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UTILIZING A ROBOTIC VEHICLE TO ACCESS AND CLEAN A HAZARDOUS UNDERGROUND TANK

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A remotely-operated robot, designed and built at Sandia National Laboratories (SNL), was used to remove approximately 600 gallons of mixed waste from a leaking underground water tank. The uniqueness of the activity was that the robot vehicle was never intended for this application, but employed only after workers were faced with what seemed to be an insurmountable challenge to safely access the tank. This paper is relevant to the development and deployment of remote, robotic, and intelligent systems to reduce hazards to personnel and the environment

I. INTRODUCTION

Measurements of water level in an underground tank (identified as Tank No. 2 in the attached section and plan diagrams) indicated loss to the soil column. Originally constructed in the 1960s, the tank was used to support a research reactor. The concrete tank was located 26 feet below grade and external to the reactor building. The reactor was removed from service in the early 1970s and since then the tank had only been used to collect liquid from basement floor drains and laboratory sinks prior to sampling and release. The tank water level was routinely measured by hand in order to ensure that the tank water volume was pumped to an offsite effluent treatment facility prior to any potential for overflow or backup of water into the parent facility. In November of 2005, the level measurement performed by a facility operator indicated water loss from the tank with no apparent reason. Thus began the quest to diagnose the problem and formulate a plan to correct the situation. Also given the tank contents, the loss of water was formally reported to the federal regulator and the New Mexico Environmental Department.

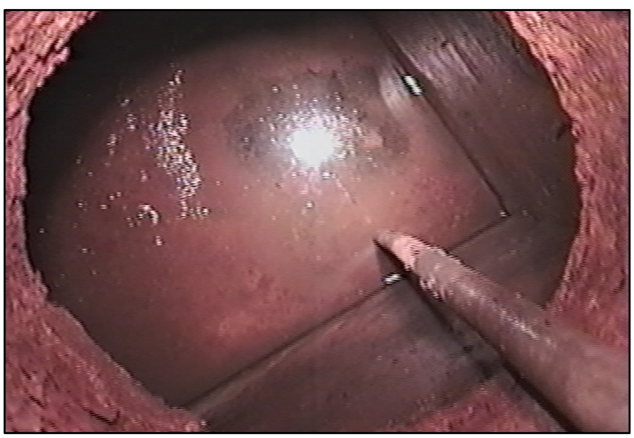

Figure 1. Top View of Underground Tank

While water sampling had never indicated any types of contamination, a sludge layer had built up in the bottom of the tank over the 40 plus years of its operation; past sampling of the sludge indicated small but detectable concentrations of radioactive nuclides such as Cobalt-60, Uranium-238, and Cesium-137 as well as the non-radioactive constituents Cadmium, Lead, and Arsenic. Several issues were encountered early on in the problem definition, which placed challenges upon the team to find a comprehensive and compliant solution to the water loss. Due to the location of the tank, personnel access to the tank proved to be challenging. Because of the age of the tank, facility documentation was poor and determining the piping configuration and interfaces with other tanks and the facility became a significant expenditure of resources. Safety oversight personnel and line management ruled out sending a worker into the tank, both for atmospheric concerns and due to the unknown structural integrity of the tank. Because of very limited resources, determining how to retrieve the material from the tank without excavation and direct personnel access became a challenge for the operations staff and leadership. A 36-inch diameter manhole at grade level reduced to an 18-inch diameter tank entrance, 21 feet directly below. Oxygen concentrations were measured to be less than 19.5%. The employment of personnel ingenuity, trial and error, modern technology and significant perseverance finally led to a successful outcome which in the beginning was not even expected to be a path for success.

II. ASSEMBLING THE TEAM

Whereas finding expertise in developing solutions to the leaking tank problem was straightforward, implementing solutions was not. The three principal near-term goals were to isolate the tank, remove the sludge, and repair the leak and return the tank to service. The schematic for the tank indicated that a smaller tank collected all the building process drain effluent and passed through an isolable section of pipe to the leaking tank. The isolation valve was closed. A team was assembled that included those who had traced out the process drain network, had experience in cleaning underground tanks, had radiological safety and industrial hygiene backgrounds, had mixed waste disposal expertise, had responsibility for discharging hazard-free water to the local sanitary sewer system, and had project management training and experience. Also, because the Department of Energy (DOE) has the exclusive responsibility for communication with the State of New Mexico Environmental Department (NMED), DOE federal representatives were part of the team from the beginning. A responsible SNL Manager was appointed and a budget of $5,000 was initially made available. All team members were working a small fraction of their time on the leaking tank problem; with an objective to demonstrate a technically feasible method of sludge removal prior to "scaling up" the project to an actual implementation of the solution.

