4. Inventory Module

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Inventory consists of the quantity of radiological and chemical constituents used and created at the Hanford Site, and their distribution in individual facilities and waste disposal sites. For the initial assessment, inventory is defined as the volume and concentration of contamination introduced annually to waste disposal sites (e.g., the solid waste burial ground), facilities (e.g., canyon building), and the environment (e.g. vadose zone via liquid discharge sites, Columbia River via reactor cooling water retention basins). In the initial assessment, export to offsite locations is provided by collecting exports at the conclusion of the analysis. The movement of onsite waste from one location to another is included in the release module. Finally, tank waste moves into the Inventory Module of the initial assessment only after it leaks to the environment or is recovered from tanks and processed into waste forms that are disposed onsite or shipped offsite.

Inventory consists of the quantity of radiological and chemical constituents used and created at the Hanford Site and their distribution in individual facilities and waste disposal sites.

A good understanding of inventory is key to any assessment because potential environmental contamination, and ultimately risk and impact to society, is proportional to the amount of radionuclides and chemicals released in a form that might migrate from discharge/disposal sites to receptors. The information needed in the Inventory Module includes the following:

- Location and time of discharges, disposals, and operations.
- Volume of discharge or disposal.
- Concentration of contaminants in waste or total mass or activity in waste.

The initial assessment looks at record data and unplanned release sites. Field data suggest that some disposals or discharges are not part of record data. For example, chromium plumes in the 100 D Area do not have corresponding source records.

The data for each disposal or release each year were summed to estimate the total inventory disposed or discharged.

Results

The simulation of inventory resulted in an annual portrait of the disposal and discharge of waste at the Hanford Site from 1944 through site closure, assumed to be the year 2050. Future analyses will include a site closure date consistent with the accelerated Hanford Site cleanup. This is the first compilation of available information to create a sitewide portrait of the inventory at Hanford. While many studies seek to analyze the effects from the present time forward or from site closure forward, this assessment included past disposals and discharges as well as the future disposition of waste.

There are instances when the inventory estimates for a particular site or group of sites (e.g., tank farms) are conservative or bounding. This has led to a concern that an overall inventory including these estimates would be overly conservative and lead to overly conservative remedial actions. If the sum of site-specific radionuclide and chemical inventories was found to be too small or large relative to the estimates of the total quantity of the material brought on site or generated in the reactors, the inventory could be scaled to a more realistic level. However, a review of the simulated site-specific inventories and comparison to estimates of total production or use of each contaminant at Hanford indicated such scaling was unnecessary.

Understanding inventory is key to creating a credible assessment.

Of all sites listed on the National Priorities List for Hanford, and others identified in the previously completed composite analysis (Kincaid et al. 1998), 890 sites were identified for consideration in the initial assessment. Each of these sites had a likelihood of containing one or more of the contaminants of interest. Some sites were combined, or aggregated, thus reducing the total to 722 sites for analysis. However, of the 722 sites chosen for analysis only 533 sites were assigned inventories because some waste disposal and unplanned release inventories were further aggregated. For example, individual disposal ditches and ponds were all identified in the list of 722 sites, but the ditch inventories were assigned to the receptor pond. Accordingly, the inventories for the ditches leading to Gable Mountain Pond, B Pond, and U Pond were assigned zero inventories.

The Inventory Module generates annual inventories for the selected contaminants, at 533 sites, for the period from 1944 through 2050, and each of 25 realizations. For the initial assessment, this represented in excess of 782,000 pieces of non-zero inventory data. Because of the large amount of data, inventory results are only summarized here. The results are grouped into six regions or subregions of the Hanford Site (i.e., 200 East, 200 West, 100 Areas, 300/400/600 Areas, U.S. Ecology and the entire Hanford Site). Waste sites are grouped into 11 waste types, (i.e., air, cement, glass, liquid, offsite [spent fuel to be exported], reactor, residual [tank], river, sludge, and soil).

The annual inventories generated by the Inventory Module are designed to support simulation of the inventory's release into the environment. Waste placement into interim storage is treated in a less precise way, and detailed timing of exports of high-level waste, transuranic waste, and spent fuel is left to the next generation inventory model. At present, the interim-stored inventory is accumulated and noted as leaving the site. A portrait of inventory showing when an contaminant was created or imported and when it is to be removed from the site will be discussed at the conclusion of this section. These two portraits of inventory are quite different. The latter showing creation, import, and export presents the greatest increase of inventory during the reactor operation era, (e.g., 1944 through 1988). The former showing release to the environment or interim storage, presents the greatest increase of inventory during the tank waste recovery and vitrification era, (e.g., 2008 through 2028). During this era, several derivatives of tank waste are projected to be released or stored including liquid waste losses during tank waste recovery, secondary waste streams (gas, liquid, and solid phases) from separation and vitrification of low and high activity waste, immobilized low-activity waste glass, and high level waste glass. In addition to tank waste, spent fuel is treated in what may appear as an illogical fashion in the method adopted to report annual inventories. It has been decided not to process the remaining spent fuel at Hanford, but rather to interim store the spent fuel until it can be shipped to a national repository. A report on the spent fuel inventory was produced in the mid-1990s, and the spent fuel inventory was entered into the Inventory Module at that moment in time. This date does not correspond to when the material was generated in a reactor, or when it will be interim stored. However, the spent fuel will not be available for environmental transport at Hanford; and, therefore, the report date is sufficient for the first compilation of inventory. Future inventories will incorporate more detail in the sequence of waste generation, interim storage, and export.

The annual inventory created by the Inventory Module includes an inventory when it is placed into the environment or when it is available for interim storage. Hence, inventories increase when tank waste is processed and not when fuel was irradiated.

