System Planning with the Hanford Tank Waste Operations Simulator – 10236w

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ABSTRACT

At the U. S. Department of Energy's Hanford Site in southeastern Washington State, 216 million liters (57 million gallons) of nuclear waste is currently stored in aging underground tanks, threatening the Columbia River. The River Protection Project (RPP), a fully integrated system of waste storage, retrieval, treatment, and disposal facilities, is in varying stages of design, construction, operation, and future planning. These facilities face many overlapping technical, regulatory, and financial hurdles to achieve site cleanup and closure. Program execution is ongoing, but completion is currently expected to take approximately 40 more years.

Strategic planning for the treatment of Hanford tank waste is by nature a multi-faceted, complex and iterative process. To help manage the planning, a report referred to as the *RPP System Plan* is prepared to provide a basis for aligning the program scope with the cost and schedule, from upper-tier contracts to individual facility operating plans. The Hanford Tank Waste Operations Simulator (HTWOS), a dynamic flowsheet simulation and mass balance computer model, is used to simulate the current planned RPP mission, evaluate the impacts of changes to the mission, and assist in planning near-term facility operations. Development of additional modeling tools, including an operations research model and a cost model, will further improve long-term planning confidence. The most recent *RPP System Plan*, Revision 4, was published in September 2009.

INTRODUCTION

The 1,518 square kilometer (586 square miles) Hanford Site, located along the Columbia River in southeastern Washington State, is home to the world's first plutonium production complex. Beginning with the Manhattan Project and throughout the Cold War, Hanford played a pivotal role in providing nuclear materials for the nation's defenses. Nine nuclear reactors produced plutonium and other nuclear materials, and multiple facilities processed the irradiated reactor fuel to separate the desirable radionuclides. Chemical waste generated from the nuclear fuel reprocessing operations contained the bulk of the fission products and were relegated to storage. At the time, little consideration was given to final waste disposition, but more than four decades of plutonium production yielded a challenging nuclear waste legacy: approximately 216 million liters (57 million gallons) of radioactive and chemically hazardous wastes are stored in 177 underground tanks varying in size from 208 kiloliters to 4.7 million liters (55,000 gallons to 1.25 million gallons). The waste composition and physical properties vary widely, necessitating a variety of unique waste retrieval and treatment methods. In addition, 149 of these tanks are decades past their intended useful life. Some of these older tanks are known or are assumed to have leaked. In the 1950s and 1960s, as much as 1 million gallons of liquid radioactive waste may have been released into the surrounding soil, contaminating the soil and groundwater and threatening the Columbia River, one of the largest river systems in the Pacific Northwest.

Today, under the direction of the Department of Energy (DOE) Office of River Protection, Hanford contractors are performing one of the world's largest and most complex environmental cleanup projects. The River Protection Project (RPP), a fully integrated system of waste storage, retrieval, treatment, and disposal facilities, is in varying stages of design, construction, operation, and future planning. These facilities face many overlapping technical, regulatory, and financial hurdles to achieve site cleanup and closure. Program execution is ongoing, but completion is currently expected to take approximately 40 more years.

Strategic planning for the treatment of Hanford tank waste is by nature a multi-faceted, complex and iterative process. To help manage the planning, a report referred to as the *RPP System Plan* [1] is prepared to provide a basis for aligning the program scope with the cost and schedule, from upper-tier contracts to individual facility operating plans. The *System Plan* also addresses current regulatory impacts and technology development needs, as well as issues, uncertainties, and mitigating actions. At the heart of the *System Plan* is the Hanford Tank Waste Operations

Simulator (HTWOS), a sophisticated computer model used to simulate the current planned RPP mission, evaluate the impacts of changes to the mission, and assist in planning near-term facility operations. Revised and updated *System Plans* are now published approximately once each year.

RPP SYSTEM ENCOMPASSES WASTE STORAGE, RETRIEVAL, TREATMENT AND DISPOSAL

The River Protection Project is comprised of a network of inter-related waste storage, retrieval, treatment and disposal facilities in varying stages of design, construction, operation, and future planning (refer to Fig. 1, Simplified Process Flow Diagram of the Hanford Site River Protection Project, below). Key elements of the process flow diagram are discussed in the following paragraphs.

Storage: Hanford's radioactive tank waste storage facilities include 177 underground tanks, in two basic designs: single-shell tanks (SST) and double-shell tanks (DST). Each of the 149 SSTs consists of a concrete tank with a concrete dome. An interior carbon steel liner covers the concrete base and walls. SST storage capacity varies from 208 kiloliters to 3.8 million liters (55,000 gallons – 1 million gallons). The SSTs were built between 1943 and 1964. Some SSTs are known or suspected to have leaked in the past. In contrast, the 28 DSTs represent a significant improvement in safe waste storage because the reinforced concrete tank shell encloses two carbon steel liners with leak detection systems between the liners. DST capacity varies from 3.8 million liters to 4.7 million liters (1 million gallons to 1.25 million gallons). The DSTs were built between 1968 and 1986. No DSTs have leaked to date, but many are approaching their design lifetime. The DSTs play three critical roles in the RPP system: they receive and store the waste retrieved from the SSTs, they stage that waste for subsequent delivery to the Waste Treatment and Immobilization Plant (WTP), and they support evaporator operations, so as to minimize the total volume of waste that needs to be stored.

All 177 waste storage tanks were built underground (constructed in a below-grade excavation and then backfilled) in order to take advantage of the passive radiation shielding provided by the earth. The tanks are clustered in 18 groups, or "farms," with 2-18 tanks per farm, spread over several square miles. Waste transfers among tanks and related facilities occur via installed double-encased underground transfer lines, or via temporary hose-in-hose above-ground transfer lines. The vast majority of tank waste in storage today exists in the SSTs and DSTs; only a small fraction of wastes are housed in the Inactive Miscellaneous Underground Storage Tanks (I/MUST) or other site facilities.

Waste Forms: The waste itself exists in three distinct physical forms: sludge, supernate and saltcake. Separations facility wastes were sent to the tanks via underground tranfer lines as a slurry. Over time, the radioactive solids settled to the bottom of the tanks, creating a sludge layer. The clarified liquid above, still radioactive, is referred to as supernate. To reduce total waste volume, the supernate is periodically decanted and evaporated. The evaporation process separates the supernate into two fractions: the evaporator process condensates, which are collected and sent to the Liquid Effluent Treatment Facility (LERF) for additional treatment, and the concentrated slurry, which contains the majority of the radionuclides and is returned to the tanks. Once back in the tanks, the concentrated slurry cools and forms "saltcake," a crystalline solid. At one time, most SSTs contained all three waste forms simultaneously. However, between 1979 and 2004, the SSTs were "interim stabilized," meaning that, to the greatest extent technically and economically feasible, the liquid portion of the waste was transferred out of the SSTs and into the DSTs, in order to minimize the risk associated with loss of tank integrity. The total Hanford tank waste inventory is currently approximately 216 million liters (57 million gallons), containing approximately 177 million curies of radionuclides.

