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PUREX TK-105-A WASTE STORAGE TANK LINER INSTABILITY AND ITS IMPLICATIONS ON WASTE CONTAINMENT AND CONTROL

by

S. J. Beard and P. Hatch
Atlantic Richfield Hanford Company
and
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PUREX TK-105-A WASTE STORAGE TANK LINER INSTABILITY AND ITS IMPLICATIONS ON WASTE CONTAINMENT AND CONTROL

I. INTRODUCTION

Irradiated fuels from the Hanford reactors are processed in the Purex plant for recovery of plutonium, uranium and other useful reactor-produced products. Nearly all of the fission products (>99.99%) and process chemicals are collected in a single small volume aqueous waste stream, neutralized with sodium hydroxide and stored in large underground tanks. Normal practice is to continually add waste to a tank while maintaining the liquid volume relatively constant at 70-80 percent of tank capacity by allowing the waste to self-concentrate from fission product decay heat. As the tank is filled, the waste separates into an insoluble sludge layer and a supernatant liquid. Nearly all of the fission product decay heat is associated with this insoluble sludge. Heat is removed from the sludge by conduction and percolation of supernate through the sludge with the latter being the major mechanism for heat removal. As the sludge layer increases in depth and as the salt concentration in the supernate increases with tank filling, the removal of heat from the sludge becomes more difficult. Experience has shown that sludge temperatures cannot be effectively controlled above a supernate sodium concentration of about 7 or 8 molar. When this supernate salt concentration is reached in a waste volume equal to about 80 percent of the tank volume, the tank is considered full.

Purex Waste Tank 105-A is a typical tank in the original Purex plant tank farm. It was the last tank to be filled (six tank farm) and was filled in a routine manner. However, the TK-105-A performance differed from the other tanks in three important respects:

1) Waste seepage was detected under the tank when the tank had received about 50 percent of the tank's capacity expressed as tons of uranium processed;

2) After the tank was filled a sudden steam release occurred which differed from other steam releases in that the circulators were reported to be in operation during the event; and

3) The bottom liner of the tank was found to be bulged upward about 8.5 feet and remains in this position.

The presence of radioactive contamination beneath the tank and the discovery that the bottom plate was bulged upward provided conclusive evidence that the tank integrity had been compromised. Engineering studies were conducted to provide guidance for controlling the tank under stable boiling conditions and also under assumed conditions of further deterioration.

The purpose of this report is to detail the history of TK-105-A activities including the engineering studies and hazard assessments that have been made.

[redacted]

II. SUMMARY

Purex Waste TK-105-A was built in 1955, and remained in reserve status with a nominal water heel until May of 1962. From May of 1962 until January of 1963 the tank was used to store aged supernate and to provide feed for cesium recovery operations in Purex and later in the C-Farm cesium loadout station. Preparation of the tank for full radiation level Purex waste storage started in January, 1963, and the tank commenced to self-concentrate in March, 1963. Filling of TK-105-A was routine except for the detection of low intensity radiation in one leak detection lateral when the tank was half filled. Since the leak became inactive after one week and since instrumentation indicated the amount leaked to be small, use of the tank was continued. Emptying the tank was not considered because no spare self-boiling tankage was available. In December, 1964, the tank was filled to capacity with waste from the processing of 11,000 tons of uranium.

On January 28, 1965, a sudden steam release occurred in TK-105-A which was believed to be more intense than any previous similar event. The release also appeared to differ from previous releases (commonly called "bumps") in that the event occurred while the airlift circulators were reported to be in operation. Inspection of the tank instrumentation and equipment revealed no major damage, and the normal tank operation was continued with special emphasis on surveillance of tank behavior and operation of tank control instrumentation.

Subsequent investigations at that time by the CPD operating and engineering staffs with technical assistance from Pacific Northwest Laboratory led to the following conclusions being reached in late 1965.

1. The tank had ceased to leak.

2. No evidence was found to indicate that the leakage was sufficient to create significant potential for contaminating the atmosphere or the groundwater.

3. The tank liner was bulged upward at one point to an elevation of 8.5 feet creating a void space of about 80,000 gallons.

4. The void under the bulge might contain vapor or supernate, but it was considered unlikely that it contained any appreciable amount of sludge.

5. The bottom liner was possibly balanced between the steam pressure underneath and the solution hydrostatic head on top. A method for venting the bulged area should be developed to prevent liner movement during removal of solution from the tank.

6. The probability of leaking sludge from the tank into the soil was very low; but if it should occur, very high temperatures at the concrete-soil interface would result.

7. Leakage of filtered supernate into the soil would not result in temperatures at the concrete-soil interface that would cause damage to the structure.

8. If solution were removed or lost from the tank and the sludge allowed to dry, temperatures in excess of 10,000 F could result.

9. If the sludge were overheated, it would denitrate and expel NO_2 gas and later release fission products at higher temperatures.

10. Under all emergency conditions a release of radioactivity to the groundwater would be less serious than a release to atmosphere since the sorption capacity of the soil would delay the movement of radioactivity to the edge of the reservation until most of it had decayed.

11. The potential hazard to the environment and the difficulty of emptying the tank would decrease with time as the fission products decay.

Based on the conclusions of the several studies, an operating plan was developed embracing four main objectives:

1) Control the tank sludge temperatures under all possible conditions of tank failure including the release of liquid to the ground;

2) Provide and maintain capability for emergency sluicing and emptying of the tank;

3) Maintain the tank status as static as possible; and

4) Continue intensive surveillance of tank leak detection and control instrumentation.

In the fall of 1965 when all arrangements had been completed for emergency sluicing and emptying TK-105-A, the behavior of the tank during the elapsed time since the steam release incident was reviewed. During the review various potential hazards were considered, particularly the possibility of extreme sludge temperatures. A decision was made to maintain TK-105-A in a static condition until such time as the tank was scheduled for Waste Management processing or until there was some evidence of further tank deterioration.

In April, 1967, a cyclic liquid level variation began to occur. A typical cycle consists of a 9-10 inch drop in liquid level in a matter of minutes followed by a relatively stable period lasting about 20 hours. The liquid level then returns to its original level in about a day. No significant movement of the liner can be detected. A logical explanation for this behavior is that part of the area under the bulge alternates between a vapor and liquid phase.

Evidence that a hole has developed in the liner is now readily apparent. The concrete vessel is almost certainly cracked, but leakage is not evident - probably because of salt deposition in the concrete cracks or surrounding soil. The possibility for the accumulation of heat-producing solids under the bulge with resulting localized temperatures as high as 1860 F has become a new concern.

A hazard analysis indicated that if the entire tank achieved temperatures limited only by the laws of nature, environmental contamination would create a problem of considerable magnitude. Total body dose in excess of 25 rems, for a 2-hour exposure at 5 miles or 24 hours at 18 miles from the tank could be anticipated if as much as 5 percent of the volatilized radionuclides escape to the atmosphere. A more likely event would be loss of all or part of the tank supernate to the ground with sludge temperature control effected by continual water additions to the tank. Under this condition contamination of atmosphere or ground surface would probably not occur, but serious groundwater contamination would result. However, contamination at the river would not be expected to approach the drinking water limit assuming a continuation of current groundwater flow patterns. Contamination of the ground and groundwater would be sufficient, however, to be a major deterrent and possibly to preclude irrigation activities in the vicinity that could change the groundwater flow pattern under the 200 Area plateau.

III. TANK FILL HISTORY

The detailed account of the waste transfers to and from TK-105-A and the resulting temperatures are summarized here and in Figure 1. The first addition was made prior to tank farm startup in 1955. Six inches of water were added to each tank as protection against possible bottom liner lifting from vacuum generated by the ventilation exhaust blower during equipment testing. The water was added as a supplemental protective measure to the safety afforded by a six-inch water seal in the tank farm vent header. The TK-105-A volume gradually increased from this initial 6 inches of liquid in 1955 to 18 inches of liquid in May of 1962. These 12 inches of liquid were the accumulation of water additions to various vapor seals over a period of 7 years. In May of 1962, 330,000 gallons of supernate were pumped from TK-103-A into TK-105-A over a period of 20 days. TK-105-A temperature increased from 46 to 56 C as a result of this solution transfer. On July 27, 1962, an additional 180,000 gallons of supernate from TK-103-A were transferred to TK-105-A causing an 8 C increase in temperature. During the period from July 27, 1962 to December 12, 1962, about 63,000 gallons of supernate were removed from TK-105-A for cesium recovery in Purex. On December 12, 1962, about 252,000 gallons of TK-101-A supernate were added to TK-105-A with a 14 C temperature increase. This transfer was made to prepare optimum feed for the TK-103-C cesium loadout feed tank. After blending with the airlift circulators in TK-105-A, 490,000 gallons of supernate were transferred to TK-103-C. Following the solution transfer to C-Farm, TK-105-A contents were pumped to TK-101-A until only

