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NORTHWEST ALASKAN PIPELINE COMPANY

1120 20th Street, N.W.
Suite S-700
Washington, D.C. 20036
(202) 872-0280

GOA-82-1121

146-A

September 29, 1982

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State of Alaska
Office of
Pipeline Coordinator

"BUSINESS" Information for Federal Government Purposes in Accordance with 10 CFR 1504 (F.R. Vol. 46, No. 240, December 15, 1981, pages 61222 thru 61234)

Mr. William Black
Director of Engineering
Office of the Federal Inspector
2302 Martin Drive
Irvine, California 92715

Re: "Thaw Mitigation Thermal Evaluation and Sensitivity Study," Forwarding Of

Dear Mr. Black:

Enclosed for your information are four (4) copies of an NWA report entitled "Thaw Mitigation Thermal Evaluation and Sensitivity Study." This document completes action on Activity #33 in NWA's Key Activity Checklist, Revision #1 of September 23, 1982. The study addresses the thermal balance during the pipeline's initial dormant period and the long-term affects thereafter.

It provides support for the pipeline segment Design Criteria Manual Vol. 1, Section 9 (Workpad Design) and Section 13 (Ditch Configuration). As one of several documents providing backup support for the site-specific design, it constitutes an up-to-date report on our work and thinking in this area.

The information in the enclosure is considered confidential/ proprietary by Northwest Alaskan Pipeline Company and remains the property of Alaskan Northwest Natural Gas Transportation Company,

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a partnership. The petition attached to this letter requests OFI to consider this document "Business" information pursuant to 10 CFR Part 1504. All rights are reserved with respect to the enclosed work, and unauthorized reproduction is prohibited; this material is protected as an unpublished work under the Copyright Law of the United States, 17 USC §101 et seq.

Yours truly,

NORTHWEST ALASKAN PIPELINE COMPANY

Edwin (Al) Kuhn
Director
Governmental Affairs

EAK/rlc

Enclosures (4 copies)

cc: J. Sizemore, OFI, Anchorage (w/4 copies)
N. Hengerer, OFI, Washington, D.C. (w/1 copy)
A. Ott, SPO, Fairbanks, (w/2 copies)
J. McPhail, Alyeska (w/2 copies)

Enclosure to Northwest Alaskan Pipeline Company letter GOA-82-1121, September 29, 1982 to Mr. William Black

PETITION FOR "BUSINESS" DESIGNATION SUBMITTED TO OFI PURSUANT TO 10 CFR PART 1504

I. The information enclosed with the above referenced Northwest Alaska Pipeline Company (NWA) letter, qualifies for a "BUSINESS" designation on the basis that it is confidential/proprietary, commercial information, the release of which may substantially impair the competitive position of the sponsors of the Alaska gas pipeline segment of the Alaska Natural Gas Transportation System (ANGTS). NWA has incurred substantial costs to develop the information, involving over four years' work and major expenditures, including both direct and indirect costs. Moreover, the sponsors do not have a final, unconditional Certificate of Public Convenience and Necessity from the Federal Energy Regulatory Commission (FERC), and the information clearly would be of substantial value to anyone contemplating construction in Alaska or in similar climates and geologic regimes. Even after a final FERC certificate has been obtained, the information contained in the document submitted is of such a nature that it might be used in third-party litigation against the sponsors. NWA has given serious consideration to a request for a "SENSITIVE" designation and to the recent order from the International Trade Commission, Department of Commerce (e.g., 15 CFR Parts 379, 385 and 399, published F.R. Vol. 47, No. 2, January 15, 1982, p. 141) restricting export of technical data related to gas transmission. Although the less restrictive "BUSINESS" designation has been requested, the technology represented by this information clearly should not be disclosed except as authorized by NWA.

II. The OFI may contact the following named persons concerning this petition:

Mr. Edwin (Al) Kuhn, Director-Governmental Affairs
Northwest Alaskan Pipeline Company
1120 20th Street, NW
Washington, D.C. 20036
Phone: 202/872-0280

Mr. William J. Moses, General Counsel
Northwest Alaskan Pipeline Company
3333 Michelson Drive
Irvine, California 92730
Phone: 714/975-4003

Mr. George P. Wuerch, Manager-Regulatory and Governmental Affairs
Northwest Alaskan Pipeline Company
3333 Michelson Drive
Irvine, California 92730
Phone: 714/975-6560

THAW MITIGATION THERMAL EVALUATION AND SENSITIVITY STUDY

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"BUSINESS" information for Federal Government purposes in accordance with 10 CFR 1504 (F.R. Vol. 46, No. 240, December 15, 1981, pages 61222 through 61234).

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NORTHWEST ALASKAN PIPELINE COMPANY	DOC. NO. H08	
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Construction activities cause disturbance of the pre-construction earth-atmosphere thermal balance that may, if unmitigated, promote degradation of existing permafrost. The gas pipeline is to be operated chilled to help maintain existing permafrost. For some aspects of design, however, it may be necessary to supplement the chilling influence of the gas pipeline operation with passive measures, such as the use of board stock insulation, to prevent or limit thaw during the dormant pre-operational period and to prevent or limit potentially excessive thaw after start-up beyond the area of chilled pipe influence.

Part of the ANNGTC approach to the examination of thaw-related concerns has been to use thermal computer models in order to assess the potential magnitude of the concerns and to investigate design alternatives. The computed thaw profiles presented in this document are considered generally conservative, particularly for areas where groundwater flow and ponding are not significant. This document summarizes the current status of the modeling approach and presents some conclusions regarding the application of the computed results to design development.

Additional work is planned to assess other conditions which affect thaw mitigative design. Finalized mode selection methodology would follow those assessments.

2.0 OVERVIEW

The work undertaken in this task is outlined and annotated in Sections 2.1 through 2.4.

2.1 ANALYSIS METHODOLOGY DEVELOPMENT

Topics of critical concern were identified, and consideration was given to the number and type of computer runs that could feasibly be accomplished. The analysis methodology evolved along with evolving design criteria and enhancements in the EPR thermal model. At the same time, project concepts about what constitutes appropriate conservatism have also evolved. This document summarizes the results of the most current analysis methods. This study focuses on classes of problems and does not simulate any site-specific conditions.

Recognizing that there are considerable uncertainties inherent in geothermal analyses, the project has used conservative model inputs and analysis methods. These are summarized as follows:

- Conservatism in Model Input

  Critical parameters that are difficult to characterize in the field were subject to conservative assumptions in the modeling analysis. The primary parameters in this category include the climate characteristics, the mean pre-construction soil temperature, the assumed post-construction snow cover properties, and the undisturbed organic layer properties.

- Conservatism in Analysis Methodology

  - Conservatism was introduced into analyses applicable south of Atigun Pass by use of run-to-run modification of organic layer thickness and properties as the primary pre-construction calibration technique. The thick resultant undisturbed organic layers ensured two critical conservatisms- that the pre-construction permafrost would be "warm" and that the warm-up effect associated with organic cover disruption during construction would be large.

  - The primary conservatisms inherent in the analyses applicable north of Atigun Pass are the warm pre-construction soil temperatures.

  - Four summers of pre-operational dormancy, assumed in most simulations applicable both north and south of Atigun Pass, is conservative with respect to thaw penetration. The actual dormant period is generally expected to be shorter than four summers.

2.2 THERMAL MODEL INPUT SELECTION

This subtask involved the details of summarizing the available data and selecting the most appropriate thermal model inputs, and included:

- o Representative Soil Thermal Properties
- o Representative Surface Thermal Characteristics
- o Bounding Values for Organic Cover Characteristics
  - Specific values were determined by calibration.
- o Conservative Long-Term Climatic Characteristics
  - "Warmest" Climate North of Atigun Pass
  - "Warmest" Climate South of Atigun Pass
- o Conservative (Warm) Gas Temperatures
- o Long-Term Insulation Thermal Properties

2.3 THERMAL MODEL SIMULATION

A three-step analysis methodology was judged to be an appropriate means of representing the effects of construction and operation on the pre-construction thermal balance.

The three-step analysis methodology is summarized as follows:

- o Pre-Construction Conditions

  The final run of each series of calibration runs had organic and snow cover characteristics that were consistent with warm permafrost and the potential for a large construction-induced warm-up effect. One series of runs was performed for each of the four combinations of native mineral soil type and base climate data sets. Two additional series of calibration runs were done to check the sensitivity of computed post-construction thaw depths to the details of the calibration process.

- o Dormant Period

  The period between ditch backfilling and pipeline start-up was simulated in order to estimate thermal conditions at start-up. To ensure conservatism with respect to thaw penetration, most simulations in this document assumed four summers of pipeline dormancy.

- o Pipeline Operation

  Long-term thermal conditions were simulated by repeating input climatic characteristics and pipe temperatures from one year to the next.

- o Iteration for Candidate Mode Development

  The results of each simulation of the dormant and pipeline operation period were examined to determine if the following conditions were met:

  - thermal performance was within existing criteria for acceptable thaw;
  - less expensive candidate modes would not be expected to meet existing thaw-related criteria;
  - performance concerns had been addressed with adequate conservatism;
  - the simulation grid had covered a large enough portion of the construction zone to adequately address the performance concern.

  If any of these conditions were not met, then additional simulations using revised input (i.e., new thermal properties or new candidate mode configurations) were performed.

2.4 INTERPRETATION OF SIMULATION RESULTS

A great deal of interpretation took place during the candidate mode development process, as the model user had considerable latitude to submit new runs based on previously obtained simulations. Decisions to iterate mode development were based primarily on the maximum thaw penetration during the dormant period, first year of operation, and twenty-fifth year of operation.

2.5 MISCELLANEOUS

The Ad Hoc Committee on Frost Heave and Thaw Settlement played an important role in selecting the types of simulations to be performed, particularly by suggesting increased conservatism in the climatic characteristics, insulation thermal resistance, and in the calibration process. The committee also recommended that sensitivity studies of the effect of variable workpad snow depths and dormant period lengths on mode thermal performance be undertaken. Runs applicable south of Atigun Pass performed prior to this recommendation had been based on Fairbanks meteorological data rather than on the "warmest" climate recommended for use by the committee. These simulations, not presented in this document, showed thaw potentials of magnitudes similar to those presented here, suggesting that some fundamental assumptions common to both phases of analyses were important enough to outweigh the many detailed differences between the two phases. This is encouraging in that the analyses appear to be somewhat insensitive to uncertainties in many of the model inputs.

3.0 GEOTHERMAL ANALYSIS METHODOLOGY

3.1 GENERAL

The geothermal analyses simulated the heat transfer among the pipeline , the construction zone soil profile, the organic cover, the snow cover, and the atmosphere. Each analyses required that a great deal of information be specified explicitly. Practical constraints limited the number of simulations that could be performed, so that certain assumptions were selected to apply to all the simulations presented in this document. Section 3.2 discusses those items. Section 3.3 briefly outlines the capabilities and constraints inherent in the EPR model, the model used for these simulations. Section 3.4 discusses input parameters, while section 3.5 summarizes the step-by-step simulation methodology.

3.2 ANALYSIS ASSUMPTIONS

3.2.1 Climatic, Soil, and Organic Thermal Characteristics

- The pipeline alignment was divided into two major climatic regions, i.e., north and south of Atigun Pass (approximate milepost 173).

- For each of the climatic regions, the analyses were based on conservative climatic parameters representing the 90% "Warm-Side" Bound of 25-year mean values from weather station recordings within the region.

- Soil thermal properties were represented by two major soil types, i.e., type A (low ice content mixed fine and coarse-grained soil) and type B (silt with moderate to high thaw strain potential).

- Snow depths after construction were assumed to be at least as great as that resulting from the one-dimensional calibrations.

- Various snow depth profiles were assumed to simulate snow plowing, blowing and drifting (especially where ANGTS pipeline workpad is contiguous with the Dalton Highway).

- A geothermal gradient of 0.01°F/foot was used as an appropriate boundary condition for the bottom of the cross sections analyzed .

- Workpad construction and ditch spoil placement/removal were assumed to disturb the surface organic layer such that its insulating properties would be no better than the underlying native soils.

- Equilibrium pre-construction mean soil temperatures were 30°F at the 5.0 foot depth for applications north of Atigun Pass. Model inputs were calibrated to achieve this condition.

- Equilibrium pre-construction mean soil temperatures were 31.5°F at the 8.0 foot depth for applications south of Atigun Pass. Model inputs were calibrated to achieve this condition.

3.2.2 Pipeline Construction Characteristics

- Minimum and maximum distances between pipe centerline and workpad shoulder were assumed to be 5 feet (for minimum 2 foot wide catchment area between ditch edge and workpad toe) and 16 feet (maximum side-boom reach), respectively [1].

- Minimum pipe cover depths (from original ground surface to top of pipe) were assumed to be 0.5 feet north of Atigun Pass and 2.5 feet south of Atigun Pass. However, north of Atigun Pass, a berm of 2 feet thickness was used over the original ground across the ditch to meet minimum cover depth requirements of the Code of Federal Regulations [2]. For applications north and south of Atigun Pass, workpad thicknesses were assumed to be 2.0 and 2.5 feet, respectively.

- Minimum pipeline ditch width for bare pipe was 6 feet [2].

- For certain thaw unstable soil areas, it was assumed that the ditch spoils may be hauled off and not placed on the ground surface near the pipeline [2]. The presence of a spoil area in areas that are potentially thaw unstable will be contingent to some degree on the results of thermal analysis.

- Various configurations of boardstock insulation under the workpad were assumed, based to some degree on the results of prior thermal analysis.

- The pipe was modeled without circular insulation for all simulations discussed in this document.

- The construction schedule potentially allows for from one to four summers of "dormant period" between initial workpad/pipeline construction and pipeline start-up. Therefore, dormancy periods of one year and four years were assumed in the simulations.

- In areas of ice-rich soils, construction will generally take place in the shoulder months [1].

- All simulations of the dormant period were commenced on March 1. Summertime beginning dates were considered to be inappropriate because boardstock insulation must be placed when the ground surface is frozen.

3.2.3 Pipeline Operation Characteristics

- The maximum pipe temperature will be 28°F. Simulations generally used mean pipe wall temperatures equal to 28°F.

- Pipeline start-up is scheduled for late fall at the end of construction/hydrotesting. November 1 was assumed in all analyses.

3.3 GEOTHERMAL MODEL CAPABILITIES AND CONSTRAINTS

The EPR program [3] models transient two-dimensional heat conduction with a change of state for a variety of boundary conditions. It uses finite difference approximations in time and finite element approximations in space. A variational technique is used to obtain continuous temperature distributions and melt/frost front location at discrete times. A surface heat balance that incorporates effects of radiation, convection, evaporation, snow melting, and conduction in the snow layer can be applied along the upper boundary of the finite element grid. The most significant constraint is that convection of energy in the ground (such as from flowing groundwater) cannot be simulated. Other constraints include the model's inability to automatically change geometry and thermal properties to represent progressive thaw settlement.

3.4 INPUT PARAMETERS

The most important parameters used in this study of thaw penetration potential were:

- Native soils, workpad, backfill and organic layer thermal properties.

- Meteorological data and surface characteristics.

- Pre-construction and pipeline start-up soil temperatures.

- Construction procedures and schedules.

- Operating pipe temperatures.

- Boardstock insulation thermal properties and dimensions.

- Snow depths across right-of-way before, during and after construction.

Descriptions of these parameters are given in Subsections 3.4.1 through 3.4.7.