Waste Retrieval Techniques: Retrieval of wastes from SSTs has already begun. As of January 1, 2010, waste from six tanks has been retrieved to below the maximum heel limit defined in the *Hanford Federal Facility Agreement and Consent Order (HFFACO)* [2], and a seventh tank is under review. Waste from four other tanks has been retrieved "to the limit of technology." A variety of waste retrieval techniques are being utilized. The retrieval method deployed in each tank depends upon the nature of the waste, tank integrity, tank design, the presence or absence of internal obstructions, and other factors. The "Modified Sluicing with DST Supernate" retrieval method is used primarily to retrieve large quantities of sludge. The main advantage of this method is that the waste is retrieved without significantly adding to the overall quantity of waste that must be stored in DSTs. Supernate is used to mobilize settled sludge; upon transfer of the supernate/sludge slurry from an SST to a DST, the sludge is

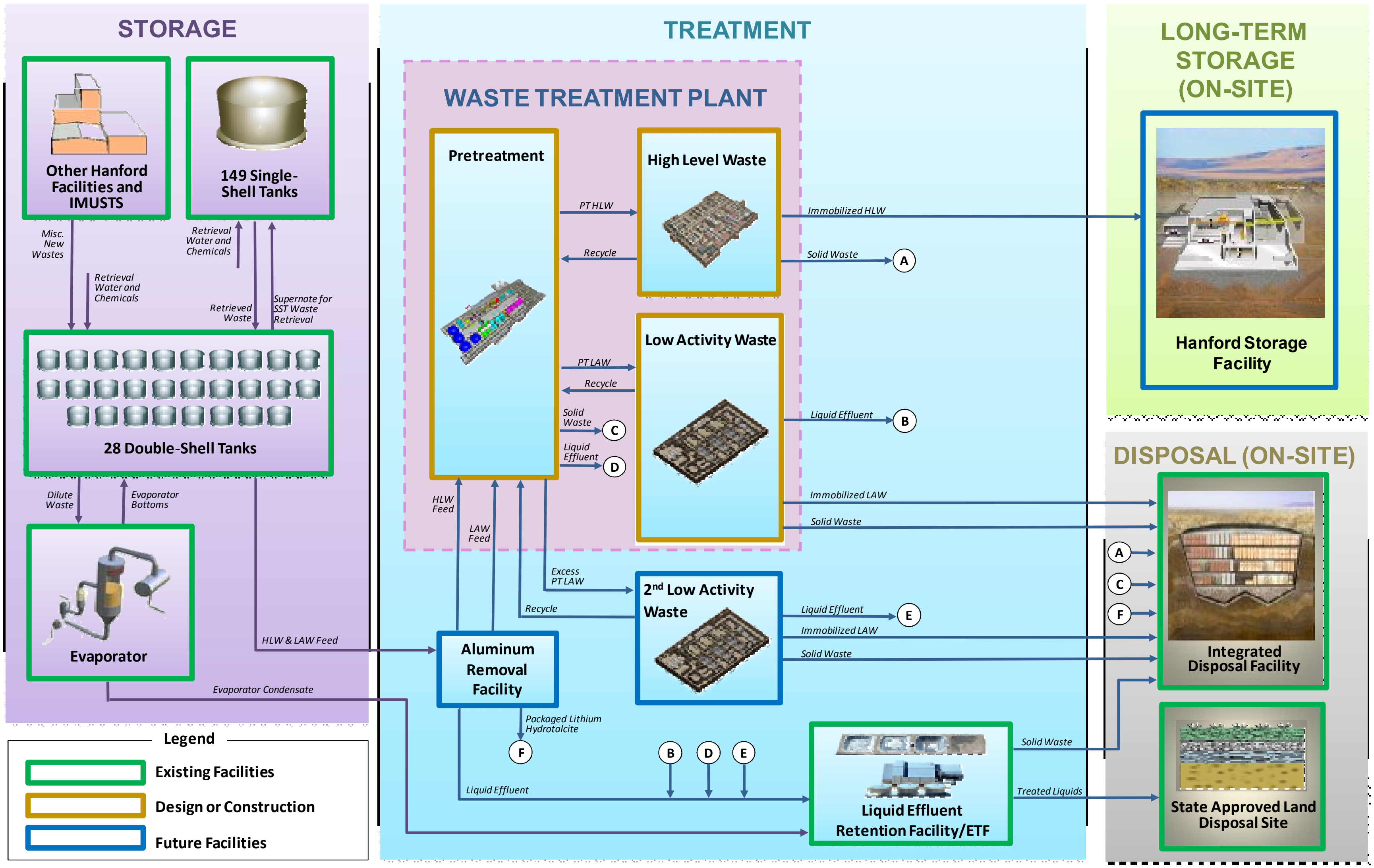

Fig. 1. Simplified process flow diagram of the Hanford Site River Protection Project

allowed to resettle and the supernate can be decanted and used again to retrieve other sludges. "Modified Sluicing with Water" is a similar method, but it is used to dissolve saltcake. In this case, supernate would not be an acceptable motive force because the supernate is already nearly saturated with sodium, and therefore would be inefficient at dissolving saltcake. The "Vacuum Retrieval" methodrelies on a mast arm inserted through the tank's central riser, capable of in-and-out, back-and-forth, and rotational movement inside the tank. Similarly, a "Mobile Retrieval System" combines a vacuum retrieval system with an in-tank tracked vehicle to push or spray waste toward the vacuum head inlet. Improvements to these technologies are being pursued. These waste retrieval technologies increase the waste volume to some degree. SST waste retrieval schedules are largely dependent upon the availability of DST space in which to store the retrieved waste.

Waste Treatment Plant: Waste retrieved from SSTs is accumulated in DSTs where it is consolidated into feed batches for the Waste Treatment Plant complex of facilities. Initial plans called for the DSTs to feed waste directly to the WTP's Pretreatment Facility, where the waste will be separated into two streams: a High-Level Waste (HLW) fraction and a Low-Activity Waste (LAW) fraction. The HLW contains most of the radionuclides, and will be vitrified (made into a borosilicate glass waste form), then stored temporarily on-site pending a final decision on disposal at an off-site repository. The LAW, which contains fewer radionuclides, also will be vitrified into a borosilicate glass waste form in a separate facility, and subsequently disposed at a permitted facility on the Hanford Site. WTP facilities are currently under construction, and at this time, they are expected to begin radioactive operations in 2019.

