of chemicals and radionuclides and the risk associated with these changes. This risk assessment shows that there is no substantial increase in overall risk as a result of the materials transported by floods following the fire.