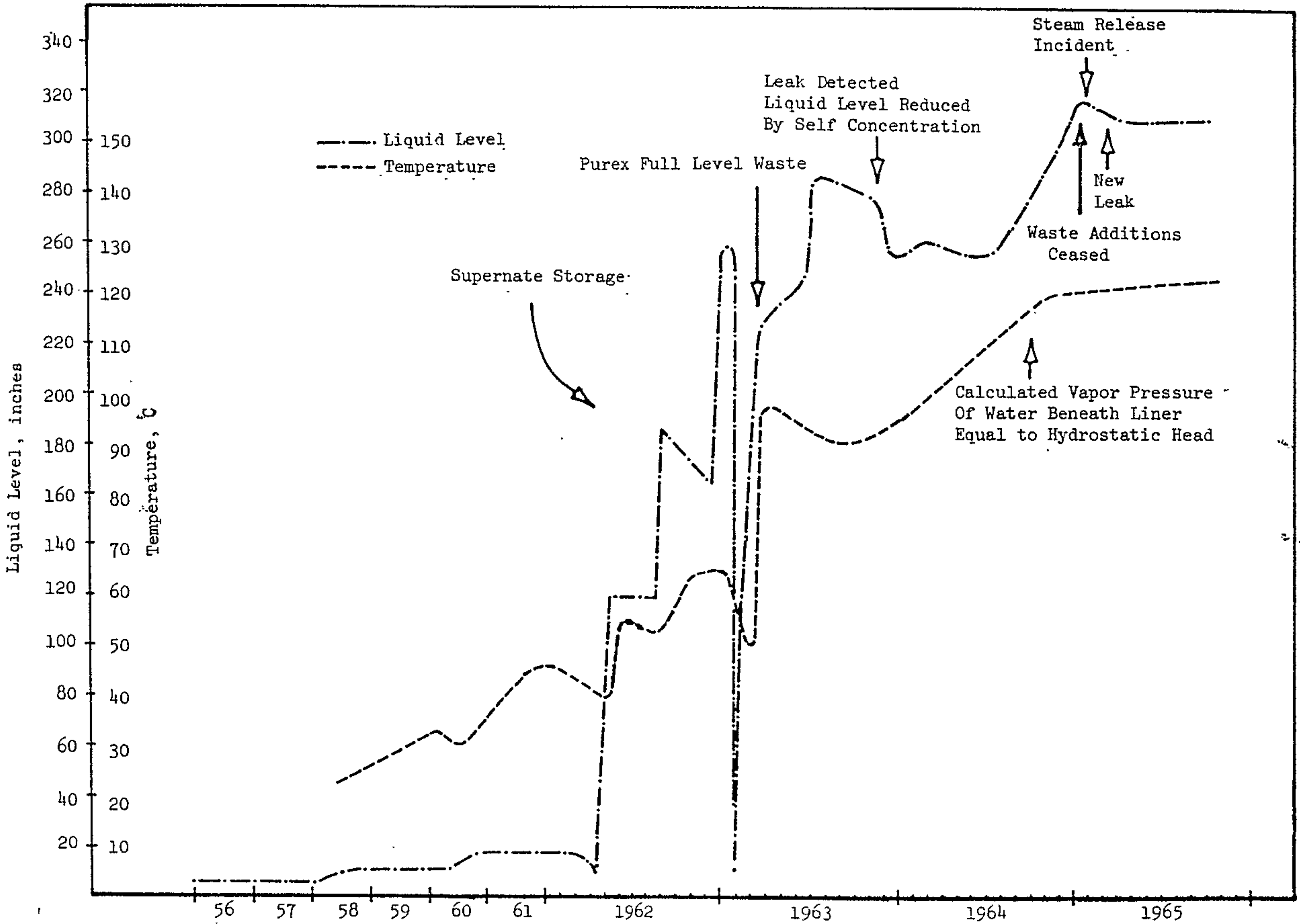

FIGURE 1

TK-105-A Liquid Level and Sludge Temperature History

[redacted]

a 10-inch heel remained. In January, 1963, 330,000 gallons of thermally hot tank farm condensate were added to TK-105-A to heat the tank and partially prepare it for receipt of Purex self-boiling waste. The tank was heated from 50 C to 62 C with 330,000 gallons of tank farm condensate, and then brought up to boiling temperature at a nearly uniform rate with full-level waste, reaching boiling on about March 5, 1963.

The filling of TK-105-A was routine until November 19, 1963, when the tank was about half filled. On this date radiation was noted in one lateral at an intensity of 17,000 c/m increasing to 150,000 c/m seven days later. Accurate conversion from c/m to mR/h is not possible, but 5 mR/h is approximately equal to 150,000 c/m for this instrument. Radiation dose rate as measured from a dry well inside the tank was 40,000 R/h indicating the size of the leak to be very small. Further, the radiation could only be detected over a very short segment of the lateral indicating that a narrow finger of contamination had approached the lateral. The intensity of the radiation in the leak detection lateral was observed to gradually decay until March 8, 1965, when an increase occurred which will be described later. During the period from November, 1963, to March, 1965, the radiation intensity decreased a factor of 3 to approximately 50,000 c/m.

It was noted that the tank liquid level had reached the range of 280 inches in July, 1963, a few months before the leak was detected. A leak in the side wall was postulated as a possibility so the tank liquid level was reduced by self-concentration to 260 inches. A slow decline of the radiation intensity in the lateral indicated the leak had stopped either because of self-sealing or because the liquid level was below the leak point. No spare tanks were available at this time; however on the basis of the available data, it probably would have been considered prudent to continue filling TK-105-A even if spare tankage were available since only 50 percent of its capacity had been used. The current spare, TK-103-A, was not available at the time because it contained 3 feet of settled sludge. Hanford and Savannah River experience had indicated that if filling of a self-heating tank is discontinued for any significant period of time (a few months), excessive temperatures will occur in the settled sludge upon the addition of fresh waste to the tank. Purex TK-101-A and TK-102-A had both experienced temperature excursions as a result of adding fresh waste to a tank containing settled sludge.

The tank appeared to behave normally in all respects while the tank liquid level was maintained at 260 inches and as the salt concentration gradually increased with waste additions to the operating limit of 7.0 M sodium. About September 1, 1964, the salt concentration operating limit was reached, and liquid level increases were permitted at a rate that maintained a salt concentration of 7.0 M sodium. In October, 1964, the postulated leak level was reached with no evidence of any new leakage occurring. In December, 1964, the tank was filled to capacity.[1]

[redacted]

IV. STEAM RELEASE INCIDENT

On January 28, 1965, a sudden steam release occurred in TK-105-A. The earth in the immediate vicinity of the tank was reported to have trembled, and a temporary lead cover on a riser on TK-103-A was dislodged allowing steam to vent from this opening for about 30 minutes. A water seal in the vent system designed to relieve tank pressure at 60 inches of water was not blown. Calculations confirm that the temporary lead cover on a TK-103-A riser should have relieved first at about 3.5 inches of water pressure.

At the time of the bump, Purex personnel were in the farm supporting Jones construction forces who were preparing to make a final weld in a line connecting TK-105-A with the 151-AX diverter station. A few gallons of liquid were ejected onto the ground in the excavation. Radiation dose rates of 400 R/h were measured one foot from the spill. A rapid survey of tank farm instrumentation and equipment stations revealed that the liquid level electrode tape in TK-105-A was broken and that the TK-105-A instrument enclosure at the tank was contaminated to levels that resulted in dose rates of 500 R/h at one foot. The water levels in the various seal loops were found to be normal with the exception of the TK-103-A overflow seal which was blown sounding an alarm in the control room. This seal is of minor importance; its function is to provide a vapor seal in the overflow cascade line between TK-103-A and TK-106-A. No wastes were added to TK-105-A the day of the incident except for tank farm condensate. A sample of tank farm condensate taken the following day had a radiation intensity of 8,000 c/m compared to a normally observed intensity of 200 c/m.

The steam release incident in TK-105-A differed from previous steam release incidents (commonly called "bumps") in that the event occurred while the airlift circulators were reported to be in operation. The event's intensity appeared to be greater also as indicated by breaking of the liquid level electrode and the ejection of droplets of supernate into the tank's instrument enclosure.

Operating efforts immediately after the incident were concerned with securing the contamination and establishing airflow to the airlift circulators. A new liquid level electrode was installed, and the liquid level measured with a high range radiation detection instrument (Victoreen) to confirm the new electrode reading. The new electrode checked with the Victoreen, but a 4-inch discrepancy was noted between the new readings and the expected level based on the old electrode reading. It could not be established with certainty whether there was a physical decrease of 4 inches in apparent tank inventory in addition to self-evaporation or whether the old tape was biased by 4 inches. The leak detection wells and laterals were monitored, but no changes in radiation status were noted.

In the absence of an identified cause of the incident, it had to be assumed additional steam releases or bumps could occur. Two immediate courses of action were pursued. One was to minimize the potential for the accumulation of superheat in the liquid, which could cause additional incidents, through the installation of a supplemental air sparger. The second was to install instruments to define the magnitude and rate of the energy release during any subsequent incident.

An air sparger was fabricated for installation in the tank's 4-inch vacuum breaker riser - see Figure 2. However, prior to installation, it was decided to probe the area below the riser because several months earlier an obstruction had been encountered below this riser during a routine sludge depth measurement. This probing confirmed that an obstruction did exist about 8 feet above the normal position of the tank bottom, and that the obstruction could not be avoided by the relatively large lateral movement permitted at the end of the 40-foot long probe by the clearance inside the 4-inch riser pipe. Attempts to install supplemental air sparging were then abandoned, and the airflow to the existing circulators increased to maximum rate.

A definition of the magnitude and rate of energy release during any subsequent incident was needed to put future TK-105-A control activities in appropriate perspective. Should the incidents continue and if serious additional damage to the tank structure were a possibility, costly and unconventional corrective actions would need to be considered. Two key instruments, a vibrometer and a fast response pressure recorder, were located onsite and installed on TK-105-A to obtain the required information.

With the tank behaving normally, special monitoring instruments in service, and intensified tank surveillance in effect to note future unusual tank behavior, a thorough engineering evaluation of the incident and its implications was initiated with technical support from Pacific Northwest Laboratory.(2) This evaluation was to include definition of the tank's structural condition, probable cause of tank deformation, and potential thermal consequences of tank leaks into the soil or overheating of the settled sludge. As this work proceeded, weekly meetings were held between operations and engineering personnel to discuss the progress of the studies and to exchange data as they became available. On a continuing basis, revisions to tank farm equipment systems, addition of backup systems, changes in operating procedures and initiation of additional studies were made as quickly as the need could be identified.