Aluminum Removal Facility: An emergent waste flowsheet concern prompted the consideration of a new Aluminum Removal Facility. Significant amounts of aluminum are present in the tank waste as a result of: 1) the addition of aluminum nitrate nonahydrate as a salting agent and for corrosion control during past separations and scrap recovery operations, and 2) from dissolution of the aluminum cladding from reactor fuel rods. High quantities of aluminum led to the production of undesirably high quantities of HLW glass, thereby increasing overall program costs. During waste treatment within the WTP Pretreatment Facility, the waste will pass through a cesium ion-exchange column at 25^{o}C and approximately 13-14 pH; under those conditions, some of the aluminum in the waste would be insoluble, fouling the ion exchange column. The problem could be managed by adding significant amounts of sodium hydroxide (NaOH) to the waste, which would keep the aluminum soluble during ion exchange; however, the additional sodium would dramatically increase the volume of LAW glass to be produced, thereby prolonging the mission duration and increasing life cycle costs. Therefore, a new Aluminum Removal Facility using a lithium-hydrotalcite process was included in *System Plan*, Revision 4, based on the assumption that this process could successfully mitigate the aluminum issue without adding sodium. More definitive studies and laboratory testing are now underway to evaluate the feasibility of this part of the flowsheet. Other methods of mitigating the aluminum issue are also being evaluated in parallel.

Second Low-Activity Waste Facility: The Waste Treatment Plant already includes one Low-Activity Waste Facility; however, the WTP LAW facility was never intended to treat all the LAW waste. Therefore, a second LAW facility is also under consideration to provide additional waste treatment capacity. Based on the assumptions used in the most recent *System Plan*, the second LAW facility throughput capacity would have to be approximately 37 metric tons (81,570 pounds) of glass per day, nearly double the capacity of WTP's LAW facility, assuming that current aluminum solubility issues can be successfully mitigated without adding sodium. If such a solution cannot be found, then the design capacity of the second LAW facility would have to be about 59 metric tons (130,071 pounds) of glass per day, in order for LAW processing to finish in parallel with HLW processing. The second LAW facility would be designed, built and operated by the Tank Farm Contractor, independent of the WTP.

Secondary Waste Treatment: The treatment of tank wastes will generate secondary liquid waste streams, which in turn will be treated at the Liquid Effluent Retention Facility/Effluent Treatment Facility (LERF/ETF). The LERF facility is designed to store evaporator process condensate and other dilute liquid waste streams for subsequent treatment at the ETF. The ETF provides for the collection, treatment, and storage of liquid low-level mixed wastes and the disposal of treated wastes meeting applicable state and federal permit requirements. Liquid effluent secondary wastes generated during WTP operations will be sent to LERF/ETF for further treatment and disposal, either as liquids at the State Approved Land Disposal Site (SALDS) or as a solidified waste form at the Integrated

Disposal Facility. Facility modifications to the ETF, including capacity improvements, are anticipated in order to enable LERF/ETF to accept and treat the additional wastes generated during tank waste retrieval and treatment.

REGULATORY IMPACTS ARE INTEGRAL TO PLANNING BASES

Consideration of regulatory impacts is essential to responsible planning. Federal and state environmental regulations bound DOE decisions and underpin waste treatment and disposal facility designs and operations. DOE conducts its planning and activities in accordance with applicable state and federal laws and regulations regarding safety and protection of human health and the environment. An all-inclusive list of such regulations is beyond the scope of the *System Plan*; however, the *System Plan* does highlight specific laws which play key roles in determining the actions DOE can pursue.

National Environmental Policy Act (NEPA): The National Environmental Policy Act (NEPA) [3] is widely considered to be the origin of Environmental Impact Statements. DOE recently released DOE/EIS-0391-D, *Draft Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington (TC&WM EIS)* [4] for public comment. This new EIS analyzes the following three key areas:

- Retrieval, treatment, and disposal of waste from 149 single-shell tanks and 28 double-shell tanks, and closure of the single-shell tank system.
- Final decontamination and decommissioning of the Fast Flux Test Facility, a nuclear test reactor.
- Disposal of Hanford's waste and other DOE sites' low-level waste and mixed low-level waste.

After consideration and disposition of all comments, DOE will publish a Record of Decision which will identify the preferred alternatives for each action evaluated in the EIS. The TC&WM EIS will provide an important basis for subsequent performance assessments supporting waste treatment and tank closure activities.

Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Hanford wastes are also subject to the *Resource Conservation and Recovery Act* (RCRA) (42 US 6901) [5] and the *Comprehensive Environmental Response, Compensation and Liability Act of 1980* (CERCLA) (42 USC 103) [6]. The Department of Energy, the US Environmental Protection Agency and the Washington State Department of Ecology (Ecology) entered into a comprehensive cleanup and compliance agreement on May 15, 1989, to achieve compliance with RCRA and CERCLA. The *Hanford Federal Facility Agreement and Consent Order* (HFFACO) [2], also known as the Tri-Party Agreement, is a legally-binding agreement for achieving compliance with RCRA treatment, storage, and disposal requirements for hazardous wastes and applicable corrective action provisions, and for CERCLA response action requirements. HFFACO milestones for specific cleanup activities are fundamental to long-range planning. In fact, during preparation of the most recent *System Plan*, "success criteria" in the form of proxy schedule dates were applied in lieu of approved milestones, because at the time, those milestones were the subject of pending litigation. In that *System Plan*, the operating scenarios were evaluated against those success criteria to determine how well each case met its intended purpose. Legal proceedings are expected to be resolved soon. The HFFACO milestones and consent decree milestones are expected to become the "success criteria" for future *System Plans*.

Nuclear Waste Policy Act: Not all of Hanford's tank wastes are necessarily "high- level waste," as defined by the *Nuclear Waste Policy Act of 1982* (42 USC 10101) [7]. DOE plans to separate the large mass of chemical wastes in its tanks from the highly radioactive radionuclides in the tanks using the Waste Treatment and Immobilization Plant (WTP) pretreatment processes. DOE also plans to use the DOE M 435.1-1 *Waste Incidental to Reprocessing (WIR) Evaluation Process* [8] to determine that following those separations and immobilization (e.g., vitrification), the resulting low-activity wastes (LAW) meet the WIR criteria, which include U.S. Nuclear Regulatory Commission (NRC) criteria (10 CFR Part 61) for the disposal as low-level wastes. DOE plans to dispose of the LAW on-site in the Integrated Disposal Facility once the WIR determination and required RCRA permit modifications are in place. The WIR process will also be used for residual wastes in tanks once DOE confirms that sufficient radioactivity has been removed from those residual wastes to meet the WIR criteria. DOE cannot apply the WIR process to either waste stream, however, until TC & WM EIS is finalized and a Record of Decision is issued that enables the WIR determinations to be made. To support future tank farm closure operations a WIR determination is expected to be needed for each of the seven SST waste management areas (the closure of DSTs is not included in the TC&WM EIS). Current estimates indicate that once an approved performance assessment (PA) is issued by DOE for each waste stream requiring a WIR determination, an additional 18 to 30 months will be required to develop the WIR, obtain public comments, complete NRC consultation, and issue each final waste determination.