Figure 4.1 shows a series of plots for technetium-99 inventory estimates. Each panel shows all 25 realizations with the median inputs case realization shown in red. Plot (a) shows the cumulative Hanford Site technetium-99 inventory, and reveals substantial increments in the mid-1990s and the 2008 to 2028 time frames. Plot (b) shows the glass waste and reveals that the majority of the inventory resides in high-level waste and immobilized low-activity waste glass during the 2008 to 2028 period. Plot (c) shows the spent nuclear fuel destined for offsite transfer and reveals that 10-15% of the technetium-99 inventory after year 2030 resides in the spent fuel. A sharp increase in technetium-99 inventory is seen because spent fuel was placed in the inventory at the time the inventory data were published in the mid-1990s, not when the fuel was irradiated. Panel (d) shows the liquid waste and reveals that liquid disposal dominated the early releases of technetium-99 to the environment at Hanford. Significant liquid disposal occurred with tank waste discharges to ground in the mid-1950s, tank leaks

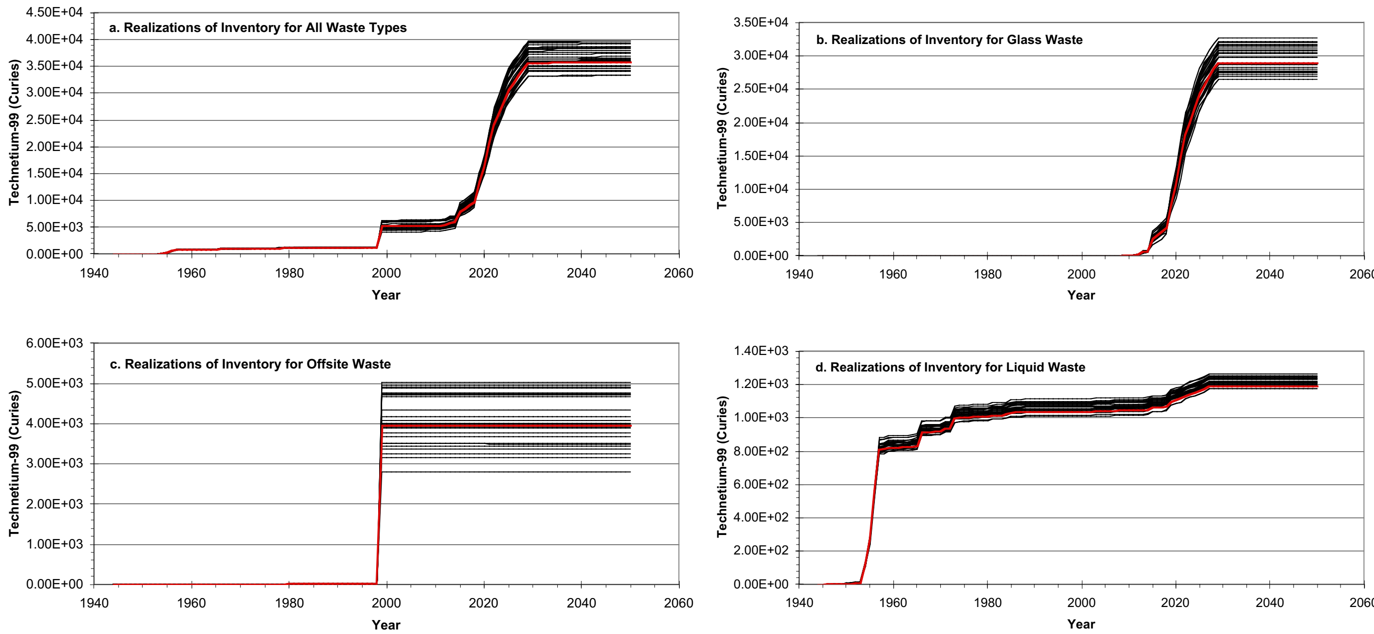

Figure 4.1. *Hanford sitewide technetium-99 plots of 25-realizations: (a) all waste types, (b) glass waste including high-level and low-activity waste, (c) spent fuel destined for offsite shipment, and (d) liquid discharges and unplanned releases.*

Table 4.1. *Summary statistics for each contaminant in the stochastic sitewide total inventory.*

	CCl4 (kg)	**Cr** (kg)	**Cs-137** (Ci)	**H3** (Ci)	**I-129** (Ci)	**Pu-239/40** (Ci)	**Sr-90** (Ci)	**Tc-99** (Ci)	**U-238** (Ci)
Minimum	1,396,000	13,480,000	29,780,000	71,000	101.0	56,300	27,730,000	33,300	16,100
Mean	1,467,000	19,053,000	36,600,000	76,700	119.8	79,400	30,900,000	36,700	18,000
Maximum	1,538,000	28,130,000	42,350,000	79,800	135.1	122,800	34,650,000	39,800	20,700
Standard Deviation	40,100	3,137,000	3,029,000	1,900	10.2	14,700	2,050,000	2,000	1,380

during the 1960s and 1970s, and losses to ground forecast to correspond with tank waste recovery between 2008 and 2028. In this initial assessment, the immobilized low-activity waste glass will reside in 200 East Area, the spent fuel is currently at the K Basins in the 100 Areas, the buildings in the 300 Area, and the Fast Flux Test Facility in 400 Area, and the major liquid discharges and all tank losses (past and future) occur in the Central Plateau.