III. DEVELOPING SOLUTIONS

III.A. Define the Problem

Contributing to initial poor job performance was a poor understanding of the changing characteristics of the sludge. An early grab sample showed a material resembling a black gelatin-like substance with definite water constituents; when allowed to dry, the sample took on the appearance of black sand. Later real-time camera images made the sludge appear as gelatinous but partially covered with a surface layer of water. Later still, when a robot was introduced into the tank, the sludge appeared as moist sand with asphalt features and of varying depth. Early sampling of floor areas away from the entry hole brought up accumulations of resin beads and striated, clay-like elements embedded in the sludge. For remotely removing sludge, it is essential to develop an understanding of the changing character of the material.

III.B. Define Success

From the outset, the goal was to remove 90% of the sludge volume. It was appreciated that there were two components to the removal: the "vertical" solution in which the material would be lifted 26 feet to the surface, and the "horizontal" solution, in which the 10 foot by 16 foot floor space could be scraped toward the tank opening. Early on, the vertical problem was believed to be the easiest to solve.

III.C. Define the Solution Space

Very early, the team recommended manned entry into the tank. The tank height is five feet, and a bucket and shovel approach was imagined to be simple and effective. Physical obstructions in the shaft (grating, piping, a pump, and pump control devices) put that choice on hold until a contractor was hired to remove the obstacles and to increase the tank opening from 18-inch diameter to 30-inch diameter. However, during the obstruction removal process, with aggressive ventilation of the air space in the vicinity of the workers, O_2 measurements were made and demonstrated that entry into the tank itself would require supplied air. Recovery equipment was purchased, a procedure was developed, and training was completed. Management approval could not be secured, however, regardless of the controls selected because the safety subject matter experts would not accept the risk of confined space entries. Also, there was the risk that the tank itself may not be structurally sound, further compounding the challenge to send personnel into the tank.

Figure 2. Tank Interference Designated for Removal

III.D. Communicate Effectively

As manned entry lost its appeal, the team recommended a variety of techniques to dilute the sludge and pump it to at-grade-level drums or tanks. DOE approval could not be secured because the work site did not have a permit to treat waste and due to the belief that the NMED would reject any proposal that would increase the potential for leaking larger quantities to the soil column. Also the actual location of the tank leak was not fully understood and water entry into the tank for mixing purposes might further aggravate any material release to the environment. At almost every turn the challenges faced by the team to meet all compliance, environmental, safety and technical constraints placed a continually tighter noose around management hopes for a reasonable and hopefully economical solution.

III.E. Make Use of the Experts

With manned entry forbidden, with the pumping of contaminated sludge virtually impossible without dilution, and with an expanded budget of $50,000, the team recommended employing trained contractor professionals to develop a manned entry plan and an estimate of costs. Three organizations were invited to participate, but none of the three would bid on the job. The contractors had extensive experience in environmental cleanup work, yet none of the solicited contractors felt that they would have a path to success given the challenges of cleaning the tank remotely. This response placed further pressure on the affected organization to find a creative solution prior to excavation options. In the interim, it was discovered that the closed isolation valve was leaking water from the upper tank to the lower tank. As a stop-gap measure, contractors were employed to replace the leaking valve, thus preventing any further loss of water to the soil column.

III.F. Conduct Experiments

A series of ideas were tested, of which several examples may be of interest. To address the vertical problem, two different designs of air flow-based eductor devices were assembled. They were pre-tested using a mixture of wheat flour and water as a sludge surrogate. The least successful clogged as the air flow dried out the wheat paste in the hose. The most successful was lowered into the tank but clogged quickly on the actual sludge material. A “shop-vac” (with a short suction hose strapped to the side of the canister) was lowered into the tank, the idea being to solve the vertical problem by raising and emptying the canister periodically. If that had worked, the thought was that the unit could be moved around the floor of the tank and operated to solve the horizontal problem. But the suction hose quickly clogged with sludge.