EFFECTIVE LONG-RANGE PLANNING IS ITERATIVE, DEMANDING COLLABORATION AND INTEGRATION ACROSS ORGANIZATIONAL BOUNDARIES

Effective long-range planning is an iterative process which demands collaboration among stakeholders and integration of program planning documents in order to succeed. Within the Hanford River Protection Project, key organizations include two government entities: the U. S. Department of Energy (DOE) and the Washington State Department of Ecology (Ecology), and two private contractors: Washington River Protection Solutions (WRPS) and Bechtel National, Inc. (BNI). Numerous planning documents, from corporate-level contracts to facility-level plans, must share essential cost, scope and schedule information. Refer to Fig. 2, Hanford Site River Protection Project System Planning Process.

At the highest level, DOE establishes its expectations for the contractors to provide safe, compliant, cost-effective, and energy-efficient services for a specific scope of work. At this time, DOE manages two main contracts within the RPP system:

- The Tank Operating Contract, held by WRPS, includes the construction, operation, and maintenance activities necessary to store, retrieve, and transfer tank wastes; provide supplemental pretreatment and supplemental LAW treatment for tank waste; and provide treatment, storage, and/or disposal of glass product and secondary waste streams.
- The Waste Treatment Plant (WTP) contract, held by BNI, includes the design, construction, and commissioning of a pretreatment facility, a vitrification facility for High-Level Waste (HLW), a vitrification facility for Low-Activity Waste (LAW), a dedicated laboratory, and supporting facilities to convert radioactive tank wastes into glass for long-term storage or final disposal.

WRPS and BNI each prepare and maintain a Performance Measurement Baseline (PMB) (document number TBD) [9], which encompass the detailed cost, scope, and schedule of the work to be completed under their respective contracts. Although a given contract period (typically five years) is significantly shorter than the schedule for mission completion (about 40 years), the PMB work scope, schedules and costs are carefully aligned with life-cycle goals. The technical scope of the PMB is collectively defined by the contract itself, the RPP *System Plan*, waste site and facility lists, approved Interface Control Documents (see below), and a six-tiered work breakdown structure. The work breakdown structure designates specific implementing organization responsibilities and budget for each task, and provides the basis for all project control system components, including estimating, scheduling, budgeting, and project performance reporting. The PMB is considered a “living document,” and can be revised if necessary during the contract period; revisions must be approved by both DOE and the contractor. In addition to the PMB, the cost, scope and schedule for the rest of the mission are provided by the outyear planning estimate range.

WRPS and DOE work together to frame the scope and scenarios to be evaluated in the next *System Plan*. In addition, DOE, Ecology and WRPS hold a series of meetings to solicit Ecology’s participation in establishing planning priorities. WRPS and DOE also collaborate to establish the DOE-approved key assumptions. These key assumptions are formulated prior to each *System Plan* analysis and are incorporated into the HTWOS model. These assumptions reflect current facility configurations and process flowsheets, tank integrity status, tank waste storage space allocations and constraints, waste blending and segregation controls, waste retrieval methodology, evaporator capacity, treatment facility throughput, and other cross-cutting assumptions. More than 130 detailed assumptions were articulated and approved in preparation of *System Plan, Revision 4*. The assumptions are published as an appendix within the *System Plan*, so as to clarify the conditions evaluated in that particular revision.

Interfaces between the tank farm contractor and the WTP contractor are defined by a set of mutually-approved interface control documents [10], which must be approved by both contractors and DOE. Each interface control document defines a specific interface, such as waste transfer from the tank farms to WTP, and further defines the physical interfaces between facilities, organizational responsibilities, administrative interfaces, and procedural interfaces as well. Interface control document requirements are incorporated into the HTWOS model as appropriate.