Summary statistics for the summed site-specific stochastic inventories used in the initial assessment are provided in Table 4.1. All radioactive inventories are decay corrected to the year 2050. The inventories in the table are summed over all waste types and locations, and include materials that will be shipped offsite (such as high-level waste and spent fuel) rather than being disposed onsite. Inventories for strontium-90 and cesium-137 report only the inventories for those isotopes and not their progeny in secular equilibrium, (i.e., yttrium-90 and metastable barium-137). An indication of the inventory of materials that may effect the Hanford Site over the next 1,000 years is provided in Table 4.2. This 'fast-release' inventory in Table 4.2 is limited to liquid releases and unplanned releases onsite and in the Columbia River, all soil disposals, and tank residuals. Again, all these radioactive inventories are decay corrected to the year 2050. For purposes of generating this table, other waste types such as glass and cement waste are assumed not to contribute an appreciable amount to the Hanford risks

Table 4.2. *Summary statistics for each contaminant in the stochastic sitewide fast-release inventory.*

	CCl4 (kg)	**Cr** (kg)	**Cs-137** (Ci)	**H3** (Ci)	**I-129** (Ci)	**Pu-239/40** (Ci)	**Sr-90** (Ci)	**Tc-99** (Ci)	**U-238** (Ci)
Minimum	747,000	13,480,000	937,000	65,100	11.1	43,300	1,932,000	1,870	11,300
Mean	813,000	19,050,000	997,000	70,400	12.2	65,300	2,333,000	1,930	13,100
Maximum	887,000	28,130,000	1,095,000	74,000	16.5	105,600	2,572,000	1,990	15,900
Standard Deviation	35,500	3,137,000	38,100	2,080	1.3	15,200	156,000	31	1,380
% Fast Release	55	100	2.7	92	10	82	7.6	5.2	73

Table 4.3. *Technetium-99 inventories at Hanford Site closure (2050) by waste type, median and mean values of initial assessment inventory, and mean value tank waste contributions.*

Waste Type	**Initial Assessment Inventory**		**Tank Waste Contribution (Ci)**
	Median Value (Ci)	**Mean Value (Ci)**	
Total Legacy[a] Inventory	~9,600	~9,900	~7,600 (77% of 9,900)
Solid Waste Burial Grounds	1,412	1,452	1,074
Liquid Discharge Sites	825	839	
Atmospheric Release	0.0055	0.010	
ILAW and Melters	5,970	6,128.8	6,150
Unplanned Releases, 200 Areas	8.25	11.4	
Facilities (canyons, tunnels)	30.4	36.7	
Other 200 Area Sites	2.65	4.54	
Reactors – graphite	0.189	0.199	
Future Tank Losses and Tank Residuals	392	403	~400
Past Tank Leaks	194	195	
Residuals of Rad Mixed Waste	697	715	
U.S. Ecology, commercial waste	60.7	66.9	
100 Areas	1.38	1.53	
300 Areas	15.0	27.9	
River	0.102	0.105	
Total Export[b] Inventory	~26,100	~26,800	~23,600 (88% of 26,800)
K Basin spent fuel	2,796	2,870	
FFTF spent fuel	462	474	
HLW glass and TRU	22,870	23,480	23,573
Total Legacy + Export	~35,700	~36,700	~31,200 (85% of 36,700)

(a) Legacy = Waste to remain on the Hanford Site.
(b) Export = Waste to be exported off the Hanford Site.
ILAW = Immobilized low-activity waste.
FFTF = Fast Flux Test Facility.
HLW = High-level waste.
TRU = Transuranic waste.

in the next 1,000 years. Also provided in the last row of Table 4.2 is the percent of the total inventory that is available for these earlier or 'fast' releases.

As an example of the Inventory Module capability, a detailed breakdown of the technetium-99 inventory in waste types is provided in Table 4.3. Waste currently in single-shell and double-shell tanks comprises the majority of the technetium-99 inventory in both the waste to remain at Hanford (legacy waste), and the waste to be exported from Hanford (export waste). Overall, 85% of the technetium-99 inventory is attributed to tank waste. Both median and mean values are shown for the initial assessment inventory. The tank waste contribution values are taken from a single Hanford Tank Waste Operation Simulator simulation and are assumed to be mean values (Kirkbride et al. 2001). Thus, the mean value of the initial assessment is presented as the comparable value. The SAC initial assessment focused on the central tendency of the stochastic analysis; hence, the median value is included as a meaningful point of reference.

The assembled inventory is as complete as Hanford Site records and estimates allow. The efforts needed to create a more consistent and holistic inventory focus on building consistency between inventory estimates and field observations of contaminant plumes. In the time it took to assemble this information and run the initial assessment, some databases and estimates were updated and are not reflected in this compilation. These improved estimates will be used in future assessments.

The assembled inventory is as complete as Hanford Site records and estimates allow. The efforts needed to create a more consistent and holistic inventory focus on building consistency between inventory estimates and field observations of contaminant plumes.

Several contaminants of key interest for long-term assessments (e.g., tritium, technetium-99, iodine-129) are not well represented in record databases. During Hanford's production mission, the key radionuclides that appear most often in waste inventory databases are isotopes of the nuclear materials uranium and plutonium and isotopes with safety issues, primarily cesium-137 and strontium-90 that became separation products in the 1960s and 1970s at the B Plant. Contaminants of central importance to long-term health and safety have long decay half-lives and are environmentally mobile. In addition to uranium, examples are technetium-99 and iodine-129. Tritium is another contaminant of interest included in the initial assessment because of the opportunity presented to history match major elements of the model. Because the process-knowledge-based models rely on process flow sheets that focus on separation products, conceptual models and process waste stream content of technetium-99, iodine-129, tritium and potentially other mobile and long-lived radionuclides and chemicals could be reviewed and improved.

At present, the Inventory Module relies on an inventory data file that merges a substantial body of inventory data, estimates, and process-knowledge-based model predictions. As interest builds in having a rapid response to evolving inventory issues, the Inventory Module could be automated, in whole or part, to incorporate the latest versions of record databases and the results of inventory analyses.

When designed with inventory issues in mind, field characterization data can confirm the presence or absence of the contaminants in the source waste stream, and confirm the mobility of contaminants. Field data on the composition of recovered waste, (e.g., solid waste, liquid discharge site soil, tank waste), could be used to confirm or modify record inventories and estimates. Field data on residual waste (e.g., sediment underlying liquid discharge site excavations, solid waste burial ground excavations) could be used to history match the residual inventory and the combined inventory, release, and vadose zone models.

The vast majority of the radioactive waste inventory at the Hanford Site was created during the production of nuclear materials.

Benefits of the inventory database and module to the Hanford Site include:

- Improved and confirmed understanding of waste streams and process knowledge.
- Improved understanding of overall onsite inventory movement and offsite exports.
- Improved assembly of realistic and uncertain inventories.