V. ANALYSIS OF TANK CONDITION

Investigation of the tank's inventory status and structural condition was started by careful inspection of the existing instrumentation. Each circulator is equipped with two dip tubes to determine solution flow from the measured pressure differential between the inside and outside of the circulator draft tube. In addition the #1 circulator has a third dip tube to measure supernate specific gravity. Static pressure readings on the #1 and #2 circulators were much lower (see Table 1) than expected indicating that all of the piping to the circulator was broken or that the circulators were physically elevated about 6 feet. The specific gravity measurement on the #1 circulator was low indicating that the vertical distance between the dip tubes had decreased; either

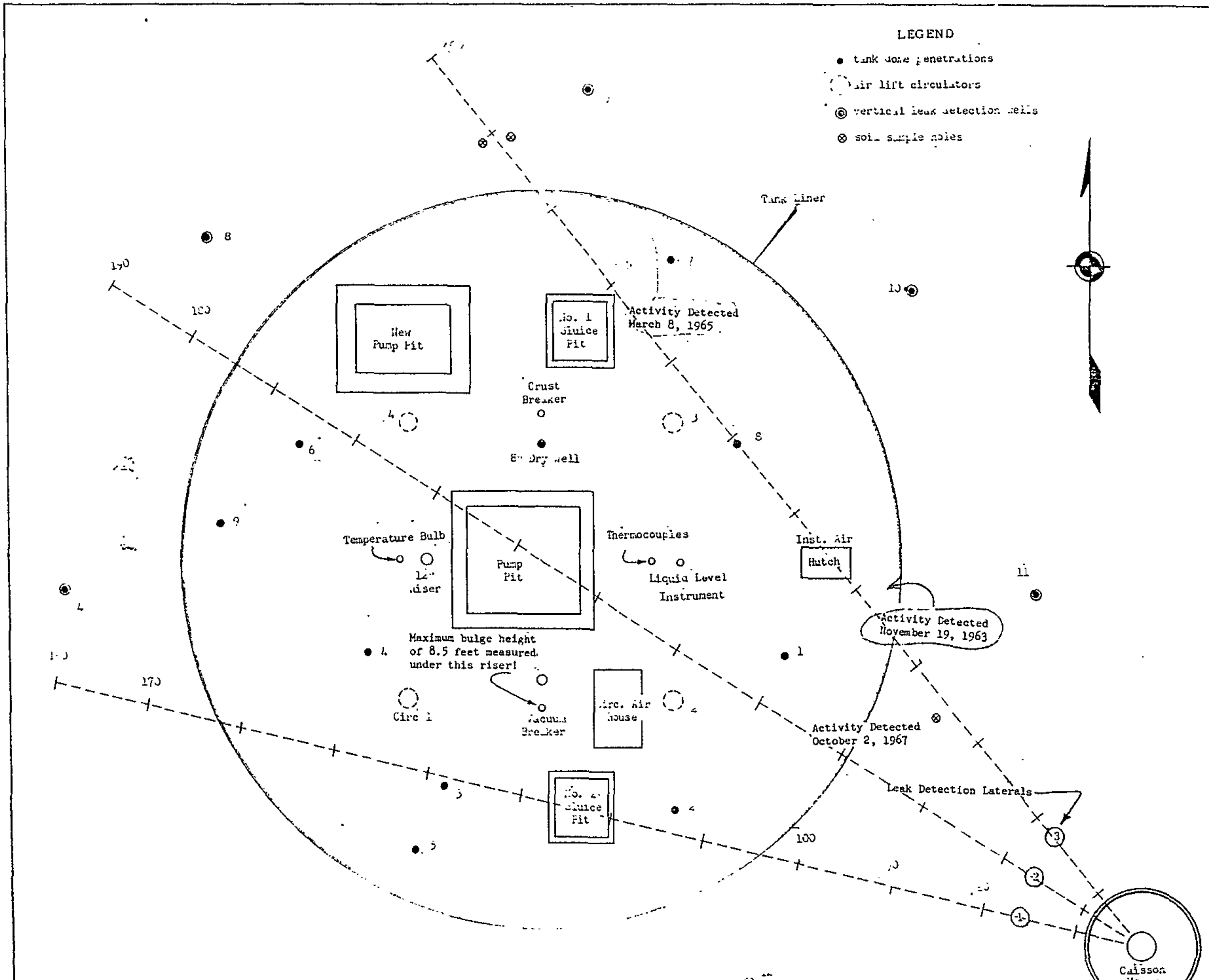

FIGURE 2

TK-105-A Plan View

a pipe was broken or the circulator was tipped. Static pressure readings on the air supply piping to the four circulators also indicated that the #1 and #2 circulator piping was damaged or that the circulators were physically elevated. Static pressure readings taken in the other five tanks were all normal.

TABLE 1
CIRCULATOR STATIC PRESSURE READINGS

		Inches of Water		
Circulator	Air Supply	High Pressure Dip Tube	Low Pressure Dip Tube	Sp Gr Dip Tube
1	262	222	219	186
2	262	224	222	
3	360	310	307	
4	360	317	314	

Note: If circulators #1 and #2 were not elevated, their static pressure readings would be essentially the same as those of circulators #3 and #4.

The static pressure readings coupled with the detection of an obstruction under the vacuum breaker riser left little doubt that the tank bottom was bulged. To determine the extent of bottom deformation, nine holes were drilled through the tank dome as shown in Figure 2. Sludge measurements and bottom measurements taken through these holes are shown in Table 2. From these measurements a void volume of 80,000 gallons beneath the bottom liner was estimated.

TABLE 2
TK-105-A BOTTOM PROBING MEASUREMENTS

Inches from Normal Position of TK Bottom Plate

	Measurements in Inches		
Hole	Sludge	Bottom Plate	Sludge Thickness
1	69	52	17
2	53	38	15
3	84½	69½	15
4	105	77½	27½
5	50½	44	6½
6	37	24	13
7	25	4	21
8	54	33	21
9	28	9	19
Vacuum Breaker	126	102	24
New Pump Pit	26	20	6

Note: Hole position given on Figure 2.

Inspection of the two installed temperature instruments shown in Figure 2 indicated normal sludge temperatures. The temperature bulb located west of the pump pit is a single measurement point near the tank bottom, and the thermocouple probe located east of the pump pit contains several thermocouples at various elevations including one near the tank bottom. To positively establish that sludge temperatures were in control, a temporary set of three thermocouples was inserted in the dry well north of the pump pit, and a thermocouple was attached to the bulb in the temperature well west of the pump pit. All four temperature measurements were normal - about 130 C.

Monitoring of the three leak detection laterals under the tank and the 7 leak detection wells along side of the tank did not initially reveal any unexpected indication of radioactive contamination. The location of radiation in the #3 lateral and its intensity remained unchanged at 50,000 c/m as discussed earlier. However, on March 8, about 39 days after the steam release incident, the radiation in the #3 lateral increased by a factor of 60 and then remained constant. No radiation increases were detected in the other laterals or the vertical wells. Three test wells were drilled along side of the tank directly over the lateral that indicated leakage. One well was drilled to a depth of 65 feet and terminated at the same depth as the laterals, 10 feet from the high radiation reading in the #3 lateral. No radioactive contamination was detected in the soil samples removed from the test wells, and the maximum temperature in the test wells was 206 F. These data indicated the leakage was small.

To gain insight into conditions under the bulged liner with respect to the accumulation of heat-producing sludge, a special probe was built to map the temperatures in the leak detection laterals. As expected, the temperatures increased as the probe passed under the tank and began to decrease as it approached the other side. For Tank 105-A, the #3 lateral, which is the one that had intercepted some leakage, had the highest temperatures, with the maximum temperatures (310 F) found to be about 90 feet horizontally from the caisson. Periodic measurements of the maximum lateral temperatures are shown in Figure 3 and do not indicate any heat accumulation under the bulge.

Consideration was given to the use of sonic, ultrasonics, and neutron thermalization techniques to determine if liquid, vapor, or a combination of both exist under the bulge.[3] After preliminary evaluation, only the neutron thermalization technique appeared to be applicable. With laboratory testing and mockup it was concluded a probe at least 12 inches in diameter would have to be lowered into intimate contact with the liner, and then its range would be limited to a depth of 12 inches below the liner. These findings were too pessimistic to proceed with a development program, and work on this approach was terminated.

The intensity of the steam release incident suggested that perhaps some gas phase reaction had participated in the event. Hydrogen formed by radiolysis is normally swept from the tanks with the steam from self-boiling. Gas samples were drawn from TK-103-A which was the least active tank in terms of air or steam purging. After water condensation, gas analyses were identical to air and no flammable gases were detectable.