3.4.1 Native Soils, Workpad, Backfill, and Organic Layer Data

Two soil types, designated as type A and type B, were used to represent native frozen soils. Only one material was used to represent the workpad and another the backfill. As a result of calibrations, organic layer materials were somewhat different north and south of Atigun Pass. The sensitivity studies were performed first with soil type B and then with soil type A. In the computer runs performed to simulate dormant or operation conditions, it was assumed that the organic layer under the workpad and spoil area would lose its insulating properties (due to disturbance such as compression) and take on the properties of the underlying native soil. Also, it was assumed that no organic layer would exist over the backfill in the ditch area.

The materials used in the simulations can be generally described as follows:

- o Native soil type A: A nearly saturated, mixed coarse- and fine-grained soil (silty sand, silty gravel, or silty sand and gravel) with low to moderate thaw strain potential (about 10%).
- o Native soil type B: A saturated, fine-grained predominantly silty soil with moderate to high thaw strain (>15%) potential.
- o Ditch backfill: An unsaturated, clean granular material (sandy gravel).
- o Workpad: An unsaturated granular material, sandy gravel or gravelly sand.
- o Undisturbed surface organic layer: Thermal properties similar to peat.

The values of specific heat, thermal conductivity, latent heat, ALP and GAM, and index properties for the materials noted above are presented in Table 3-1. Undisturbed soil profiles, used in simulations of pre-construction conditions, are shown schematically in Figure 3-1.

3.4.2 Meteorological Data and Surface Characteristics

All one-dimensional calibration runs and two-dimensional dormant and operation runs were made using two base climate data sets. These data sets represented estimates of the "warmest" regional 25-year average climatic parameters for the alignment north and south of Atigun Pass. Representative surface characteristics were used in conjunction with the climate parameters to complete definition of the surface heat balance.

The values of the climatic parameters and surface characteristics are given in Tables 3-2, 3-3 and 3-4. The annual average air temperatures of these climates are about 11.5°F and 27°F for north and south of Atigun Pass, respectively. The corresponding air freezing and thawing indices (F/T) are about 8480/1050 and 4700/3020 degree days, respectively.

The regional estimates of snow depth and snow density were modified using multipliers that are part of the EPR model during the calibration process as a way of achieving the desired mean pre-construction soil temperatures. This is described further in Section 3.5.

3.4.3 Pre-construction and Pipeline Start-Up Soil Temperatures

Equilibrium pre-construction temperatures computed by the final run of each calibration series were used to establish the initial temperatures for dormant period simulations. Similarly, each dormant period simulation yielded soil temperatures that were used as the initial temperature profiles for subsequent operational runs.

3.4.4 Construction Procedures and Schedules

Thermally significant aspects of construction procedures and schedules were simulated as faithfully as practical given the constraints of the model. These constraints do not permit practical simulation of many construction details which occur over brief time scales, say, less than one month. Subsection 3.2 lists the assumptions made regarding aspects of construction that are considered thermally significant.

3.4.5 Operating Pipe Temperatures

During the early stages of this study the criteria for pipeline gas temperature required only that it not exceed 32°F. Several EPR thermal model simulations were performed using 31.7°F as the constant pipe wall temperature (see Figures 4-93 through 4-96). As may be expected, thaw potential in the pipe vicinity was computed to be unacceptably high. Figures 4-93 and 4-95 compare computed thaw potential at mean temperatures of 31.7°F and 28°F. Mode thermal performance is significantly better at the lower temperature. This comparison was a partial basis for the decision to lower the criteria for maximum pipe temperature to 28°F. In order to be conservative and consistent with the current design criteria, most of the simulations have assumed mean pipe temperatures equal to 28°F. Some runs (applicable south of Atigun Pass) reported in this document were completed prior to the final decision on this criteria change; they assumed an annual sinusoidal pipe temperature fluctuation defined by 28±

1.6°F, a variation based on preliminary gas thermal hydraulics computations. Differences in computed thaw between a simulation using 28± 1.6°F sinusoidal variation in pipe temperature and one using a constant 28°F would be considered insignificant.

3.4.6 Boardstock Insulation Thermal Properties and Dimensions

Some of the computer simulations of the buried pipeline and construction zone were performed assuming boardstock insulation across the top of the pipe ditch and/or under part of the workpad and ditch spoil areas. The insulation properties are given in Table 3-5. The thickness and extent of boardstock insulation was varied from run to run according to the results of the preceding runs.

3.4.7 Snow Depths

Estimated regional mean pre-construction snow depths are presented in Tables 3-2 and 3-3. The snow depth on top of the workpad, ditch and spoil area during the dormant and operation periods was varied from 70% to 150% of the regional mean pre-construction depths.* In addition, the simulations with the Dalton Highway in the grid north of Atigun Pass used variable snow depths across the surface to represent plowing and drifting of snow. As much as 500% of the regional mean pre-construction snow depth (i.e., seasonal average and maximum depths of 4.3 and 5.2 feet, respectively) was simulated on the shoulder of the Dalton Highway.

3.5 STEP-BY-STEP GEOTHERMAL SIMULATION PROCESS

The thermal analyses consisted of a three-step sequence of computer simulations:

- One-dimensional calibration:

  First, the organic layer thickness, the organic properties, and/or snow depth and density were adjusted from run to run until the average annual equilibrium soil temperature was 30.0°F at 5.0 feet below the ground surface north of Atigun Pass, and 31.5°F at 8.0 feet below the ground surface south of Atigun Pass for both native soil types A and B. The final run of each calibration series conservatively simulated pre-construction alignment permafrost conditions, and the computed temperatures became the basis for initial temperatures used in dormant period simulations.

*150%, used for simulations North of Atigun Pass, equates to (seasonal average and maximum snow depths of 1.3 and 1.5 feet, respectively; and 70%, 75%, 90% and 150% used for simulations South of Atigun Pass, equates to seasonal average/maximum depths of 0.9/1.3, 1.0/1.4, 1.2/1.7 and 1.9/2.8 feet, respectively.

- o Dormant Period:

Second, the same climatic parameters used in the final run of each calibration series* were input to one- or four- year simulations of the dormant period. These simulations predicted thaw penetration and soil temperature profiles prior to pipeline start-up.

- During dormant period simulations the pipe was at ambient soil temperature. The organic layer was stripped over the ditch and its properties under the workpad and in the spoil area (if present) were changed to properties of the underlying native soils.

- While construction activity is likely to result in snow compression or removal by heavy machinery, to ensure conservatism it was assumed that the snow depths on top of the workpad, over the ditch, and over the spoil area were maintained at the "calibrated" depth (i.e., the depth established by the calibration runs described in step 1 above) or increased to 150% of the regional mean pre-construction depths.

- o Operation Period:

Third, the operation conditions were simulated using the ground temperature profile obtained during step 2 above and the operating gas temperature. Most operation period simulations continued for 25 years.

- In all cases where the workpad was away from the Dalton Highway snow depths during simulations of the operation period were maintained at the depths used in the dormant period simulations. Simulations that included the Dalton Highway in the grid employed modified snow depths to represent plowing and blowing of snow.

*Except for simulations with the Dalton Highway included in the grid where snow depths were changed to represent plowing and blowing of snow. The other exception is the simulation whose results are presented in igures 4-56 through 4-58, in which snow depths equal to 150% of the regional mean pre-construction depths were used.

4.0 RESULTS OF GEOTHERMAL SIMULATIONS

4.1 GENERAL

The results of the analyses are discussed in Sections 4.2 and 4.3.

Trumpet curves based on the final run of each of the six calibration series are given on Figures 4-1 through 4-6. Each combination of the two climate zones and the two soil types (A and B) required one series of calibration runs. In addition, two calibrations duplicated the objectives of two of the others, in that two different combinations of calibrated model inputs resulted in mean soil temperatures approximately equal to 31.5°F at the 8.0 foot depth for both simulated native mineral soil types. As discussed in Section 4.3.1, the alternative calibrations did not yield significant differences in computed thaw during the dormant and operation periods.

Results of the analyses of thaw penetration north of Atigun Pass where ANGTS is not adjacent to Dalton Highway or TAPS fuel gas line are summarized in Tables 4-1 and 4-2 and discussed in Section 4.2.1. The potential for maintaining "cold" soil temperatures beside the buried pipeline at sidebends in frozen "creep" susceptible soils north of Atigun Pass was analyzed and the results are discussed in Section 4.2.2. Section 4.2.3 presents results of the analyses north of Atigun Pass where ANGTS is adjacent to the Dalton Highway but not to the TAPS fuel gas line.

Results of the analyses indicating the sensitivity of thaw penetration to soil type, snow depth, spoil area presence, width of disturbed area between ditch and workpad, length of dormant period, boardstock insulation dimensions are summarized in Tables 4-5 and 4-6 and discussed in Sections 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.3.6 and 4.3.7, respectively.

4.2 RESULTS OF THE ANALYSES OF THAW PENETRATIONS NORTH OF ATIGUN PASS

4.2.1 North of Atigun Pass Where ANGTS Is Not Adjacent to Dalton Highway or TAPS Fuel Gas Line

Figure 4-7 shows the thaw penetration across the construction zone at the end of the fourth summer of dormancy for soil type B and a "disturbed" spoil area. Computed thaw penetration is maximum in August of each year and increases in each successive year of dormancy. Snow depths during the dormant and operation periods were simulated uniformly across the surface using the same values used in the final run of the pre-construction calibration process. The simulation of the dormant period predicts no thaw penetration below the pipe bottom, a maximum of 1.5 feet of thaw penetration beneath the workpad (which refreezes each winter) and 3.0 feet of thaw below original ground surface within the spoil area (this also refreezes each winter). After start-up, the maximum seasonal thaw depths across the construction zone do not change significantly except near the gas pipeline, where thaw does not penetrate below the top of the pipe. See Figures 4-8 and 4-9 for thaw penetrations during the 1st and 25th year of operation, respectively.

Soil type A results are presented on Figures 4-10 for the dormant period, 4-11 to the 1st year of operation and 4-12 for the 25th year of operation. Maximum dormant period thaw penetration under the pipe at centerline, workpad and spoil area are 0.0, 3.0 and 6.3 feet, respectively. Under the shoulder of the workpad opposite to the pipe ditch, thaw reaches 4.5 feet. These thaw depths are relative to the original ground surface. Thawed areas refreeze completely during each winter of the dormant period. During operation simulations thaw does not penetrate below the top of pipe within the ditch but does increase with time under the workpad shoulder and spoil area. The maximum depth of thaw reaches 10.1 feet and 9.4 feet under the workpad shoulder and spoil area, respectively, in August at the end of the 25 year simulation (Figure 4-12). These thawed areas do not entirely refreeze in the winter months.

Next, the effect of "no spoil area disturbance" was evaluated. For soil type B (Figures 4-13 and 4-14) the maximum thaw beneath the undisturbed organics, 1.6 feet, occurs seasonally during both dormant and operation periods. This is no different near the pipe or, under the workpad than the previous results for "disturbed" spoil area. For soil type A (Figures 4-15 through 4-17) the maximum thaw beneath the undisturbed organics is 3.7 feet. As was the case with soil type B, this depth occurs seasonally, during both dormant and operation periods and is no different near the pipe or under the workpad than the previous results for "disturbed" spoil area (compare Figure 4-17 to Figure 4-12).

Analyses were then performed with boardstock insulation across the top of the ditch extending under the workpad and spoil area. Figures 4-18 through 4-22 demonstrate the effect of 3-inch thick by 19-foot wide boardstock insulation on the thaw penetrations. Near the pipeline, 6 feet from centerline, the native soil does not thaw below the top of the pipe during the dormant or operation periods for either soil type A or B. The maximum seasonal thaw penetration beneath the disturbed spoil area is about 2.3 feet for soil type B and 6.3 feet for soil type A (Figures 4-19 and 4-22). In both cases these thawed areas refreeze during the coldest winter months for each year of the simulation.

For results of predicted thaw penetrations with wider boardstock insulation see the discussion in Section 4.2.3.

The next section discusses the effect of 3-inch thick by 19-foot wide boardstock insulation on long-term soil "creep" considerations for pipeline sidebends in frozen soils.

4.2.2 The Effect of Boardstock Insulation (Ground Surface) on Pipeline Sidebends in Ice-Rich "Creep" Susceptible Soils

The magnitude of the deformation (creep) of ice-rich soils under long-term load is highly dependent on the soil temperature,i.e., warmer temperatures allow more creep deformation. At sidebend locations, the temperatures of the soil in the area near the pipe are of interest in the pipe-soil interaction analyses. North of Atigun Pass the soil temperatures are at least a few degrees colder than south of Atigun Pass and the possibility exists for maintaining these "cold" soil temperatures via a combination of ground surface insulation and chilled gas flow.

Figures 4-18 through 4-22 show the area predicted to remain frozen beside the gas pipeline when a 3-inch thick by 19-foot wide boardstock insulation is placed over the ditch. Tables 4-3 and 4-4 summarize the monthly average soil temperatures within the area of interest during the "warmest" periods for soils types A and B, respectively. The "warmest" periods are the fourth year of dormancy and the first year of operation. After the first year of operation the soil temperatures decrease by about 0.5 to 1.0°F, and they remain about this cold through the duration of gas pipeline operation.

4.2.3 North of Atigun Pass Where Adjacent to Dalton Highway*

The configurations analyzed and resulting 32°F isotherms are shown on Figures 4-23 through 4-34 for soil type B and Figures 4-35 through 4-46 for soil type A. Depths of thaw are summarized in Tables 4-1 and 4-2.

Assuming that snow plowing and blowing would lead to accumulations of snow on the shoulder of the Dalton Highway that are 300%** of regional mean pre-construction snow depths, thaw penetration reaches a maximum depth of about 1.7 feet below the bottom of the workpad near the shoulder of the Dalton Highway for soil type B (Figures 4-23 through 4-25) when there is no boardstock insulation. For soil type A this thaw depth is about 2.5 feet as shown in Figure 4-37. Thaw does not penetrate below the centerline of the pipeline during dormant or operation periods for either soil type.

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*But not TAPS fuel gas line.

**300% of pre-construction snow depths means multiplying each of the monthly input values for snow depth given on Table 3-2 by 3 prior to performing heat transfer calculations. For 300% snow depth factor the seasonal average snow depths and maximum seasonal snow depths are 2.6 feet and 3.1 feet, respectively.

With 500%* snow depth on the shoulder of the Dalton Highway and soil type B, the thaw reaches a maximum penetration of about 4.5 feet into the native soil beneath the workpad near the Dalton Highway shoulder (Figure 4-28). With soil type A the maximum thaw depth is about 9.0 feet (Figure 4-40). Again, thaw does not penetrate below the centerline of the pipeline for either soil type.

With boardstock insulation of 3-inch thickness across the full width of the workpad and 300% snow depth on the Dalton Highway shoulder, thaw penetrations into the subsoils at the end of 25 years of operation are reduced from 1.7 and 2.5 feet to 0.8 feet and 1.5 feet for soil type B and type A, respectively (Figures 4-25, 4-31, 4-37 and 4-43). For 500% snow depth and the same dimensions for boardstock insulation, the thaw penetrations are a maximum of 1.2 and 2.0 feet below the bottom of the workpad near the shoulder of the Dalton Highway for soil type B and type A, respectively (Figures 4-34 and 4-46).

4.3 RESULTS OF ANALYSES OF THAW PENETRATIONS SOUTH OF ATIGUN PASS

4.3.1 Comparison of Thaw Penetrations During Dormant and Operation Periods Given Two Different Sets of Organic Layer Properties

As mentioned in Section 4.1, two different series of calibration runs were performed for the same climate and mineral soil type. The important differences in the two calibrations, both of which used soil type B and the "warmest" regional mean climate south of Atigun Pass, are listed in Table 4-5.