An overarching benefit of the assembled data is that it provides the basis for developing a joint understanding of the inventory at Hanford among DOE, regulatory agencies, Tribal Nations, and stakeholders.

Conceptual Model

The vast majority of the radioactive waste inventory at the Hanford Site was created during the production of nuclear materials. A conceptual model of the Hanford Site during the production operations is shown in Figure 4.2. There were three distinct steps in the production process: fuel fabrication, fuel irradiation, and chemical separation. During the first decades at the Hanford Site, it was common to locate waste disposal sites relatively close to waste-generating facilities. This practice resulted in numerous and varied disposal sites. The most dangerous radioactive waste was stored in large single-shell tanks in the 200 Areas (Agnew 1997; Kupfer et al. 1997). Large

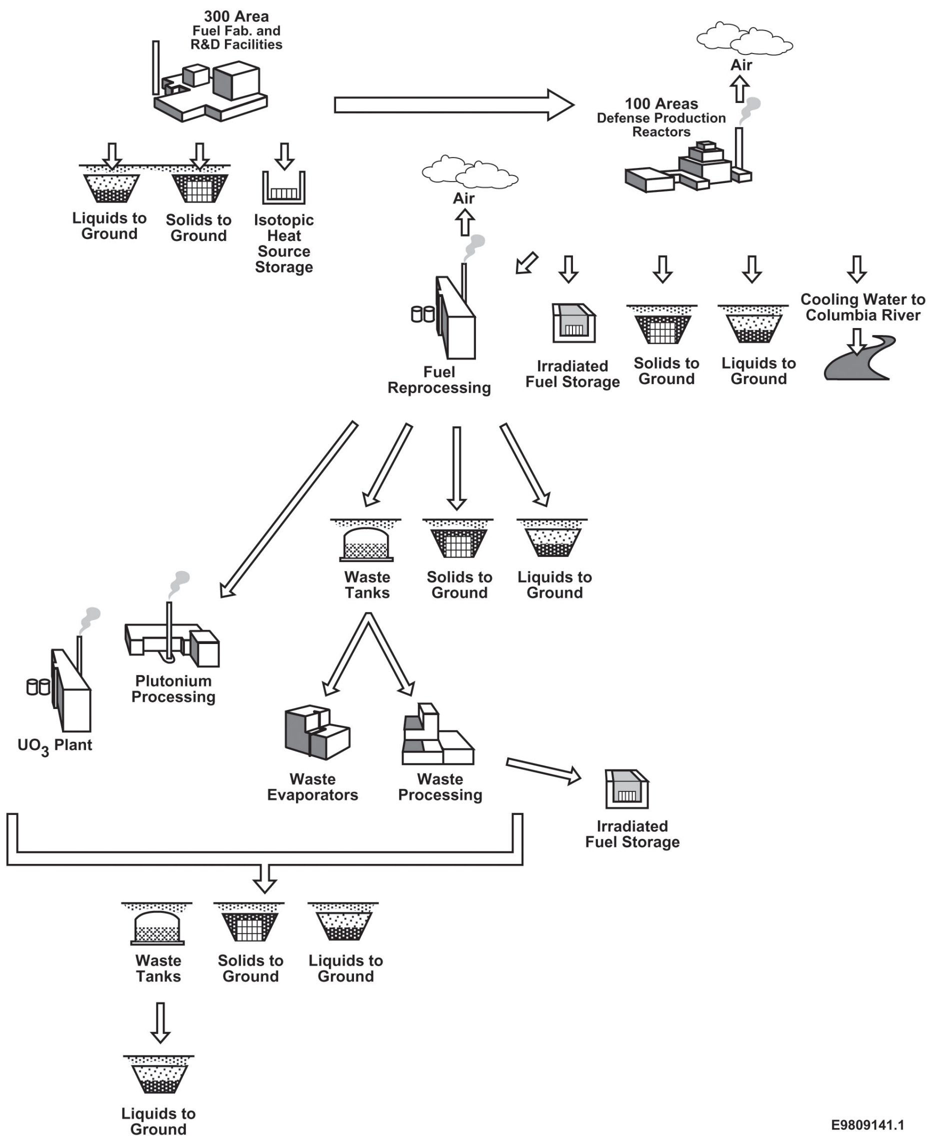

Figure 4.2. *Conceptual model of the Hanford waste generation process.*

Process-Knowledge-Based Models. *These models use historical chemical process inform ation such as process flowsheets to obtain waste volumes and compositions. Using the chemical process flowsheets of the PUREX process and based on a particular feed rate of fuel (e.g., tons of uranium per quarter), the initial assessment could determine that waste of a certain volume and composition was generated and distributed to waste receiving facilities, including tanks. Where available, these models incorporate knowledge of chemicals used, past operational practices, tons of uranium processed, fuel exposure and cooling times, and documented waste volumes produced to better define waste volume and composition in the SAC models.*

volumes of solid waste (e.g., contaminated tools and protective clothing) were disposed in burial grounds, and large volumes of relatively low-level radioactive liquid waste were discharged to shallow subsurface cribs, french drains, injection (or reverse) wells, and specific retention trenches. More recently, all fuel fabrication and reactor operations ended and cleanup of past-practice units began in the 300 and 100 Areas. Low-level waste from ongoing operations is disposed in burial grounds in the 200

West and 200 East Areas. Most liquid discharges of radioactive waste have been discontinued, an exception being tritium disposal to the State-Approved Land Disposal Site, which receives treated water from the 200 Area Effluent Treatment Facility.

To determine an inventory estimate at a moment in time (e.g., now or at site closure), one needs to amend Figure 4.2 to include two aspects. First, the quantities of radionuclides and chemicals imported and exported from the Hanford Site are introduced or extracted at several points in the operation (e.g., materials fed into the fuel fabrication process, chemicals fed into the reactor operation and chemical separation processes, and uranium and other special nuclear materials left the Hanford Site). Second, the figure presents the production mission, and needs to be overlaid with the current cleanup mission. Decisions regarding the remediation, decontamination and decommissioning, and disposal actions will impact virtually all facilities and wastes depicted in Figure 4.2. These cleanup actions will define the end-state configuration (i.e., both location and stability or form) of the waste.