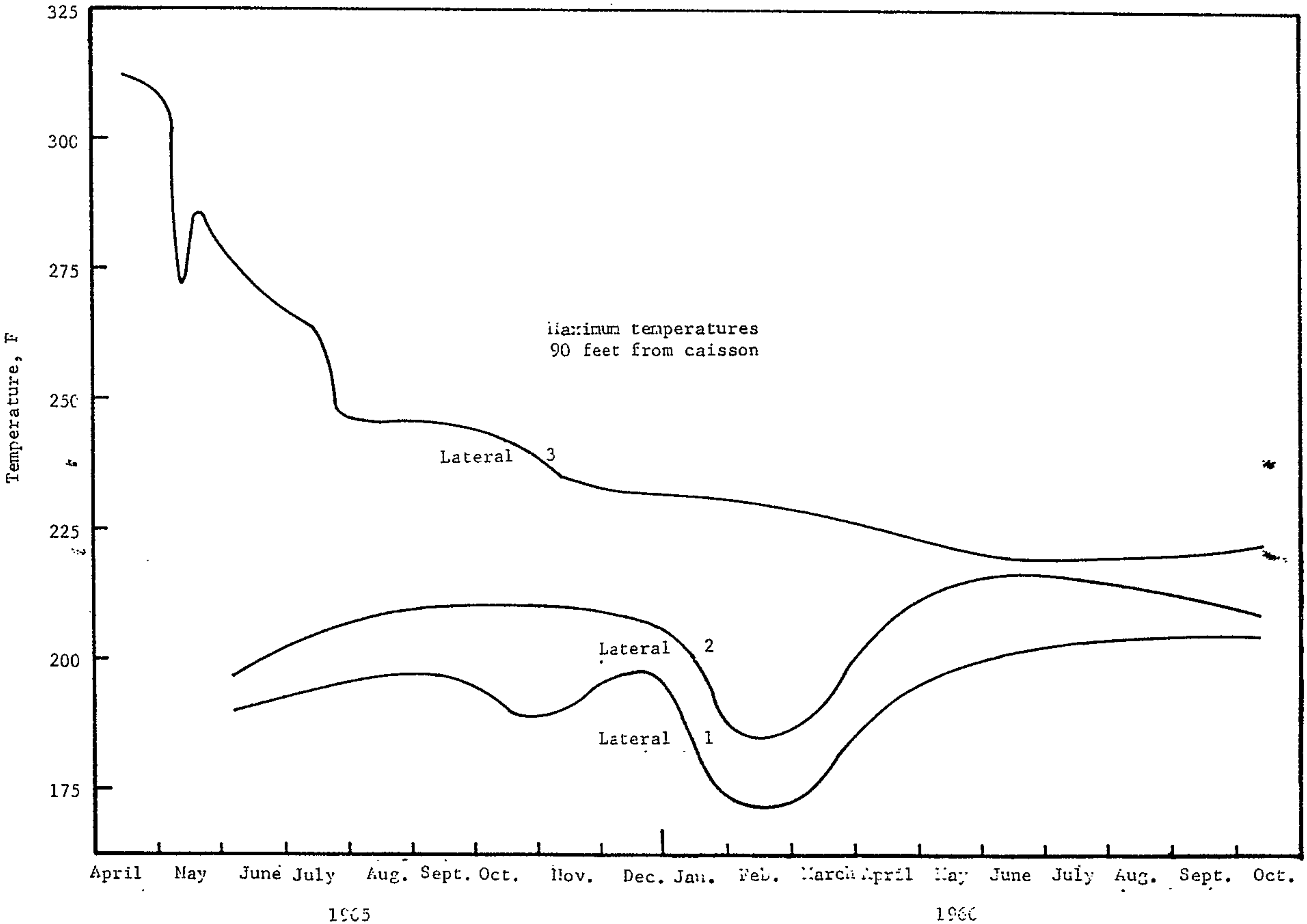

FIGURE 3
TK-105-A Lateral Temperature History

[redacted]

VI. POSTULATED LINER INSTABILITY MECHANISMS

The postulated tank liner instability mechanisms were quickly reduced to two modes: 1) restraint exerted by the differential thermal expansion between the concrete cylinder and the bottom liner plate; and 2) lifting of the liner plate by water vapor trapped between the bottom liner and concrete. Engineering calculations on the effects of thermal expansion clearly showed that the bottom liner would be stable under a hydrostatic head of 14-15 psig, and that differential thermal expansion could not cause an 8-foot deformation if the tank were empty. For thermal expansion to be the primary cause, the steel plate would have to receive its buckling load from bearing against the concrete wall thus causing a fixed condition at the "T" joint between the cylinder steel and bottom steel plate; therefore, any deflection seen by the plate would have to come from differential thermal expansion and not be supplemented by movement of the steel cylinder. Under these conditions and with the tank empty, a bottom uplift of approximately 1.9 feet could relieve the thermal forces. Uplift by steam pressure between the steel liner and the concrete appears to be the primary cause of liner deformation, with thermal expansion contributing initially. Equations to determine the critical buckling stresses were taken from the "Handbook of Structural Stability, Part III[4] and the text "Theory of Plates and Shells."[5] Calculations show that the full 8-foot liner displacement could be achieved only if the cylinder wall deformed inward up to the first stiffening ring located two feet from the bottom. The nonsymmetrical buckling as witnessed in TK-105-A is not uncommon. This phenomenon has been described by A. Kaplan and Y. C. Fung.[6] Also, as shown in Figure 2, the position of the dry well in TK-105-A may have influenced the nonsymmetrical buckling mode.

A previous analysis of the TK-113-SX failure supports the postulate of the buckling load being derived from entrapped steam.[7] Before bulging by steam pressure could occur, water would have to accumulate between the steel liner and the concrete, and a sludge temperature would have to be sufficiently high to produce a vapor pressure exceeding the hydrostatic head of liquid in the tank. Both of these conditions were shown to be probable. During startup of the tanks in the AX Tank Farm in 1965, water was driven out of the concrete, collected by channels and accumulated in leak detection wells. Volumes amounting to several hundred gallons were collected from TK-103-AX and TK-104-AX. In A-Farm no channels or leak detection wells were provided for this water to escape. If the water could not escape through cracks developed in the concrete pad or seep through the natural porosity of the concrete, it would remain trapped between the liner and its supporting concrete pad.

The hydrostatic head of liquid in TK-105-A produces a pressure on the tank bottom of 14-15 psig. A temperature of 250 F would produce water vapor pressure that would balance this hydrostatic head, and higher temperatures could generate steam pressures which could cause the liner to lift. Temperature data of record during TK-105-A filling indicate this condition was reached in October, 1964, when the tank was 80 percent filled, and this condition still exists.

[redacted]

A 0.096 to 1 scale model of TK-105-A was constructed to verify the theorized calculations of liner instability caused by applying pressure beneath the bottom plate of the tank.[8] In the model a differential pressure of 0.63 psig produced a bulge height of 4.625 inches. The model bulge occurred at the side of the tank bending in below the first stiffener. Final failure occurred with rupturing of about two inches of the joint which connects the bottom to the side of the tank. Pictures of the scale model are shown in Reference 8.

Visual appearance of the model failure closely resembled the estimated shape of the TK-105-A bulge. Extrapolation of the height of the model bulge to TK-105-A would indicate a bulge 48 inches in height compared to an actual bulge of 102 inches. A difference of this magnitude in a scale model test of this scale reduction is not unusual.

VII. THERMAL AND CHEMICAL CONSIDERATIONS

Dip samples of TK-105-A were obtained in February, 1965, to evaluate the alternatives available for handling the TK-105-A contents in the event a sustained leak were to occur. Sample results are shown in Table 3, and the calculated tank fission product inventory is shown in Figure 4.

TABLE 3
TK-105-A SLURRY COMPOSITION[1]
CURIES/LITER

	Separated Sludge[2]	Supernate
Sr-90	33	0.009
Cs-137	6.5	8.1
Ce-144	216	<0.005
Ru-106	68	<0.02
ZrNb-95	220	<0.005

(1) On May 1, 1965, sample taken of slurry above settled sludge.
(2) Centrifuged sample 14 volume percent sludge.

These analyses indicated about 40% of the fission product heat was associated with the settled sludge, and the remaining 60% was associated with the supernate as a slurry. It was concluded that any solution transferred from TK-105-A would have to be received by a self-boiling waste tank containing very little settled sludge to avoid excess sludge temperatures. Further, any long distance transfers to another tank farm could be considered only under conditions of extreme emergency.

Thermal effects that could result from precipitate or solution leaking into the soil were evaluated. As detailed in Reference 9, a volume of precipitate as small as 175 gallons transferred into the soil could result in temperatures in excess of 1500 F at the concrete soil interface. Solution leaks (free of sludge)

9 1 1 2 5 2 1 5 ?