The results of two-dimensional dormant and operation period simulations based on these different organic layer calibrations are presented on Figures 4-47 through 4-52. Comparison between the following two sets of figures (Figures 4-47 through 4-49 and Figures 4-50 through 4-52) shows that no significant differences in thaw penetrations resulted from the two different calibrations when soil type B was used. No simulations of the dormant or operation period were performed using the calibration for soil type A represented in Figure 4-6 as computed thaw profiles were not expected to be significantly different from those based on the calibration represented in Figure 4-4.

*500% snow depths can be represented by a seasonal average snow depth of 4.3 feet and a maximum seasonal snow depth of 5.2 feet for this climate input.

4.3.2 Results of Analyses with No Boardstock Insulation, Calibrated Snow Depths*, 2.5-Foot Thick Workpad, 28°F Gas Temperature and Type A and B Soils

These results are presented on Figures 4-47 through 4-49 and 4-50 through 4-52 for soil type B and Figures 4-53 through 4-55 for soil type A; they are summarized in Table 4-6. Maximum thaw penetration below pipe bottom during the dormant period is 4.6 feet for soil type B and 9.7 feet for soil type A (Figures 4-50 and 4-53). After pipeline start-up there is complete freeze-back beneath the pipe in soil type B during the first year of operation. However, for soil type A the thaw continues during pipeline operation reaching a maximum of 28.2 feet below bottom of pipe during September of the 25th year. Also, a frost bulb forms around the pipe as can be seen in Figures 4-54 and 4-55.

4.3.3 Results of Analyses with No Boardstock Insulation, 150% of Pre-construction Snow Depths, 2.5-Foot Thick Workpad, 28°F Gas Temperature and Soil Type B**

Figures 4-56, 4-57 and 4-58 present the 32°F isotherms for the 4th year of dormancy and the 1st and 25th years of operation under the assumed conditions. The thaw penetration beneath the pipe bottom reaches a maximum of 4.8 feet in September following four summers of dormancy (Figure 4-56 and Table 4-6) but completely disappears after pipeline start-up (Figures 4-57 and 4-58 and Table 4-6). Comparisons between Figures 4-50 through 4-52 and Figures 4-56 through 4-58 show that doubling the snow depths (from calibrated depths, for which the snow depth factor was 75%, to 150% of regional mean pre-construction depths) does not cause noticeable differences in the thaw depths beneath the pipe at centerline. The purpose had been to examine the magnitude of the increased thaw that would result if snow depths across the construction zone were much deeper than they generally had been prior to construction of the pipeline.

*Snow depths were maintained the same as depths established by the calibration runs.

**Snow depths assumed during pipeline dormancy and operation were double the depths established by the calibration runs.

4.3.4 Comparison of the Results of Analyses Performed With and Without a Disturbed Spoil Area

Figures 4-50, 4-51 and 4-52 when compared to Figures 4-59, 4-60 and 4-61 demonstrate the effect of having no disturbed spoil area on the thaw penetrations for soil type B. During the dormant period the thaw penetration beneath the pipe bottom is reduced from about 4.6 feet (Figure 4-50) to about 4.3 feet (Figure 4-59) when the spoil area is not assumed disturbed. After pipeline start-up there is no thaw beneath the pipe bottom in either case.

The same comparison was made for soil type A (see Figures 4-53, 4-54, 4-55 and 4-62, 4-63, 4-64). Thaw penetration beneath the pipe bottom during the dormant period is reduced from about 9.8 feet (Figure 4-53) to about 7.5 feet (Figure 4-62). After start-up, the pipeline progressively refreezes the soil directly beneath it but a very steep frozen/unfrozen interface develops on the workpad side of the gas pipeline ditch (Figure 4-64).

4.3.5 Comparison of the Results of Analyses Performed with Minimum (about 2 Feet) and Maximum (about 16 Feet) Space* between Pipeline Ditch Edge and Workpad Shoulder For Soil Type B

This comparative analysis was performed to gauge the sensitivity of thaw penetration beneath the pipeline to the "open space" left between pipe ditch edge and workpad shoulder. This "open space" was assumed to have the organic layer disturbed but not stripped, no subsequent gravel cover, and post-construction snow depths equal to or greater than the pre-construction "calibrated" snow depths.

Comparing the results presented in Figures 4-50 through 4-52, which used the 2 foot minimum "open space", to those presented in Figures 4-65 through 4-67, which used the 16 foot maximum "open space" we can see no significant change in the thaw penetration below pipe bottom. Dormant period maximum thaw penetration below pipe bottom was computed to be 4.6 feet for the 2 foot "open space" versus 4.8 feet with the 16 foot "open space". There is no thaw below pipe bottom in either case after pipeline start-up.

4.3.6 Comparison of Thaw Penetrations with One-Year Dormant Period and Four-Year Dormant Period For Soil Type B

A run was performed with pipeline operation beginning on November 1 of the first year after pipeline construction. Figures

*The maximum simulated distance is a little more than the maximum side-boom reach of 16 feet from workpad shoulder to pipeline centerline but the effect of this slightly wider open space on thaw penetrations is not significant.

4-68, 4-69 and 4-70 show the 32°F isotherms just prior to start-up, in September of the first year of operation, and in September of the 25th year of operation. Thaw penetration below pipe bottom was only about 0.8 feet following one summer of dormancy (Figure 4-68) as compared to about 4.6 feet (Figure 4-50) when four summers of dormancy were simulated. After start-up there was no thaw beneath pipe bottom in either case (Figures 4-51, 4-52, 4-69 and 4-70). See Table 4-6 for a summary of thaw depths.

4.3.7 Results of Analyses with Boardstock Insulation

Analyses were performed for soil types A and B, and the following boardstock insulation configurations (centered on pipe centerline):

Thickness (in.)	Width (ft.)
6	11
4	24
6	24
6	50

Simulation results for all cases analyzed are shown on Figures 4-71 through 4-83 for soil type B and Figures 4-84 through 4-92 for soil type A. Thaw depths are summarized in Table 4-7.

4.3.7.1 Type B Native Soil

With 4-inch thick by 24-foot wide insulation the simulation shows no thaw beneath pipe bottom during the dormant period for soil type B (Figure 4-71). If the boardstock width is reduced to 11 feet and the thickness increased to 6 inches, the 32°F isotherm reaches about 1.5 feet below pipe bottom during the dormant period (Figure 4-72). After pipeline start-up at 28±1.6°F there is no thaw below the pipe for 23 years of simulated operation (Figures 4-73 and 4-74). Though the simulation did not complete 25 years of operation, it is not expected that significant additional thaw would occur during the two unsimulated years.

As can be seen on Figures 4-75, 4-76 and 4-77, when the boardstock insulation is increased to 24-foot width and the thickness is kept at 6 inches, there is no thaw below the pipe during or after the dormant period. Even with the post-construction snow depths increased to 150% of regional mean pre-construction depths, the thaw penetration does not go below pipe bottom during or after pipeline start-up (Figures 4-78, 4-79 and 4-80).

Six-inch thick by 50-foot wide boardstock insulation maintains a wider area frozen at pipe springline (Figures 4-81, 4-82, and 4-83) than does 11-foot or 24-foot wide insulation.

4.3.7.2 Type A Native Soil

Simulations with soil type A show considerable thaw penetration beneath the pipeline during both dormant and operating periods with six-inch thick by 11-foot wide boardstock insulation (Figures 4-84 through 4-86 and Table 4-7). When the boardstock width is increased to 24 feet the thaw below pipe bottom into native soils is prevented (Figures 4-87 and 4-88) but the long-term thaw penetrations result in a very narrow frozen pedestal below the pipeline (Figure 4-89). This frozen pedestal may not provide adequate pipeline support and restraint. A more favorable situation results with boardstock insulation six-inches thick and 50 feet wide. Short- and long-term thaw is limited so that a sizeable, though not necessarily adequate, frozen zone remains below the pipeline (Figures 4-90 through 4-92).

4.3.8 Results From Using 31.7°F Pipe Temperatures

These analyses are presented primarily to add perspective to the analyses discussed in Section 4.3.1 through 4.3.7. As noted in Section 3.4.5, some thermal analyses using mean pipe temperatures higher than 28°F had been performed prior to the decision to lower the maximum allowable pipe temperature to 28°F. Figures 4-93 and 4-95 highlight the thaw mitigation benefits that are expected to result from this criteria change. Figures 4-94 and 4-96 illustrate some concerns that had been associated with the previous pipe temperature criteria, which had permitted temperatures as high as 32°F.

5.0 CONCLUSIONS

5.1 NORTH OF ATIGUN PASS

5.1.1 Away from State and TAPS Facilities

5.1.1.1 Pipe Settlement

- Where the thermal effects of ponding and convection are insignificant, thaw beneath pipe centerline during as many as four years of pipeline dormancy and after start-up will most likely not occur in areas where the mean organic layer thickness is not greater than 0.5 feet. Pipe settlement is likely to be no more than a minor concern even in areas with thicker organic cover as long as water related thermal problems are not severe, regardless of whether or not there is a disturbed spoil area (see Figures 4-7 through 4-17 and Table 4-1 for specific computational results). This conclusion is a consequence of the minimal thaw penetration expected below pipe bottom along pipe centerline.

5.1.1.2 Soil Restraint at Bends

- Where the thermal effects of ponding and convection are insignificant, a block of frozen native soil approximately two pipe diameters wide can probably be maintained beside the pipeline by placement of three-inch thick by about 19-foot wide boardstock insulation over the top of the ditch (Figures 4-18 through 4-22). Monthly average soil temperatures within the frozen block of soil are given on Tables 4-3 and 4-4 for soil types A and B, respectively. The insulation does not need to be centered on pipe centerline but rather can (and should) be shifted to the pipeline side where bend resistance is needed.

5.1.2 Adjacent to Dalton Highway but not to TAPS Fuel Gas Line

5.1.2.1 SDFAC = 3.0 on Dalton Highway Shoulder

- In areas where the snow depths on the highway shoulder are assumed to be 300% of the regional mean pre-construction depths and where the thermal effects of ponding and convection are insignificant, the maximum thaw penetration below the highway shoulder into subgrade soils will be only about 2 feet for soil type B and 3 feet for soil type A (see Figures 4-23 through 4-25 and 4-35 through 4-37 and Table 4-1). It is considered that these limited thaw penetrations do not significantly alter the existing thermal balance beneath and around the Dalton Highway.

It is uncertain at the present time whether or not boardstock insulation would be necessary to mitigate thaw, as design criteria for acceptable thaw have not been finalized and the current thermal conditions adjacent to the Dalton Highway also are not known in detail.

5.1.2.2 SDFAC = 5.0 on Dalton Highway Shoulder

o Where the snow depths on the highway shoulder are assumed to be 500% of regional mean pre-construction depths and the thermal effects of ponding and convection are insignificant, the maximum thaw penetration below the highway shoulder into subgrade soils will be about 5 feet for soil type B and 9 feet for soil type A (see Figures 4-26 through 4-28 and 4-38 through 4-40 and Table 4-1). Computed thaw depths in the vicinity of the highway shoulder are considered to be very conservative for areas where water-related thermal problems are not significant because highway shoulder snow densities were assumed equal to the calibrated pre-construction snow densities. This thaw penetration occurs with or without a disturbed spoil area, and with the minimum 2 feet or the maximum 16 feet clear space between pipe ditch wall and workpad shoulder. Thaw will not penetrate below the pipeline bottom for either soil type.

Since thaw below the shoulder of the Dalton Highway may already be substantial in areas where the snow is deep, boardstock insulation, about 3 inches thick will be considered for placement under the ANGTS workpad. (See Figures 4-32 through 4-34 and 4-44 through 4-46 and Table 4-2.) Since current thermal conditions adjacent to the Dalton Highway are not known in detail, the concern warrants further assessment.

5.2 SOUTH OF ATIGUN PASS

5.2.1 Away From TAPS and State Facilities

5.2.1.1 Pipe Settlement

o Type B Soil

- Four-summer dormant period:

  Where the thermal effects of ponding and convection are insignificant, thaw penetration beneath the pipeline will reach a maximum of 4 to 5 feet during a four summer dormant period and then the chilled pipeline will refreeze the thawed profile beneath the pipe (see Figures 4-56 through 4-61 and 4-65 through 4-67 and Table 4-6). Thaw settlement of the pipeline could be avoided by removal of 5 feet of silt and replacing it with thaw stable material prior to pipe placement. As one alternative to this overexcavation, boardstock insulation of 6-inch thickness and 24-foot width could be placed over the pipeline ditch centered on the pipe centerline. (See Figures 4-75 through 4-79 and Table 4-7.)

- One-summer dormant period:

  For dormant periods of one summer or less, thaw penetrations beneath the pipeline within alignment sections south of Atigun Pass are expected to be less than one to two feet requiring only a limited depth of over-excavation, approximately two feet, and replacement with thaw-stable material in order to avoid pipeline settlement due to thawing subsoils. (See Figures 4-68 through 4-70.) If some limited differential pipe setlement can be tolerated, then the need for ditch over-excavation may be reduced or eliminated.

o Type A Soil

- Four-summer dormant period:

  In predominantly granular soils with low to moderate thaw strain potential, the expected thaw penetrations below pipe bottom at centerline are considerable, about 10 feet during the dormant period and 28 feet during the operation period (Figures 4-53 through 4-55 and Table 4-6). Thaw strains of 10% could result in about 2.8 feet of pipe settlement during the pipeline design life. Eliminating the use of the spoil area decreases the thaw penetration during the dormant period by a couple of feet but indicates a very steep frozen/unfrozen interface beside the pipeline during operations (Figures 4-62 through 4-64). If these predicted values and configurations of thaw penetration are considered unacceptable by pipeline structural analysis or by trafficability requirements, then boardstock insulation should be placed over the pipeline ditch centered on pipe centerline.

- One-summer dormant period:

  Operation period thaw potential following a one-year dormant period has not yet been simulated, but it is expected to be less severe than that expected for longer dormant periods.

5.2.1.2 Soil Restraint at Bends

Due to the very warm soil temperatures beside the pipeline indicated by simulations of soil type B with 6-inch thick by 50-foot wide boardstock insulation, it is concluded that the performance of side bends in silts with moderate to high thaw strain potential needs to be analyzed or assessed in terms of the long-term creep potential (see Figures 4-81 through 4-83). If long-term creep is determined to be excessive, then other mitigative measures, such as removal of thaw unstable soils and replacement with thaw stable material, should be employed.

5.2.1.3 Long-Term Thaw Under Workpad and/or Spoil Area

Long-term thaw under the workpad and/or spoil area may be substantial even when boardstock insulation up to 50 feet in width, centered over the pipe, is employed. This potential is particularly evident in Figures 4-77, 4-80, 4-83, 4-89 and 4-92. The impact of this will be evaluated during detailed design. Mitigation might be implemented through design refinement, workpad/spoil area maintenance, or combination of the two techniques.

6.0 REFERENCES

The following documents have been specifically or generally referenced in preparation of this report:

1. Northwest Alaskan Pipeline Company, Pipeline Design Criteria Manual, Section 9.0.

2. Northwest Alaskan Pipeline Company, Pipeline Design Criteria Manual, Section 13.0.

3. "General Purpose Permafrost Program - Version 9 - Program Description", J. A. Wheeler and T. W. Miller, Exxon Production Research Company, July, 1979.