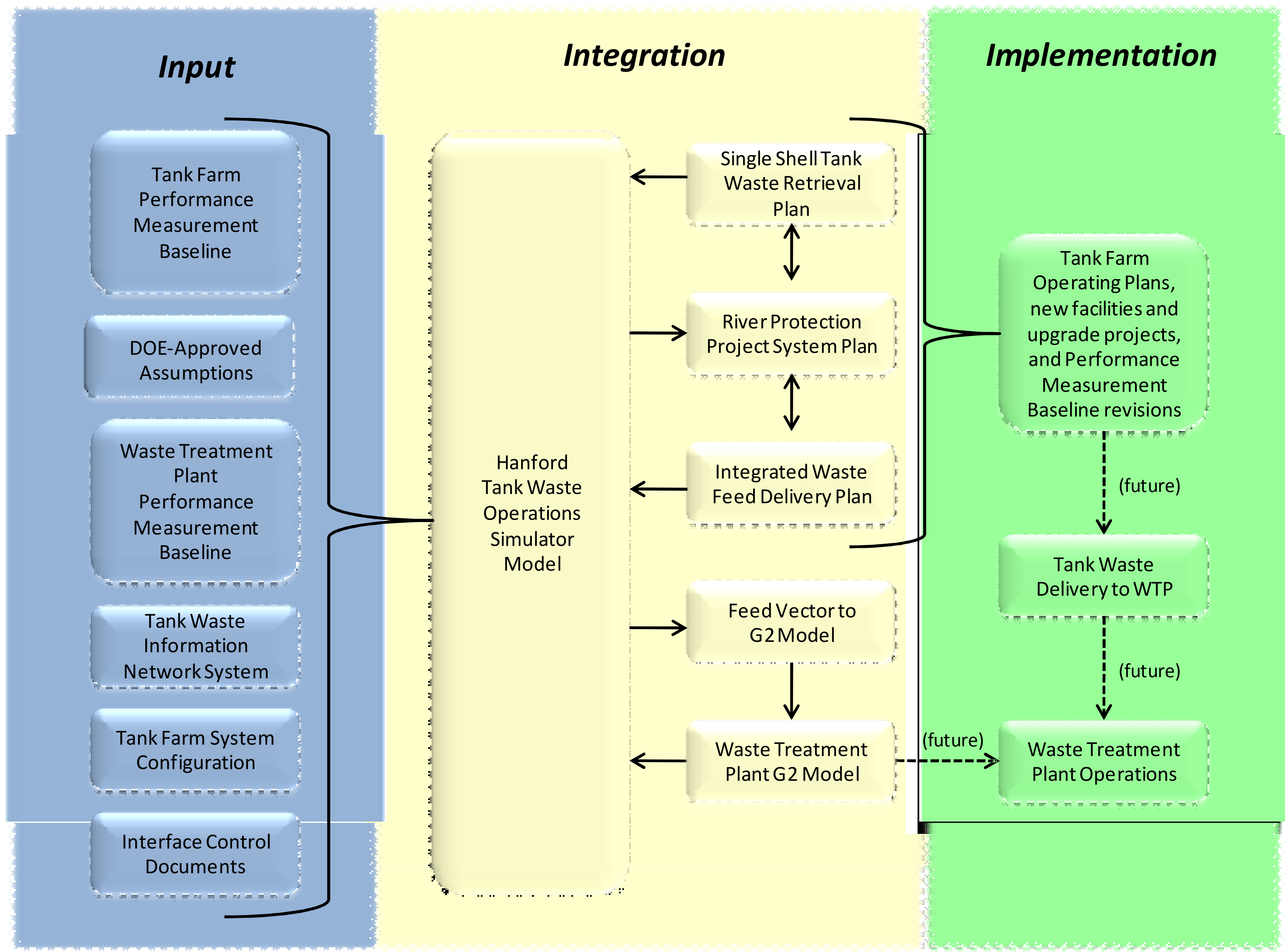

Fig. 2. Hanford Site River Protection Project System Planning Process

An iterative relationship exists among the PMBs, the RPP *System Plan,* and other related documents, as shown in Fig. 3, Hanford Site River Protection Project Planning Document Integration*,* below. PMB planning bases are incorporated into the *System Plan* as appropriate, and the results of system planning may subsequently be incorporated in revisions to the PMB. In addition, both the *System Plan* and the PMB may be updated to reflect the outcome of key technical and programmatic decisions and the results of risk handling activities. The PMB may adjust the schedule of certain activities to comply with funding guidance or other DOE direction. Running the HTWOS model yields results regarding the timing of planned field operations and operation of waste treatment processes, which may be used in the short term to refine previous plans, including the PMB, the SST Retrieval Plan, and the Integrated Waste Feed Delivery Plan. In the long term, HTWOS results may affect decisions related to trade studies and risk management, which again may influence the PMB, SST Retrieval Plan, and/or the Integrated WFD Plan.

Thus, the contents of the most recent *System Plan*, Revision 4, reflect the input of DOE, Ecology, WRPS and BNI. WRPS had the overall lead in preparation of the *System Plan* – their personnel performed the mission modeling, wrote the *System Plan*, and developed the related documents, including the Tank Farm PMB and the Tank Farm outyear estimate planning range , the *Single Shell Tank Retrieval Plan* (SSTRP) and the *Integrated Waste Feed Delivery Plan* (IWFDP). In accordance with DOE direction, key features of the process flowsheet and modeling assumptions for the WTP and certain feed screening criteria all developed by BNI were adopted, as well as WTP facility schedule updates.

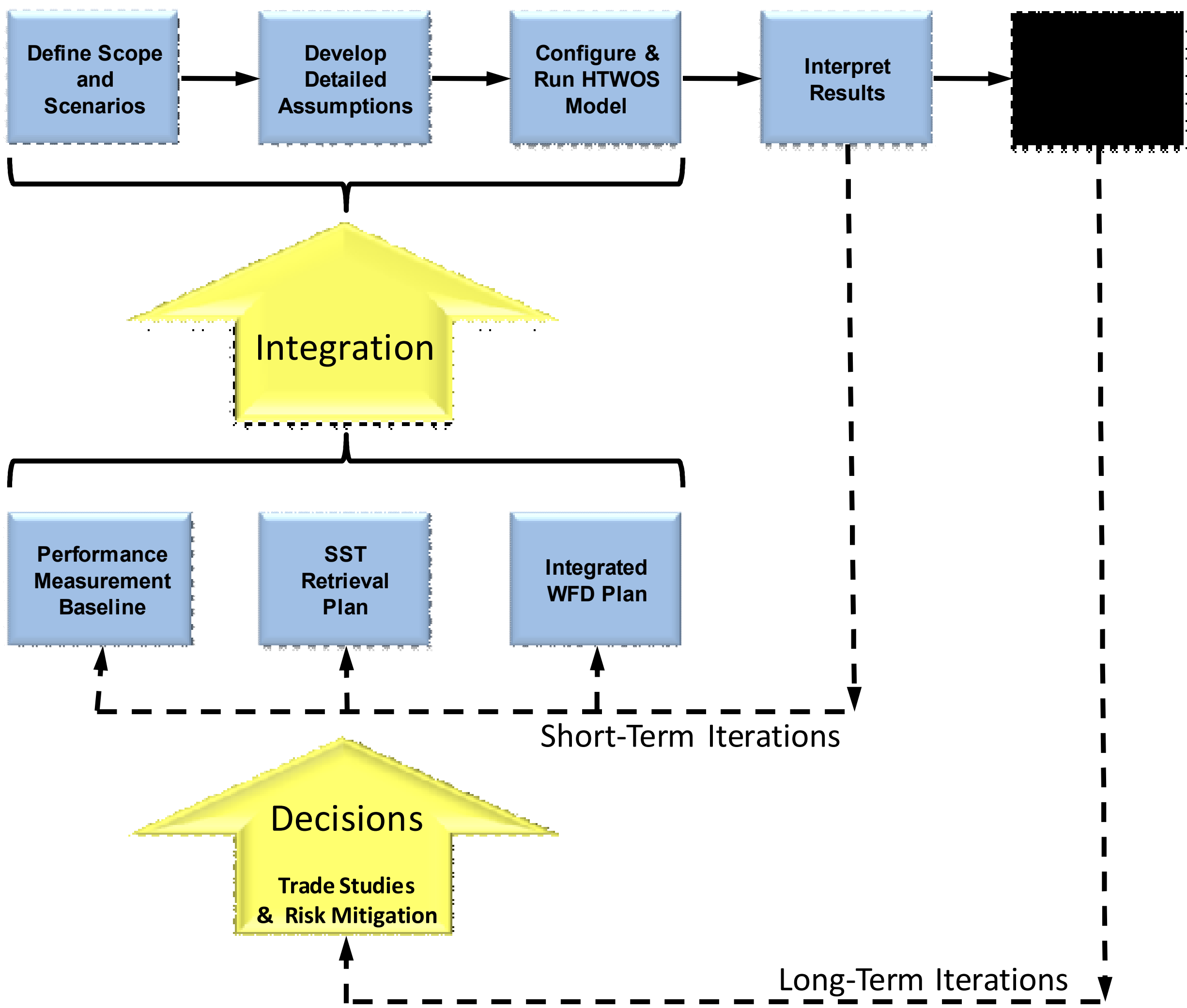

Fig. 3. Hanford Site River Protection Project Planning Document Integration

COMPUTER MODELS INTEGRATE A BROAD SPECTRUM OF PLANNING ELEMENTS

Hanford Tank Waste Operations Simulator: Sophisticated computer models are employed to plan and evaluate operating scenarios within the RPP system, each with its own strengths and purpose. WRPS's Hanford Tank Waste Operations Simulator (HTWOS) model calculates the flow of events occurring as the waste moves through storage, retrieval, feed staging, and multiple treatment processes, from the present day until the end of the RPP mission. HTWOS predicts the outcomes of various proposed operating scenarios, including the quantities and composition of the primary and secondary waste streams, the timing of key process steps, life-cycle system mass balances, and mission end dates. Configuration control and quality assurance of the HTWOS model are managed under appropriate site plans and procedures [11, 12, 13, 14, 15, 16].