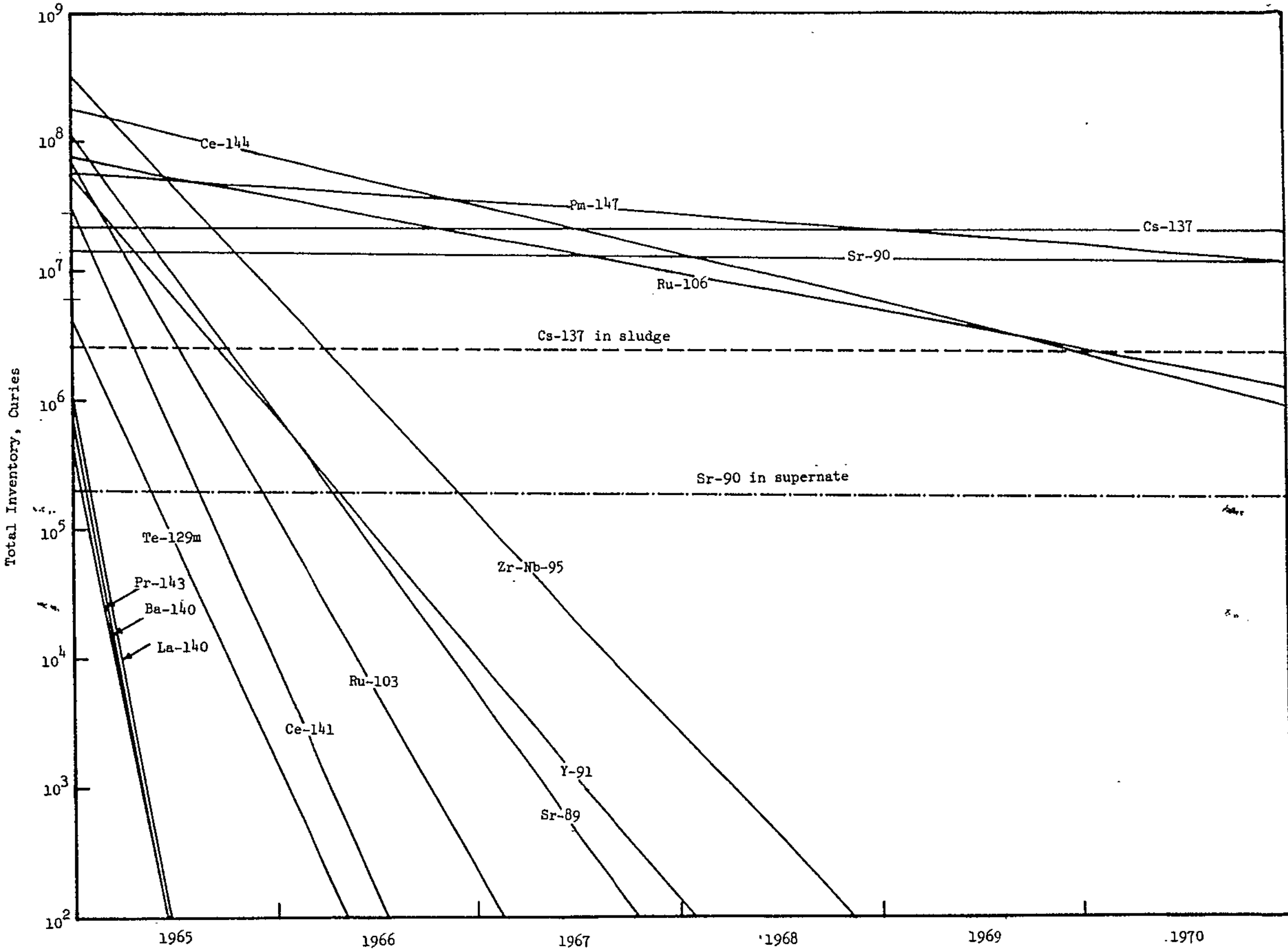

FIGURE 4
TK-105-A Fission Product Inventories

as large as 50,000 to 100,000 gallons were shown to be tolerable from thermal considerations. Laboratory filtration studies with synthetic waste and soil indicate sludge particles as small as two microns would filter out in the first 2 inches of soil. From these laboratory investigations it was concluded that a leak per se would not be hazardous to the tank structure unless it subsequently caused excess sludge temperatures inside the tank. A leak resulting in contamination of groundwater is discussed in the Hazards Analysis - Section XII of this report.

Of primary concern were sludge temperatures that could occur if the solution were removed from the tank and the sludge allowed to dry. Potential equilibrium sludge temperatures and rate of sludge heating, as shown in Figures 5 and 6, were calculated for various waste ages. It was judged that if the solution leaked from the tank and the sludge became dry, catastrophic conditions could follow in a matter of days. Laboratory volatility studies were made with actual tank supernate and sludge to evaluate this potential hazard.[10,11] These data indicated denitration of sludge will begin to occur with NO_2 gas release at about 400 F. At 1500 F cesium, ruthenium and cerium begin to appear in the off-gas with large releases occurring at 2200 F. However, before these temperatures could be reached, the tank structure would be expected to fail. It was therefore concluded that every effort should be made to ensure that the sludge remained covered with liquid to prevent overheating.

VIII. TANK EVALUATION CONCLUSIONS

As a result of the various studies conducted on behalf of the TK-105-A waste storage problem, several conclusions were reached in the fall of 1965.

1. The tank had ceased to leak.

2. No evidence was found to indicate that the leakage was sufficient to create significant potential for contaminating the atmosphere or the groundwater.

3. The tank liner was bulged upward at one point to an elevation of 8.5 feet creating a void space of about 80,000 gallons.

4. The void under the bulge might contain vapor or supernate, but it was considered unlikely that it contained any appreciable amount of sludge.

5. The bottom liner was possibly balanced between the steam pressure underneath and the solution hydrostatic head on top. A method for venting the bulged area should be developed to prevent liner movement during removal of solution from the tank.

6. The probability of leaking sludge from the tank into the soil was very low; but if it should occur, very high temperatures at the concrete-soil interface would result.