TABLE 3-1

SOIL THERMAL PROPERTIES FOR GEOTHERMAL ANALYSIS

	W	γ_d	S	k_f	k_u	C_f	C_u	HFUS[1]	ALP	GAM
	Winter/Summer (% dry wt)	Winter/Summer (pcf)	(%)	(Btu/ft. hr.°F)		(Btu/ft.³ °F)		(Btu/ft³)	(°F)	
Organics-So. of Atigun #1[2]	200/100	19/20	83/41	0.54	0.09	29.0	25.0	2300	0.1	1.0
Organics-So. of Atigun #2[2]	190/100	15/16	59/31	0.7	0.1	19.0	25.0	3000	0.1	1.0
Organics-No. of Atigun	245/175	19/20	100/71	1.0	0.2	32.0	44.0	5900	0.1	1.0
Soil Type A	19	110	96	2.1	1.4	28.0	39.0	3000	0.3	1.0
Soil Type B	46	75	100	1.26	0.7	30.0	48.0	5000	0.7	1.0
Workpad Material	8	110	41	1.0	1.1	22.0	27.0	1270	0.1	1.0
Backfill Material	13	100	50	1.1	1.0	22.0	29.0	1830	0.1	1.0

LEGEND

W - initial moisture content

γ_d - initial dry density

S - degree of saturation

k_f - thermal conductivity in frozen state

k_u - thermal conductivity in unfrozen state

C_f - specific heat in frozen state

C_u - specific heat in unfrozen state

HFUS - latent heat of fusion

ALP - parameter which determines the shape of the curve of unfrozen moisture versus temperature

GAM - the fraction of the moisture which freezes at temperatures below 32°F

NOTES:

1 Latent heat varies as a function of temperature below 32°F. The listed values constitute the total extractable latent heat.

2 #1 Properties used for EPR calibration runs JV0301 and JV0477.
#2 Properties used for EPR calibration runs JV0640 and JV0647.

TABLE 3-2

BEST ESTIMATED "WARMEST" 25-YEAR AVERAGE CLIMATE
NORTH OF ATIGUN PASS

INPUT VALUES FOR EPR MODEL[1]

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Air Temp. (°F)	-13.3	-19.9	-17.4	-0.1	23.7	39.7	45.0	45.7	33.0	14.9	-1.5	-12.8
Solar Radiation (Btu/ft^2-D)	0	173	641	1408	1515	1983	1873	1172	625	240	0	0
Wind Speed (MPH)	17.1	14.8	15.3	12.6	13.6	12.1	11.9	12.2	14.5	15.7	16.5	14.6
Cloud Cover[2] (Fraction of sky covered)	0.76	0.60	0.56	0.61	0.85	0.81	0.80	0.87	0.88	0.82	0.76	0.76
Pre-Construction[3] Snow Depth (ft)	1.03	0.94	0.87	0.80	0.80	0	0	0	0.44	0.98	0.99	0.93
Snow Density[4] (gm/cm^3)	0.333	0.333	0.333	0.333	0.333	0	0	0	0.333	0.333	0.333	0.333
Evapotranspiration[5] (Btu/ft^2-D)	0	0	0	0	0	103	130	96	0	0	0	0

	Background Radiation (Btu/ft^2-hr):	RIR = 52
	Longwave Emissivity (Dimensionless):	EMS = 0.90, EMW = 0.95
NOTES:	Surface Roughness(ft):	HTCS = 0.5, HTCW = 0.05

1 The given values represent monthly means. For simulation purposes these are input as mid-month values.

2 No cloud cover data is available for November-January; the given values are averages of values for the nine months of the year for which there is data.

3 Mean annual snow appearance is estimated to occur on September 15 and disappearance on May 31.

4 No measured data available; values calculated from Bilello's correlation with mean winter wind speed.

5 Evapotranspiration is assumed to occur only in the absence of snow cover.

TABLE 3-3

BEST ESTIMATED "WARMEST" 25-YEAR AVERAGE CLIMATE
SOUTH OF ATIGUN PASS

INPUT VALUES FOR EPR MODEL[1]

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Air Temp. (°F)	-4.9	1.7	12.5	30.0	46.5	56.4	59.3	54.8	43.6	25.6	7.1	-5.1
Solar Radiation (Btu/ft^2-D)	114	267	727	1235	1707	2053	1706	1387	917	381	140	55
Wind Speed (MPH)	5.2	5.2	3.5	4.8	5.0	3.9	2.8	3.6	4.4	4.4	4.8	4.6
Cloud Cover (Fraction of sky covered)	0.47	0.63	0.58	0.75	0.73	0.72	0.81	0.78	0.72	0.79	0.68	0.66
Pre-Construction Snow Depth[2] (ft)	1.84	1.40	1.53	1.44	0	0	0	0	0	0.28	0.76	1.72
Snow Density (gm/cm^3)	0.170	0.173	0.182	0.202	0	0	0	0	0	0.119	0.125	0.163
Evapotranspiration[3] (Btu/ft^2-D)	0	0	0	0	116	187	192	136	68	0	0	0

Background Radiation (Btu/ft^2hr): RIR = 70
Surface Roughness (ft.): HTCS = 0.5, HTCW = 0.05
Longwave Emissivity (Dimensionless): EMS = 0.90, EMW = 0.95

NOTES:

1 The given values represent monthly means. For simulation purposes they are input as mid-month values.

2 Mean annual snow appearance is estimated to occur on October 1 and disappearance on April 22.

3 Simulated evapotranspiration occurs only in the absence of snow cover.

TABLE 3-4

ESTIMATED REPRESENTATIVE SURFACE COVER CHARACTERISTICS

Parameter	Workpad Embankment & Backfill	Undisturbed Organic Cover	Snow
Shortwave Absorptivity[1]	0.75	0.82	0.30
Longwave Emissivity	0.90	0.90	0.95
Evapotranspiration Factor	0.4	1.0	0.00
Surface Roughness (ft.)	0.2	0.5	0.05

NOTES:

[1] Absorptivity = 1 - Albedo

TABLE 3-5

INSULATION THERMAL PROPERTIES[1]

	W	γ_d	S	k_f	k_u	C_f	C_u	HFUS[2]	ALP[2]	GAM[2]
	(% dry wt)	(pcf)	(%)	(Btu/ft-hr-°F)		(Btu/ft³-°F)		(Btu/ft³)	(°F)	
Boardstock Insulation (polystyrene)	20%[3]	2.5	-	0.02	0.02	2.3	2.5	72	0.1	1.0

NOTES:

[1] See legend in Table 3-1 for explanation of terms.

[2] The EPR model requires input for the total extractable latent heat (HFUS) and for the parameters that govern the extraction of this latent heat as a function of temperature below 32.0°F (ALP and GAM).

[3] Calculated from the following: W (% dry wt) = (water content by % vol)/(γ_d/w). Water absorption for polystyrene assumed to be 0.8% by volume.

SOIL MODEL FOR ONE DIMENSIONAL RUNS
UNDISTURBED SOIL PROFILES

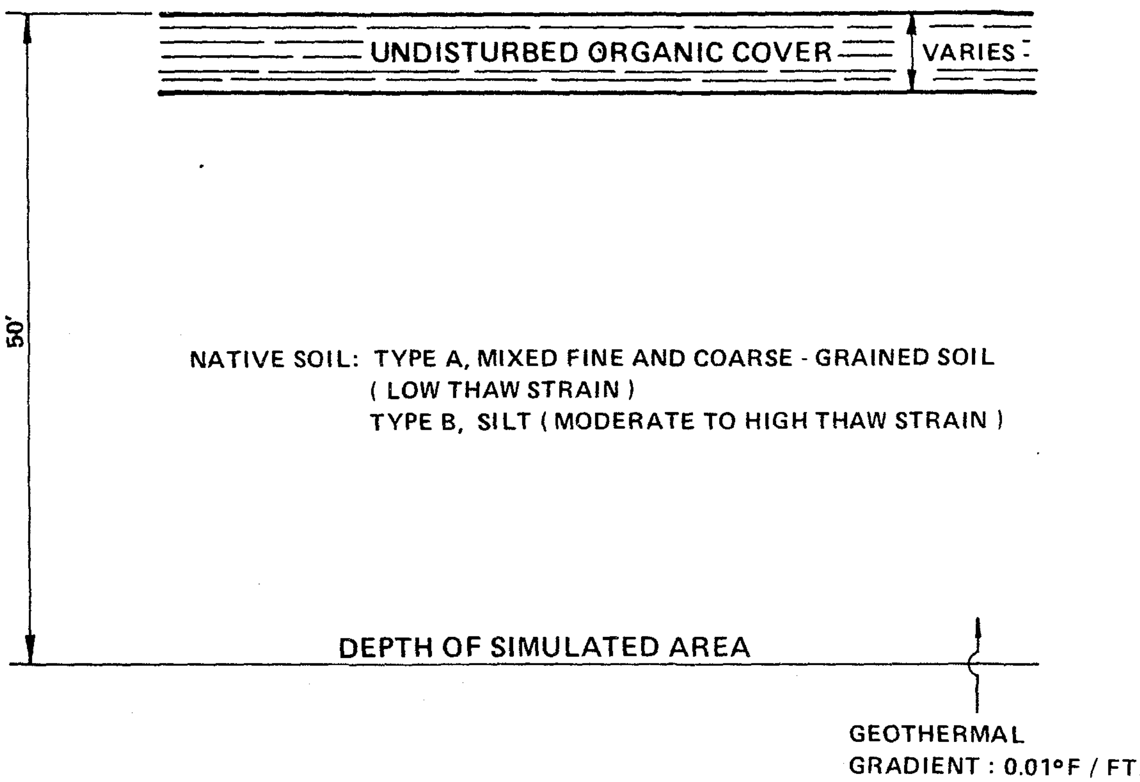


FIGURE 3 - 1

TABLE 4-1

SUMMARY OF COMPUTATIONS, NORTH OF ATIGUN PASS

DEPTH OF THAW BELOW PIPE BOTTOM AT CENTERLINE/MAXIMUM THAW DEPTH UNDER WORKPAD/SPOIL AREA[1], FT.

NO GROUND SURFACE INSULATION, 2.0 FT. THICK WORKPAD, DISTURBED SPOIL AREA, 4 YEAR DORMANT PERIOD, T_{gas} = 28°F.

Location	SOIL TYPE A: 4th Year of Dormant Period	SOIL TYPE A: 1st Year of Operation	SOIL TYPE A: 25th Year of Operation	SOIL TYPE A: Maximum Thaw (Yr. of Operation)	SOIL TYPE B: 4th Year of Dormant Period	SOIL TYPE B: 1st Year of Operation	SOIL TYPE B: 25th Year of Operation	SOIL TYPE B: Maximum Thaw (Yr. of Operation)
North of Atigun Pass,(2) away from Dalton Highway	0.0/4.5/6.3	6.0/5.0/7.3	0.0/10.1/9/4	0.0/10.1/9.4 (25th year)	0.0/1.5/3.0	0.0/2.3/3.0	0.0/2.8/3.0	0.0/2.8/3.0 (25th Year)
North of Atigun Pass and Adjacent to Dalton Hwy.(3) (SDFAC=300%)	0.0/3.0/-	0.0/3.0/-	0.0/3.0/-	0.0/3.0/- (25th year)	0.0/1.7/-	0.0/1.7/-	0.0/1.7/-	0.0/1.7/- (25th year)
North of Atigun Pass and Adjacent to Dalton Hwy.(4) (SDFAC=500%)	0.0/5.3/-	0.0/6.2/-	0.0/9.0/-	0.0/9.0/- (25th year)	0.0/3.0/-	0.0/3.7/-	0.0/4.5/-	0.0/4.5/- (25th year)

Notes:
(1) Depths of thaw under workpad and spoil area are with reference to original ground surface.
(2) Snow depths across construction zone surface = 150% of pre-construction depths. See Figures 4-7 through 4-17. Without disturbance to the spoil area the maximum thaw depths under the spoil area are 3.0 ft. and 1.6 ft. for soil types A and B, respectively.
(3) Snow depths on shoulder of Dalton Highway = 300% of pre-construction depths. See Figures 4-23 through 4-25 and 4-35 through 4-37.
(4) Snow depths on shoulder of Dalton Highway = 500% of pre-construction depths. See Figures 4-26 through 4-28 and 4-38 through 4-40.

TABLE 4-2

SUMMARY OF COMPUTATIONS, NORTH OF ATIGUN PASS

DEPTH OF THAW BELOW PIPE BOTTOM AT CENTERLINE/MAXIMUM THAW DEPTH UNDER WORKPAD/SPOIL AREA[1], FT.

3-INCH THICK GROUND SURFACE INSULATION, 2.0 FT. - THICK WORKPAD, DISTURBED SPOIL AREA, 4 YEAR DORMANT PERIOD, T_{gas} = 28°F.

Location Ground Surface Insulation Dimensions, (Snow Depth Factor)	SOIL TYPE A				SOIL TYPE B			
	4th Year of Dormant Period	1st Year of Operation	25th Year of Operation	Maximum Thaw (Yr. of Operation)	4th Year of Dormant Period	1st Year of Operation	25th Year of Operation	Maximum Thaw (Yr. of Operation)
North of Atigun Pass, 3"x 19' Insulation(2), (SDFAC=150%)	0.0/2.7/4.3	0.0/3.0/5.8	0.0/2.8/6.3	0.0/2.8/6.3 (25th year)	0.0/1.5/2.3	- (no figure)	- (10 year run only)	0.0/1.5/2.3 (10th year of Operation)
North of Atigun Pass and Adjacent to Dalton Hwy.,(3) 3"x44' Insulation(3), (SDFAC=300%)	0.0/1.5/ -	0.0/1.3/ -	0.0/0.0/ -	0.0/0.0/ - (25th year)	0.0/1.0/ -	0.0/0.8/ -	0.0/0.8/ -	0.0/1.0/ - (4th year of Dormant Period)
North of Atigun Pass and Adjacent to Dalton Hwy.,(4) 3"x44' Insulation(4), (SDFAC=500%)	0.0/2.0/ -	0.0/2.0/ -	0.0/2.0/ -	0.0/2.0/ - (25th year)	0.0/1.2/ -	0.0/1.2/ -	0.0/1.2/ -	0.0/1.2/ - (25th year)

Notes:
(1) Depths of thaw under workpad and spoil area are with reference to original ground surface.
(2) Snow depths across construction zone = 150% of pre-construction depths. Disturbed spoil area, see Figures 4-18 through 4-22.
(3) Snow depths on shoulder of Dalton Highway = 300% of pre-construction depths. See Figures 4-29, 4-30, 4-41, 4-42, 4-43.
(4) Snow depths on shoulder of Dalton Highway = 500% of pre-construction depths. See Figures 4-32, 4-33, 4-34, 4-44, 4-45, 4-46.

