5.0 ROUTINE CONTAMINANT RELEASES TO SURFACE WATERS

The report of Tasks 3 and 4 detailed the history of the system of ponds that have been developed at the site to receive various plant effluents and site runoff. Historical plant operations resulted in the release of contaminants into the pond systems, and in some cases, directly into site drainages. Surface waters provide a means of transporting contaminants off the site where exposures to the public may have occurred. For the purposes of this project, we are interested in characterizing the extent to which the contaminants of interest have traveled off-site in surface waters.

The contaminants of interest for further study on the project include both radioactive and nonradioactive materials. The nonradioactive materials of interest are all volatile solvents, with the exception of beryllium, which is a metal. Studies indicate that the primary removal process of volatile organic compounds from surface water is evaporation. Half-lives for volatile organic compounds can range from minutes to days depending on the physical properties of the compound and mixing condition of the water body (Dilling, 1975; Dilling, 1977; Schwarzenbach, 1979 and Cohen, 1978). Based on this information, volatile contaminants of concern released in liquid effluents by the facility are assumed to be readily evaporated from surface waters. Since the early days of Rocky Flats operations, liquid wastes discharged from the facility were temporarily stored in retention ponds prior to release. As a result, volatile contaminants of concern released with liquid effluents are unlikely to have been transported off-site in surface waters to any significant extent.

With the exception of tritium, the radioactive materials of interest are metals. Tritium is readily transported in surface waters. The metals of concern have low solubility in water and will tend to be adsorbed by soils or sediment. This tendency would have reduced the concentration of dissolved contaminants in water.

The following sections review the history of the surface water bodies in the vicinity of the Rocky Flats Plant and the availability of surface water monitoring data. Additionally, the approach to quantifying contaminant concentrations in surrounding surface waters is described.

5.1 Surface Water History

The Tasks 3 and 4 report discussed the history of the surface waters surrounding the Rocky Flats plant. This section briefly revisits the development of holding ponds and reservoirs.

5.1.1 Retention Ponds

A number of retention ponds were constructed along the creeks that drain the Rocky Flats site for use in management of plant wastes and surface water runoff. The purpose of the retention ponds was to hold wastewater on-site for a period of time to allow any volatiles contained in the wastewater to evaporate and to allow any metals to settle out and/or bind to pond sediments. The ponds that historically received plant releases are now known as the A-series and B-series ponds. They are located on North Walnut Creek and South Walnut Creek. The C-series ponds, which received runoff from the site, are located on Woman Creek. Prior to the pond reconstruction activities that took place in the early 1970s, the ponds were not given letter designators. Plant documents prepared prior to 1973 refer to each pond by number. Table 5-1 presents the original number and current designator of each pond still in operation in 1992. Figure 5-1 depicts the holding ponds as they exist today (1992).

5.1.1.1 North Walnut Creek Drainage

The history of activities related to the North Walnut Creek drainage is depicted on the time line in Figure 5-2. Between 1953 and 1957, the plant reported that approximately 2.23 mCi of low-level contaminated laundry wastes were discharged either directly to North Walnut Creek or to Pond A-1 after it was completed in July 1953 (USDOE, 1991a). In 1957, laundry wastewater was rerouted to Building 774, where it was treated along with process wastes and released to South Walnut Creek. After 1957, Pond A-1 was reported to have received overflow laundry wastewater, cooling tower blowdown, and steam condensate. The laundry wastewater discharges to North Walnut Creek resulted in the accumulation of plutonium in the sediments of Pond A-1 and North Walnut Creek. In the early 1970s, Pond A-1 underwent a major reconstruction and retention Ponds A-2 and A-3 were added to the North Walnut Creek drainage. The reconstruction activities resulted in sediment resuspension from Pond A-1 and likely increased the potential for release of plutonium to Great Western Reservoir. When the reconstruction activities were completed, Ponds A-1, A-2, and A-3 received cooling tower blowdown and steam condensate from process and laboratory facilities until 1974. From 1974 to 1980, Pond A-2 was isolated from North Walnut Creek and Ponds A-1 and A-3 collected surface runoff. In 1980, Pond A-4 was completed. From 1980 to 1989, Ponds A-3 and A-4 collected surface runoff, while Ponds A-1 and A-2, isolated from North Walnut Creek, received water from Pond B-2.

5.1.1.2 South Walnut Creek Drainage

The South Walnut Creek drainage pond history is also depicted in Figure 5-2. Ponds B-1, B-2, and B-3 were constructed prior to the start of production activities at Rocky Flats. The three B-

series ponds received decontaminated process wastewater, sewage treatment plant effluent, and laundry wastewater from 1952 to 1970. The water was passed through each holding pond and

5-1 Retention Pond Original and Current Designations

5-1 Rocky Flats Holding Ponds and Creeks, 1992

5-2 Time Line of Events for the North and South Walnut Creek Drainage

was finally released to South Walnut Creek through an outlet in Pond B-3. Similar to the North Walnut Creek drainage, the South Walnut Creek drainage (Ponds B-1, B-2, and B-3) underwent reconstruction in the early 1970s. Pond B-4 was constructed at that time. This reconstruction of the streambed upstream of Pond B-1 resulted in the disturbance of sediments containing plutonium. As a result of the sediment disturbance, much of the upstream sediment migrated into Pond B-1 and subsequently increased the plutonium inventory of all the B-series ponds. As with the reconstruction activities on North Walnut Creek, resuspended plutonium from the ponds potentially migrated downstream to Great Western Reservoir during this period.

In the mid-1970s, the plant adopted a zero-release policy for process wastewater. Plant documentation suggests that the process wastewater was discharged into Pond B-2 and pumped to Pond A-2 from which it was spray evaporated with the objective of meeting zero-release. In 1980, Pond B-5 was completed to serve as an overflow pond. From 1980 to 1989, Ponds B-1 and B-2 were used for surface water control. Pond B-3 was used for spray evaporation, and Ponds B-4 and B-5 were used to store stormwater runoff from the central portion of the site. Throughout this time period, liquid sanitary wastes were still discharged to South Walnut Creek through Pond B-4. Although no detailed information on pond releases after the adoption of the zero release policy was located, it is clear that the recent admission of Resource Conservation and Recovery Act (RCRA) violations during this period by Rockwell indicate that the zero discharge policy was an objective that was not met.

5.1.1.3 Woman Creek Drainage

The history of the Woman Creek drainage is depicted in Figure 5-3. Pond C-1 was built in 1952 and received surface runoff, cooling tower blowdown, and filter backwash from the water treatment facility. Ponds 6, 7, and 8 were built on the Woman Creek drainage in 1955 (Dow, 1953-1973). Pond 6 was located south of the water treatment plant, Pond 7 was located south of the Building 881 sewage lift station, and Pond 8 was located south of the Building 881 dock area (Dow, 1953-1973). No information regarding the use of these ponds or the time of their closure was found. However, one interviewee indicated that Pond 6 may have been used to capture filter backwash from the water treatment plant (Hill, 1992). From 1973 to 1980 Pond C-1 was used to control and capture surface runoff. In 1980, Pond C-2 was built to detain runoff water from the South Interceptor Ditch, thus isolating Pond C-1 and Woman Creek from any Rocky Flats runoff. After a period of retention in the C-2 pond, captured water was released into Woman Creek until the line to the Broomfield Diversion Ditch was constructed, and may have periodically been diverted via Mower ditch to Mower Reservoir (Brunch, 1993).

5-3 Time Line of Events for the Woman Creek Drainage

5.1.2 Reservoirs

Three possibly impacted reservoirs are in the immediate vicinity of Rocky Flats. They are depicted in Figure 5-4 and include Great Western Reservoir, Standley Lake, and Mower Reservoir. Each of these reservoirs is briefly described in this section.

5.1.2.1 Great Western Reservoir

Great Western Reservoir is located approximately 0.25 mile east of the Rocky Flats Plant's eastern buffer zone boundary (Indiana Street). The reservoir receives runoff from Clear Creek through Church Ditch, Coal Creek through McKay Ditch, Upper Church Ditch, and Walnut Creek. Originally, the reservoir was 42 feet deep and had a storage capacity of 1,420 acre-feet. In 1955, the Turnpike Land Company bought the reservoir and established the Broomfield Heights Mutual Service Association to own and operate water and sewer utilities for the Broomfield Heights development. In 1958, the reservoir was enlarged to its present storage capacity of 3,250 acre-feet (City of Broomfield, 1991). In 1962, the city of Broomfield bought the water and sewer services from the Turnpike Land Company.

Great Western Reservoir water was used for agricultural irrigation until 1955. Since 1955, the sole water use has been as the city of Broomfield's municipal water supply.

5.1.2.2 Standley Lake

Standley Lake is a large reservoir located approximately one mile from the southeast corner of the Rocky Flats Plant's eastern buffer zone boundary (Indiana Street). It is owned by the Farmers Reservoir and Irrigation Company (FRICO). From 1914 to 1966, water from Standley Lake was used only for irrigation. The city of Westminster first used the lake as a drinking water source in 1966. Presently, the city of Westminster owns 37.3 percent of the shares in the Standley Lake Division, and the cities of Thornton and Northglenn own 13.3 and 17.7 percent of the shares, respectively. The remaining shares (31.7 percent) are still owned by FRICO.

5.1.2.3 Mower Reservoir

Mower Reservoir is a small, privately owned impoundment located just southeast of the Rocky Flats Plant (USDOE, 1991c). The reservoir is fed by Woman Creek via Mower Ditch, an irrigation ditch that originates within the Rocky Flats boundary (USDOE, 1991c). Mower Reservoir is used for stock watering, domestic lawn watering, and irrigation of approximately 80 acres (State of Colorado, 1973).

5-4 Possibly Impacted Reservoirs Near Rocky Flats

5.2 Available Monitoring Data

The first step in identifying the most effective approach to estimating surface-water-related contaminant releases from the plant was to determine the availability of contaminant monitoring data for the terminal ponds on North and South Walnut Creek and for the three reservoirs that received plant effluents or runoff. The following sections provide a history of the contaminant monitoring activities associated with the terminal ponds and the reservoirs.

5.2.1 Radionuclide Data

As discussed in Section 2, the plant retained an extensive record of airborne effluent radionuclide data in a relatively consistent format that was generally easily understood and reproducible. However, the plant did not maintain a similar data set for surface water effluents. Unlike the health physics group, the waste disposal group did not have an organized system for records retention. Many of the waste disposal group's monthly reports are available; however, raw data supporting these reports were not located.