The HTWOS model, illustrated in Fig. 4, The Hanford Site River Protection Project HTWOS Model Input and Output, is at the center of the RPP system planning process. HTWOS is a dynamic flowsheet simulation and mass balance model developed for DOE using commercially available Gensym Corporation software. This model:

- Simulates the current planned RPP mission.
- Evaluates the impact of proposed changes to the RPP mission.
- Evaluates integrated sets of technical and programmatic assumptions for internal consistency.
- Assists in generating tank-specific SST waste retrieval flowsheets.
- Assists with or helps validate near-term transfers, evaporator operations, baseline change requests, and project planning.

HTWOS currently models the key tank farm facilities, including: 149 single-shell waste storage tanks, two waste retrieval facilities, 28 double-shell waste storage tanks, the 242-A evaporator, waste transfer and routing systems, a supplemental TRU waste treatment system, a second (proposed) LAW facility, and the Liquid Effluent Retention Facility/Effluent Treatment Facility. A module representing the proposed Aluminum Removal Facility was recently added and will be used during model runs to support *System Plan*, Revision 5 in 2010. HTWOS also models key parts of the Waste Treatment Plant, including the Pretreatment Facility, the Low-Activity Waste Vitrification Facility, and the High-Level Waste Vitrification Facility. In all, HTWOS incorporates about 670 waste treatment vessels and operations, and unenumerated transfer and routing system segments.

Waste characterization data is taken from the Best-Basis Inventory (BBI), which is the preferred database for waste characterization at Hanford. The BBI is a compilation of tank waste data derived from process records and laboratory analysis. Quarterly updates encompass 25 chemicals, 46 radionuclides, and numerous supplemental analytes present in the 177 waste tanks. The BBI provides waste composition data necessary to support the RPP process flowsheet modeling work, safety analyses, risk assessments, and system design for waste retrieval, treatment, and disposal operations. In addition to the BBI, wash and leach factors and other supplemental characterization data are tracked in the Tank Waste Information Network System (TWINS) and entered into HTWOS.

Tank farm system conditions (e.g., current tank integrity status), transfer routes, selected WTP waste acceptance criteria [10], and other data are also incorporated into HTWOS, as documented in *Hanford Tank Waste Operations Simulation (HTWOS) Model Design Description* (RPP-17152) [11]. HTWOS generally models relevant physical constraints (e.g., connections between unit operations, volumes of vessels, flow rates of pumps, capacities, and efficiencies of the equipment) and approximates waste chemistry (e.g., phase equilibriums and reaction extents). Unit operations are based on process flowsheets and/or mass balances when available and include project schedules and net operating capacities. HTWOS also incorporates the programmatic constraints from current plans or strategies, including (but not limited to) capacity, volume, performance, dates of availability, outages, and commissioning. Some parameters may be modified by customer direction, emerging information, or simplifying assumptions. Sets of specific assumptions are used to define one or more proposed operating scenarios. The feasibility of these scenarios are evaluated by running the HTWOS model, which tracks the movement of waste throughout the RPP System from the present day through the mission end dates, approximately 40 years from now. WRPS analyzes the HTWOS modeling results to determine how well the various assumptions are integrated, identifying any mismatches. This fosters better integration, both within the scope of the Tank Operating Contract, and across the entire River Protection Project.

Results from the HTWOS model also are used to prepare flowsheets and mass balances for the entire mission or for parts of the mission. Of particular importance is the generation of the WTP feed vector, which describes the feed that the tank farm will be providing to WTP under the conditions modeled. This electronic file describes over 100 unique chemical and radiological characteristics in both soluble and insoluble forms, and other attributes, in more than 400 separate batches of waste projected to be sent from the tank farms to WTP over the life of the program. In general, each feed batch contains waste from several SSTs and DSTs. Feed vector details for each batch include the DST tank where the batch is staged immediately prior to transfer to WTP, the total waste volume, weight percent solids, waste feed composition data, leach factors, and other information. The contents of the WTP feed vectors are used as input to the WTP Dynamic (G2) model.

G2 Model: The WTP contractor, BNI, uses the WTP Dynamic (G2) [1] model to focus on various aspects of WTP operations, including equipment utilization, reagent demand, process and facility design options, technical integration with the tank farms, and waste acceptance activities. Like the HTWOS model, the WTP Dynamic model is based on Gensym Corporation G2 software. The G2 model:

- Evaluates WTP tank and equipment utilization, unit operation, and plant performance.
- Predicts reagent demand.
- Supports WTP process and facility design.
- Supports preoperational planning assessments.
- Supports technical integration with the tank farms regarding waste feed staging.
- Supports product and secondary waste acceptance activities.

In addition to the tank farm feed vector, input to the WTP Dynamic model includes vessel volumes, pump flow rates, chemical reagents, sampling turnaround times, and appropriate research and technology data (e.g., filter flux data and melter off-gas data). Output data includes waste batch delivery predictions; volume history data, with plots for each vessel; sodium molarity and weight percent solids for each process vessel; cumulative mass transfer for every process stream; cumulative glass production; and waste loading and limiting constituents of glasses. These data are interpreted to determine: utilization rates for chemical reagents, process condensate and demineralized water; utilization of cesium ion exchange resin; utilization of mineral glass formers; the volume and composition of pretreated LAW and HLW feed, and various internal recycle streams. The volume and composition of secondary liquid waste is also calculated.

[1] G2 and Gensym are registered trademarks of Gensym Corporation, Austin, Texas.