TABLE 4-3

AVERAGE SOIL TEMPERATURE BESIDE THE PIPELINE - NORTH OF ATIGUN PASS *
DURING 4th YEAR OF DORMANT PERIOD AND 1st YEAR OF OPERATION
SOIL TYPE A - RUN NO. JV0657

DORMANT PERIOD 4th YEAR

MONTH	AVERAGE GROUND SURFACE TEMPERTURE, (°F)**	MONTHLY AVERAGE SOIL TEMPERATURE (°F) AT EACH DEPTH (FT.) ***								
		2.0	2.5	3.0	3.6	4.4	5.0	5.6	6.4	7.0
NOVEMBER	20.15	31.15	31.78	31.88	31.88	31.84	31.80	31.76	31.70	31.65
DECEMBER	18.17	30.83	31.20	31.49	31.67	31.73	31.72	31.70	31.67	31.64
JANUARY	14.70	29.57	30.03	30.47	30.93	31.34	31.44	31.49	31.52	31.53
FEBRUARY	13.09	27.71	28.16	28.61	29.15	29.82	30.24	30.56	30.82	30.96
MARCH	16.55	27.00	27.31	27.63	28.01	28.50	28.85	29.18	29.57	29.83
APRIL	24.80	28.64	28.76	28.88	29.03	29.24	29.40	29.55	29.75	29.89
MAY	42.92	31.49	31.35	31.27	31.32	31.20	31.14	31.09	31.04	31.02
JUNE	48.23	31.98	31.73	31.57	31.43	31.53	31.42	31.36	31.32	31.29
JULY	47.01	32.24	31.94	31.78	31.62	31.48	31.40	31.49	31.43	31.40
AUGUST	33.31	32.02	31.94	31.86	31.77	31.68	31.75	31.65	31.57	31.52
SEPTEMBER	31.74	31.97	31.94	31.88	31.82	31.84	31.78	31.72	31.64	31.60
OCTOBER	29.50	31.92	31.88	31.84	31.73	31.59	31.51	31.45	31.40	31.38

OPERATION PERIOD - 1st YEAR

MONTH	AVERAGE GROUND SURFACE TEMPERTURE, (°F)**	MONTHLY AVERAGE SOIL TEMPERATURE (°F) AT EACH DEPTH (FT.)***								
		2.0	2.5	3.0	3.6	4.4	5.0	5.6	6.4	7.0
NOVEMBER	19.72	30.70	30.97	31.07	31.05	30.96	30.90	30.87	30.87	30.90
DECEMBER	17.67	29.75	30.12	30.41	30.61	30.64	30.62	30.61	30.64	30.68
JANUARY	13.96	27.87	28.30	28.71	29.18	29.68	29.87	30.00	30.15	30.25
FEBRUARY	12.32	26.87	27.28	27.75	28.33	28.70	29.02	29.33	29.54	29.68
MARCH	16.12	26.38	26.69	26.99	27.32	27.74	28.02	28.27	28.59	28.82
APRIL	24.46	28.04	28.15	28.26	28.39	28.55	28.68	28.81	28.99	29.13
MAY	42.92	30.24	30.05	30.45	30.24	30.04	29.96	29.92	29.92	29.95
JUNE	48.22	31.07	30.73	30.46	30.17	30.42	30.27	30.19	30.18	30.19
JULY	46.98	31.46	31.14	30.83	30.48	30.16	30.57	30.37	30.33	30.33
AUGUST	33.28	30.85	30.77	30.66	31.05	30.67	30.67	30.55	30.49	30.48
SEPTEMBER	31.74	31.10	31.07	31.01	30.92	30.75	30.65	30.57	30.53	30.53
OCTOBER	38.99	30.88	30.90	30.87	30.79	30.66	30.58	30.53	30.50	30.51

* BETWEEN PIPE DITCH WALL AND ABOUT 8 FT. FROM DITCH WALL.
** AVERAGE OF SURFACE TEMPERATURES BETWEEN EDGE OF PIPE DITCH AND ABOUT 8 FT. FROM DITCH EDGE.
*** DEPTH AS MEASURED FROM TOP OF WORKPAD. 2.0 FT. REPRESENTS BOTTOM OF BOARDSTOCK INSULATION AND 5.0 FT. REPRESENTS HORIZONTAL PIPE CENTERLINE.

TABLE 4 - 4

AVERAGE SOIL TEMPERATURE BESIDE THE PIPELINE - NORTH OF ATIGUN PASS *
DURING 4th YEAR OF DORMANT PERIOD AND 1st YEAR OF OPERATION
SOIL TYPE B - RUN NO. JV0651

DORMANT PERIOD 4th YEAR

MONTH	AVERAGE GROUND SURFACE TEMPERTURE, (°F)**	MONTHLY AVERAGE SOIL TEMPERATURE (°F) AT EACH DEPTH (FT.)*** 2.0	2.5	3.0	3.6	4.4	5.0	5.6	6.4	7.0
NOVEMBER	19.49	30.81	31.23	31.36	31.36	31.28	31.20	31.13	31.04	30.97
DECEMBER	17.34	29.68	30.26	30.70	30.89	30.95	30.95	30.94	30.91	30.88
JANUARY	13.47	27.74	28.44	29.10	29.70	30.14	30.32	30.43	30.53	30.59
FEBRUARY	11.15	25.05	25.72	26.36	27.09	27.97	28.46	28.88	29.30	29.56
MARCH	14.64	24.39	24.85	25.31	25.84	26.51	26.97	27.40	27.92	28.51
APRIL	23.36	26.55	26.71	26.88	27.09	27.38	27.61	27.83	28.12	28.33
MAY	42.90	30.55	30.78	30.41	30.22	30.02	29.91	29.83	29.76	29.73
JUNE	48.23	31.56	31.13	30.95	30.99	30.74	30.62	30.52	30.41	30.34
JULY	47.02	31.86	31.44	31.18	31.38	30.91	30.82	30.74	30.64	30.58
AUGUST	33.31	31.79	31.65	31.49	31.53	31.24	31.09	30.98	30.86	30.78
SEPTEMBER	31.72	31.84	31.80	31.71	31.57	31.37	31.22	31.11	30.99	30.91
OCTOBER	29.04	31.57	31.59	31.50	31.36	31.12	30.97	30.86	30.78	30.73

OPERATION PERIOD - 1st YEAR

MONTH	AVERAGE GROUND SURFACE TEMPERTURE, (°F)**	MONTHLY AVERAGE SOIL TEMPERATURE (°F) AT EACH DEPTH (FT.)*** 2.0	2.5	3.0	3.6	4.4	5.0	5.6	6.4	7.0
NOVEMBER	19.22	30.12	30.53	30.66	30.62	30.48	30.39	30.32	30.31	30.32
DECEMBER	17.04	28.92	29.50	29.93	30.10	30.11	30.09	30.07	30.08	30.11
JANUARY	13.16	27.00	27.69	28.33	28.90	29.33	29.48	29.59	29.21	29.79
FEBRUARY	11.05	25.03	25.69	26.31	26.99	27.75	28.16	28.50	28.84	29.06
MARCH	17.39	25.02	25.48	25.93	26.43	27.02	27.39	27.71	28.09	28.35
APRIL	23.63	27.03	27.19	27.60	27.55	27.79	27.96	28.13	28.34	28.50
MAY	42.90	28.83	29.55	29.83	29.60	29.37	29.28	29.22	29.21	29.23
JUNE	48.22	30.78	30.28	29.98	30.17	29.82	29.93	29.59	29.54	29.53
JULY	46.99	31.07	30.56	30.16	29.78	29.89	29.76	29.68	29.64	29.64
AUGUST	33.28	30.52	30.38	30.21	29.98	30.17	30.00	29.88	29.81	29.79
SEPTEMBER	31.72	30.41	30.33	30.18	30.50	30.23	30.07	29.96	29.90	29.88
OCTOBER	28.28	30.60	30.63	30.57	30.43	30.21	30.08	29.98	29.93	29.91

* BETWEEN PIPE DITCH WALL AND ABOUT 8 FT. FROM DITCH WALL.
** AVERAGE OF SURFACE TEMPERATURES BETWEEN EDGE OF PIPE DITCH AND ABOUT 8 FT. FROM DITCH EDGE.
*** DEPTH AS MEASURED FROM TOP OF WORKPAD. 2.0 FT. REPRESENTS BOTTOM OF BOARDSTOCK INSULATION AND 5.0 FT. REPRESENTS HORIZONTAL PIPE CENTERLINE.

TABLE 4-5

COMPARISON OF TWO DIFFERENT SETS OF CALIBRATED INPUT FOR THE SAME MINERAL SOIL TYPE AND BASE CLIMATE

	Refer to Figure 4-3	Refer to Figure 4-5
Organic Layer Thickness (ft)	1.5	2.0
Organic C_f, C_u (Btu/ft^3-°F)	19, 25	19, 25
Organic K_f, K_u (Btu/ft-hr-°F)	0.54, 0.09	0.7, 0.1
Latent Heat of Organics (Btu/ft^3)	2300	3000
Snow Depth Factor*	75% (or 0.75)	90% (or 0.90)
Snow Density Factor**	125% (or 1.25)	145% (or 1.45)
Average Annual Equilibrium Soil Temperature at 8' Depth	31.59°F	31.49°F

*Snow depth factor (SDFAC) is simply a multiplier which acts on each monthly input value of snow depth [for example, March snow depth = 1.53 ft. (input value) x 0.75 (SDFAC) = 1.15 ft.] prior to heat transfer calculation.

**Snow density factor (SRFAC) is simply a multiplier which acts on each monthly input value of snow density [for example, March snow density = 0.182 (input value) x 1.25 (SRFAC) = 0.228] prior to heat transfer calculations.

TABLE 4-6

SUMMARY OF COMPUTATIONS, SOUTH OF ATIGUN PASS

DEPTH OF THAW BELOW PIPE BOTTOM AT CENTERLINE/MAXIMUM THAW DEPTH UNDER WORKPAD/SPOIL AREA(1), FT.

NO GROUND SURFACE INSULATION, 2.5 FT. THICK WORKPAD, 4 YEAR DORMANT PERIOD, T_{gas} = 28°F, 28±1.6°F.

Workpad Location, Spoil Area Condition, (Snow Depth Factor)	SOIL TYPE A 4th Year of Dormant Period	 1st Year of Operation	 25th Year of Operation	 Maximum Thaw (Yr. of Operation)	SOIL TYPE B 4th Year of Dormant Period	 1st Year of Operation	 25th Year of Operation	 Maximum Thaw (Yr. of Operation)
Workpad at Ditch(2) Edge, Disturbed Spoil Area, (SDFAC=70%, 90%)	9.8/14.5/18.2	- / 17.5/19.5	28.3/ - /42.5	28.3/ - /42.5 (25th year)	4.6/9.0/10.0	0.0/9.8/11.2	0.0/25.5/23.7	0.0/25.5/23.7 (25th year)
Workpad at Ditch(3) Edge, Disturbed Spoil Area, (SDFAC=150%)	-	-	-	-	4.8/10.2/11.2	0.0/11.0/11.3	0.0/26.5/26.0	0.0/26.5/26.0 (25th year)
Workpad at Ditch(4) Edge, No Disturbed Spoil Area, (SDFAC=70%, 75%)	7.5/14.5/2.3	0.0/16.5/2.5	0.0/>42.5/2.5	0.0/>42.5/2.5 (25th year)	4.3/8.9/0.9	0.0/10.2/2.3	0.0/23.8/2.3	0.0/23.8/2.3 (25th year)
Workpad at 16 ft.(5) From Edge of Ditch, Disturbed Spoil Area, (SDFAC=75%)	-	-	-	- [1 yr. Dormant Pr.	4.8/9.8/10.7 0.0/3.8/5.7	0.0/11.0/11.3 0.0/5.8/7.3	0.0/26.3/24.8 0.0/23.2/22.3	0.0/26.3/24.8 0.0/23.2/22.3] (25th year)

Notes:
(1) Depths of thaw under workpad and spoil area are with reference to original ground surface.
(2) Snow depths across construction zone same as snow depths required to establish pre-construction calibrations for soil type A (SDFAC=70%) and soil type B (SDFAC=90%). See Figures 4-50 through 4-55.
(3) Snow depths across construction zone = 150% of calibrated snow depths for soil type B. Soil type A not analyzed. See Figures 4-56 through 4-58.
(4) Snow depths across construction zone = 70% of pre-construction depths for soil type A and 75% for soil type B. See Figures 4-59 through 4-64.
(5) Snow depths across construction zone = 75% of pre-construction depths for soil type B. Soil type A not analyzed. See Figures 4-65 through 4-67.

TABLE 4-7

SUMMARY OF COMPUTATIONS, SOUTH OF ATIGUN PASS

DEPTH OF THAW BELOW PIPE BOTTOM AT CENTERLINE/MAXIMUM THAW DEPTH UNDER WORKPAD/SPOIL AREA[1], FT.

GROUND SURFACE INSULATION, 2.5 FT. THICK WORKPAD, 4 YEAR DORMANT PERIOD, T_{gas} = 28°F.

Ground Surface Insulation Dimensions, (Snow Depth Factor)	SOIL TYPE A				SOIL TYPE B			
	4th Year of Dormant Period	1st Year of Operation	25th Year of Operation	Maximum Thaw (Yr. of Operation)	4th Year of Dormant Period	1st Year of Operation	25th Year of Operation	Maximum Thaw (Yr of Operation)
4"x24' Board (2)(4) stock Insulation, (SDFAC=70%, 75%)	-	-	-	-	0.0/8.5/11.0	-	-	-
6"x11' Board- (2) (5) stock Insulation, (SDFAC=70%, 75%)	7.0/14.5/18.0	0.0/17.5/19.0	26.0/>45/42.2	26.0/>45/42.2 (25th year)	1.5/8.8/10.7	0.0/9.3/10.3	0.0/25.0/24.0	0.0/25.0/24.0 (25th year)
6"x24' Board- (2) (6) stock Insulation, (SDFAC=70%, 75%)	0.6/13.8/18.0	0.0/16.2/18.7	0.0/>45/42.5	0.0/>45/42.5 (25th year)	0.0/8.7/10.8	0.0/9.3/10.3	0.0/25.2/22.7	0.0/25.2/22.7 (25th year)
6"x24' Board- (3)(7) stock Insulation, (SDFAC=150%)	-	-	-	-	0.0/9.0/10.8	0.0/10.3/11.2	0.0/22.0/26.0	0.0/22.0/26.0 (25th year)
6"x50' Board- (2)(8) stock Insulation, (SDFAC=70%, 75%)	0.0/14.8/14.3	0.0/17.0/16.3	0.0/>45/35.7	0.0/>45/35.7 (25th year)	0.0/8.8/9.0	0.0/10.7/10.3	0.0/26.2/16.5	0.0/26.2/16.5 (25th year)

Notes: (1), (2), and (3) same as on Table 4-5.
(4) See Figure 4-71.
(5) See Figures 4-72 through 4-74 and 4-84 through 4-86.
(6) See Figures 4-75 through 4-77 and 4-87 through 4-89.
(7) See Figures 4-78 through 4-80.
(8) See Figures 4-81 through 4-83 and 4-90 through 4-92.