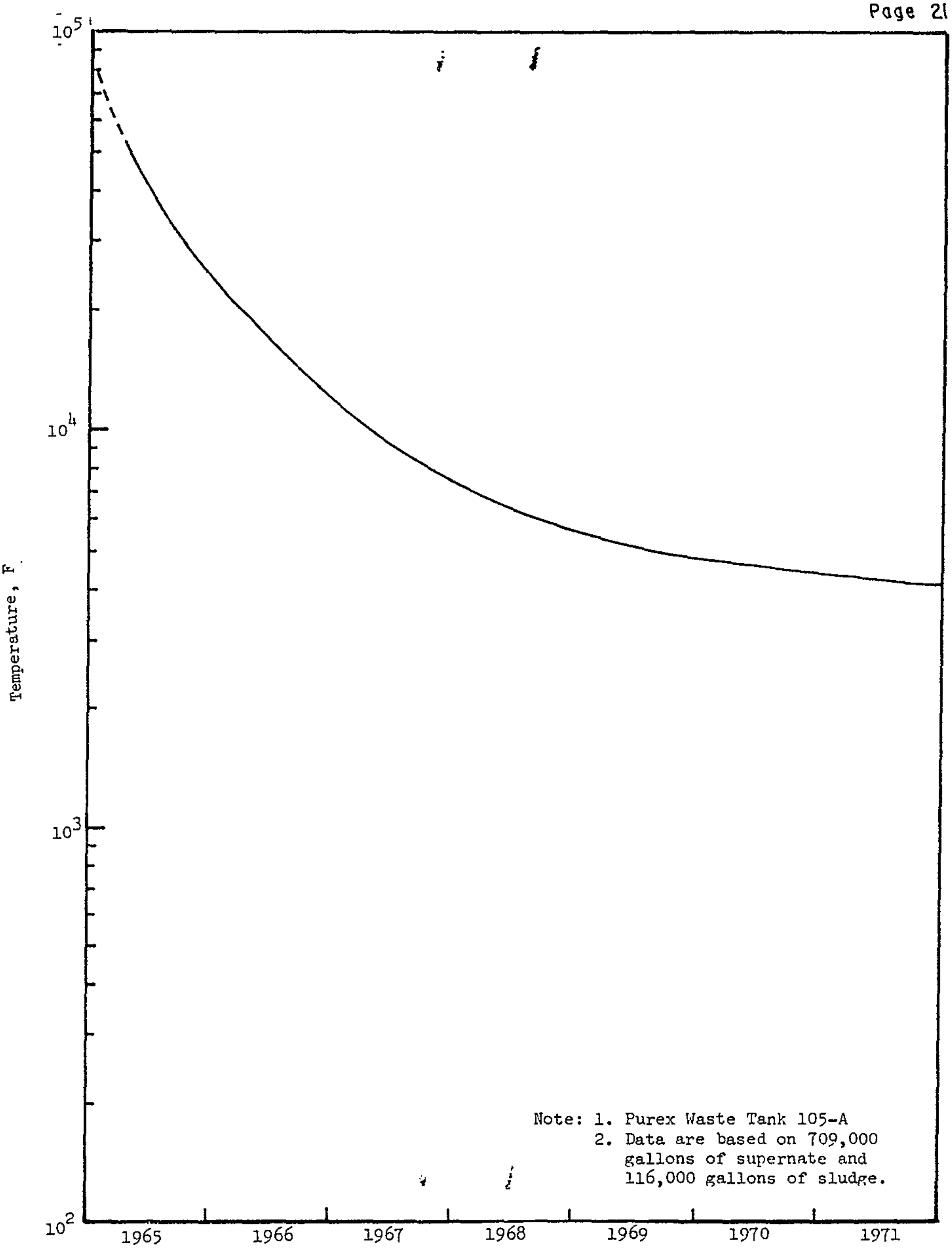

FIGURE 5

Predicted Settled Sludge Temperatures For Uncontrolled Conditions

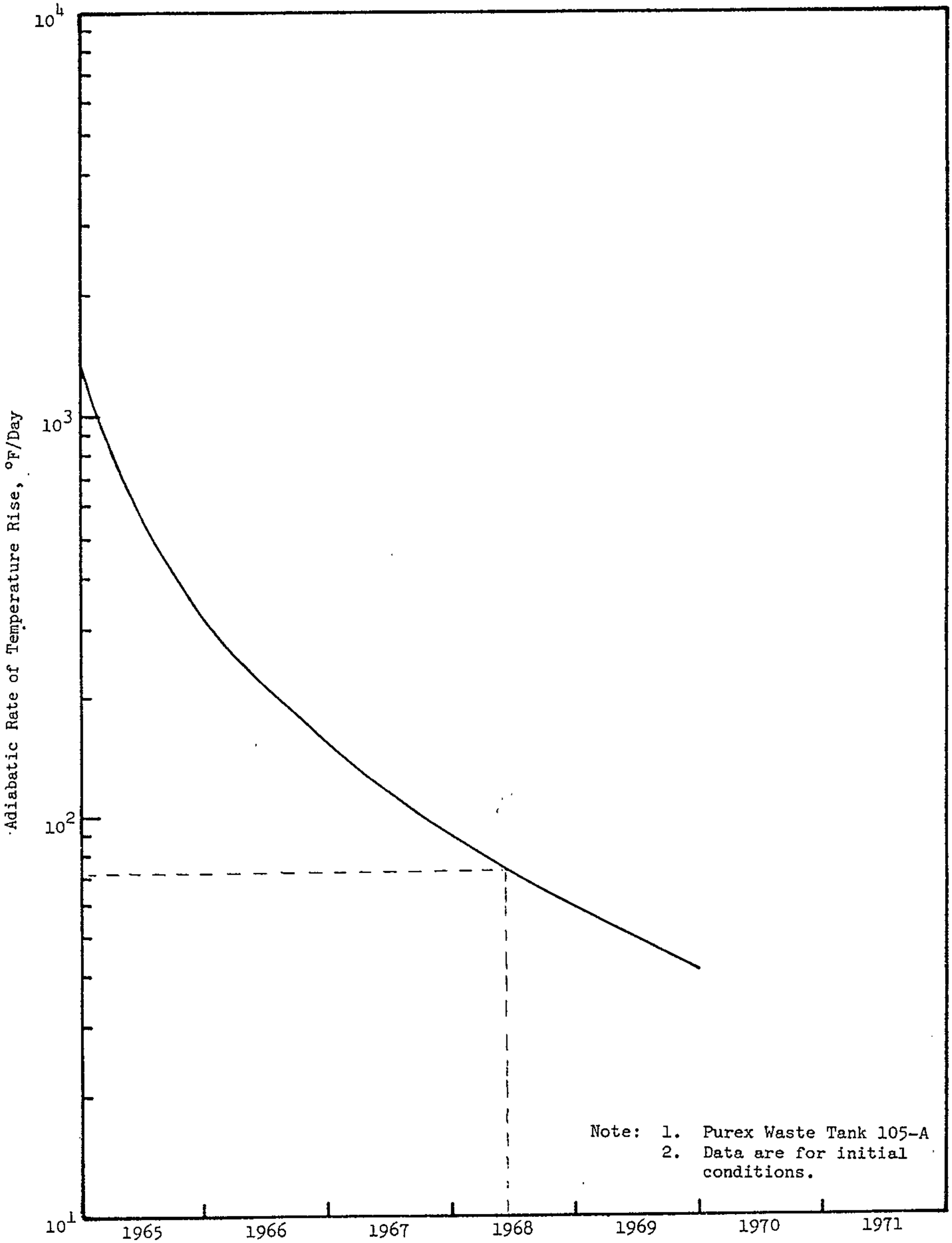

FIGURE 6
Rate of Temperature Rise in Dry Sludge

7. Leakage of filtered supernate into the soil would not result in temperatures at the concrete-soil interface that would cause damage to the structure.

8. If solution were removed or lost from the tank and the sludge allowed to dry, temperatures in excess of 10,000 F could result.

9. If the sludge were overheated, it would denitrate and expel NO_2 gas and later release fission products at higher temperatures.

10. Under all emergency conditions a release of radioactivity to the groundwater would be less serious than a release to atmosphere since the sorption capacity of the soil would delay the movement of radioactivity to the edge of the reservation until most of it decayed.

11. The potential hazard to the environment and the difficulty of emptying the tank would decrease with time as the fission products decay.

IX. OPERATING PLAN

Based on the conclusions of the several studies an operating plan was developed embracing four main objectives:

1) Control the tank sludge temperatures under all conditions of tank failure including the release of liquid to the ground;

2) Provide and maintain capability for emergency sluicing and emptying of the tank;

3) Maintain the tank status as static as possible; and

4) Continue intensive surveillance of tank leak detection and control instrumentation.

The first two objectives were met stepwise by providing the required control capability as rapidly as possible. Initially an emergency water spray unit was built that could be manually inserted through the 4-inch vacuum breaker riser to permit cooling of the sludge on the bulge in the event of sudden tank failure resulting in the complete loss of supernate. As construction efforts got underway, the next capability provided was raw water sluicing over the bulged area. Full sluicing capability with two recirculating sluicers was provided in November, 1965, and finally a tool for venting the bulged area, if required, (see Figure 7) was built and tested in the machine shop under simulated tank conditions.[12]

During this construction period several equipment modifications were made to improve operating control and surveillance of the tank. Recording instruments with alarms were installed on the air supply lines to the circulators, and a

PT NO	DESCRIPTION
1	ARRANGEMENT
2	2" DRILL STEM ASSEMBLY
3	3" CAISSON ASSEMBLY
4	6 CASING ASSEMBLY
5	8 FLANGE
6	FLANGE 8" 150# S.O.
7	PIPE, 8" SCH. 40
8	GLAND RING
9	5/8" ASBESTOS PACKING
10	3/4" STUD BOLTS X 4½" LONG W/NUTS
11	3/8 HEX. HD MACH. SCREW X 1½" LONG

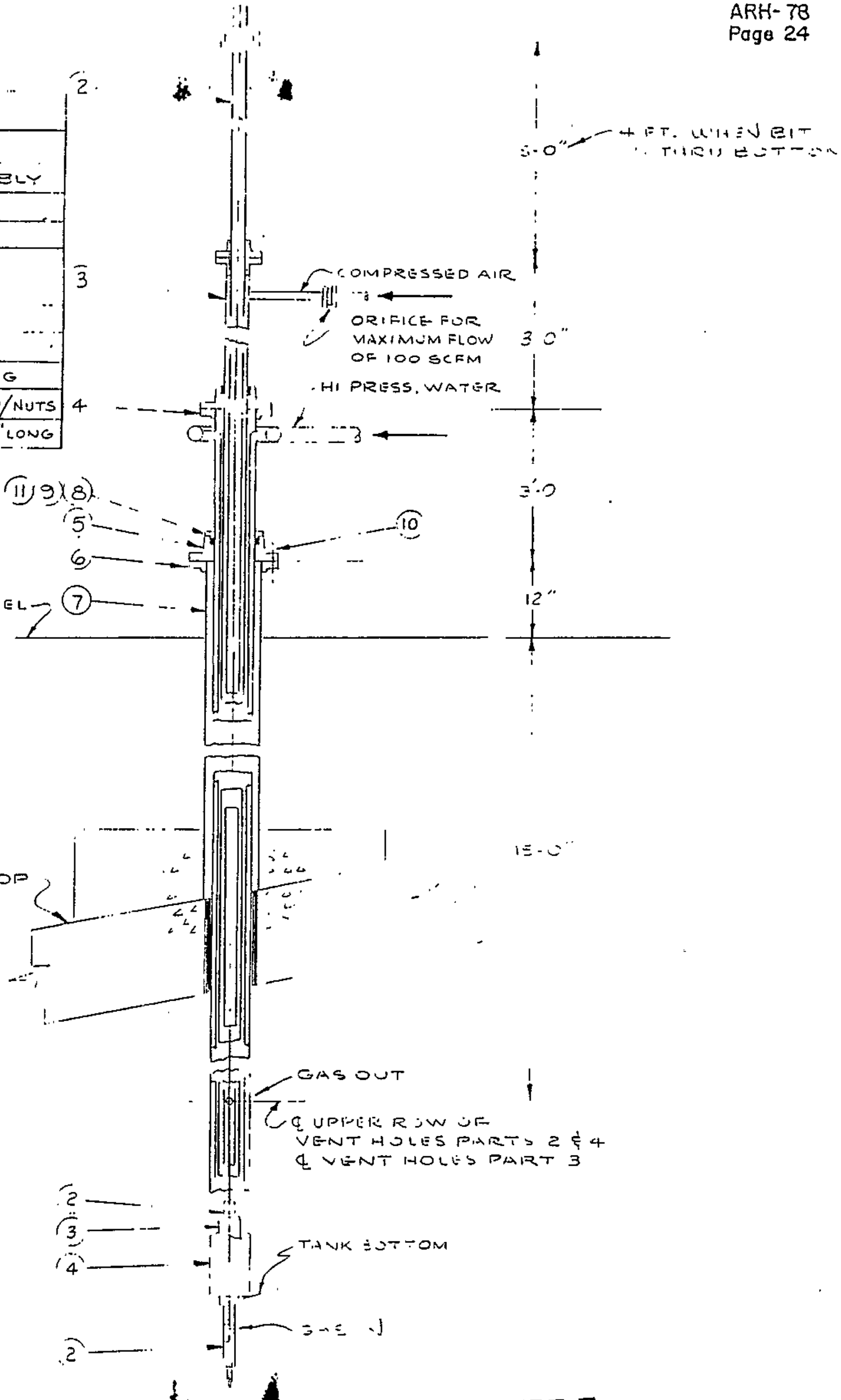

FIGURE 7

Elevation View of Bulge Venting Tool

backup portable air compressor was connected to the air supply system. These changes reduced to a practical minimum the possibility of loss of air to the circulators. Bulge movement detectors were installed at two locations to detect movement or shifting of the bottom liner. Temperature elements were included as an integral part of these instruments. A recent improvement in protecting the tank against pressure surges consisted of equipping the bypassed obsolete contact condensors so they would be activated during any pressure surge in the tank farm vent header. This modification supplements the condensing capability of the surface condensors under steam release conditions.

As the construction effort neared completion, operating procedures for sluicing TK-105-A were prepared. A hazard review covering the new sluicing equipment system and emergency procedures was also completed.(13)

When all arrangements had been completed for emergency sluicing and emptying TK-105-A, the behavior of the tank during the elapsed time since the steam release incident was reviewed. During the review various potential hazards were considered, and a decision was made to maintain TK-105-A in a static condition until such time as the tank was scheduled for Waste Management processing or until there was some evidence of further tank deterioration. The Tank Farm Process Specifications and Standards were revised to require section management approval to alter any operating condition affecting TK-105-A.(14)

X. CHANGE IN TANK STATUS

In April, 1967, a cyclic liquid level variation began to occur in TK-105-A. A typical cycle consists of a 9-10 inch drop in liquid level in a matter of minutes followed by a relatively stable period lasting about 20 hours. The liquid level then gradually returns to its original level in about a day. No significant movement of the liner can be detected. The only logical explanation that has been identified for this behavior is that the area between the bulged tank liner and its concrete pad alternates between a vapor and liquid phase. A possible detailed explanation of this behavior and thermal implications follow.