Uranium occurs naturally in very low concentrations in soil, rock, surface and groundwater. Isotopes of uranium, including ***uranium-238****, were used as nuclear reactor fuel and uranium waste can be found in the vicinity of fuel fabrication activities (300 Area), nuclear reactor operational areas (100 Areas), and chemical separation plants (200 Areas). Uranium-238 has a long half-life (4.5 billion years). Uranium is moderately mobile in Hanford soil. The dominant health concern regarding uranium ingestion is kidney damage. For these reasons, uranium-238 was included as an example of a moderately mobile contaminant in the list of contaminants analyzed in the initial assessment*

Certain assumptions were used to estimate inventory for SAC. For example, all CERCLA cleanup waste in the 100, 200, and 300 Areas are disposed in the Environmental Restoration Disposal Facility trench. Thus, the remediated fraction of the inventory in 100, 200, and 300 Area remedial action sites moves to the Environmental Restoration Disposal Facility. The residual inventory remains in the environment at the original site. Similar transfers of waste inventory arise in the decontamination and decommissioning of facilities, including the production reactors, canyon buildings, and tunnels. A significant step in the translation of the current setting to a stable closure is the recovery, separation, solidification, and disposal of tank waste.

The inventory conceptual model provides a framework from which to estimate location, quantity, and composition of the radionuclide and chemical inventory including uncertainty. Application of the remediation and closure rules would yield projections of inventory at times of interest. Corresponding to the time of Hanford Site closure, the inventory model would yield a final inventory used for long-term risk and impact assessment.

Implementation Model

The purpose of the inventory implementation model is to provide an estimate of the annual placement of contaminants into the environment and an estimate of the associated uncertainty. The environment is the vadose zone, groundwater, and Columbia River. Examples of waste site inventories included in the assessment are:

- Disposal to solid waste burial grounds or caissons.
- Discharge to any of several types of liquid waste disposal facilities (e.g., cribs, specific retention trenches, french drains, injection wells).
- Materials permanently residing in facilities (e.g., canyons, tunnels).

Where inventory data do not exist, similar types of waste or releases are combined to produce an estimate of the waste disposed.

All of this waste contains contaminants that could leach and/or migrate to the vadose zone, groundwater, or Columbia River. However, some contaminants require release from the waste form or container before reaching the environment. All inventories are treated as stochastic. Once the time of site closure is reached, no further inventory will be generated, imported, or exported, and the inventory is complete.

The Inventory Module in the SAC computational package uses the inventory database and assessment setup data to generate stochastic realizations of inventory, to aggregate inventories for sites identified for aggregation, to account for decay to the end of each year, and, if deemed necessary, to normalize the site-specific inventories to an independently derived total inventory (Figure 4.3).

Within the implementation model, all disposal actions are described as contaminant concentrations within a disposal volume. The volumes and concentrations are both treated as stochastic quantities. Disposal actions take place only on an annual basis. However, disposal actions for a group of sites can be aggregated into a larger release unit. Disposal actions occur as the waste becomes available for release to the environment, which often is not the same time as when the waste was generated because waste is often stored and treated prior to disposal.

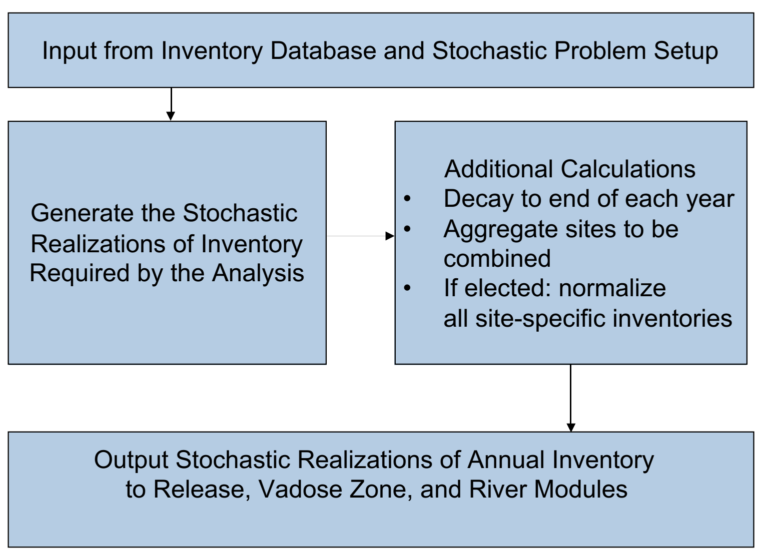

Figure 4.3. *Primary implementation model components for the Inventory Module.*

Waste in single- or double-shell tanks is not included in the Inventory Module until the waste is processed. However, tank leaks are entered into the inventory at the year of the leak.

The inventory model is designed as a stochastic model. However, it is possible to run a single realization with a fixed set of inputs. Two key simplifying assumptions are the generation of annual inventory deposits, and the aggregation of site inventories. Annual inventories are assumed to offer sufficient temporal resolution of events. However, we know that tank waste was discharged to cribs and that unplanned releases, including tank leaks, occurred over shorter time intervals – months, weeks, or days. Aggregation of sites offers potential computation time and data collection savings by reducing the number of sites requiring analysis and the amount of detailed data. The response of each aggregated site is assumed to approximate the aggregate response of the sites if they were simulated individually.