PRECONSTRUCTION SOIL TEMPERATURE PROFILE
EPR RUN NO. JV0634
NORTH OF ATIGUN PASS

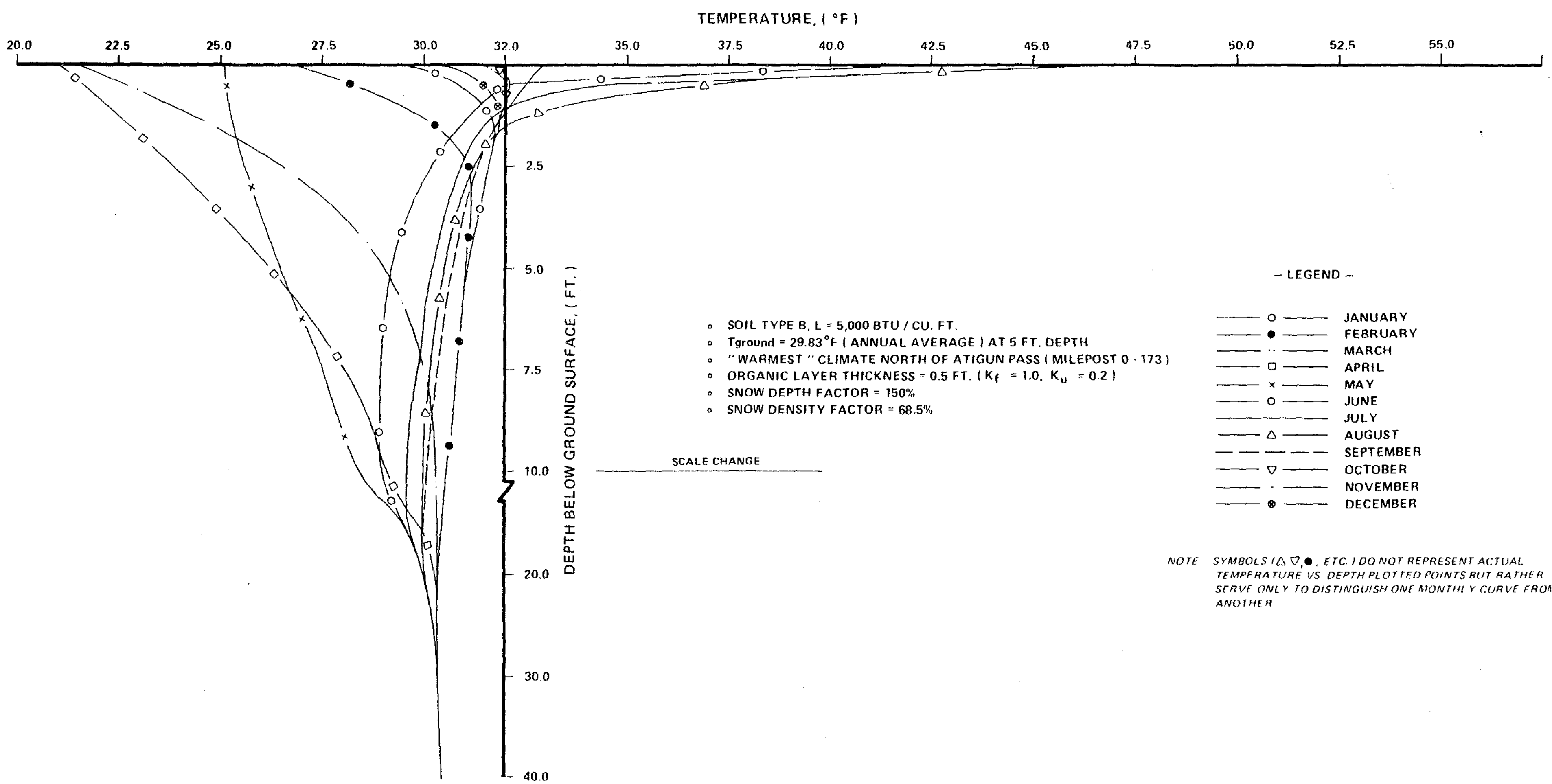


FIGURE 4 - 1

FIGURE 4-2

PRECONSTRUCTION SOIL TEMPERATURE PROFILE
EPR RUN NO. JV0635
NORTH OF ATIGUN PASS

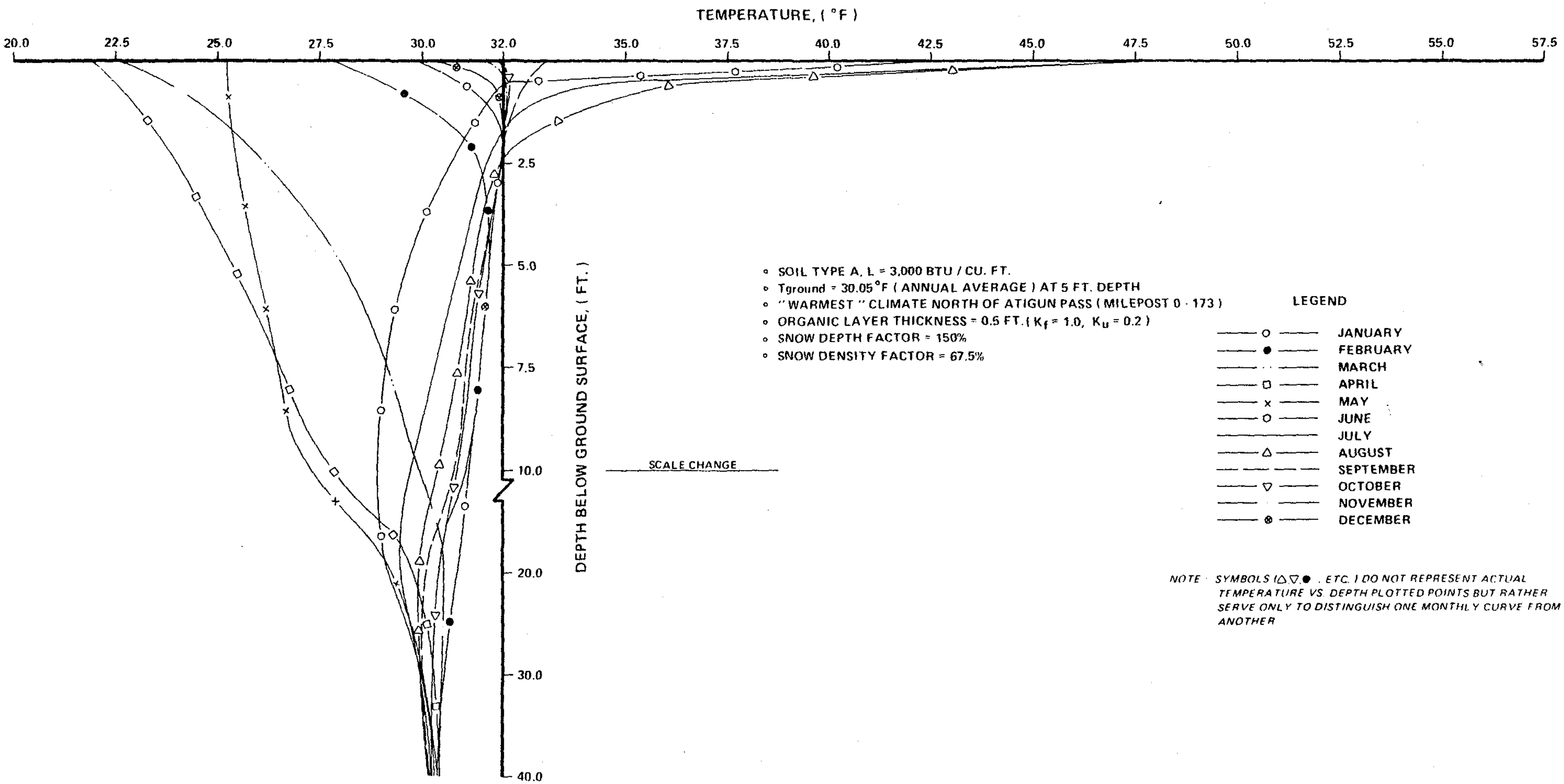
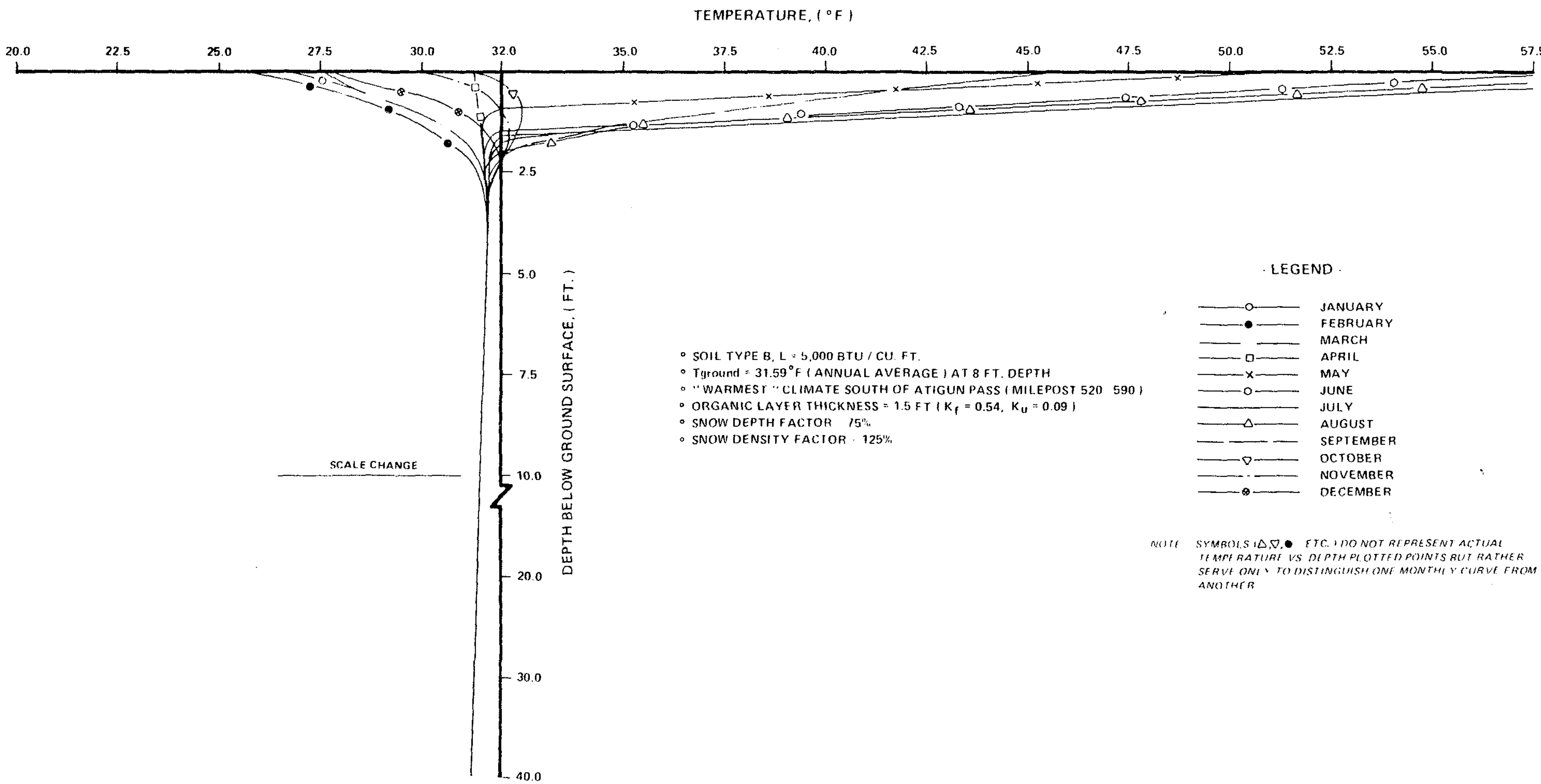


FIGURE 4-3

PRECONSTRUCTION SOIL TEMPERATURE PROFILE
EPR RUN NO. JV0301
SOUTH OF ATIGUN PASS



WA

THAW MITIGATION THERMAL

FIGURE 4 - 4

PRECONSTRUCTION SOIL TEMPERATURE PROFILE
EPR RUN NO. JV0477
SOUTH OF ATUGUN PASS

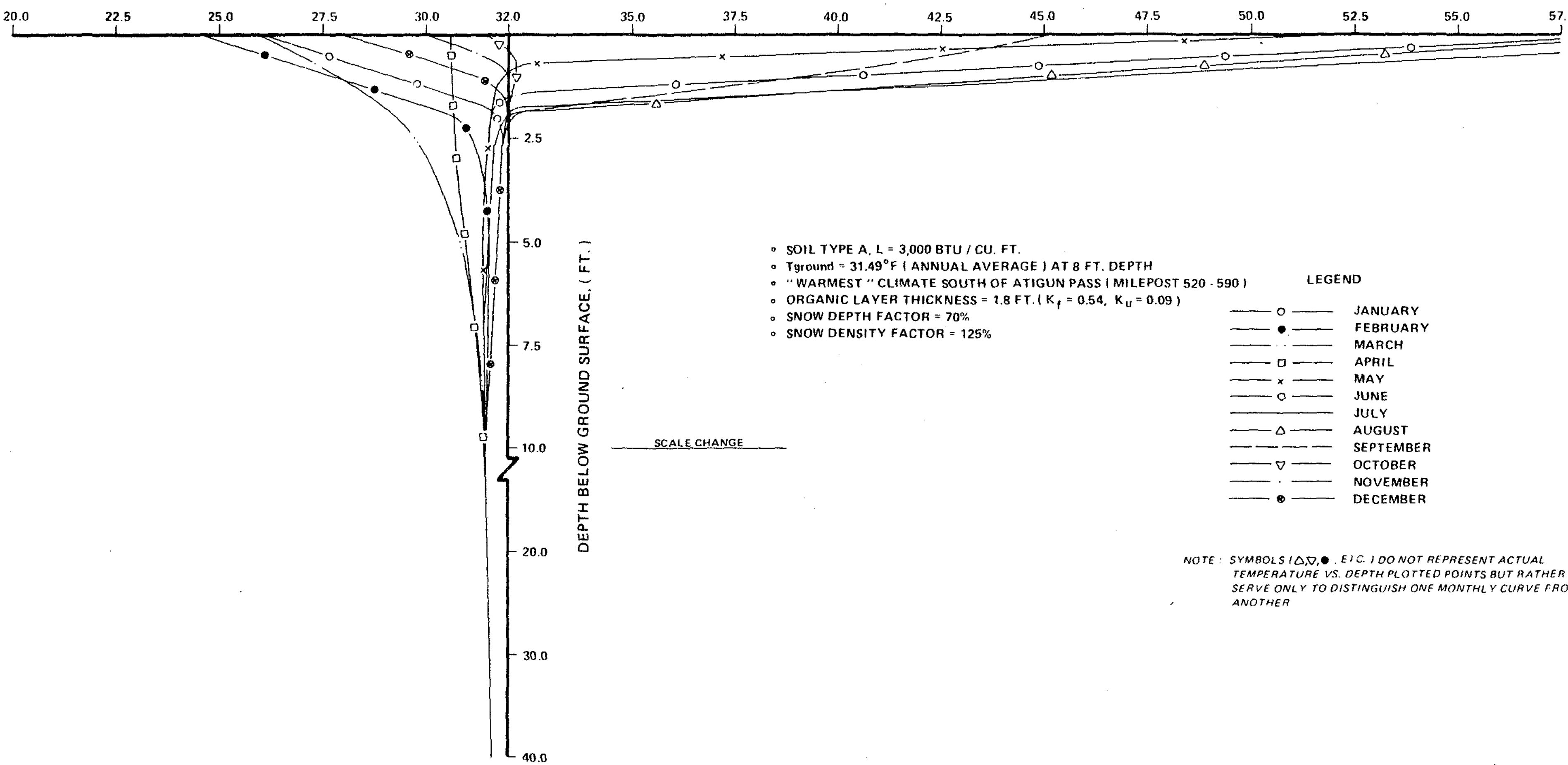
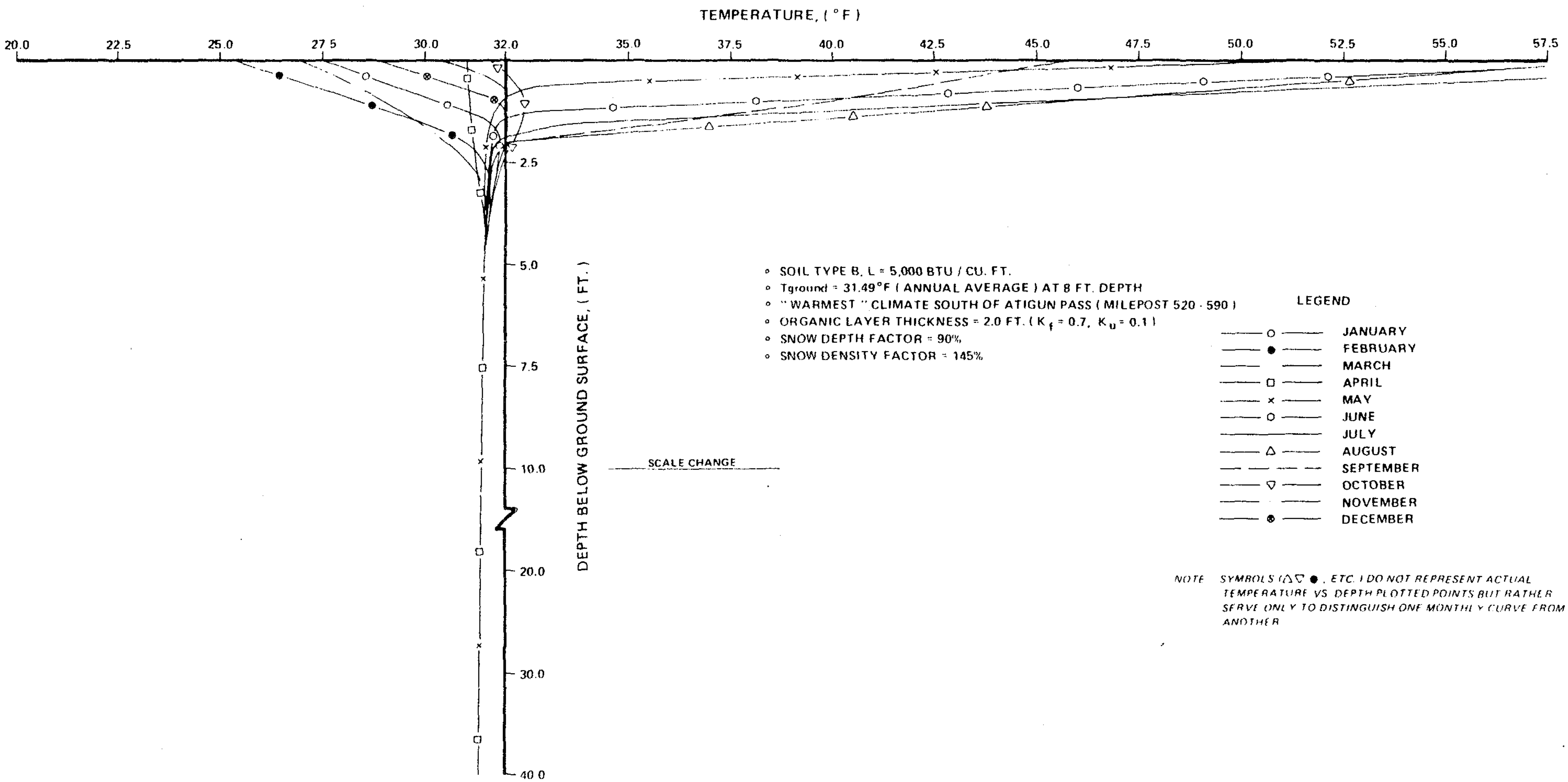