Two different types of surface water sampling data were located for use in evaluating plant releases. The first type of data is effluent information. In general, this information was obtained from the waste disposal coordination monthly progress reports (Dow, 1953-1973) and the DOE Off-Site Discharge Information System (ODIS). The information provided in the waste disposal reports is quite comprehensive for effluents discharged to South Walnut Creek from 1953 to 1970. The ODIS also provides information on effluents discharged to South Walnut Creek from 1971-1989. However, information regarding effluents (primarily surface runoff) discharged to North Walnut Creek and Woman Creek was not routinely reported.

The second type of data is reservoir and drinking water monitoring data. Rocky Flats has monitored both surrounding reservoirs and drinking water from various cities from 1952 to the present. Additionally, the Colorado Department of Health (CDH) monitored reservoirs and drinking water from July 1970 to the present. The completeness and usefulness of each of these data sources are described in the following sections.

5.2.1.1 Effluent Information

Data on effluents from the ponds to off-site streams are available in Monthly Waste Disposal Coordination Reports (1952 to 1970), Annual Environmental Monitoring Reports (1971 to 1988), Monthly Environmental Monitoring Reports (December 1986 to July 1990), and the ODIS (1971-1989).

The Monthly Waste Disposal Coordination Reports (1953-1971) contain the following information:

- point of release (e.g., building),
- receiving surface water stream (e.g., South Walnut Creek),
- volume released (in gallons),
- gross alpha radioactivity concentration (Ci L^{-1}), and
- total activity released (Ci).

The data in these reports are not complete in that they do not cover the entire period for all ponds. For example, all of the above information is available for both Pond A-1 and Pond B-3 from July 1953 through September 1955. However, from October 1955 to August 1971, the above information is only available for Pond B-1.

The Annual Environmental Monitoring Reports for 1971 to 1988 quantify contaminant concentrations in the final holding pond in each drainage system. However, no data are available on the volume of releases from the ponds.

The Monthly Environmental Monitoring Reports quantify volumes of waste released from holding ponds A-4, B-5, C-1, and C-2 for December 1986 through July 1990. Release volumes per day and per month are given.

ODIS contains data for 1971-1989 that indicate the total curies of americium, plutonium, uranium, and tritium released to South Walnut Creek from the B-series ponds.

Figure 5-5 summarizes the availability of data on waterborne releases monitored by Rocky Flats.

The absence of data for Woman Creek and North Walnut Creek during the majority of the plant's existence limits our ability to develop site-wide contaminant release estimates. However, the available records can be used to evaluate whether contaminants released to Walnut Creek produced a measurable effect on the radioactivity levels in Great Western Reservoir. This evaluation is discussed in greater detail in subsequent sections of this report.

5.2.1.2 Reservoir and Drinking Water Monitoring

As previously mentioned, there are two sets of reservoir and drinking water monitoring data available. The first data set was collected by the Rocky Flats Site Survey group from 1952 to the present. The second was collected by CDH from July 1970 to the present. For the purposes of this analysis, data generated by the Site Survey group have been examined for the 1952 to

5-5 Waterborne Effluent Release Information

1970 time period and the data generated by CDH have been examined for the period after 1970. The following sections provide an overview of each data source.

Site Survey Reservoir and Drinking Water Monitoring, 1952-1970

In 1952, prior to the start-up of operations at Rocky Flats, a survey of environmental background gross alpha concentrations was conducted by a group from the Hanford Reservation in Washington (Quimby, 1952). Part of the survey included sampling the reservoirs surrounding the site and sampling the drinking water of nearby cities. Additionally, once operations began at Rocky Flats, the Site Survey group at Rocky Flats continued to sample reservoirs and city drinking water near the facility at intervals ranging from annually to monthly. All samples throughout the 18-year time period were analyzed for gross alpha activity. Over the years, the radioactivity in over 20 lakes and reservoirs remote from the plant was also monitored. However, few were monitored on a consistent basis. ChemRisk contacted USGS, USEPA, CDH and the Northern Colorado Water Conservancy District in an unsuccessful attempt to locate a body of water that is more distant from Rocky Flats and has a gross alpha monitoring record that could serve as a source of "background" measurements for comparison with data collected from surface waters near the plant. Information gathered from the above-mentioned sources indicate that specific radionuclide data were rarely collected prior to 1971. For instance, no monitoring data for plutonium were located for specific water bodies suggested as possible background locations (Carter Lake and Yrandby Lake), and uranium monitoring data are only available from 1990 to the present.

Figure 5-6 depicts monitoring data availability for Great Western Reservoir, Standley Lake, Baseline Reservoir, and Mower Reservoir. Baseline Reservoir is located six miles north of the plant and did not receive waterborne effluents from the plant. For the purposes of our analysis of potential direct releases of contaminants to surface water, the radioactivity levels measured in Baseline Reservoir may be considered unaffected by Rocky Flats or “background” measurements.

Drinking water samples included water from the cities of Arvada, Boulder, Broomfield, Denver, Golden, Lafayette, Louisville, Thornton, and Westminster. Figure 5-7 depicts the availability of drinking water monitoring data for each of these cities. It is important to note that Great Western Reservoir was not a drinking water source for the city of Broomfield until 1955. Standley Lake was not a drinking water source for the city of Westminster until 1965.

5-6 Availability of Gross Alpha Reservoir Monitoring Data Collected by the Site Survey Group at Rocky Flats 1952-1969

5-7 Availability of Drinking Monitoring Data Collected by the Site Survey Group at Rocky Flats 1952-1969

Colorado Department of Health Reservoir and Drinking Water Monitoring, 1970-1989

In July 1970, CDH began a sampling program monitoring the reservoirs and drinking water for cities surrounding the Rocky Flats plant. The cities included in this analysis are Arvada, Boulder, Broomfield, Golden, and Westminster. The samples were screened for gross alpha and gross beta concentrations and then analyzed for Pu-238, Pu-239/240, natural uranium, and tritium. The drinking water from the cities of Broomfield and Westminster was sampled on a bimonthly basis and the drinking water from Arvada, Boulder, and Golden was sampled either quarterly or biannually. Since July 1970, these data have been reported in monthly Rocky Flats Plant Surveillance reports (CDH, 1970-1991).

The cities of Broomfield (after 1955) and Westminster (after 1965) received a majority of their drinking water from Great Western Reservoir and Standley Lake, respectively, both of which have possibly been impacted by effluents or runoff from Rocky Flats. Until the early 1980s, the city of Arvada received a majority of its water from Ralston Reservoir. The city of Boulder receives the majority of its water from the Arapahoe Glacier in the Rockies. The city of Golden receives all of its water from Clear Creek. The water supplies for the cities of Arvada, Boulder, and Golden do not receive runoff or effluent from Rocky Flats and therefore represent unaffected waters with "background" radioactivity levels in drinking water (Terry, 1992).

In addition to the drinking water samples that were collected by CDH, water samples were occasionally collected directly from Great Western Reservoir, Mower Reservoir, and Standley Lake. As with the drinking water samples, these samples were screened for gross alpha and beta contamination, and then analyzed for Pu-238, Pu-239/240, natural uranium, and tritium.

Some shortcomings of this data set are: 1) the lack of plutonium and uranium drinking water samples from background reservoirs for 1976 and 1977; 2) the lack of plutonium samples for the city of Westminster drinking water in 1977; and 3) the absence of sampling at Mower Reservoir until 1980. These shortcomings notwithstanding, the quantity and isotope-specific nature of the data, in addition to the fact that the data were collected by an organization independent of Rocky Flats, make this data set particularly useful in performing an independent evaluation of potential plant impacts relative to surface water.

Summary: A variety of data sources are available that quantify radionuclides in surface waters. However, many of the data sets are incomplete and are not sufficient for estimating site-wide radionuclide releases. However, the data can be used to identify any major release events and to determine whether there were greater levels of radioactivity in the reservoirs receiving water from the plant than in other reservoirs in the region.

5.2.2 Monitoring of Chemical Contaminants in Surface Waters

Throughout the first 30 years of operations at Rocky Flats, data were not collected on the waterborne effluents for any of the nonradioactive chemicals of concern. Measurements of chemical parameters which are not addressed in this study are available for the 1971-1989 time period. These parameters were measured in effluent at USEPA-NPDES discharge permit points. These data, which include pH, nitrate, phosphate, fluoride, total solids, and hexavalent chromium, are presented in the Annual Environmental Monitoring Reports.

As discussed previously, the volatile chemicals of concern readily evaporate from surface waters and were therefore unlikely to have been transported off-site in surface waters to any significant extent. Beryllium is the only nonradioactive contaminant of concern having the potential to be transported off-site in surface waters. Although the 1980 Final Environmental Impact Statement states that beryllium was among eleven elements analyzed for in plant waterborne effluents, only the 1971 and 1972 annual environmental reports report waterborne beryllium effluent data. However, beryllium is a metal that has low solubility in water and will tend to be adsorbed by surface soils or sediment. This tendency would likely have reduced the extent to which beryllium was transported off-site in surface waters. The only information available for addressing past releases from the plant would be measurements of beryllium in reservoir sediments. To date, only one study to determine beryllium concentrations in the sediments of Great Western Reservoir and Standley Lake has been located (USEPA, 1975). This study did not investigate the beryllium concentrations in background reservoirs and did not draw any conclusions as to whether or not the beryllium concentrations in Great Western Reservoir and Standley Lake were elevated. The analytical results of the study are summarized below:

- Beryllium concentrations in sediment dredge samples from Great Western Reservoir sediments ranged from <0.5 - 1.5 parts per million (ppm), with a mean of 1.0 ppm.

- Beryllium concentrations in core samples from Great Western Reservoir ranged from <0.5 - 1.9 ppm, with a mean of 1.0 ppm.

- Beryllium concentrations in sediment dredge samples from Standley Lake ranged from 0.7 to 1.4 ppm, with a mean of 1.1 ppm.

- Beryllium concentrations in core samples from Standley Lake were all reported as less than 2.0 ppm.

In an attempt to determine whether or not the beryllium concentrations in Great Western Reservoir sediment could be considered elevated, the Colorado State University Soils Testing Laboratory at Fort Collins and the Geologic Division of USGS were contacted (Self, 1993; Modreski, 1993). Neither organization was able to provide regional beryllium concentration in soil or sediment information. However, beryllium soil concentrations in Colorado, as reported in a scientific literature, range from not detectable to 5.0 ppm, with a mean of 1.0 ppm and a standard deviation of 1.2 (Dragun and Chiasson, 1991).

Summary: No data were identified that could be used to quantify historical releases of nonradioactive materials to area surface waters. Of the stable materials under study, only beryllium would be likely to remain in surface waters where it would most likely be associated with sediments. Beryllium concentrations measured in the sediments of Great Western Reservoir and Standley Lake by USEPA in 1975 are in the same range as those measured in soil samples from other regions of Colorado.