A common garden rake was attached to 30 feet of PVC pipe to lift sludge into a bucket, which was then raised and lowered with an attached rope. This pointed to a solution of the vertical problem, except that controlling the rake from 30 feet away was very difficult and the amount of the material collected was miniscule. To address the horizontal problem, a snow shovel was attached to a pair of PVC pipes 30 feet long. A third PVC pipe between the first two was used to articulate the angle of the shovel. The idea was to make use of the flexibility of the PVC and bend the shovel around the tank opening so that the shovel could pull sludge toward the opening. But the shovel was difficult to position and too light-duty to move the sludge. Next, an electrically powered, mostly plastic, snow blower was found that could fit into the 30” opening. The idea was to use the blower to throw sludge toward the opening. But it was ineffective at throwing sludge and awkward to reposition on the tank floor.

IV. ENTER THE ROBOT

From the beginning of the project, robotic solutions were suggested as a horizontal solution. The project team looked into the availability of custom and commercial robots. But those systems were estimated to cost up to $300,000 for the hardware, plus matching set-up costs and undetermined disposal costs. None of these methods fell in line with budget realities.

Inquiries were made to the Intelligent Systems Controls Department at SNL. The department happened to have a used small tracked vehicle robot that could be modified at reasonable cost (~$5000) to be operated from grade level and, more importantly, fit into the 30-inch diameter access hole at the top of the tank. The motorized robot has approximate dimensions of 2'W x 2'L x 1'H. It is powered by four DC motors controlling each wheel independently. The tracked wheels, combined with independent wheel control, provided a highly maneuverable vehicle to assist in traversing the tank bottom.

Figure 3. Initial Field Test of Robot

Dubbed “Swarmy,” the robot's first tests were disappointing. When the robot was first tried, it was weighted with metal plates and equipped with a snow-plow feature. At the time, the idea was to use the robot to solve the horizontal problem by plowing sludge toward the entry point and lifting the sludge (somehow). But the sludge was wet and the robot heavy and the plow set low. So the robot became trapped in the sludge and churned to a halt.

After a discussion with the robotics group, the treads of the robot were modified with the addition of “ice screws” to improve the traction of the treads. At the same time, the snow plow was removed and the metal plates replaced with bags of steel shot, so that the weight of the robot could be adjusted remotely, and to make raising and lowering of the robot into and out of the tank easier. A remotely-operated camera and lighting system were lowered into the tank. Surprisingly, the robot navigated over the surface of the (relatively dried-out) sludge. In fact, with the aid of the camera, the robot could be navigated to the far corners of the tank. This breakthrough led to the idea to place a bucket on the robot and drive the robot to a point in the tank when a rope (attached between the bucket and an operator above ground) was pulled. The bucket quickly filled with sludge and was pulled to the surface and emptied. The process was repeated and was successful at solving both the horizontal and vertical problems. The three contractors employed to complete the job included two "tech-savvy" individuals who quickly mastered the robot and camera controls. Thus in very short order, over a period of two weeks, these workers were able to clean up the material from the tank in a manner far exceeding anyone's original expectations. They continued to improve the process as the work proceeded. With the sludge scraped down to the concrete floor, they came up with the idea of trying a small shop-vac pushed around by the robot in order to brush and vacuum the rough floor surface and, especially, clean the corners. It was also a success. Over 99% of the sludge was safely removed.

Figure 4. Final Success in Using Robot to Clean Tank

V. CONCLUSIONS

Sandia successfully solved a problem that would have been expensive and dangerous to fix if human beings had to enter and clean the tank. The robot, "Swarmy," in combination with simple mechanical devices, did it quickly, economically, and safely. While the original hope was to find an external company to come in and solve the problem, it was quickly realized that there was not an "off-the-shelf" solution readily available. Management was concerned that proceeding down a path of excavation, while always a last resort option, might quickly become a project costing well into the multimillions of dollars and create further hazards for both workers and passersby. The ultimate solution of advanced technology, simple mechanical systems, and human ingenuity all worked together to offer an optimized solution to a seemingly insurmountable challenge faced by the team. Getting to that solution taught several lessons that if known ahead of time, could have greatly shortened the time required to remove the sludge. Among these are (1) accurately define the problem by understanding the characteristics of the sludge, (2) build a team with people who are either uninformed of all of the obstacles or who are too stubborn to believe they can't get the job done, (3) demand effective communication between the various regulating authorities, (4) appeal to experts, (5) experiment, and (6) above all, persistence counts – surrender is not an option.