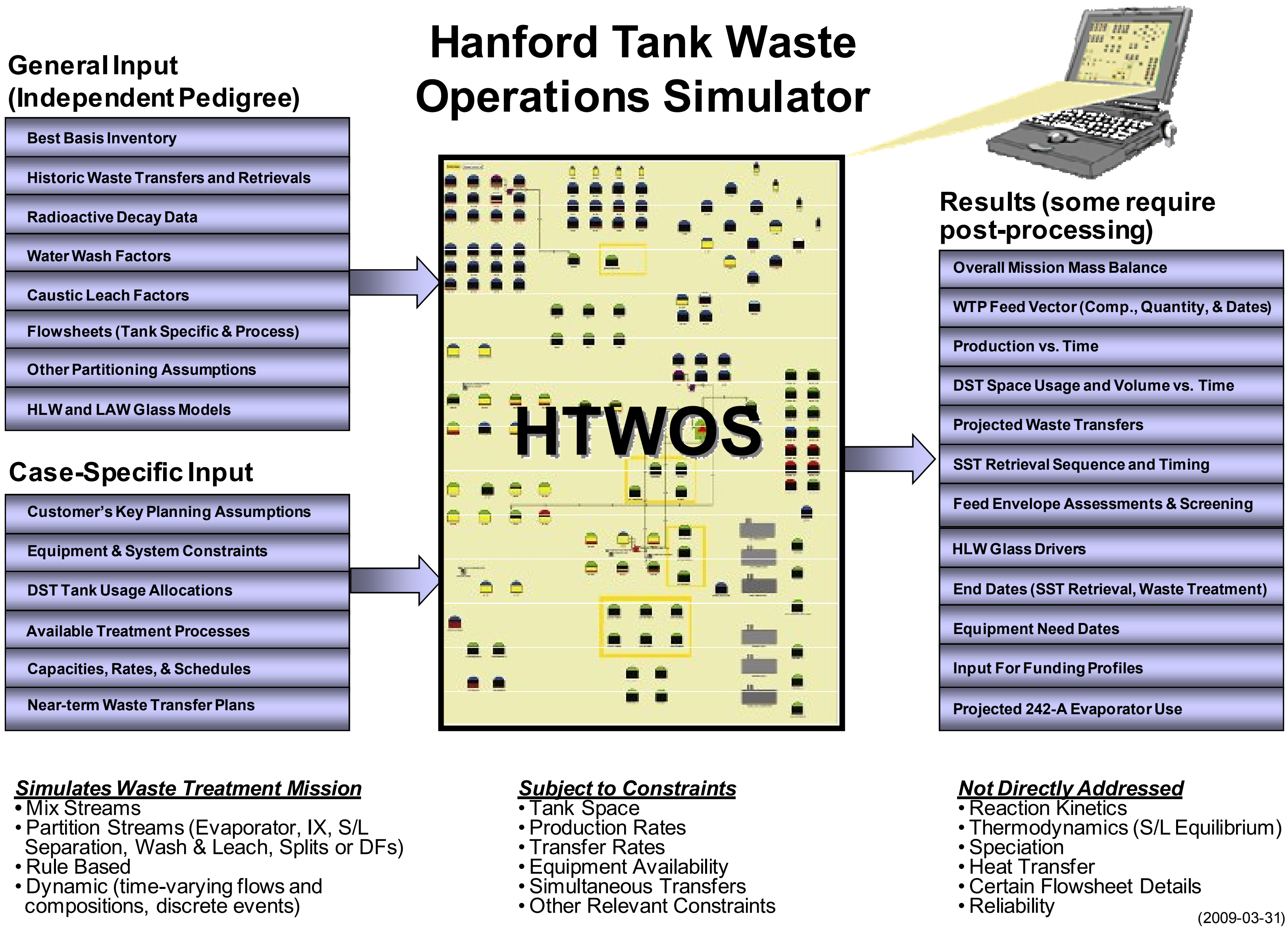

Fig. 4. The Hanford Site River Protection Project HTWOS Model Input and Output

SYSTEM PLAN RESULTS ARE INTEGRAL TO FACILITY LEVEL PLANNING

The results of the latest *System Plan* reflect information sharing among many facility-level planning and execution documents. Chief among these is the *SST Waste Retrieval Plan* (RPP-PLAN-40145) [17], which outlines specific plans for the deployment of appropriate waste retrieval technologies in each of the 149 SSTs. The waste retrieval technologies take into account the unique details of each tank's design, history, waste composition, and other factors. Plans for the sequence in which tanks are retrieved are partially driven by the *System Plan*. For example, early *System Plans* allowed the tank retrieval order to be determined by balancing each tank's eventual contribution to HLW and LAW glass production, in the general order of largest to smallest tank volume, in an effort to maximize waste feed availability to treatment operations; and by separating tanks with similar glass-limiting constituents to reduce the resulting quantity of HLW glass. While this approach is theoretically feasible, such a retrieval order presents significant operational hurdles. Infrastructure to support retrievals would have to be installed in multiple farms in parallel and kept operational for decades; these same facilities would likewise require operational staffing and monitoring for decades, until the last tank in each farm completed retrieval. The additional complexities and operating costs associated with executing such a scenario more than offset the potential benefits expected from optimizing feed availability. Therefore, this option was rejected and, with input from the *SST Waste Retrieval Plan*, the HTWOS model was used to evaluate other waste retrieval strategies. A more efficient waste retrieval strategy was identified, in which waste retrievals are scheduled farm by farm, and tanks are prioritized for retrieval within each farm. While this does partially limit opportunities for waste blending, HTWOS modeling determined that the impact was acceptable compared to the operational benefits of a farm-based approach. Therefore, this approach was reflected in the most recent *System Plan* and incorporated in the *SST Waste Retrieval Plan* as well. Facility upgrade projects to support waste retrieval operations are being planned and scheduled accordingly, and evolving details will be incorporated into future versions of the System Plan.

Another critical aspect of planning SST waste retrievals is the availability of DST space in which to stage the retrieved waste until it can be transferred to a treatment facility. SST retrievals are DOE's primary method for reducing the environmental risk posed by SST waste, and retrievals have already begun; however, waste treatment facilities are still under construction at this time and are not expected to be operational until 2019. Therefore, after retrieval, the SST waste is temporarily stored in the DSTs. Hanford's 28 DSTs have a combined capacity of 121 million liters (32 million gal), but they are already storing approximately 102 million liters (27 million gal) of waste. Of the remaining 19 million liters (5 million gallons) of head space, approximately half must be reserved to: satisfy safety basis concerns, meet emergency storage requirements, support planned evaporator operations, and isolate already-qualified feed to WTP. The HTWOS model simulates various operating scenarios to determine how well they support SST waste retrieval, while simultaneously maximizing the use of the remaining DST space. Model results are published in the *System Plan* and reflected in appropriate facility-level planning documents.

System Plan results also influence the *Integrated Waste Feed Delivery (WFD) Plan* (RPP-40149) [18], which defines the scope of work, objectives, and project management approach necessary to reliably and continuously transfer tank farm waste to the WTP or other treatment facilities as necessary. The *Integrated WFD Plan* scope of work includes project planning; the engineering, procurement, construction and commissioning of system upgrades; coordination of project activities with existing plant operations, and WFD operations. In particular, the initial feed delivery schedule developed by HTWOS and published in the *System Plan* serves as a foundation for the technical scope and timing of the work described in the IWFDP, which is further translated into facility-level planning documents. Changes within the cost, scope or schedule of the IWFDP will be incorporated into future versions of the *System Plan*.

The most recent *System Plan*, Revision 4, identified many important project metrics, including SST retrieval schedules, DST storage space projections throughout the life of the project, evaporator campaign parameters, the number of waste transfer operations required annually, simplified mass balances of key waste constituents throughout the mission, metric tons of waste glass produced, quantities of secondary waste streams produced, interim milestone completion dates, and final mission completion milestone dates. A few of the key metrics are included below:

Table I. System Plan, Revision 4, Baseline Case Key Metrics

Key Metrics	Projected Value
Complete all SST Retrievals (year)	2041
Close all SSTs (year)	2048
Treat all tank waste (year)	2045
Total LAW Glass Mass	448,800 metric tons (989 million pounds)
WTP LAW Glass Canisters (quantity)	29,785
2nd LAW Glass Canisters (quantity)	46,025
WTP HLW Glass Mass (MTG)	42,899 metric tons (94 million pounds)
WTP HLW Glass Canisters (quantity)	14,111

MODELING IMPROVEMENTS INCREASE PLANNING CONFIDENCE

The iterative nature of long-range planning includes ongoing improvements to modeling tools. Revisions may be prompted by resolution of known issues; identification of new issues; completion of new research; implementation of new risk management strategies; changes to facility designs, flowsheets or operating plans; or for other reasons. In order for the HTWOS model to continue its role as an effective planning tool, it must be revised accordingly. In addition, two new models – an operations research model and a cost model – are under development at this time. These improvements will be reflected in subsequent revisions of the *System Plan*.