5.3 Surface Water Data Evaluation Approach

The monitoring of contaminants in plant effluents to off-site waterways has been relatively limited and is inadequate for the purposes of developing reasonably accurate estimates of historical contaminant releases from the plant. Our observations regarding the availability of data for source term development are consistent with a number of statements made in the plaintiff's sentencing memorandum in the criminal prosecution brought by the U.S. Department of Justice against Rockwell International Corporation (USA, 1992). This memorandum indicates that there were periodic releases of various industrial and hazardous wastes through the sewage treatment plant during the 1980s, and that the improper operation of the spray irrigation fields during this same period contributed to off-site dispersal of contaminants. In addition, the memorandum goes on to note that:

> "[T]here was no regular monitoring of other industrial or toxic pollutants either entering or leaving the STP [sewage treatment plant], being sent to the holding ponds or being spray irrigated" (USA v. Rockwell International Corporation, 1992, p. 72).

The focus of the surface water investigations was therefore shifted to the monitoring data for city water supplies that may have been impacted by plant releases. It should be noted, however, that the use of reservoir and drinking water data for the purposes of assessing plant impacts is complicated by the potential presence of contaminants resulting from other sources or from natural background levels of contaminants.

Based on the sources and availability of reservoir monitoring data described previously, the evaluation of surface water contaminants is addressed for two distinct time periods. The first time period, 1952-1970, represents the period for which some limited documentation of effluents and plant-generated monitoring data for reservoirs and drinking water in the form of gross alpha measurements are available. These data were used in the following manner to evaluate whether, on an annual basis, the reservoirs or drinking water were measurably affected by radioactive releases from the plant:

- Direct comparisons were made of pond effluent monitoring data (annual average gross alpha releases) from Walnut Creek to measured gross alpha concentration in Great Western Reservoir to establish whether plant releases were associated with measurable increases in radioactivity in receiving reservoirs.

- Potential theoretical increases in gross alpha concentrations in Great Western Reservoir were estimated based on estimates of annual gross alpha activity releases to Walnut Creek.

- Direct comparison were made of gross alpha activity in possibly impacted drinking water from Broomfield and Westminster to gross alpha activity in "background" drinking water from Arvada, Boulder, and Golden.

- Direct comparison were made of gross alpha activity in Great Western Reservoir (1955-1970) and Standley Lake (1965-1970) to gross alpha activity in a "background" reservoir, Baseline Reservoir.

The second time period, 1971-1989, represents the period in which the plant adopted a "zero release" policy for process waste water. As a result, only a very limited data set on plant effluents is available. However, a rather complete set of isotope-specific reservoir and drinking water

monitoring data is available from sampling conducted by the Colorado Department of Health. The Colorado Department of Health data were used to make direct comparisons between isotope-specific concentrations in possibly impacted drinking water (i.e., drinking water from Broomfield and Westminster) and nonimpacted drinking water (i.e., drinking water from Arvada, Boulder, and Golden).

5.4 Surface Water Monitoring Data Evaluation for 1952-1989

The following sections provide the results of comparisons of surface water monitoring data for the period 1952-1989.

5.4.1 Effluent Data Evaluation

Reported annual releases of gross alpha radioactivity to Walnut Creek for 1952-1970 are summarized in Table 5-2. Over this 18-year period, the plant reported the release of 54,400 μCi of gross alpha activity. This release estimate is primarily derived from monitored releases from Pond B-3 into South Walnut Creek; any contaminant release associated with surface runoff is not accounted for in this estimate. Another point that should be noted is that the water the plant receives for use contains natural radioactivity; therefore, a portion of the radioactivity in water released from plant holding ponds is not derived from plant operations. In order to estimate the impact of the release of gross alpha to Walnut Creek on the water quality of the Great Western Reservoir between 1953 and 1970, it is also necessary to know the time history of reservoir volume. As no data on the volume of the Great Western Reservoir prior to 1971 were located, annual rainfall at Rocky Flats was investigated as a possible surrogate of reservoir volume. Associated annual rainfall data are shown in Table 5-3. For the purpose of identifying if there is a correlation between plant releases and gross alpha levels detected in the reservoir water, annual gross alpha activity releases, and annual gross alpha activity releases per unit annual rainfall are plotted with annual average gross alpha concentrations detected in Great Western Reservoir in Figure 5-8. It should be noted that the enlargement of Great Western Reservoir in 1958 might have affected gross alpha concentrations in reservoir water.

A qualitative review of these data suggests that there is no clear relationship between plant releases and gross alpha activity in Great Western Reservoir between the years of 1959-1962, when an approximately twofold increase in the amount of gross alpha activity released from the plant was not associated with a similar increase in measured gross alpha activity in Great Western Reservoir. On the other hand, the data from 1966 to 1970 suggest that plant releases may have influenced the observed activity in Great Western Reservoir, at least during 1966. However, other events, such as the abortive reentry of the plutonium-238-powered SNAP 9-A navigational satellite power supply in the upper atmosphere in 1964 (Eisenbud, 1987), cannot be ruled out as potential sources of the increased gross alpha concentrations in 1966.

A calculation to establish whether there was any correlation among the data sets indicated that the reported annual plant releases of gross alpha activity and the reported annual plant releases of gross alpha activity per annual rainfall are not correlated with radioactivity in Great Western Reservoir (correlation coefficients of -0.04 and 0.21, respectively).

To further evaluate the potential for plant releases of radioactivity to increase observed activity in Great Western Reservoir, some simple dilution calculations were performed. These calculations were used to estimate the possible increase in radioactivity in the reservoir that would result once

a plant release was diluted by the water in the reservoir. This simple analysis assumed that plant releases were diluted by a volume of water equal to 75 percent of the total

5-2 Reported Annual Gross Alpha Radioactivity Releases to Walnut Creek, 1952-1970

5-3 Annual Rainfall at the Rocky Flats Plant

5-8 Total Gross Alpha Activity Release (mCi) to Walnut Creek and the Annual Average Gross Alpha Concentration (pCi/L) in Great Western Reservoir 1953-1970

capacity of Great Western Reservoir. This calculation is believed to be conservative in that it assumes that an annual release quantity is diluted by less than a single reservoir volume and that there was no inflow or outflow during the year that would further dilute the radioactivity. In addition, the analysis assumes that all of the contamination released by the plant reaches Great Western Reservoir, which is more than a mile downstream. The annual total increase in the gross alpha concentration in Great Western Reservoir that would be expected to result from the release of radioactivity to Walnut Creek based on these simplifying assumptions can be calculated as follows:

$$\text{Increase in alpha activity at Great Western Reservoir} = \frac{\text{total alpha activity released (pCi)}}{(0.75) \times (\text{total capacity of Great Western Reservoir, L})}$$

For 1953:

$$\text{Increase in alpha activity at Great Western Reservoir} = \frac{1.13 \times 10^9 \text{ pCi}}{0.75 \times (1.75 \times 10^9 \text{ L})} = 0.86 \text{ pCi L}^{-1}$$

Table 5-4 presents the results of this calculation for each year for which effluent data are available. The estimated increases of gross alpha activity in Great Western Reservoir due to the reported annual effluent releases from the plant range from 0.86 to 2.0 pCi L^{-1}. This should be considered a very conservative estimate of the possible influence of plant releases on Great Western Reservoir.

Examination of the two data sets discussed in this section does not provide any clear evidence that plant releases of contaminants in surface water resulted in measurable increases in radioactivity in Great Western Reservoir. A simple dilution calculation suggests that reported plant releases conservatively had the potential to elevate activity in Great Western Reservoir on average by little more than 1 pCi L^{-1} during the 1960s.

5.4.2 Reservoir Water Monitoring Data Evaluation

Another evaluation was performed to further examine whether radioactivity levels or their fluctuations in Great Western Reservoir or Standley Lake differed from those measured in other reservoirs in the region, in this case Baseline Reservoir. Associated data are shown in Figure 5-9 and Table 5-5. A qualitative review of these data suggests that the gross alpha concentrations and their fluctuations in these three reservoirs appear similar during this time period, with the exception of 1966. As noted previously, an increase in the release of radioactivity from the plant during 1966 appeared to be possibly associated with a corresponding increase in the gross alpha concentration in Great Western Reservoir. The cause of the increase

5-9 Annual Average Gross Alpha Concentration (pCi/L) for the Great Western Reservoir, Standley Lake, and Baseline Reservoir 1952-1970

5-5 Annual Gross Alpha Concentration in Baseline and Great Western Reservoirs and Standley Lake (pCi/L^{-1})

in gross alpha concentration in Standley Lake is not known. No data are available for Baseline Reservoir for 1953 and 1954.

While the concentration of alpha activity in Baseline Reservoir is about the same as Great Western Reservoir and Standley Lake for most years during this period, alpha activity was on average approximately 0.5 and 0.3 pCi L^{-1} greater in Great Western Reservoir and Standley Lake, respectively, than in Baseline. If the correlation between the data from each of these reservoirs is calculated for the years in which data are available, fluctuations in radioactivity in Baseline Reservoir are not highly correlated with either Great Western Reservoir (correlation coefficient = 0.26) or Standley Lake (correlation coefficient = 0.34). However, radioactivity levels in Standley Lake and Great Western Reservoir are closely correlated (correlation coefficient = 0.9).

It is also important to note that although minimal amounts of contaminants were likely released into the atmosphere or creeks from the Rocky Flats Plant in 1952, gross alpha concentrations measured in Great Western Reservoir and Standley Lake in that year are similar to those measured in the later years. The average of gross alpha measurements in Great Western Reservoir in 1952 was 1.4 pCi L^{-1}, about 31 percent lower than the average level measured between 1952 and 1970. Similarly, the average of gross alpha measurements in Standley Lake in 1952 was 1.2 pCi L^{-1}, about 33 percent lower than the average level measured between 1952 and 1970. These data indicate that a major portion of the gross alpha activities measured in Great Western Reservoir and Standley Lake between 1953 and 1970 may be attributed to natural background.

Mower Reservoir Monitoring

From 1952 to 1953, nine samples were collected and analyzed for gross alpha activity from this reservoir. These data are presented in Table 5-6. This data set is too limited to draw conclusions from regarding the long-term impacts plant effluents may have had on the reservoir.