The model addresses the waste as it comes in contact with the environment, (e.g., disposed to solid waste burial, contained in facilities that have been decontaminated and decommissioned, discharged to the vadose zone via liquid disposal facilities). Material or waste stored or contained in facilities for subsequent recovery, treatment, or repackaging is not included until it is disposed. Thus, waste in single- and double-shell tanks is not included in the 'inventory' until tank waste is recovered, separated, vitrified and disposed. And then, only the losses during waste recovery, low-activity fraction of tank waste, secondary waste streams (e.g., captured and solidified off-gas waste), and melters from the vitrification process are disposed at Hanford. However, tank leaks are entered into the inventory at the year of the leak.

Inventory data, especially for some key contaminants of interest, are sparse in Hanford Site records and are supplemented by estimates based on a group of simple to complex models. The assembled inventory data represent a union of record data, simple estimation methods that build on individual record data, and complex models based on process knowledge and operational records.

Record data have been drawn from the Solid Waste Information Tracking System database for all solid waste burial grounds, the Environmental Release Summary database for liquid discharge sites (Diediker 1999), the best basis inventory for tank waste (Kirkbride et al. 2001), and from various documents reporting facility decommissioning. These databases rely on older references including Maxfield (1979) and Stenner et al. (1988), as well as the tank waste characterization data contained in the Tank Waste Inventory Network System database.

Simple methods applied to estimate annual inventories are summarized by Coony (2002). The methods include a linear interpolation of a record or simulated cumulative multi-year inventory, use of uranium isotopic ratios to represent all isotopes and generate a total uranium estimate, a fuel-ratio method for estimating the fission product concentrations, a standard activation product method, and a surrogate site-inventory method.

Complex models applied to estimate annual and cumulative inventories include the Hanford Defined Waste Model (Agnew et al. 1997), the Hanford Soil Inventory Model (Simpson, Corbin, and Agnew 2001), and the Hanford Tank Waste Operation Simulator (Kirkbride et al. 2001). The Hanford Defined Waste and Hanford Soil Inventory Models are both process-knowledge-based models that provide estimates of waste stream discharges to ground. The Hanford Tank Waste Operation Simulator Model begins with the best basis inventory of tank contents, and, based on an assumed scenario of when tank waste is recovered, produces an estimate of the annual production of high-level waste glass, low-activity waste glass, secondary waste streams, and tank residuals. Results from these complex inventory models represent a significant fraction of the past-practice liquid discharge inventory and the majority of the projected waste disposals from today until Hanford Site closure.

For this initial assessment, inventory data are categorized by operational area and waste type. Database entries and prior model results are valued equally.

For all sites not quantified by the stochastic Hanford Soil Inventory Model, the Inventory Module of the initial assessment simulates contaminant concentration as uncertain using a lognormal (natural logarithm) distribution with the median set to the record or estimated value, and a geometric standard deviation set to a multiple of the record or estimated value. Inventories prior to 1970 were assigned a standard deviation of two or twice the record or estimated value. Accordingly, individual site-specific inventories could be 20-fold uncertain during this operational era. All inventories since 1970 were assigned a standard deviation of one quarter the record or estimated value. Accordingly, inventories could be two-fold uncertain since 1970 when disposal and discharge records were first required. All volume discharges were assigned a 20% uncertainty about the record or estimated volume of waste. This approach to uncertainty was adopted after consulting with current and retired Hanford staff familiar with inventory records. The uncertainty model is identified and data provided in the inventory data files read by the inventory model.

The results from the inventory model appear reasonable. However, inventories for some individual waste sites need to be investigated further.

Numerical Model

The numerical inventory tracking and disposition model is named INVENTORY. User instructions for this new code within the System Assessment Capability family of codes are included in Eslinger et al. (2002a, b). The design objectives of the code are outlined in Kincaid et al. (2000). The analyses performed by INVENTORY are the creation of stochastic realizations, aggregation of disposal actions, accounting for radioactive decay, and optionally, normalization of results to an expected total inventory. If a single stochastic realization is called for, then a single-valued deterministic simulation is performed.

Inputs to INVENTORY describe the complete series of annual disposal and discharge actions for waste sites being analyzed. A site name, a year, the volume disposed or discharged, and the concentration of each radionuclide or chemical contaminant in the volume identify each disposal action. The volume and concentration parameters are defined as stochastic variables. The INVENTORY program generates sample values for each parameter with the number of values being the number of stochastic realizations. An aggregation action involves a simple summation of values for a specific list of sites that are to be simulated as a single aggregated site, (e.g., all solid waste burial grounds in the northern portion of 200 West Area are modeled as a single solid waste burial). Radioactive decay is performed using a general decay algorithm to describe chain decay with branching. The optional normalization action involves a simple summation of all site-specific inventories and normalization of each to a specified value.

History Matching

The approach used in the initial assessment to evaluate the adequacy of the Hanford inventory was to estimate the total inventory at the entire Hanford Site in two ways and compare them. This was first done by estimating the total curies of radioactive isotopes created in the production reactors, and the total kilograms of chemical compounds imported and used in creating and irradiating the fuel, processing the spent fuel, and stabilizing the waste. The second estimate was achieved by summing the site-specific inventories.

Two metrics of total inventory were applied to determine whether an adequate history match was achieved, and, hence, whether scaling of the overall inventory was necessary. The first metric compared the mean of the summed site-specific inventory to the mode or most probable value of the Hanford Site total inventory, (i.e., the total generated in reactors and imported). If the ratio of the two was no more than two and no less than a half, then scaling was deemed unnecessary. Because risk is linearly related to inventory in general, use of a factor of two implies the median inventory is not responsible for more than a factor of two change in risk. The second metric compared the 5%-trimmed range of the summed site-specific values to the range in the Hanford Site total inventory estimate. The 5%-trimmed range is the range obtained after eliminating the lower 5% of the sampled values and the upper 5% of the sampled values. When 20 sampled realizations are used, the 5%-trimmed range is computed after eliminating the smallest and largest values. Note that using a trimmed statistic for comparison is a common statistical approach to eliminate the disproportionate effect of a single small or large value. If the ratio of the two ranges was no more than three and no less than a third, then scaling was also deemed unnecessary. Selection of a factor of three for the range metric is subjective, but allows for a reasonable spread in a total inventory that is believed to be fairly well known based on the nuclear physics of reactor operation and process chemistry knowledge.