The HTWOS modeling improvements currently in progress will improve alignment between the model and anticipated field operating conditions:

- The use of the DSTs in the HTWOS model will be made consistent with the plans and equipment defined in the *Integrated Waste Feed Delivery Plan*. Each DST will be assigned one or more functions over the treatment mission, including:
  - Receiving retrieved waste slurry within either East Area or West Area.
  - Sending or receiving retrieved waste (in the form of slurry or supernate) across the site from West Area to East Area.
  - Staging feed for the LAW facility.
  - Performing settling and decant functions for intermediate HLW feed staging.
  - Final HLW feed staging.

These different functions will necessitate the installation of different support equipment, including the number and type of mixer pumps, transfer pumps and other infrastructure improvements. The model will reflect scheduled outages while the new equipment is installed, as well as the capabilities of the equipment when in operation. In addition, the operational logic of the DST system will be revised to improve waste blending, which will increase waste oxide loading in product glass, which in turn will reduce mission length and project life-cycle cost.

- The 242-A Evaporator logic will be updated to more realistically stage feed and define evaporator campaigns as necessary to support SST waste retrieval, while minimizing the volume impact in DST storage.
- The HTWOS model is being aligned with the most recent WTP flowsheet assumptions since some of the assumptions used by current version of HTWOS have become dated as the WTP flowsheet and design has evolved. Areas of alignment include:
  - The chemical reactions, process splits and offgas reactions are being updated in accordance with the latest WTP process flowsheet, operating modes and facility design.
  - The model of the WTP's Pretreatment Facility will include more detail related to the operation of the ultra-filters and the ion exchange columns.

- o The unit operations associated with WTP's Pretreatment, High-Level Waste and Low-Activity Waste facilities are being expanded to include certain previously-omitted process vessels. This will allow WRPS personnel to more easily pinpoint the origin of possible process issues.
- o Labeling of unit operations within HTWOS is being updated to match nomenclature already in use at WTP, in order to improve communications between the two contractors.

- The HTWOS model currently lumps the WTP's LAW facility with the proposed Second LAW facility capacity to simplify the model. This will be changed to model two separate LAW facilities with independent waste processing schedules, flowsheets and assumptions.
- Recently completed research from the Pacific Northwest National Laboratory (PNNL) has been documented in the report *Glass Property Data and Models for Estimating High-Level Waste Glass Volume,* (PNNL-18501) [19] and incorporated into a new glass properties model, which in turn is being integrated into both HTWOS and the WTP G2 model. The new glass model will provide more accurate predictions of needed chemical additions and the resultant glass volumes. This change in particular will enable HTWOS to better predict overall mission length and facilitate waste blending decisions by identifying the constituents driving the HLW glass mass.

Operations Research Model: In addition, a Waste Feed Delivery Operations Research (OR) model [20] is being created using Witness[2] software. The OR model will interface with HTWOS output via an Excel[3] spreadsheet. HTWOS incorporates a simplifying assumption that the melters will achieve 70% total operating efficiency, and that other systems can operate to support that rate. The new OR model will present a more realistic prediction of operating efficiency for other equipment by incorporating tank farm component reliability data based on actual Hanford experience. The OR model will address the reliability, availability, maintainability, and inspectability of approximately 525 individual components, such as waste mixing pumps, transfer pumps, valves, jumpers, leak detection instruments, and other equipment associated with the 28 DSTs and the 242-A Evaporator. Based on this data and HTWOS system planning output, WRPS personnel will calculate the mean time between failures (MTBF), failures on demand, and mean time to restore operability. This data will then be combined in Witness[R] to simulate failures and repair times, which will enable planners to identify and mitigate reliability-related cost and schedule drivers. In the near future, the OR model will be expanded to include additional supporting facilities and waste treatment processes.

Cost Models: A cost model will help WRPS quickly evaluate the near-term and life-cycle cost impacts of proposed operational and flowsheet changes within the RPP system. Currently, two separate software programs are used jointly to project cost impacts: HTWOS, which defines the operating scenario by simulating field operations like waste transfers, retrievals, evaporator operations and waste treatment processes; and Primavera Enterprise Project Portfolio Management[4] (P6), which tracks project resources, costs and schedules, including earned value metrics, milestones dates, work breakdown structure summaries, and other project management tools. Each program offers certain strengths, but using them in tandem as currently configured to predict life-cycle cost impacts presents some concerns. For example, both models incorporate RPP-specific assumptions, but there is no easy way to confirm that the assumptions in one model are fully consistent with the assumptions in the other model. Also, data sharing between these two programs must be done manually, and the results analyzed by individual subject matter experts rather than an automated system, which could be verified and validated. The length of time required for generation of scenario input and completion of HTWOS model runs and to iterate with P6 to generate a schedule with escalated costing data, does not facilitate timely evaluation of life-cycle cost and schedule impacts. Consideration was given to implement a new tool to address these concerns, but that option was rejected because of the costs associated with purchasing a new tool; the additional time required for personnel to become proficient at using the new tool; the lack of existing resources, personnel and equipment available to support the addition of a new tool; and the additional complexities of managing the assumptions for yet another tool. Therefore, work is underway to plan, design, develop and deploy a life-cycle cost management tool as a module within the HTWOS model that will integrate data used by both HTWOS and P6, and ultimately allow implementation of optimization strategies and objectives.

[2] Witness is a registered trademark of Lanner Electronics Inc., in the United States and Taiwan.
[3] Excel is a registered trademark of Microsoft Corporation in the United States and/or other countries.
[4] Primavera Enterprise Project Portfolio Management is a registered trademark of Primavera Systems, Inc., in the United States and other countries.

CONCLUSION AND PATH FORWARD

Successful storage, retrieval, treatment and disposal of legacy radioactive tank wastes at the Hanford Site requires iterative, integrated planning among both government and private organizations, and from upper-tier contracts to facility-level operating plans. Planning activities must be conducted iteratively, in order to incorporate new program guidance, technology developments, data, and field experience. Annual publication of the RPP *System Plan*, supported by rigorous HTWOS and G2 computer simulations, provides a strong platform for orchestrating those integrated plans. Additional planning confidence will be gained upon the implementation of an Operations Research model and a Cost Model. The next *System Plan*, Revision 5, is scheduled to be published in September 2010. In the future, the Washington State Department of Ecology is expected to have an expanded role in the development of possible operating scenarios to be evaluated in the System Plan, beginning with Revision 6 in 2011.

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