5.4.3 Drinking Water Monitoring Data Evaluation

Comparisons were also made between the concentration of gross alpha activity in drinking water from the cities of Broomfield and Westminster and "background" concentrations in drinking water from Arvada, Boulder, and Golden. The annual average drinking water concentrations from Arvada, Boulder, and Golden are plotted in Figure 5-10. Gross alpha activity concentrations ranged from 0.1 pCi L^{-1} to 4.4 pCi L^{-1}. Similarly, the annual averages of the Broomfield and Westminster data are plotted in Figure 5-11. As noted in Figure 5-11, Broomfield did not begin receiving water from Great Western Reservoir until 1955 and Westminster did not begin receiving water from Standley Lake until 1966. Gross alpha activity

5-6 1952-1953 Mower Reservoir Monitoring Data

5-10 Annual Average Gross Alpha Concentration in Drinking Water for the Cities of Arvada, Boulder, and Golden 1952-1970

5-11 Annual Average Gross Alpha Concentration in Drinking Water for the Cities of Broomfield and Westminster 1952-1970

concentrations in Broomfield and Westminster drinking waters ranged from 0.1 pCi L^{-1} to 19.2 pCi L^{-1}. It is important to note that the maximum of 19.2 pCi L^{-1} measured in Broomfield drinking water occurred prior to the use of Great Western Reservoir as a drinking water source. A qualitative evaluation of these data suggest that the gross alpha concentrations in drinking water from Broomfield and Westminster are similar to gross alpha concentrations in drinking water from Arvada, Boulder, and Golden.

As indicated in Table 5-7, the average radioactivity in the "background" cities' drinking water for the period from 1955 to 1970 was slightly higher than that of Broomfield or Westminster during the time in which these cities derived their water from Great Western Reservoir and Standley Lake. However, in 1966 gross alpha activity measured in drinking water of Broomfield was 1.5 pCi L^{-1} higher than that measured in the "background" cities. This single-year elevation of radioactivity may be attributable to the plant; but such fluctuation was not inconsistent with levels often found in "background" drinking water supplies.

5.5 Surface Water Monitoring Data Evaluation for 1970-1989

In the 1970-1989 time period, the water supplies for the cities of Broomfield and Westminster were primarily drawn from Great Western Reservoir and Standley Lake, respectively. As discussed previously, CDH primarily sampled finished drinking water for Broomfield and Westminster, rather than sampling Great Western Reservoir or Standley Lake during this period. CDH also collected samples of drinking water from Arvada, Boulder, and Golden, three cities that receive water from reservoirs at a considerable distance from Rocky Flats and that do not receive runoff or effluents from Rocky Flats (Terry, 1992). The sampling of the distant water supplies during this period provides a reference point for the comparison of the level of radioactivity found in waters possibly impacted by the plant. The CDH reports provide information on concentrations of plutonium, natural uranium, and tritium in the sampled waters.

In order to evaluate the large amount of data collected by Colorado Department of Health from 1970 to 1989, a database was created in which all plutonium, uranium, and tritium data for the cities of Broomfield, Westminster, Arvada, Boulder, and Golden were entered. It is important to note that, on average more than 70 percent of the samples for all water supplies were below limits of detection. A summary of the frequency of detection and the maximum values is presented in Tables I-3 through I-6 in Appendix I of this report.

The first step taken in examining these data sets was to calculate the annual average Pu-239/240, Pu-238, natural uranium, and tritium concentrations for each of the five cities. The annual average radionuclide concentrations in drinking water are tabulated in Tables I-7 through I-10 in Appendix I of this report.

5-7 Annual Gross Alpha Concentrations for Drinking Water (pCi/L)

In order to examine whether releases or runoff from Rocky Flats measurably altered plutonium, uranium, or tritium concentrations in Broomfield or Westminster, concentrations of these contaminants in drinking water from Broomfield and Westminster were plotted and compared to data plots for the cities of Arvada, Boulder, and Golden (Figures 5-12 through 5-19). A qualitative review of these data suggests:

- From 1972 to 1974, Pu-239/240 concentrations in the drinking water of Broomfield and Westminster may have risen as a result of pond reconstruction, which resuspended sediments in the North and South Walnut Creek drainage.

- The accidental release of tritium in 1973 and 1974 clearly elevated the tritium concentrations in Broomfield drinking water.

Tables 5-8 through 5-11 present the average "background" reservoir data and Westminster and Broomfield average radionuclide concentrations in drinking water for the period 1970-1989. As indicated earlier, a large number of samples were below the detection limit. In calculating the annual average values, one-half the detection limit was used whenever non-detect results were reported. When using one-half the limit of detection for non-detect results, calculated annual averages often fell below the limit of detection. It is important to note that because there are so many non-detect results, it is not likely that the adjusted data are normally (or even lognormally) distributed; therefore, the average does not necessarily provide an accurate representation of the data. However, the average likely overestimates the actual contaminant concentration in drinking water. An alternative approach for evaluating the data to that described here is presented in Appendix I. While there are no known direct statistical tests that can be used when so many non-detects are involved, the generalized likelihood-ratio test was used to give an approximate solution to this problem in the case of large sample sizes. The application of this test to the data is discussed in Appendix I. The test results did not suggest that the concentrations of radionuclides in drinking water from Broomfield and Westminster differed from that found in drinking water from Arvada, Boulder, or Golden.

As indicated in Tables 5-8 and 5-9, the Pu-238 and Pu-239/240 concentrations in the "background" cities' drinking water averaged for the entire period from 1970-1989 were slightly higher than the plutonium concentrations in the drinking water of Broomfield and Westminster over the same period. The annual data indicate that the two-year period of pond reconstruction (1972-1974) along the North and South Walnut Creek drainage systems may have elevated levels of plutonium in Great Western Reservoir. The data suggest that from 1972 to 1974, the pond reconstruction may have elevated the plutonium levels in the Broomfield drinking water as much as 0.16 pCi L^{-1}. However, this elevated value is not inconsistent with the year-to-year fluctuations of plutonium in the drinking water from the "background" cities.

5-12 Annual Average Concentration of Pu-238 in Drinking Water for the Cities of Arvada, Boulder, and Golden 1970-1983

5-13 Annual Average Concentration of Pu-238 in Drinking Water for the Cities of Broomfield, and Westminster 1970-1983

5-15 Annual Average Concentration of Pu-239/240 in Drinking Water for the Cities of Broomfield, and Westminster 1970-1989

5-17 Annual Average Concentration of Uranium in Drinking Water for the Cities of Broomfield, and Westminster 1971-1988

5-8 Annual Average Drinking Water Concentration of Pu-238 (pCi/L^{-1})

5-9 Annual Average Drinking Water Concentration of Pu-239/240 (pCi/L^{-1})

5-10 Annual Average Drinking Water Concentration of Natural Uranium (pCi/L)

5-11 Annual Average Drinking Water Concentration of Tritium (pCi/L^{-1})

Another way to evaluate the effects of this release event is to compare the levels of plutonium-239/240 in Broomfield water and Westminster water. In the 1970-1989 time period, the water supplies for the cities of Broomfield and Westminster were primarily drawn from Great Western Reservoir and Standley Lake, respectively. Both reservoirs are located downwind from the RFP and were likely to have been approximately equally impacted by airborne emissions from the plant; however only Great Western Reservoir received water directly from the North and South Walnut Creek drainage systems and was likely to have been impacted by contaminants released to the creeks. As plutonium-239/240 contaminated sediment was released into the North and South Walnut Creek drainage systems, drinking water monitoring data for the cities of Broomfield and Westminster taken between 1971 and 1975 with finer resolution than the annual were plotted to evaluate the impact of this release event. As shown Figure 5-20, with the exception of a few data points, levels of plutonium-239/240 in drinking water of Broomfield and Westminster measured during that period of time are about the same, less than 0.2 pCi L^{-1}. The two highest plutonium-239/240 levels measured, 1.3 pCi L^{-1} and 4.5 pCi L^{-1}, are associated with water samples collected from Broomfield in early November 1972 and in late April 1973. No similar elevation of plutonium-239/240 concentrations is observed in the water monitoring data for Westminster. Therefore, the two elevated levels of plutonium-239/240 in Broomfield water between 1972 and 1973 may be attributable to the pond reconstruction activities.

As shown in Table 5-10, the "background" natural uranium average concentration of 2.9 pCi L^{-1} for the entire period from 1970-1989 was below the Broomfield average of 3.1 pCi L^{-1} and above the Westminster average of 2.2 pCi L^{-1}. A review of the annual average Broomfield data indicates that this increased average is primarily due to a single year (1976) in which the average natural uranium concentration was almost three times greater than any other year. As indicated in Figures 5-16 and 5-17, drinking water from the individual "background" cities demonstrated similar episodes of elevated concentrations of natural uranium.

Both the Westminster and Broomfield 1970-1989 average tritium drinking water concentrations exceeded the "background" cities' tritium concentration in drinking water. At 1200 pCi L^{-1}, the long-term average tritium concentration for the Broomfield drinking water is clearly elevated above the "background" tritium concentration of 360 pCi L^{-1}. As mentioned previously, this is primarily due to the accidental release of tritium in 1973 and 1974. At 420 pCi L^{-1}, the 1970-1989 average tritium concentration in Westminster drinking water was slightly elevated above "background." A more detailed analysis of this accident can be achieved by comparing the levels of tritium measured in the Broomfield and Westminster water collected between 1971 and 1975 that are shown in Figure 5-21. As mentioned earlier, because liquid wastes were released into the North and South Walnut Creek drainage systems, only Great Western Reservoir and Broomfield water are expected to be directly impacted by the release of tritium to surface waters. As shown

in Figure 5-21, before April 1973, levels of tritium in drinking water of Broomfield and Westminster are about the same, about 1,000 pCi L^{-1}. However, starting from

5-20 Pu-239/240 in Broomfield and Westminster Water, 1971-1975

5-21 Tritium in Broomfield and Westminster Water, 1971-1975

April 2, 1973, tritium concentration in Broomfield water increased sharply and peaked at about 23,000 pCi L^{-1} in May 1973; it remained at a relatively high level for another two years before dropped back to the pre-1973 levels. No such changes were observed in the water samples collected from Westminster. It is likely that the accidental release of tritium to the Walnut Creek drainage systems in 1973 caused the observed elevation of tritium concentrations in Broomfield drinking water.

Mower Reservoir

CDH did not monitor Mower Reservoir for plutonium until 1980. During the 1980s, only seven samples were analyzed for Pu-238 and Pu-239/240. Three of the seven samples contained detectable concentrations of Pu-239/240, and no samples contained detectable concentrations of Pu-238. The maximum Pu-239/240 concentration was 0.12 pCi L^{-1}. The limit of detection for Pu-239/240 analyses was 0.02 pCi L^{-1}.

From 1974-1985, nine samples were analyzed for natural uranium. Three of nine samples contained detectable concentrations of natural uranium. The maximum concentration was 3.6 pCi L^{-1}. The limit of detection for the natural uranium analyses was 2.0 pCi L^{-1}.

From 1974-1986, thirteen samples were analyzed for tritium. Four of thirteen samples contained detectable concentrations of tritium. The tritium concentrations ranged from 360 to 770 pCi L^{-1}. The limit of detection for tritium was 350 pCi L^{-1}.