Table 4.4 presents the results of the two metrics for seven of the nine contaminants. Uranium and plutonium comparisons were not completed because of their status as special nuclear materials and the significant fraction of inventory exported. Generally, a ±5% variation on the baseline total inventory was used for the range of the baseline. Exceptions were tritium with ±10%, iodine-129 with ±20%, chromium with +25% and – 20%, and carbon tetrachloride with +100% and – 50%. These ranges were obtained from a panel of former and current Hanford staff familiar with inventory records and calculations. The range of the summed site-specific inventories of carbon tetrachloride shown in Table 4.1 is quite narrow, implying confidence in the inventory. However, the uncertainty associated with the total inventory of carbon tetrachloride, obtained from the panel of former and current Hanford staff, was fairly significant. This results in a small range ratio; however, the mean-to-mode ratio is excellent.

The range ratios of cesium-137 and strontium-90 are larger than others. This reflects a broad distribution in the summed site-specific inventory. The greater uncertainty apparent in the summed inventory is a function of the presence of cesium-137 and strontium-90 at a large number of sites, and a relatively high uncertainty in early discharges and disposals for many of those sites.

What is history matching?
History matching compares model calculations against field observations and experimental measurements. The use of the term "history matching" in the SAC development effort is intended to emphasize the concept that the longer the history matched period, the more reliable the predictions of the model will be.

Table 4.4. *Comparison of the baseline total inventory with summed site-specific stochastic inventory estimates.*

	CCl4 (kg)	**Cr** (kg)	**Cs-137** (Ci)	**H3** (Ci)	**I-129** (Ci)	**Pu-239/40** (Ci)	**Sr-90** (Ci)	**Tc-99** (Ci)	**U-238** (Ci)
Baseline Total	1,450,000	18,900,000	38,112,612	50,844	76	81,700[a]	30,696,418	36,094	16,800[b]
Range Ratio [c]	0.05	1.07	2.33	0.65	1.01	—	2.11	1.76	—
Mean to Mode Ratio[c]	1.01	1.01	0.96	1.51	1.57	—	1.01	1.02	—

(a) Pu-239/240 is "normal operating loss" plus U.S. Ecology estimate. Isotopes of plutonium are special nuclear material and total values are not available for the Hanford Site's generated, imported, and exported plutonium.
(b) U-238 is "normal operating loss" plus U.S. Ecology estimate plus waste disposal forecast. Uranium is a nuclear material, and the inventory of imported and exported uranium greatly overshadows the waste inventory.
— means comparisons not generated.
(c) Values of 1 for the ratios reflect perfect matches between inventory estimation methods.

The relatively high, but acceptable mean-to-mode ratios for tritium and iodine-129, reflect an overestimate of the mean summed site-specific inventory. In the case of tritium, this may represent overestimating crib discharges associated with process knowledge. In the case of iodine-129, this is a function of double accounting for iodine-129 in atmospheric releases and in tank waste.

Figure 4.4 presents graphically the ranges of technetium-99. The distributions of summed site-specific inventory of technetium-99 (shown as stochastic data) are compared to that of the Hanford Site total inventory (shown as total baseline). The plot shows the mean and mode values for the two distributions. Minimum and maximum values reveal the full ranges; however, the trimmed range for the summed site-specific inventory is 6,340 curies while the full range of the total inventory estimate is 3,610 curies. Thus, the ratio of mean/mode is 1.02 and the ratio of ranges is 1.76, meaning the criteria were satisfied for technetium-99.

Of the seven contaminants for which metrics were calculated, all meet the mean-to-mode ratio criterion. The carbon tetrachloride inventory is the only one that does not meet the range criterion. Because all other contami-

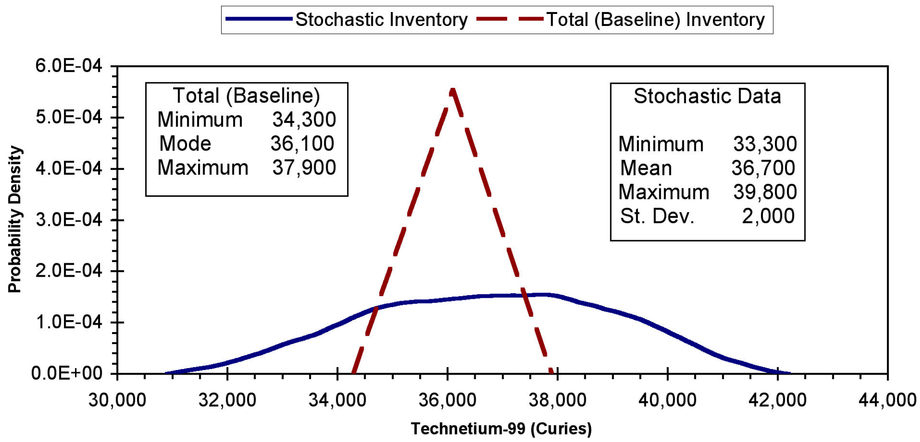

Figure 4.4. *Two estimates of total technetium-99 inventory at Hanford Site closure (2050); total from generation, import, export; and summed site-specific stochastic inventory.*

nants met both criteria it was decided that the site-specific inventory did not require scaling or adjustment to conform to the Hanford Site total baseline inventory.

Because the long-term waste inventory depends on future remediation and land-use decisions, a baseline estimate of end-state inventory was defined for this initial assessment.

The criteria described in the preceding paragraphs evaluate the total inventory of contaminants that were created at Hanford and remain on the Hanford Site. The initial assessment revealed another class of waste – contaminants that were also nuclear materials. Tritium, uranium, and plutonium isotopes are examples. Each of these contaminants were generated, separated, and exported. Other metrics are needed to evaluate these contaminant inventories. For this initial assessment comparisons were made between summed site-specific inventory and records of waste management total, inventory difference, and normal operating losses. A review of these quantities relative to their use as history matching metrics for nuclear materials is warranted. Adequate criteria for the evaluation of inventories of waste with nuclear material elements or isotopes are needed to define clearly the adequacy of our knowledge of waste inventories for these materials.