From contour measurements, Table 2, the volume under the bulge is estimated to be about 80,000 gallons. Normally, about 26,000 gallons of the bulge space is postulated to be filled with steam, which flows in a steady stream at rates up to 1000 ft^3/min from one or more holes in the liner, the highest of which is at an elevation estimated to be about 4 feet above the normal position of the tank bottom. The lower two-thirds of the bulge is believed to be filled with supernate slurry and an undetermined amount of settled sludge.

Occasionally an instability causes the supernate to begin to flow back through the hole into the vapor space beneath the bulge. The liquid being held by circulation at its atmospheric boiling point is cool enough to condense the steam under the bulge. Laboratory experiments have shown that once a suck-back begins, it will continue until the entire space under the bulge is filled with supernate

[redacted]

slurry. Water addition appears to be a major cause of instability since 20 of the 26 suck-back occurrences since April, 1967, have occurred immediately after addition of water to the tank. Airlift recirculation of the supernate slurry maintains the entire mass of liquid at its normal atmospheric boiling point of 230 F when it enters the bulge. About 18 to 24 hours are required to heat this liquid to its boiling point of 255 F under the hydraulic head under the bulge. After this induction period, steam begins to form under the bulge displacing supernate and slowly raising the apparent liquid level in the tank until steam again issues from the hole. By filling the tank as full as possible, water addition has been avoided for as long as six weeks, permitting stable operation over this period with no suck-back events.

A possible danger in the cyclic operation of the tank lies in the potential for filling the space under the bulge with settled sludge which could overheat and achieve temperatures as high as 2900 F. Thermal calculations based on the 19-hour induction period observed on May 19, 1967, indicated that the total heat transferred to the liquid under the bulge was 300,000 Btu/h immediately after a suck-back. Adjusting for decay and assuming no accumulation of sludge under the bulge, the calculated induction period on August 29, 1967, should be 21.8 hours which is in excellent agreement with the observed induction period of 22 hours. If the sludge associated with the 19 solution suck-backs that occurred between May 19, 1967 and August 29, 1967, had all settled out under the bulge, the induction period would have decreased to 12 hours. Since the observed induction period has not decreased, it can be concluded that the space under the bulge is not acting as a good settling chamber and is not rapidly filling with sludge.

It is of interest to note that if the bulge were to act as a perfect settling chamber with the historical 8.2 day cycle, the sludge would build up to the hole in the liner in about a year at which time about 500,000 Btu/hr of heat would be generated below the bulge with a maximum temperature of 1860 F. If the suck-backs were spaced 6 weeks apart, it would take about 5 years to fill the void, at which time the heat generated would be 190,000 Btu/hr, and the temperature would approach 850 F.

A concentration mechanism is also available which could eventually fill the bulge with solidified supernate; since the water evaporated to form the steam issuing from the bulge must be replaced by supernate slurry at a rate of 0.6 gpm, there must be a continual flow of salt into the bulge. If no cycling had occurred, in about 190 days after steam began to issue from the bulge, the bulge up to the hole would have filled with solidified supernate which could heat to temperatures approaching 600 F. Since cycling did occur, the solution under the bulge was periodically diluted with supernate slurry. With minimum settling of sludge, a steady state condition could be reached. For a supernate sodium concentration of 7 $\underline{M}$ and the average cycle spacing of 8.2 days, the sodium concentration under the bulge would reach equilibrium at 9 $\underline{M}$. If suck-backs were to occur only every six weeks, the Na concentration would reach equilibrium at 17 $\underline{M}$ which would probably cause the gradual accumulation of precipitated salt.

[redacted]

At the present time (October, 1967) a mixture of settled sludge and solidified supernate beneath the liner would result in a range of temperatures between 450 and 2900 F. Figure 8 summarizes predicted equilibrium temperatures for various blends of solids versus decay time.

XI. REVISED OPERATING PLAN

On October 2, 1967, low-level radiation was detected in the #2 leak detection lateral for the first time, indicating some new seepage or migration of waste from the previous inactive leak. Also, the heat generation rate of the waste in this tank has decreased a factor of four since the steam release event in January, 1965. Potential hazards associated with emptying TK-105-A have decreased but are still large as discussed later. Alternative plans are being evaluated, and preparations are being made to sluice, empty and stabilize the tank.

The various alternatives being considered include three mechanical systems and two different sluicing fluids. An emergency sluicing system involving low sluice fluid pressures (200 psig) and TK-103-A and TK-105-A is now available and could be used. In about 2 months, the 244-AR Vault will be completed and could be used for sluicing the tank. The vault offers several advantages over the emergency sluicing system including remote maintenance capability for a portion of the equipment and temperature control of the sluicing fluid. The vault sluicing system like the emergency system uses low pressure pumps. The third system being considered is the Savannah River high pressure jet system (2500-3000 psig).[15] It is believed to have the advantage of being able to empty a tank faster than the low pressure systems.

Either of the low pressure sluicing systems could use water or high salt supernate as the sluicing fluid. The high pressure Savannah River system would be limited to water. When the leak potential resulting from leaching and removing the salt that is sealing the cracks in the concrete shell is considered, the advantage of sluicing with supernate instead of water is apparent. This advantage may be offset by the Savannah River system's time advantage in sluicing a tank. While the potential for opening up leak areas with high pressure water may be large, the duration of time that material could leak would be reduced. Which system would result in the lowest net release of radioactivity to the ground is open to speculation. However, the length of time that the tank emptying operation takes is also the time period that involves maximum exposure to fission product release hazards. Being able to empty the tank rapidly minimizes this exposure to high risk and is an advantage of the high pressure system.

XII. HAZARDS ANALYSIS

Three situations were postulated to represent conditions that could occur in the event TK-105-A fails completely. Similar waste tank hazard analyses have been made at Oak Ridge National Laboratory.[16]

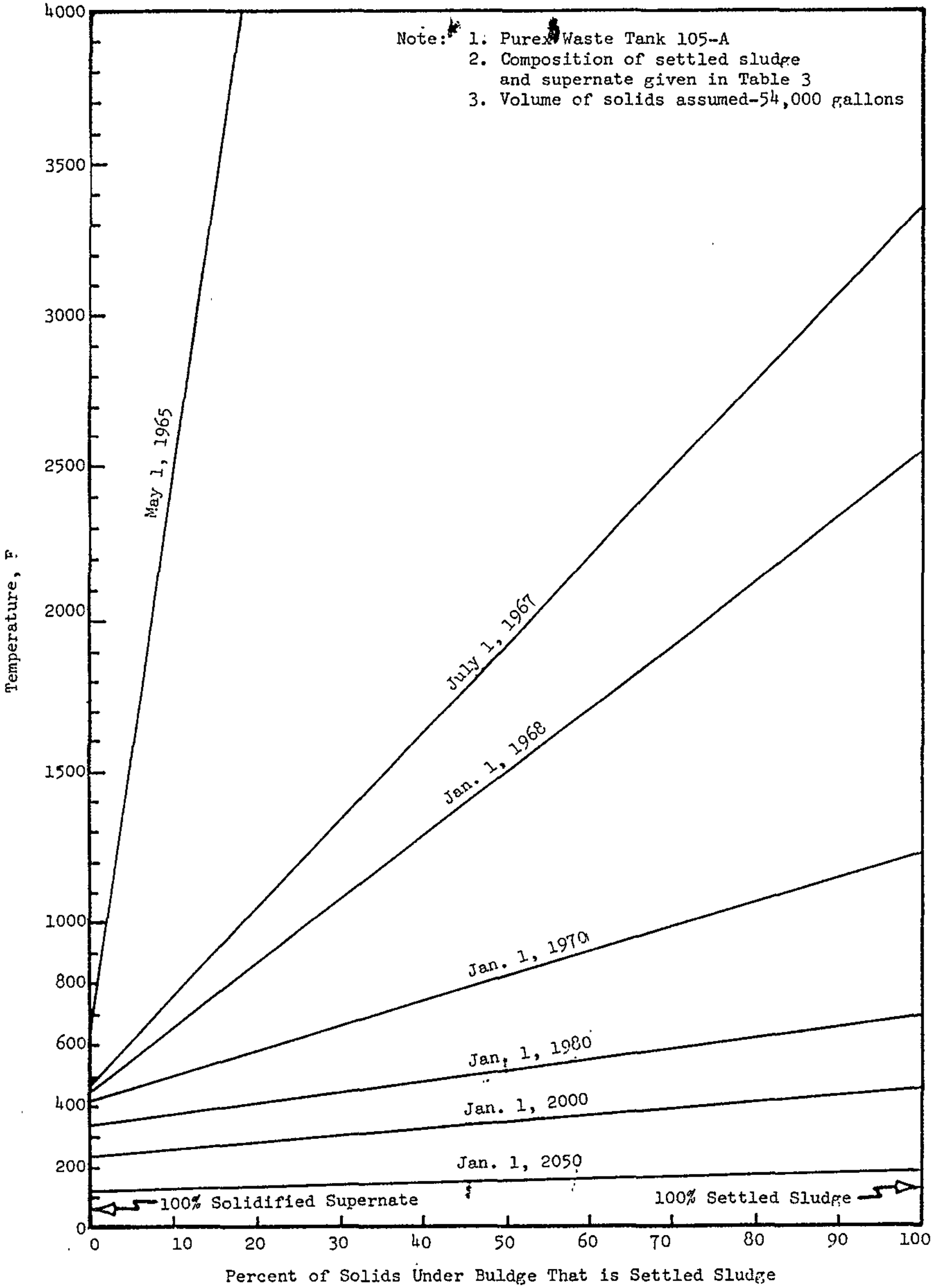

FIGURE 8
Predicted Temperatures Generated In Mixtures Of Settled Sludge And Solidified Supernate

Condition 1 - Total tank contents evaporate to dryness and achieve a maximum temperature as controlled by the laws of nature.