5.6 Results of Surface Water Monitoring Data Evaluations

The results of the examination of surface water monitoring data are presented in this section for 1952 to 1970, for 1970 to 1989, and for Mower Reservoir.

5.6.1 Conclusions for 1952 to 1970

On average, only a slight difference was detected between the gross alpha activity in background reservoirs and drinking water and the alpha activity in Great Western Reservoir, Standley Lake, and the drinking water of Broomfield and Westminster. The data suggest that throughout the 1952-1970 period, some single-year fluctuations of alpha activity in drinking water that may be attributable to the plant could have been as high as 1.5 pCi L^{-1}, but such fluctuations were not inconsistent with levels often found in "background" drinking water supplies.

5.6.2 Conclusions for 1970 to 1989

It is difficult to draw any conclusions regarding relative concentrations of radionuclides in drinking water during this period because of the large number of non-detect values in the data set for plutonium and uranium. Only a slight qualitative difference was observed in the average Pu-238 and Pu-239/240 drinking water concentrations of Broomfield, Westminster, and "background" cities. The pond reconstruction of the early 1970s may have caused an increase of 0.02 pCi L^{-1} and 0.15 pCi L^{-1} for Pu-238 and Pu-239/240, respectively, over a two-year period, but such levels were not inconsistent with levels often found in "background" water supplies.

The long-term average and annual average natural uranium concentrations in drinking water for the cities of Westminster and Broomfield were similar to those observed in the "background" cities.

Tritium concentrations for the city of Broomfield were clearly elevated above background. In single-year fluctuations, this elevation was as much as 8,100 pCi L^{-1}. Over the period from 1970-1989, the average elevation in tritium levels in Broomfield drinking water was 840 pCi L^{-1}.

The statistical analysis provided in Appendix I did not suggest any significant differences in the concentration of the sampled radionuclides in the waters of either Broomfield or Westminster compared to the "background" cities over the long-term with the possible exception of uranium, but even this is only weakly supported. Given the nature of the data set that are available none of these analyses should be construed as being definitive.

5.6.3 Conclusions Regarding Mower Reservoir

There is an insufficient amount of data to draw conclusions regarding the impact the plant may have had on Mower Reservoir. However, the limited sampling data available provide no indication that impacts to Mower Reservoir were significantly different than those discussed for Great Western Reservoir and Standley Lake for the periods sampled. In fact, no Pu-238, Pu-239/240, natural uranium, or tritium concentrations exceeded the long-term average concentrations for the "background" cities.

5.7 Sediment Sampling

Another potential source of information relative to surface water contamination is sediment sampling data. Over the last twenty years, a number of studies have addressed the plutonium concentrations in the bottom sediments of Great Western Reservoir and Standley Lake. An extensive summary of these studies is available in the Historical Information Summary and Preliminary Health Risk

Assessment for Operable Unit No. 3 (USDOE, 1991c). This section will briefly discuss the findings of these studies.

Seven studies have addressed the plutonium concentrations in the bottom sediments of Great Western Reservoir (USEPA, 1971; USEPA, 1973; USEPA, 1975; Dow, 1974; Battelle, 1981; Rockwell, 1979; Rockwell, 1985, as provided in USDOE, 1991c, Appendix D). The range of average plutonium concentrations reported in these seven studies was 0.11-3.5 pCi g^{-1} for surface sediments and 0.24 - 2.7 pCi g^{-1} for sediment cores. It should be noted that three of the seven studies were based on fewer than ten sediment samples (USDOE, 1991c). The results of these studies indicate that on average the plutonium concentrations in Great Western Reservoir sediments were greater than the USEPA estimated baseline level for area surface waters of $\leq$0.1 pCi g^{-1} (USEPA, 1973, as provided in USDOE, 1991c, Appendix D). Five of the seven studies concluded that the elevated plutonium concentrations and deposition patterns could be linked to historical releases from the Rocky Flats Plant.

Seven studies have addressed the plutonium concentrations in the sediments of Standley Lake (USEPA, 1971; USEPA, 1973; USEPA, 1975; Dow, 1974; Battelle, 1981; USDOE, 1978; Rockwell, 1984, as provided in USDOE, 1991c, Appendix D). The range of average plutonium concentrations reported in these seven studies was 0.04 - 1.3 pCi g^{-1} for surface sediments and 0.016 - 0.19 pCi g^{-1} for sediment cores. The results of these studies suggest that the plutonium concentrations in Standley Lake were greater than the estimated baseline of $\leq$0.1 pCi g^{-1} (USEPA, 1973, as provided in USDOE, 1991c, Appendix D). However, the conclusions of these studies are conflicting. Two of the USEPA studies concluded that the elevated plutonium levels resulted from unspecified releases from Rocky Flats (USEPA, 1971; USEPA, 1973; as cited in USDOE, 1991c), while, in 1975, the USEPA study concluded that there was no discernable plutonium contamination in Standley Lake attributable to Rocky Flats releases (USEPA, 1975, as cited in USDOE, 1991c). In 1978, a USDOE study concluded that 70 percent of the plutonium in Standley Lake was attributable to releases from Rocky Flats and speculated that this plutonium was transported both by airborne particulates and by surface water (USDOE, 1978, as cited in USDOE, 1991c).

From this brief review of the available sediment studies, it can be concluded that the plutonium concentrations in the bottom sediments of Great Western Reservoir are greater than the estimated baseline concentration of $\leq$0.1 pCi g^{-1}. It is also well understood that these elevated concentrations are likely due to historical releases from Rocky Flats. In a majority of the studies, the average plutonium concentrations in Standley Lake exceeded the reported baseline concentration of $\leq$0.1 pCi g^{-1}. Although the conclusions in a number of the reports are inconsistent, it is likely that the elevated plutonium concentrations are due to releases from Rocky Flats.

Summary: Available data are not sufficient for reconstructing contaminant releases in surface water from the plant. Except for previously identified accidental releases of plutonium-239/240 and tritium, the reservoir and drinking water monitoring data do not provide a clear indication of other plant contaminant release events. The magnitude of exposures associated with some of the observed fluctuations in radioactivity can be quantified, but we cannot determine whether the plant was the source of these fluctuations.

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6.0 NONROUTINE CONTAMINANT RELEASES

A number of nonroutine events have resulted in the release of contaminants from the Rocky Flats Plant. The events include accidents that have occurred, others represent operating practices that resulted in unintended releases of contaminants, while still others represent waste disposal practices that were associated with some expected release. Nonroutine contaminant releases identified as a result of an extensive search of classified and unclassified records are described in detail in the Tasks 3 and 4 report (ChemRisk, 1992). Documented accidents primarily involve the release of radionuclides, specifically plutonium.

Published records suggest that most of the plutonium released from the plant was released from the 1957 fire, the 1969 fire and the leaking oil drums on the 903 Pad. These events are the main focus of accident source term reconstruction. Other radionuclide releases include the accidental releases of plutonium through the filter plenum exhaust vents in 1965 and 1974, tritium in 1968 and the early 1970s, and depleted uranium in 1965. A well-publicized chemical release that resulted in some degree of on-site contamination is the 1989 release of chromic acid. The circumstances of these accidents as they relate to source term reconstruction will be discussed in some detail in this section.

There have been several attempts to estimate accidental radionuclide releases from Rocky Flats. After the May 11, 1969 fire, inquiries by Dr. E. Martell and the Colorado Committee for Environmental Information led to studies of plutonium deposition in the soils around Rocky Flats as a means of estimating total radionuclide releases from Rocky Flats. Such studies were published by Krey and Hardy (1970), Poet and Martell (1972), and Krey (1976). These studies drew attention to the importance of accidental releases. The 1980 USDOE FEIS contains some information on accidents at Rocky Flats. In 1981, C. W. Barrick, a former long-term Rocky Flats Plant employee, completed a Rocky Flats report summarizing the status of information about accidental radionuclide releases. Attention has also been drawn to accidental releases of radionuclides from Rocky Flats by the work of Dr. Carl Johnson, and by S. Chinn in connection with the Church litigation (see glossary).

This section summarizes available information relevant to source terms for accidental releases of radionuclides to the area surrounding the Rocky Flats Plant. Quantitative data necessary to develop accident source term estimates have been found in many places, including papers in the open scientific literature and in Rocky Flats reports. USDOE and Rocky Flats accident reports, available to the public in the Rocky Flats Reading Room, have also been used. In the case of the 1968 tritium accident, the accident has been acknowledged in the 1980 USDOE FEIS, but additional information is limited.

Since it is not possible to go back in time and duplicate or verify measurements and observations made at the time of the accidents, the approach to developing source terms involves careful review of data for plausibility and internal consistency, and cross-checking estimates with ambient data collected by the Rocky Flats Plant, the Colorado Department of Health, and others whenever possible.

6.1 Major Release Events

Major plutonium accidents with previously estimated releases greater than 1,000 microcuries (µCi) include the 1957 fire, the 1969 fire and the 903 Pad incident. The development of source terms for these major accidents involves the use of various types of documentation of these events, including monitoring and sampling data. The development of source terms for these events also required computer transport modeling of the ambient plutonium concentrations expected to result from different release scenarios consistent with available information about the accidental releases. The predicted plutonium concentrations in air and soil were compared to the available ambient measurement data to identify the source terms most likely to have produced the measured results. Description of this computer modeling activity is covered in the Task 6 report and will not be repeated here. Resulting estimates of source terms for the 1957 fire, the 1969 fire and the 903 Pad releases are included in this section.

6.1.1 1957 Fire

The 1957 fire began in Building 771 at about 10 p.m. on September 11, 1957 when metallic plutonium casting residues spontaneously ignited in a glove-box in Room 180. The fire then spread to an exhaust filter plenum, Rooms 281 and 282, consuming a considerable quantity of filters and damaging the ductwork and fan system. Because the samplers in the 771 Building stack were disabled by the filter plenum explosion during the early stages of the fire, there are no measurements of the release from the 771 stack during the fire. The limited data available from ambient air and vegetation monitoring during and after the fire were used in Task 6 to estimate the amount of plutonium released.

1957 Fire Source Term Estimation

A detailed description of the 1957 fire modeling is provided in the Task 6 report; only a summary of the modeling effort and source term estimation is presented here. Based on the historical information of the accident, modeling of the 1957 fire was divided into two periods: coarse particles released from the filter plenum explosion and fine particles from subsequent unfiltered fire emission. As particles of different size ranges and deposition characteristics were released in these two periods, they are also modeled separately in Task 6.