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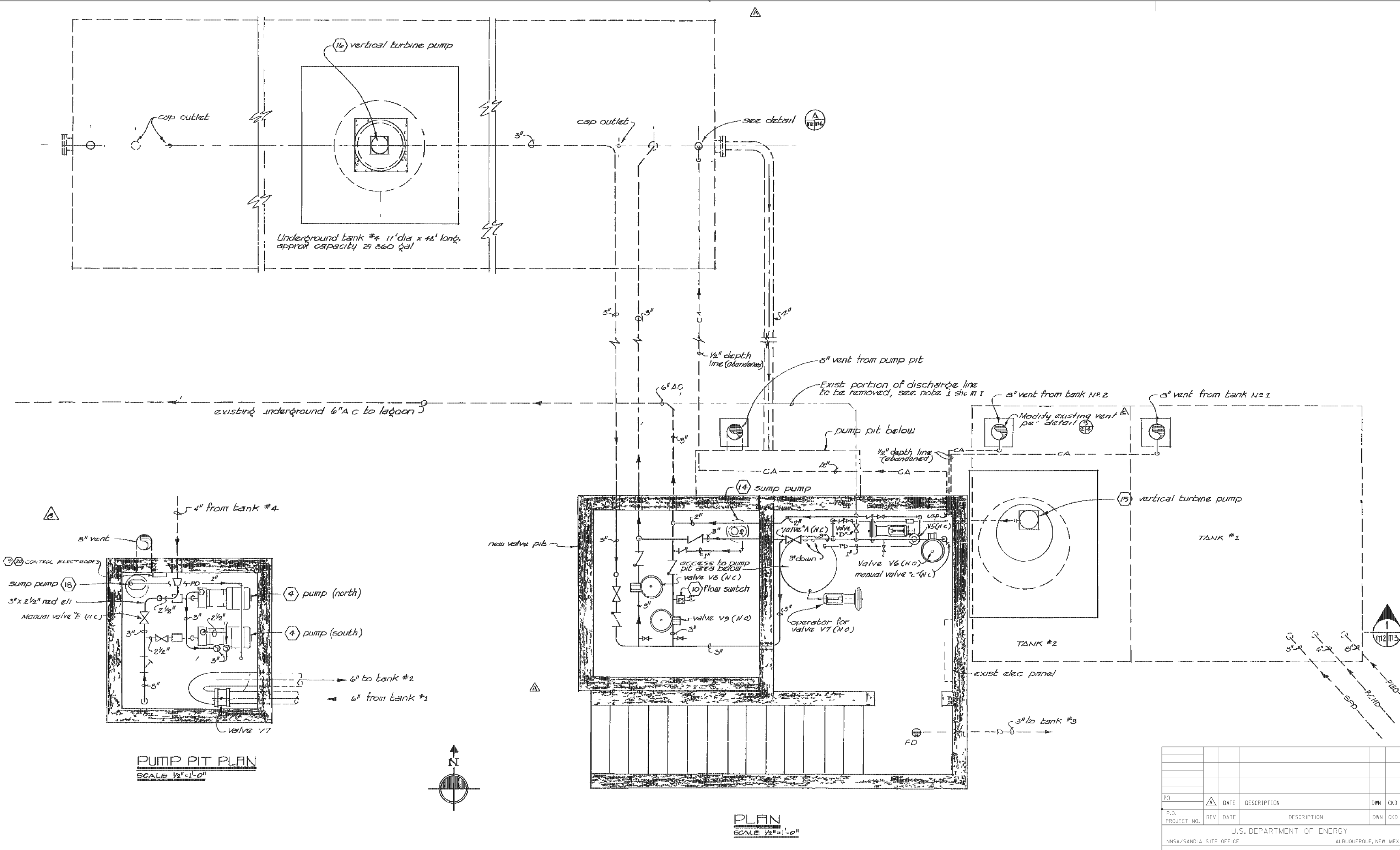