Condition 2 - Tank supernate is lost from tank - sludge achieves maximum temperatures as controlled by the laws of nature.

Condition 3 - Tank supernate is removed, sludge is removed except for a quantity trapped beneath the bulged liner. Quantity beneath the liner varies from all solidified supernate to all solidified sludge.

Estimates of the environmental consequences resulting from each of these conditions are presented to provide guidance to management in arriving at decisions which may be required during the TK-105-A sluicing effort. Conditions 1 and 2 are very unlikely to occur, but estimated environmental consequences of these two conditions are included to provide an appreciation of the magnitude of the potential hazards.

An estimate of the inventory of radionuclides in TK-105-A as a function of time is summarized in Figure 4. The environmental consequences of the three postulated conditions have been estimated for four dates: January 1, 1965; May 1, 1965; July 1, 1967; and January 1, 1968, as shown in Table 5.

Condition 1

Volatilization fractions for several radionuclides from both simulated and actual wastes have been measured by Barton.[10, 11] On the basis of these measurements, volatilization fractions, tabulated in Table 4, have been assumed.

The atmospheric release of the volatilized radionuclides is difficult to predict. In this analysis three arbitrary atmospheric release fractions of 1, 0.1 and 0.01, are assumed. For example, for sludge plus supernate an atmospheric release fraction of 1 would assume all of the volatilized cesium would be released to the atmosphere. Since 0.15 is the volatilized fraction assumed for cesium (Table 4), an atmospheric release fraction of 1 in this example corresponds to an atmospheric release for cesium of 15 percent.

Estimates of the dose to bone and total body for the first year following exposure have been made for persons remaining in the cloud for 2 and 24 hours at selected downwind distances. For Condition 1 the limiting mode of exposure is inhalation, and this results in the total body as the most critical organ. Total body doses via this mode of exposure have been estimated using mathematical models described by Watson.[17] Table 5 summarizes these estimated doses. External exposure of persons in the cloud from air-borne radionuclides is insignificant compared to doses received from inhalation. Exposures near the tank would be severe as discussed later.

From Table 5, it can be calculated that a total body dose in excess of 25 rem, 2 hours' exposure at 5 miles or 24 hours' exposure at 18 miles, can be anticipated

[redacted]

TABLE 4
VOLATILIZATION FACTORS
TK-105-A

	Sludge + Supernate(10,11)		Sludge Only(10,11)	
	Synthetic	Tank Waste	Synthetic	Tank Waste
Ru	0.36	0.022	0.0019	-
Cs	0.64	0.091	ND*	-
Ce	-	0.0052	-	-
B-emitters	0.065	-	0.00032	-

* Not Detected $<10^{-6}$

Assumed Volatilization Factors

	Sludge + Supernate	Sludge Only
Ru	0.05	0.0003
Cs	0.15	5×10^{-6}
Ce	0.02	1×10^{-4}
All Other	0.02	1×10^{-4}

[redacted]

[redacted]

TABLE 5
CALCULATED TOTAL BODY DOSE - TK-105-A
CONDITION 1

Distance (Miles)	Exposure Time (hrs)	Date	Dose* for Atmospheric Release Fractions Equal to:		
			1.0	0.1	0.01
5	2	1/1/65	400	40	4.0
		5/1/65	380	38	3.8
		7/1/67	360	36	3.6
		1/1/68	360	36	3.6
	24	1/1/65	2000	200	20
		5/1/65	1900	190	19
		7/1/67	1800	180	18
		1/1/68	1800	180	18
18	2	1/1/65	100	10	1.0
		5/1/65	99	9.9	0.99
		7/1/67	93	9.3	0.93
		1/1/68	93	9.3	0.93
	24	1/1/65	520	52	5.2
		5/1/65	500	50	5.0
		7/1/67	470	47	4.7
		1/1/68	470	47	4.7

* Rem in first year following exposure.

[redacted]

whenever the fraction of volatilized radionuclides escaping to the atmosphere exceeds 0.05. Although this postulated condition is unlikely, the estimated consequences are of sufficient magnitude as to warrant preventive action to insure that the tank contents do not evaporate to dryness.

Condition 2

It is postulated under this condition that all of the supernate is suddenly lost to the ground, and the remaining sludge layer evaporates to dryness. The environmental consequences of this type failure include contamination of the groundwater and release of volatilized radionuclides to the atmosphere. Due to much lower release fractions from solidified sludge, Table 4, dose estimates at both 5 miles and 18 miles are considerably below permissible occupational dose levels. If water were added to the tank as required to control the sludge temperatures, the release to atmosphere would be prevented. Since total loss of supernate to the ground is assumed, any additional contamination of the groundwater resulting from the addition of cooling water would be insignificant.

The contamination of groundwater at the Columbia River has been estimated on the basis of groundwater flow under existing flow conditions using a simplified model which does not take credit for either ionic exchange with the soil column between the tank and the groundwater or dilution of the released radionuclides in the groundwater.[18]

Figure 9 shows the estimated future strontium-90 and cesium-137 concentrations in groundwater at any distance from the input source as a function of groundwater travel time. The times, indicated in Figure 5, to reach a distance of five miles and the Columbia River assume existing groundwater flow conditions remain unchanged over the next several thousand years. These concentrations are based on radioactive decay assuming that Sr-90 and Cs-137 move at 1/50 and 1/500 the rate of groundwater, respectively. Adsorption studies have shown that these relative migration rates are reasonable estimates for the existing flow conditions.[18] However, if the competing cation concentrations in groundwater should increase (especially calcium and potassium) or if the aquifer elevation should increase and include more inert gravelly soil material, the migration rates could increase. Dispersion (dilution caused by mixing) was not considered. Neglecting this mechanism results in conservative estimates which do not accurately predict initial radionuclide arrival and predict higher than actual peak concentrations.

Though the travel time associated with the present groundwater flow path from the vicinity of the 241-A Tank Farm to the Columbia River is about 27 years, it is highly likely that flow paths (and associated travel times) will change appreciably in the very long period following the accident postulated in this study. Such changes could be relatively drastic in either direction - longer or shorter travel times - depending upon the myriad of possible causation factors (e.g., dam, irrigation, processing modifications, etc.). The infinite number of possible cause and effect relationships do not permit accurate forecasting for new flow conditions. The minimum travel time, for groundwater moving from the vicinity of 200 East Area to the Columbia River, noted in previous simulation studies was about 2.5 years.

No credit has been taken for the time of travel of wastes in the vadose zone. This could be essentially infinite in the case of TK-105-A or on the order of several weeks, depending primarily on the volume of waste leaked. Also, the effects of self-heating of waste within the soil matrix was not evaluated insofar as the effects on waste travel are concerned.

Condition 3

Condition 3 results in environmental consequences of considerably less magnitude than either Conditions 1 or 2. If the area under the bulge were completely filled with solidified supernate, the maximum temperature that could occur as of January 1, 1968, would be less than 500 F which would not volatilize significant amounts of fission products. If the area were filled with settled sludge, temperatures of 2500 F could result. However, the volatilization factors for sludge, that are free of supernate, are 4 orders of magnitude lower than for mixtures of sludge and supernate. Thus the maximum consequences would occur when the bulged area contains the maximum amount of solidified supernate in combination with enough settled sludge to produce volatilization temperatures.

On January 1, 1968, the worst case is estimated to be a mixture of 15 volume percent solidified supernate and 85 volume percent settled sludge. The environmental consequences for this worst case and for settled sludge alone are summarized in Table 6.

General

For all release conditions dose rates near the tank farm would be severe. For Condition 1 on January 1, 1968, an atmospheric release fraction of 0.10 would result in estimated dose rates of 1 R/h at 100 meters from the tank. Air contamination would require respiratory protection equivalent to fresh air to avoid excessive exposure from inhalation. Condition 2 on January 1, 1968, would be about 10-fold less severe or an increase in the atmospheric release fraction to 1.0 would produce about the same exposures as described for Condition 1. It is thus apparent that partial loss of sludge temperature control could result in releases that would deny manned access to critical tank farm control equipment with subsequent deterioration to Conditions 1 or 2. It is concluded from this study that the alternative of cooling the tank wastes with water even under conditions of gross leakage of wastes to ground is far less serious than permitting waste temperatures to rise.

[redacted]

TABLE 6
CALCULATED TOTAL BODY DOSE - TK-105-A
CONDITION 3 AS OF JANUARY 1, 1968

Distance (miles)	Exposure Time (hrs)	Type of Wastes in Bulge	Dose for Atmospheric Release Fractions Equal to: 1.0	0.1	0.01
5	2	Supernate + Sludge*	3.9	0.39	0.039
		Sludge **	0.02	0.002	0.0002
	24	Supernate + Sludge	20	2.0	0.20
		Sludge	0.09	0.009	0.0009
18	2	Supernate + Sludge	1.0	0.10	0.010
		Sludge	0.09	0.009	0.0009
	24	Supernate + Sludge	5.1	0.51	0.051
		Sludge	0.02	0.002	0.0002

* Dose for release from supernate + sludge is in REM, total body for first year following inhalation exposure.

** Dose for release from sludge is in REM, bone for first year following inhalation exposure.

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