Coinciding with the explosion in the main filter plenum, a single "puff" of coarse particles is assumed to have been released at 10:40 p.m. on September 1957. The released particles were relatively large and primarily deposited within relatively short distances, leading to the observed plutonium contamination on vegetation. The USEPA INPUFF model was used to predict the dispersion and deposition of released plutonium particles. The amount of plutonium released during this period was estimated by matching the plutonium deposition pattern predicted by the model with the measured vegetation data. Using this approach, it is estimated that 60 µCi of plutonium could have been released by the explosion. The estimates of the upper and lower bounds of the 95 percent confidence interval about the best estimate are 1900 µCi and 1.9 µCi, respectively.

After the explosion, fine particles of plutonium produced by the burning HEPA filter and the fire in Building 771 were released into the atmosphere. The INPUFF model was used to model the average plutonium concentrations in air at several on-site and off-site locations during the 13.5-hour fire event. The appropriate release estimate was determined by matching the predicted air concentrations with those obtained from the routine on-site and off-site air samplers. Once the plutonium release estimate was established, predicted air concentrations at other locations were compared with additional air measurements taken by portable air samplers to increase the confidence level of the predictions. The total estimated release of fine particles from the fire is 0.07 Ci. The estimates of the upper and lower bounds of the source term of the 1957 fire are 2.4 Ci and 0.002 Ci, respectively.

There are considerable uncertainties associated with the release estimates because of the many assumptions that have been made and the generally poor quality of the available sampling and meteorological data. In addition, much of the estimating process for the fine particle release relied upon results at or below the detection limit, which would produce bounding estimates rather than best estimates of the release.

Previous Estimates of 1957 Fire Release

Barrick (1981) provides the largest published estimate of the total release of radioactivity to the environment from the September 11, 1957 fire at Rocky Flats. Barrick estimates that the release was between 0.7 and 1.3 Ci, with a most probable value of 1.0 Ci. At 0.0734 Ci per gram of plutonium, a release of 1 Ci corresponds to 14 grams of plutonium.

The 1980 USDOE FEIS estimated the total release from the 1957 fire as 25,618 µCi, or 0.35 gram of plutonium. Barrick (1981) notes that the FEIS estimate was obtained by subtracting the average of stack sampler readings from those months of 1957 unaffected by the accident from the amount of total alpha activity (assumed to be all plutonium) recorded by the Building 771 stack sampler from September through December 1957. However, this approach neglects the fact that the Building 771

stack samplers were not operating from one hour after the fire began until eight days later on September 19, 1957. Barrick (1981) says that, for the above reasons, the estimate provided in the USDOE 1980 FEIS cannot be supported nor can an estimate of "one gram of plutonium off-site" often ascribed to Hammond.

Arguments presented during the Church lawsuit suggested that large amounts of plutonium could have been present on HEPA filters, and therefore could have been released during the fire. The estimates of plutonium loading on the filters presented in the trial arguments ranged from 10 to 250 kilograms (760 to 18,400 Ci).

6.1.2 The Building 903 Drum Storage Area

As described in the Tasks 3/4 and 6 reports (ChemRisk, 1992, 1993), the 903 Pad release began when plutonium-contaminated cutting oil and solvents, stored in drums to await recycling for recovery of plutonium, leaked into the soil. Soil particles contaminated with plutonium were subsequently carried off-site by the wind. This release from the 903 Pad is believed to have been the largest release of plutonium from Rocky Flats. The amount of plutonium released from the 903 Pad was estimated in Task 6 by using an air dispersion model and environmental monitoring data collected around the plant. A brief description of the modeling effort and the release estimate obtained in Task 6 are provided in this section.

903 Pad Source Term Estimation

The distribution of soil contamination observed in late 1969 and the early 1970s is the most important source of information regarding the 903 Pad release. However, it represents the cumulative result of releases from the pad and provides no insight into the time history of the release. Many different release scenarios were analyzed in Task 6, ranging from one large single day release to releases over the entire life of the pad. Based on the predictions of the Fugitive Dust Model (FDM) (Winges, 1990), the release scenario that gave the best fit to all the available data and assumptions used in the reconstruction was one that extended over a number of years. Actual releases from the pad were likely to have varied from day to day, being closely related to specific activities that led to disturbance of the pad. However, there is insufficient information on these daily activities to permit the evaluation of short time-span releases. The analysis performed in Task 6 was therefore focussed on the prediction of releases over the entire release period. FDM deposition modeling indicates that a total of 25 Ci were released from the 903 Pad:

- 11.4 Ci were redeposited on the pad,
- 13.6 Ci escaped from the pad,
- 8 Ci escaped from the plant exclusion area boundary, and

- 6.8 Ci escaped from the buffer zone boundary.

There are considerable uncertainties associated with the release estimates because of the many assumptions that have been made and the use of surrogate meteorological data. It was estimated in Task 6 that the uncertainty about the amount of plutonium that escaped from the buffer zone boundary is about a factor of 10.

During the 903 Pad releases, air samples were routinely collected at several on-site and off-site locations. As shown in Figure 6-1, three on-site samplers (S-6, S-7 and S-8) are of particular importance. S-6 and S-7 are located near the pad while S-8 is located downwind from the pad. To increase our confidence on the modeling result, the predicted respirable airborne concentrations based on the soil contamination were compared with those measured by the three on-site air samplers. The five-year average S-8 air concentration predicted by FDM is 0.45 pCi/m^3, about 4 times higher than the measured value of 0.12 pCi/m^3. The predicted average for S-6 is 0.040 pCi/m^3, about 3 times higher than the measured value of 0.014 pCi/m^3, and the predicted average for S-7 is 0.12 pCi/m^3, about 6 times higher than the measured value of 0.02 pCi/m^3. The observed values are within the range of predicted uncertainty.

Previous Estimates of Total 903 Pad Release

Krey estimated a total 903 Pad release of 11.4 Ci +/- 20 percent. Assuming that the release was predominantly plutonium, the mass of plutonium released can be calculated by assuming 0.0734 Ci per gram of plutonium. The Krey estimate of 903 Pad releases is based on environmental measurements of soil plutonium concentrations and exceeds (by a factor of 1.8) the estimated release of 86 grams of plutonium (6.3 Ci at 0.0734 Ci per gram of plutonium) referenced by Seed *et al.* (1971). The Seed *et al.* (1971) estimate was based on the total number of leaking barrels and an estimated average plutonium concentration in the oil.

6.1.3 1969 Fire

Similar to the 1957 fire, the 1969 fire started when pressed plutonium briquettes spontaneously ignited in a glove box in Building 776. The fire subsequently spread to other inter-connected glove boxes and caused considerable damage to the building and its equipment. The fire burned for approximately four hours with some relatively minor flare-ups discovered as much as six hours after the first fire alarms.

6-1 On-Site Air Samplers at Rocky Flats

Fire contaminants were reported to be almost completely contained within the buildings. Some smoke was observed coming out of the west end doors when they were opened and some smoke was observed coming from the roof and roof exhaust vents. One report theorizes that some of the observed smoke at the roof was from thermal decomposition of the roof itself (Willging, 1969). The fire did not breach the building roof.

1969 Fire Source Term Estimation

Because the stack samplers on Building 776 were disabled during the fire, measurements of the releases from the building during the fire are incomplete. In Task 6, the air monitoring data and meteorological data collected during and after the fire were used to estimate releases from the fire. Based on the prediction of INPUFF model, a total release of 2.8 mCi of plutonium is considered consistent with the air monitoring data. Three sources of uncertainty were identified in reconstructing the fire release: air dispersion model, air monitoring data, and time resolution/number of data points. The overall uncertainty of the source term of the 1969 fire was estimated to be about a factor of 20.

Previous Estimates of the 1969 Fire Release

In the 1980 Final Environmental Impact Statement (FEIS), a release of 856 µCi plutonium is attributed to the 1969 Fire (USDOE, 1980). No estimate of the amount of plutonium released to the environment is provided in the U.S. AEC 1969 Fire report (USAEC, 1969b). However, based on the information provided in the report it was estimated in Task 6 that approximately 2.6 to 5.9 mCi of plutonium were deposited on or in the vicinity of Building 776 during the 1969 Fire. This estimate cannot be directly compared to the estimate derived in Task 6, since it is based on activity deposited on-site and the approach employed in the Task 6 report accounts for only the airborne activity that had the potential to travel off-site.

6.2 Other Accidental Releases

Several smaller release incidents involving radionuclides and chromic acid were also identified in the Tasks 3 and 4 report (ChemRisk, 1992). Two plutonium accidents are discussed here; however, these releases have been included in the estimates of routine releases.

6.2.1 Plutonium Accidents

Accidental plutonium releases estimated in the 1980 USDOE FEIS at around 1,000 microcuries (µCi) each include the 1965 glove-box drain fire and the 1974 control valve failure. All of these releases were emitted through the filter plenum exhaust vents and were measured by stack samplers. In

comparison, the annual releases of plutonium from normal operations at Rocky Flats, as estimated in the 1980 USDOE FEIS, exceeded 1,000 µCi in all years from 1957 through 1965. ChemRisk's search of classified and unclassified records at Rocky Flats has not identified any other plutonium accidents likely to have caused releases of this magnitude.

6.2.1.1 1965 Glove-Box Drain Fire

On October 15, 1965, a fire occurred during a maintenance operation that involved unplugging a coolant recirculation line for a tape-controlled turning machine in Building 776/777. A double-bagged center punch was being used to dislodge an obstruction in the coolant recirculation line. Sparking occurring when the punch was struck, and a flash fire resulted. The fire vented to the room air and contaminants were spread throughout the building by the general ventilation system. The fire lasted 30-90 seconds before being extinguished with carbon dioxide.

Emissions from this accident were released through the main exhaust plenum filters. Therefore, this release is incorporated in the normal emission data and does not have to be modeled separately. The 1980 USDOE FEIS provides a release estimate of 1,170 µCi compared to releases from normal operations for 1965 of 5,348 µCi.

6.2.1.2 1974 Control Valve Failure

On April 2, 1974, radioactive particulates escaped through a roof exhaust vent on Building 707 following a glove-box atmosphere control valve accident. The accident was caused by a series of events when the inert atmosphere exhaust valve from the Building 707 storage vault was being closed during a glove-box maintenance procedure. A pressure surge caused contaminated gas to flow upstream through the inert gas supply system and back through the chiller and standby recirculation fan that had been turned off as part of the maintenance procedure. The contaminated gas was then pumped into the atmosphere by the purge exhaust fans through the exhaust vent.

The 1980 USDOE FEIS provides a release estimate of 934 µCi. Based on an interview with a former plant employee (Hornbacher, 1991), it was reported that the release estimate of from 233 to 236 µCi supplied in the Rocky Flats "Report of Investigation of Incident with Inert System No. 2 in Building 707 — April 2, 1974," by Freiberg *et al*. (1974), was later updated to agree with the estimate provided in the FEIS. The radionuclide release for normal operations for 1974 was 22 µCi, significantly lower than pre-1965 years due to the addition of 2 filter stages to plutonium processing building ventilation controls (in 1965) and upgraded filters in 1970 (USDOE, 1980). This release from the control valve failure did not bypass the stack monitors and has been included in the routine release estimates for 1974.