Total inventory of the seven contaminants for which metrics were calculated is known with confidence. However, total inventory metrics and criteria did not evaluate the accuracy and adequacy of site-specific inventories. Completion of the initial assessment with inventories for nine contaminants has revealed that some site-specific inventories are representative of the field observed setting and some are not. When a single crib or suite of cribs is responsible for a single groundwater plume, a comparison of the combination of inventory, release, vadose zone and groundwater can confirm or refute our ability to simulate the successive events that created the plume. The tritium plume originating from several PUREX Plant cribs provides a confirmation that model and field data match reasonably well. This match infers the inventory of tritium discharged to the cribs is reasonable.

A review of the assembled technetium-99 inventory compared to groundwater plumes underlying the Central Plateau reveals the virtual absence of technetium-99 in discharges associated with the technetium-99 plume underlying U Plant. Conversely, the Inventory Module places a substantial inventory of technetium-99 in the BC cribs and trenches located south of 200 East Area, and a significant groundwater plume develops in the model simulation. However, remnants of such a plume do not appear to exist in groundwater today. Possible explanations are the plume has dispersed to the low levels observed, the uranium-scavenged waste stream composition overpredicted technetium-99, or vadose zone migration is slower in reality than the model predicts. Contributing to a conservative bias and uncertainty in the technetium-99 inventory at Hanford is the omission in process-knowledge-based models of chemical separation of technetium-99 and its export and import with uranium shipped to and from reprocessing sites in the DOE complex, (e.g., Fernald, Ohio).

__Technetium-99__ is a gray metal, and with the exception of natural reactors, all technetium on earth has been created by man. Technetium-99 is found in spent nuclear fuel and high-level radioactive waste resulting from the operation of nuclear reactors and fuel reprocessing plants. Technetium-99 has a half-life of approximately 213,000 years and the element is highly mobile in the Hanford environment. Because of the magnitude of the technetium-99 inventory, (e.g., >30,000 Ci), its mobility if released in the Hanford environment, and its level of health risk if ingested, technetium-99 has been identified as a radionuclide of primary concern. For this reason, technetium-99 was included as an example of a highly mobile contaminant in the initial assessment.

A similar review of the assembled iodine-129 inventory data and groundwater plumes suggests the inventory of the iodine-129 plume originating at the PUREX Plant is poorly represented in record databases and process-knowledge-based models. The inventory of iodine-129 reported as atmospheric release also appears low for the chemical separation plants. Taken together, these under-reported atmospheric and subsurface releases suggest that the process-knowledge-based conceptual models of iodine-129 movement through the chemical separation plants (PUREX, REDOX, T and B Plants) and their waste streams need to be revised to create a consistent holistic model of the iodine-129 inventory. In addition to better definition of environmental releases, such an inventory review could reduce the iodine-129 inventory in tanks and better define requirements for tank waste separation and vitrification.

A review of the assembled chromium inventory data and groundwater plumes suggests the source of releases causing specific plumes in some of the 100 Areas are not all captured in current records and by existing estimation methods. Alternatives to the existing inventory data and estimation methods for chromium need to be identified and incorporated before chromium plumes can be adequately simulated in all areas.

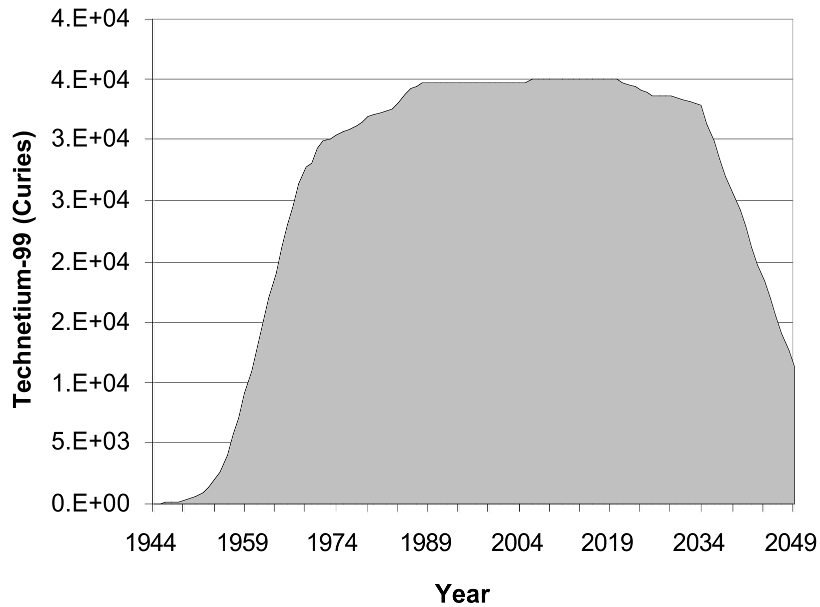

Figure 4.5. *Total inventory of technetium-99 showing generation and export.*

Clearly, a more detailed examination of inventory information, evaluated against field observations of groundwater plumes, can reveal areas of agreement and issues requiring resolution for site-specific inventories. The cumulative ability of inventory, release, vadose zone, and groundwater modules to match existing groundwater plumes needs to be examined as a means of evaluating the site-specific inventory estimates, especially for more mobile contaminants including carbon tetrachloride, chromium, tritium, technetium-99, iodine-129, and uranium.

Recently, inventory information was merged with planned export information to illustrate the growth and decline of sitewide inventories. Figure 4.5 shows the technetium-99 inventory as an example. Spent fuel, high-level waste, and transuranic waste exports all contribute to the decline in technetium-99 while other forms of waste are expected to remain onsite after site closure. Future revisions of the Inventory Module need to present this more complete portrait of the history of Hanford Site waste inventories.