FIGURE 4-5

PRECONSTRUCTION SOIL TEMPERATURE PROFILE
EPR RUN NO. JV0640
SOUTH OF ATIGUN PASS



PRECONSTRUCTION SOIL TEMPERATURE PROFILE
EPR RUN NO. JV0647
SOUTH OF ATIGUN PASS

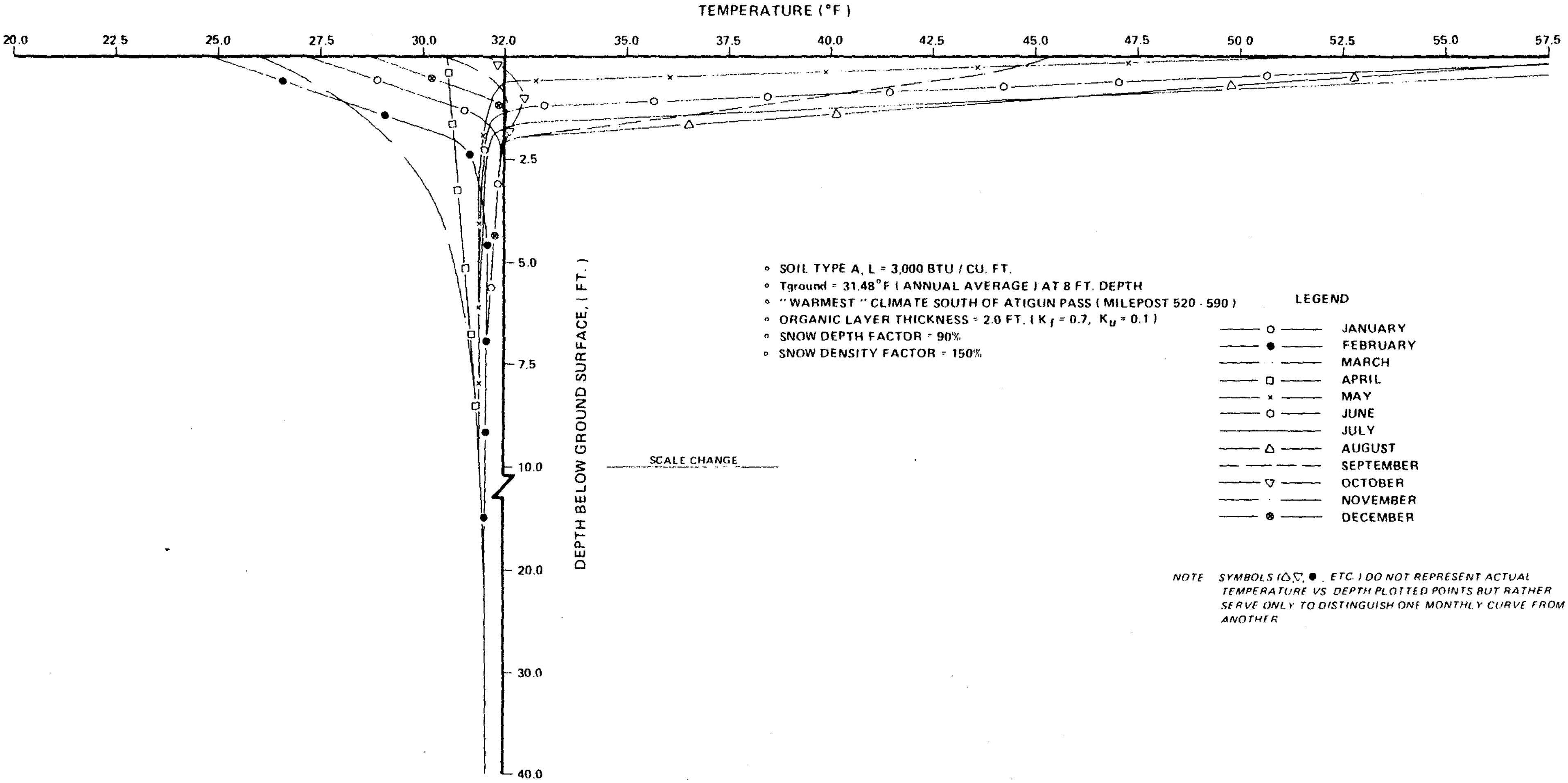


FIGURE 4-6

NA

THAW MITIGATION THERMAL

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD
RUN NO. JV 0832

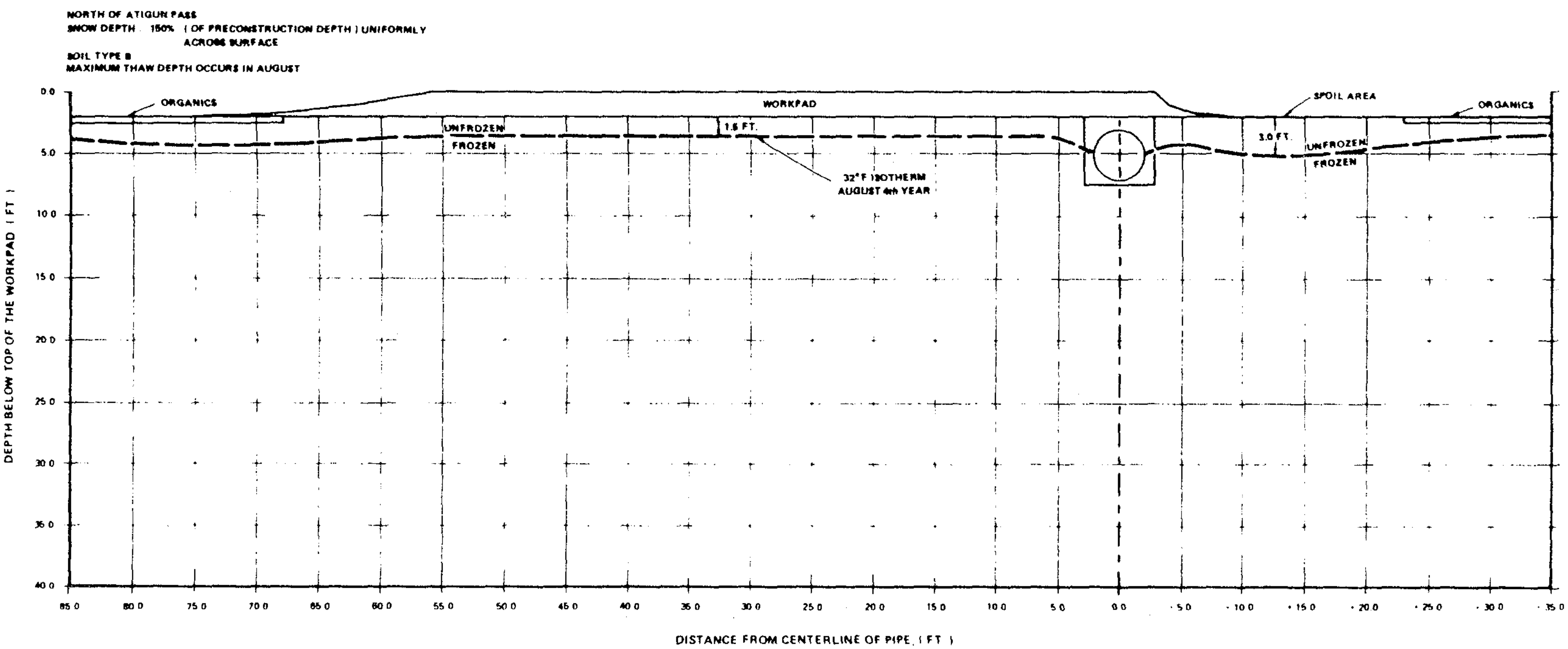
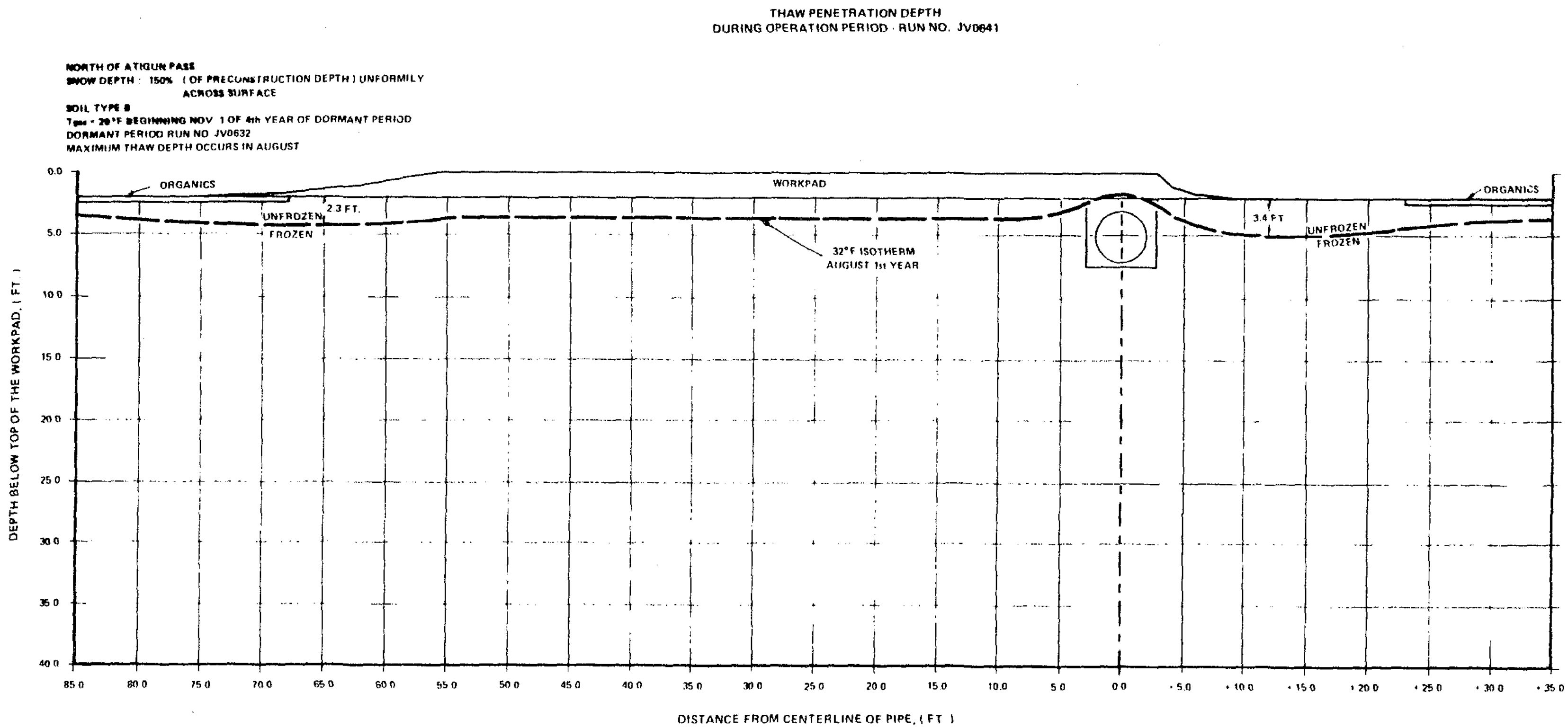