6.2.2 Depleted Uranium Burning

Depleted uranium in several physical forms was historically burned at the Rocky Flats Plant. Oils contaminated with depleted uranium were burned during the late 1950s and early 1960s as a method of waste disposal, until this practice ceased in 1965. Air emissions during burning oils were monitored by Rocky Flats Health Physics personnel. Wooden pallets contaminated with liquid containing depleted uranium were reportedly burned at a single on-site location in 1965. Also in 1965, similar wooden pallets containing sheets of depleted uranium were inadvertently burned at a single on-site location. This section identifies and discusses the data that are available to evaluate exposure of the off-site public as a result of these practices.

6.2.2.1 Open Pit Burning of Oils

The burning of radionuclide contaminated oil is known to have occurred in two on-site areas designated as oil burn pits #1 and #2 during the late 1950s and early 1960s. Airborne releases and any resuspension of contaminated soils are of potential concern for off-site health impacts.

Oil Burn Pit #1

Oil burn pit #1 has been referred to as the "garage oil burning pit" (Putzier, 1970). Approximately ten drums of waste oil containing depleted uranium from Buildings 444 and 881 were burned on August 18, 1956 as a waste disposal experiment (Owen and Steward, 1974). Based on available records, this seems to have been the only burning to have taken place in pit #1 (USDOE, 1992). The radionuclide content of the waste oil was not measured. Burn residue was left in place and covered with backfill (Unknown, 1975). Building 335 was then constructed over the burn pit (Owen and Steward, 1974). According to the above information, the burn residue is confined to the site and no off-site releases of contaminated soil have occurred to date. However, some quantity of depleted uranium was likely released to the air during burning.

Air monitoring was performed as part of the 1956 oil burning experiment. Total alpha radiation readings ranged from 0.1 to 30 dis min^{-1} m^{-3}. The lower reading was taken from the roof of Building 123 and the higher reading was approximately 60 feet south of the burn pit, directly in the visible smoke plume. These readings can be compared with background values of 0.9 and 3.5 dpm/m^3 taken immediately prior to the experiment (Chapman, 1956). This experiment indicated to Rocky Flats personnel that burning oils contaminated with depleted uranium did not pose a health hazard.

The available air monitoring results do not provide sufficient information to estimate total radionuclide emissions from burning the contaminated oil. Air sampling locations are not specified in detail; burn durations, temperatures, and dispersion patterns of emissions are unknown. In addition, all the parameters affecting emissions dispersion, such as wind speed, direction, temperature profiles, are also unknown.

Oil Burn Pit #2

Oil burn pit #2 was actually two trenches excavated parallel to each other. As a result of the 1956 experiment conducted in oil burn pit #1, a total of at least 1354 drums (USDOE, 1992) of waste oil, coolant, and still bottoms contaminated with depleted uranium from Buildings 444 and 881 were burned during the period of 1957-1965 (Freiberg, 1991). The burning was not continuous, but approximately 80 drums of oil were burned in a typical month during some periods (Ryan, 1965). The radionuclide content of the burned waste was not measured.

The burn residue and some flattened drums were originally covered with fill and the area was posted in 1959 to warn of contamination (Hill, 1959). Oil burning was discontinued in 1965 and oil burn residue and some flattened drums were covered with fill (Freiberg, 1991). In 1978, approximately 13,440 cubic feet of contaminated soil was excavated and shipped off-site for disposal. The volume of depleted uranium residue in the area was estimated to be 10,000 cubic feet (Unknown, 1985).

Oil burning in oil burn pit #2 was conducted at night to minimize concern from the smoke. Air monitoring was routinely performed by Rocky Flats Health Physics personnel. Available air monitoring results are summarized in Table 6-1. The results range from 0.0 to 16.7 dis min^{-1} m^{-3} (Dow Chemical, 1955-1965). Based on the evaluation performed in Task 6, it was estimated that a total of about 0.01 Ci could have been released from the oil burns.

6.2.2.2 Pallet Burning

Rocky Flats records indicate that wooden pallets containing depleted uranium were burned on the Rocky Flats Plant site in 1965 in two locations. Pallet burning is not reported to have been a routine practice. It was conducted southwest of oil burn pit #2 in 1965. According to persons interviewed for the Comprehensive Environmental Assessment and Response Program (CEARP) Phase I investigation, pallets believed to have been contaminated with a liquid containing depleted uranium were burned (USDOE, 1986). The quantity of contamination and details of the event are unknown. No documentation was located and long-term employees of the Rocky Flats Plant were not able to verify that wooden pallets were burned at this site (USDOE, 1992). The burn site was reported to have been "removed" in the 1970s (USDOE, 1986). "Removed"

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typically means that contaminated soil was excavated from a site. In conclusion, the occurrence of wooden pallet burning at this location cannot be substantiated. In addition, a source term for a potential release cannot be constructed due to the lack of any information on what was actually burned and in what quantities.

Pallet burning of depleted uranium was also reported to have occurred in a burning pit south of Building 881 in May 1965. Three sheets (60 kg) of depleted uranium were inadvertently burned with the pallets. The depleted uranium sheets were positioned between large pallets for shipment from Medina, Texas, and possibly not well labeled. Records indicate that some portion of the depleted uranium residue remained after the burn because two barrels of contaminated soil were removed for disposal after discovery of the event (Young, 1965). No details of the quantity of residue are available.

If the value of 0.24 percent for the airborne amount of burning plutonium metal presented in the Rocky Flats FEIS is assumed to apply to uranium, the burning of 60 kg of uranium would have liberated 144 grams of uranium or 58 microcuries of alpha radioactivity [based on an alpha specific activity for depleted uranium of 4×10^{-7} Ci g^{-1} (Rich *et al.*, 1988)].

6.2.3 Tritium Release Incidents

Tritium is known to have been released during operations at Rocky Flats. A low level of routine releases was observed and several accidents resulted in emission of larger quantities of tritium to off-site air and surface waters. This section describes source term aspects of three accidental releases of tritium reported from the Rocky Flats Plant.

The 1968 Tritium Release

The 1980 USDOE FEIS acknowledges that several hundred curies of tritium were released from Rocky Flats in an accident during 1968. The accident resulted in the release of 600 Ci of gaseous tritium to the ambient air (USDOE, 1980). The details of this accident are classified, but several classified documents describing the event have been reviewed by ChemRisk project personnel. No additional information could be located to either support or refute the release estimate.

The 1973 Tritium Release

The first evidence of this release was from a routine monthly water sample collected by the Colorado Department of Health from Walnut Creek that indicated 3,000,000 pCi L^{-1} of tritium. This concentration was well above background and equaled the maximum permissible concentration for

uncontrolled areas. This anomalous result could not be explained based on routine Rocky Flats sources. Subsequent Walnut Creek sample results showed decreasing tritium concentrations indicating an isolated release. The 1973 tritium release occurred when contaminated scrap plutonium received from Lawrence Livermore Laboratory was handled in a process not designed for tritium control.

Barrick (1981) says:

> "...an estimated 350 to 1600 Ci of tritium was released in exhausted air and 150 to 400 Ci was located in process and waste waters. Processing of the waste waters...resulted in 100 to 300 Ci tritium in on-site tanks, basins and ponds and 50 to 100 Ci in the Great Western Reservoir (average 0.01 microcurie/liter for 3 months)." (page 29)
>
> "It was calculated that a typical Broomfield resident drinking Great Western Reservoir water would receive less than 1.4 millirem compared to a maximum permissible level of 170 millirem." (page 32)

In comparison, a Rockwell International December 1986 news release claims:

> "...100 to 500 curies of tritium were released in exhausted building air; 150 to 400 curies were located in process and waste water on plant site. An USEPA report indicated 56 curies of tritium migrated into Great Western Reservoir, the drinking water supply for the city of Broomfield."

The USAEC report, "Investigation of the Tritium Release Occurrence at the Rocky Flats Plant" (USAEC, 1973), concludes:

> "In summary, approximately 500-2000 curies of tritium were transferred to Rocky Flats from LLL in the scrap shipment. This tritium was released in large part up the stack of Building 779A where it was dispersed to the environment. Due to the small size of the airborne releases, coupled with the low contamination levels found in the Rocky Flats environs, Dow (Rocky Flats) staff...concluded that no significant off-site contamination or public exposure could have resulted from the atmospheric releases.
>
> "The remaining tritium followed the liquid waste processing flow sheets of the scrap and the associated wastes therefrom, resulting in dispersal to Buildings 779, 771, 774, 881, 444 and other areas which handled the scrap. The treated liquid wastes from these buildings were subsequently discharged to the sanitary sewer or to the evaporation ponds, in a time sequence which could account for the calculated

> accumulation of 100 - 300 curies in the evaporation ponds and the 50 - 100 curies found in Great Western Reservoir.
>
> "Dow (Rocky Flats) analysis of the tritium levels in the Great Western Reservoir indicates that a Broomfield resident drinking water from Great Western Reservoir continually during 1973 would receive less than 1.4 millirem during 1973 or less than 1 percent of the radiation protection guidelines for the public. Elevated trace levels of tritium which were found below the Rocky Flats sanitary landfill could have originated from `cold wastes' from areas not contaminated by plutonium but which could have been unknowingly contaminated with low levels of tritium or by deposition from the original airborne release." (pp. 27 and 28)

The 1973 findings associated with the tritiated plutonium initiated an investigation of other possible similar shipments and processing of tritiated plutonium. The investigation discovered three other shipments with maximum estimated tritium releases of 57 Ci (April 1969), 40 Ci (March 1971), and 29 Ci (November 1971).

The 1974 Tritium Release

The 1974 tritium release is believed to have been caused by a problem with a pressure cooler operation in Building 776/777. The report "Investigation of a Tritium Release Occurring in Building 777 on September 3-4, 1974" (USAEC, 1974, page 28) estimates this release as 1.5 Ci.

6.2.4 Chromic Acid Spill

On February 22, 1989, waste chromic acid overflowed a tank and a secondary containment berm into the basement of Building 444. The solution leaked into the foundation of the building to the footing drain system, which was piped to the plant's sewage treatment plant. The contamination moved through the treatment plant in about 24 hours and was discharged to retention pond B-3. The B-3 pond water was pumped to the east spray field and spray irrigated onto frozen ground. Consequently, the chromium-contaminated spray water ran off the hillsides adjacent to the spray field and was collected in the water impoundment ponds on-site. Chromium was not identified as a contaminant until February 28 (USDOE, 1989).