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PLAN - PROCESS WASTE SYSTEM

Reactor Facility

P.O.
PROJECT NO.
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SNL ENGR
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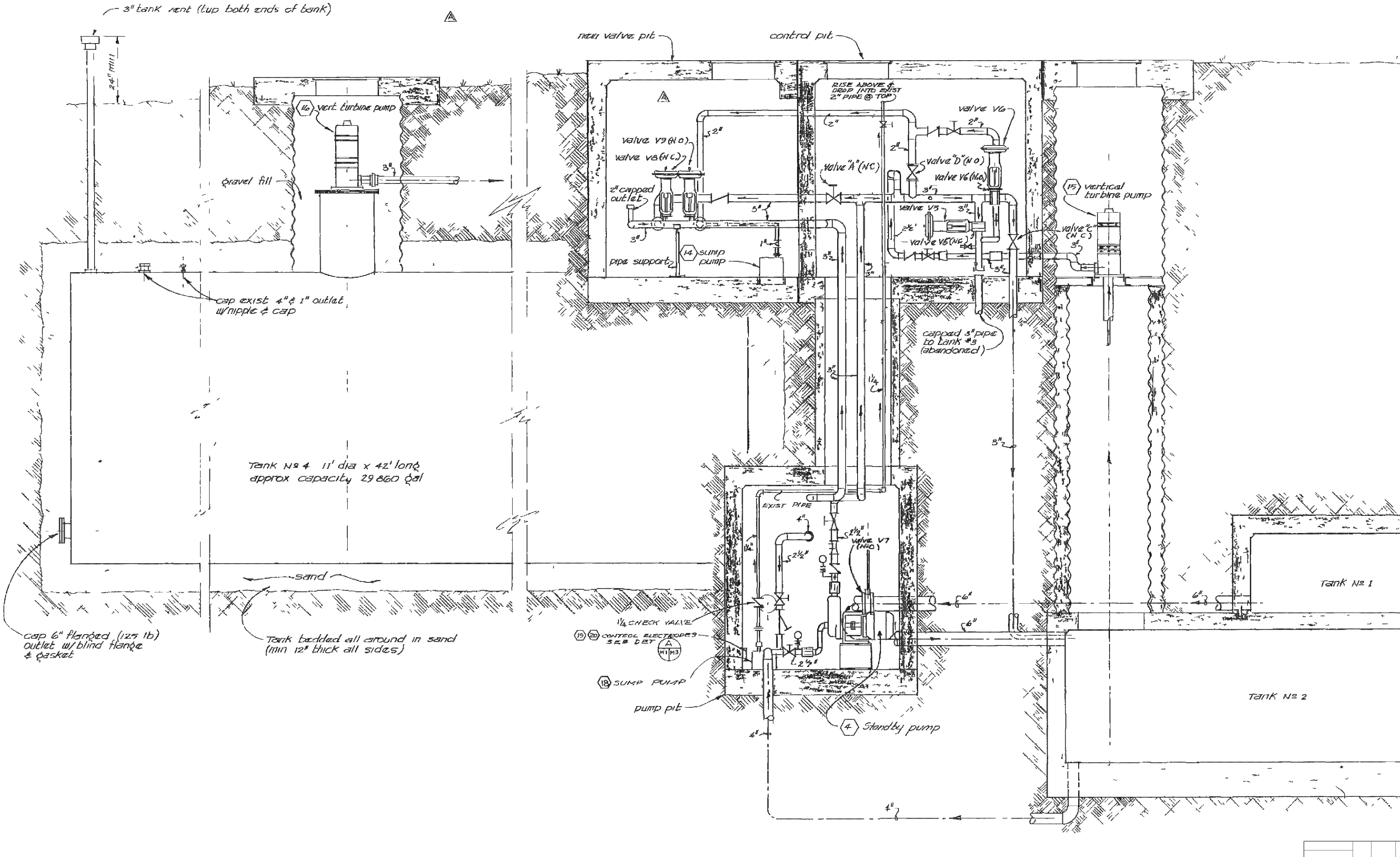

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SECTION - PROCESS WASTE SYSTEM

Reactor Facility

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