Seventy pounds of dry chromic acid (hexavalent chromium) had been placed in the tank just prior to the spill on February 22. An investigation estimated that 750 gallons of chromic acid entered the drain on February 23. The material entering the sewage treatment plant on February 23 was 13 ppm chromium, and the treated effluent exiting the sewage treatment plant was 2 ppm chromium.

Approximately 2,763,000 gallons of B-3 pond water was spray irrigated from February 23 to March 4. On March 4, the B-3 pond was sampled and contained 0.19 ppm total chromium. Most of the B-3 pond water ran into the B-5 and C-2 ponds. The total chromium concentrations of these two ponds were 0.08 and 0.06 ppm, respectively. The spray field runoff water contained from 0.03 to 0.08 ppm total chromium (USA, 1992). The USDOE report on the chromic acid accident (USDOE, 1989) states:

> "No off-site release of the chromium contaminant occurred. An estimated 30 pounds of chromium were released to the sanitary sewer system and approximately 5 pounds passed through the sewage treatment plant and were distributed in the spray fields and ponds.
>
> "After chromium was identified as the contaminant on February 28, soil samples taken at one and six inch depths in the spray fields showed chromium levels to be within site background levels. Daily water samples taken from the impoundment ponds after the ice thawed on the ponds, thus permitting representative sampling, indicated chromium levels below the Clean Water Act drinking water standard of 0.05 ppm. Borehole samples indicated no chromium contamination above background levels in the gravels and soils adjacent to the Building 444 foundation drain system."

No documentation of off-site contamination was located for the event.

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7.0 SUMMARY

This report completes an important step in the process of historical dose reconstruction in providing the emission estimates that will form the basis for subsequent contaminant transport modeling in project Task 6 and exposure and dose assessment in Task 8. The principle elements of this effort have included the following:

- A review and evaluation of the airborne radioactive effluent monitoring program, which has provided the basis for establishing quantitative annual estimates of routine releases of the radioactive materials of concern and the uncertainties associated with these releases.

  Quantitative estimates of airborne releases can be derived for each of the radioactive materials of concern, with the exception of Th-232, using the effluent monitoring program data. Th-232 has not been specifically monitored, saw only limited use at the plant, and is not believed to have been associated with significant emissions historically.

  The nature of the data generated by the plant's historical airborne effluent monitoring program and the similarity in the dose factors for the radioisotopes of concern argue for consideration of the use of composite dose factors and emission estimates that would combine emissions for a number of isotopes, as opposed to evaluating all isotopes individually.

- Routine airborne emissions of nonradioactive materials, which can be developed from monitoring program data only in the case of beryllium. Routine monitoring for the organic solvents of concern was not performed by the plant. Estimates of the plausible ranges of historical emissions for these materials were developed using various types of documentation and information obtained from personnel interviews. In many cases, these emission estimates are based on very limited information. However, the identified range of emissions is believed to bound the actual plausible emissions from the plant for these materials.

- Review of information regarding surface-water-borne contaminant releases from the plant indicating relatively limited availability of data to directly quantify the release of materials of concern. What data were available were used to examine whether plant releases measurably increased the radioactivity present in potentially impacted reservoirs and drinking waters. While the review of the data suggested that it was plausible that plant-related releases may have on some occasions measurably increased

radioactivity in the waters of the receiving reservoirs, the resulting measured levels of radioactivity were similar to levels found in other unaffected reservoirs in the area.

- A review of information and data associated with nonroutine releases of contaminants from the plant providing the basis for further modeling of major release events (1957 fire and 903 Pad) and for evaluation of the relative magnitude of lesser events in comparison to routine emissions. The information presented in this report relative to the major events will be employed in contaminant transport modeling efforts in Task 6 to finalize an emission estimate and to provide the basis for estimating off-site exposures from these events.

GLOSSARY

activity fraction	The fraction of a mixture of materials that a radionuclide constitutes in terms of its contribution to the total radioactivity of the mixture. This is in contrast to the mass fraction, which reflects a portion of the total mass of mixture.
aerodynamic equivalent diameter	The diameter of a unit density (1 g cm^{-3}) sphere with the same settling velocity as the particle in question
aerosol	A suspension of fine solid or liquid particles in gas.
alpha emitter	A radioactive material that releases energy in the form of alpha particles.
alpha pulse-height analysis	A method for identifying and quantifying alpha-emitting radionuclides by recording the frequency of emission of alpha particles of specific energies.
alpha track method	A method for measuring alpha radiation by recording the passage of alpha particles on photographic film.
back-calculation	A calculation technique used to work back from a known or given result of a calculation to determine an unknown input value to the calculation.
"background" radioactivity	Radioactivity normally present in the natural environment, or not attributable to a particular known source of interest.
beta emitter	A radioactive material that releases energy in the form of beta particles.
blowdown	Cooling tower water routinely released from the system to maintain water quality (total dissolved solids) at an acceptable level.
cfm	Cubic feet per minute — a volumetric rate measurement.
Church litigation	Lawsuits brought against the Rocky Flats Plant by neighboring landowners.

computer modeling	A series of mathematical calculations used to predict the effect of such things as physical, chemical or environmental processes that are performed with the aid of a computer.
Count median diameter	For a distribution of particles of various sizes, the count median diameter identifies the size for which half the total *number* of particles collected is contributed by smaller particles and half by larger particles.
critical mass experiments, or criticality tests	Tests performed with a sufficient quantity of fissile materials to produce a nuclear fission chain reaction.
criticality safety program	A plant program involving the use of critical mass experiments for the purposes of developing routine practices for avoiding spontaneous nuclear fission chain reactions.
curie (Ci)	The conventional unit of activity equal to 3.7×10^{10} nuclear disintegrations per second.
cutting oil	A liquid applied to a cutting tool to assist in the machining operation by washing away the chips and serving as a lubricant or coolant.
decay product	Nuclide formed from the disintegration of an unstable atom.
degrease	To remove grease from.
depleted uranium	Uranium in which the fraction of the U-235 isotope has been decreased below the 0.7 percent found in nature.
disintegrations per minute (dpm)	The rate of nuclear transformations exhibited by a radionuclide. Nuclear transformations are the events that lead to emission of radiations as the atom changes to a more stable form.
dose coefficient	A constant used to convert from a quantity of radionuclide to which a person is exposed to some measure of the resulting dose.
EG&G, Inc.	Current operator of the Rocky Flats Plant for the Department of Energy.
effluent	Any gas or liquid emerging from a pipe or similar outlet; waste products from industrial plants as stack gases or liquid mixtures.

emission point — Location of release.

enriched uranium — Uranium in which the fraction of the fissionable U-235 isotope has been increased above the 0.7 percent found in nature.

filter plenum — The portion of a building air exhaust or ventilation system that contains media to collect or separate out matter carried by the air.

fission — The splitting of a heavy atomic nucleus into approximately equal parts, accompanied by release of a large amount of energy.

fission product — Nuclides formed as a result of fission.

fission track method — A method for characterizing fissionable materials by placing samples in a neutron source and detecting tracks produced by resulting fission fragments in materials held in contact with the sample during irradiation.

gamma emitter — A radionuclide that emits photons which are identical in form to X rays.

glove box — A sealed, protectively lined compartment having holes to which are attached gloves for use in handling dangerous materials inside the compartment.

gram — A metric unit of mass and weight equal to one-thousandth of a kilogram and nearly equal to one cubic centimeter of water at its maximum density.

gross alpha activity — Radioactivity measured in terms of alpha particles emitted, with no determination of their energy or the identity of the specific radionuclides from which they were emitted.

groundwater — Water within the earth that supplies wells and springs.

half-life — The time required for an unstable element or nuclide to lose one-half of its radioactive intensity in the form of alpha, beta, and gamma radiation.

halogen — Any of the five elements fluorine, chlorine, bromine, iodine, and astatine that form part of the group VII A of the periodic table of elements.

HEPA filter — High efficiency particulate air filter.

isokinetic sampling	Refers to the removal of a sample from an air stream where the velocity of the air entering the sampling device is the same as the velocity of the air in the duct at the sampling point.
isotopes	Atoms having the same atomic number but different atomic weights; they have similar chemical properties but different physical properties.
kilogram	The basic metric unit of mass nearly equal to 1,000 cubic centimeters of water at the temperature of its maximum density.
liquid scintillation counter	An instrument which measures radioactivity by placement of a sample in a liquid "cocktail" that emits light that can be related to the quantity of radioactivity present.
lognormal	Refers to a statistical distribution of a data set relating to or being a normal distribution that is the distribution of the logarithm of a random variable.
long-lived alpha activity	Alpha-emitting radioactivity from which short-lived radionuclides have been allowed to decay away or have been subtracted using an algorithm designed to quantify only those nuclides with long half-lives.
mass median diameter	For a distribution of particles of various sizes, the mass median diameter identifies the size for which half the total *mass* of material collected is contributed by smaller particles and half by larger particles.
microcurie (μCi)	One-millionth of a curie.
noble gases	Any of a group of rare gases that include helium, neon, argon, krypton, xenon, and sometimes radon that exhibit great stability and extremely low reaction rates.
nuclide	An individual species of an atom characterized by its mass number (number of protons plus neutrons in its nucleus), atomic number (number of protons in its nucleus), and the energy state of its nucleus.
organic solvents	Non-polar carbon-containing substances (hydrocarbons) capable of dissolving another substance.
particle size distribution	Frequency of occurrence of particles by size as measured by diameter.

particulate	Of or relating to minute separate particles.
radioactive daughter	An atomic species that is the product of the radioactive decay of a radionuclide and is itself radioactive.
radionuclide	A radioactive form of an element distinguished by its atomic number, atomic weight, and energy state.
runoff	To drain off.
sampling train	All the components or devices used to collect a sample.
source term	Information relating the quantity and characteristics of a contaminant release.
specific activity	The total activity of a given radionuclide per gram of a compound, element, or radioactive nuclide.
spectrophotometry	An important technique of instrumental analysis involving measurement of the absorption of radiant energy by a substance as a function of the energy incident upon it.
spectroscopy	A branch of analytical chemistry devoted to identification of elements and elucidation of atomic and molecular structure by measurement of the radiant energy absorbed or emitted by a substance.
spontaneous fissioning	The property of certain materials which undergo splitting without the external application of neutrons.
surface water	Water present on the earth's surface, e.g. rivers, streams and lakes.
totalizer	An instrument that indicates or records a cumulative measure of a parameter of interest, for example the total volume of air which is exhausted through a stack in a given period.
tritiated water	Water in which one or more hydrogen atoms have been replaced with tritium, the radioactive form of hydrogen.
weapons grade	Plutonium that is approximately 94 percent Pu-239 by mass, with about

plutonium	5.8 percent Pu-240 and small amounts of Pu-238, Pu-241, Am-241, and Pu-242.