FIGURE 4 - 7

THAW MITIGATION THERMAL

FIGURE 4 - 8



WA

THAW MITIGATION THERMAL

FIGURE 4 - 9

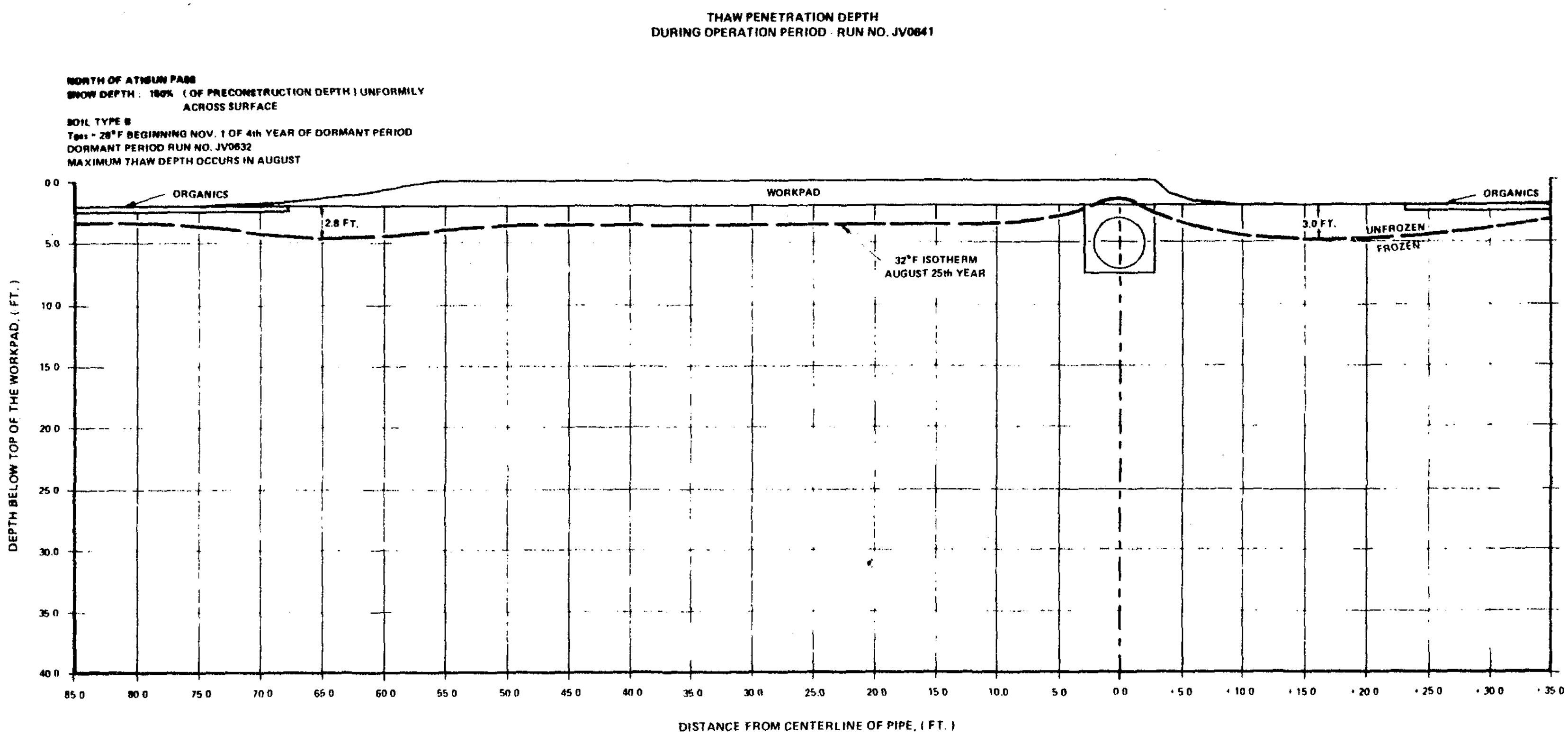


FIGURE 4 - 10

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO. JV0652

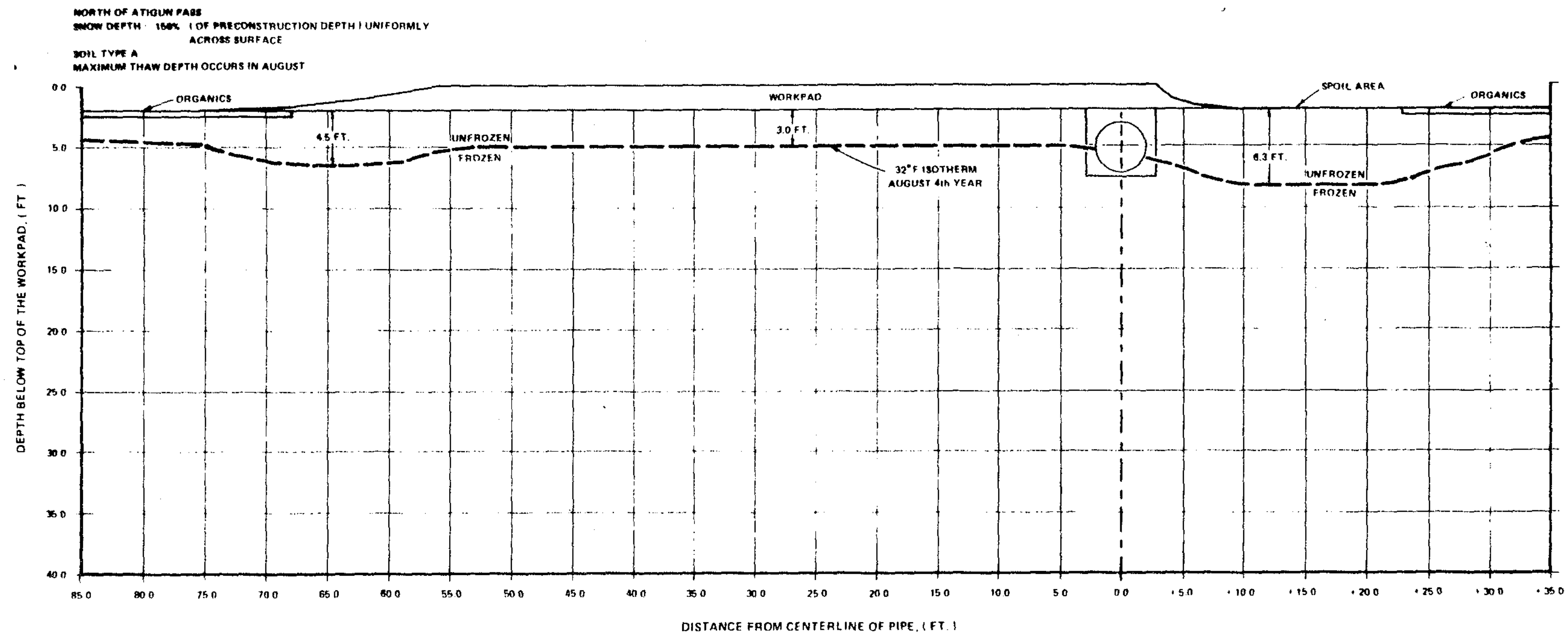
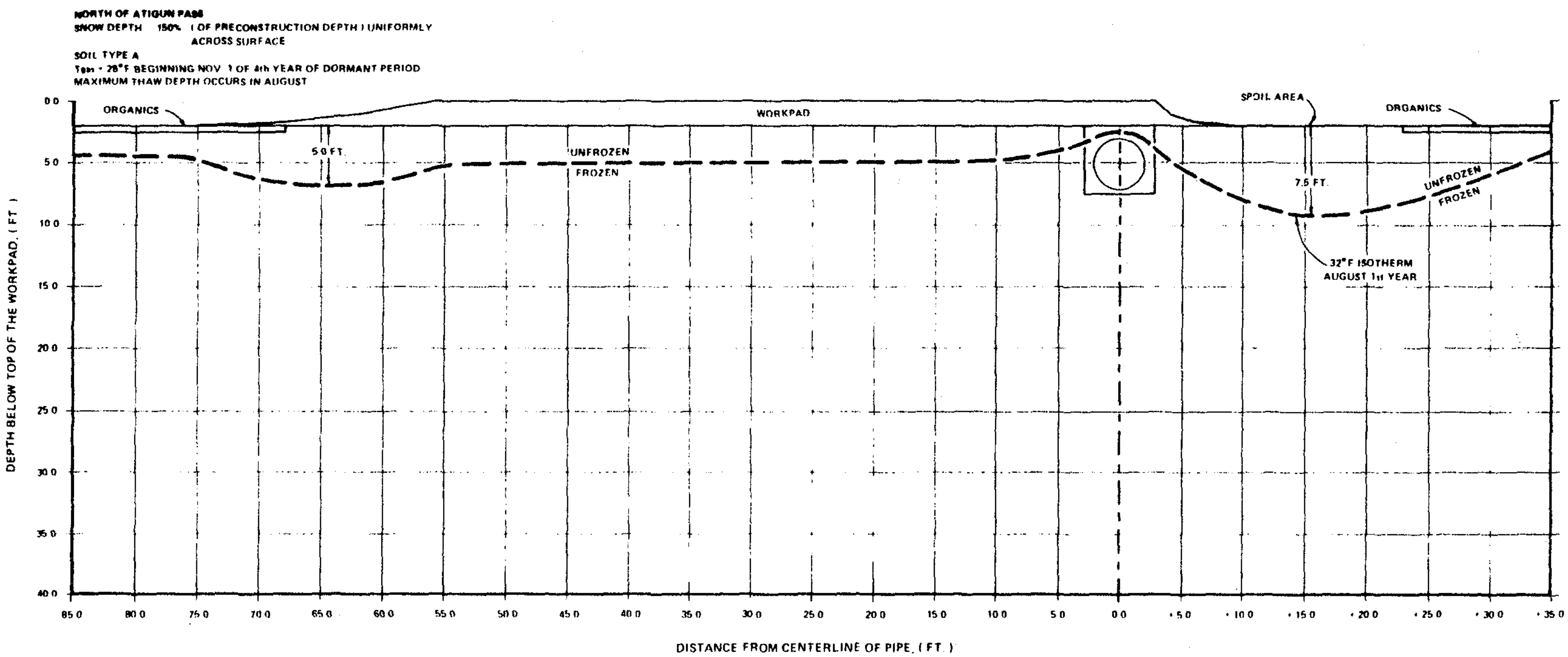


FIGURE 4 - 11

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0852



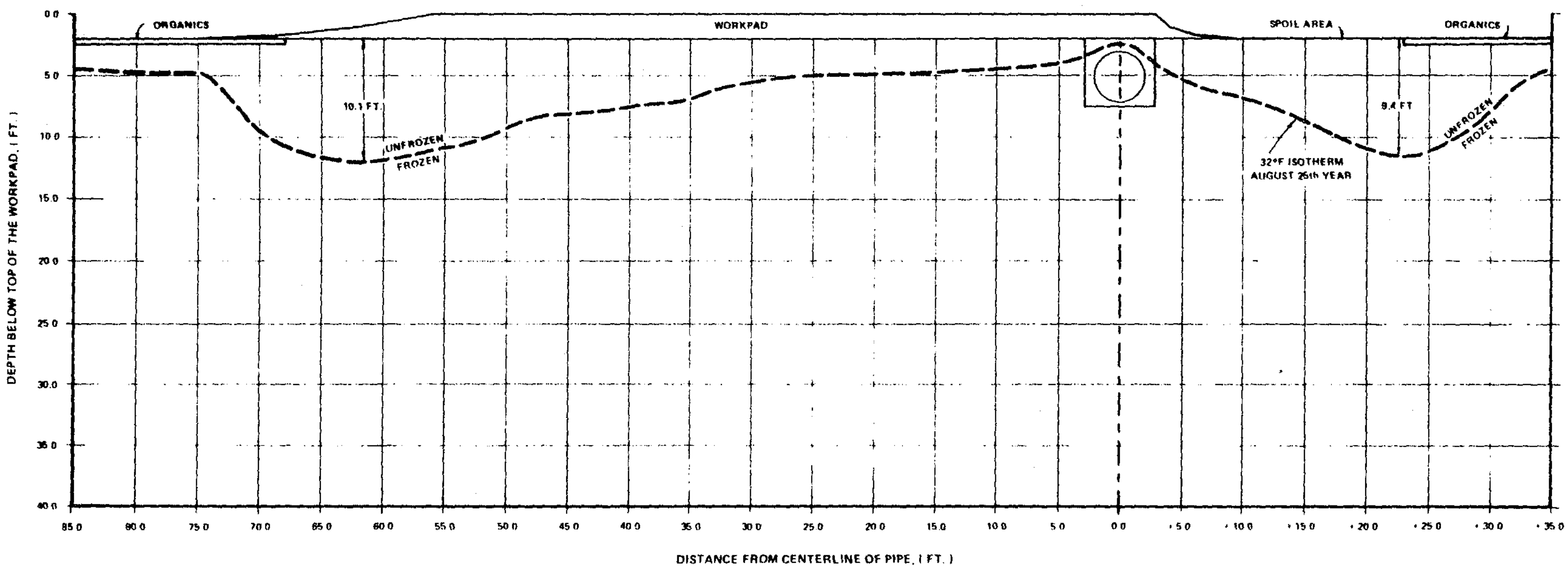
NA

THAW MITIGATION THERMAL

FIGURE 4 - 12

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0662

NORTH OF ATIGUN PASS
SNOW DEPTH : 150% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
T... = 20°F BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST



IWA

THAW MITIGATION THERMAL

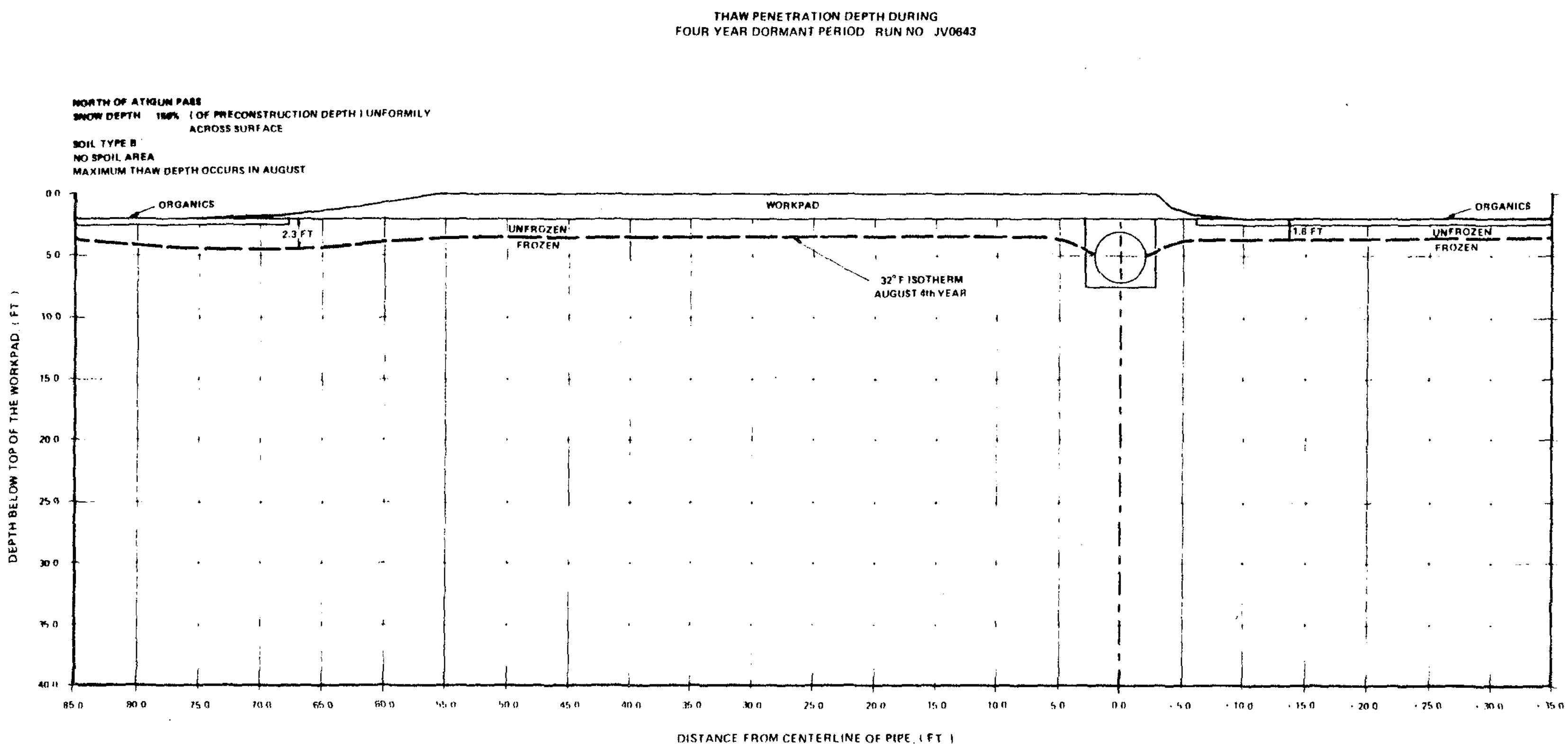


FIGURE 4 - 13

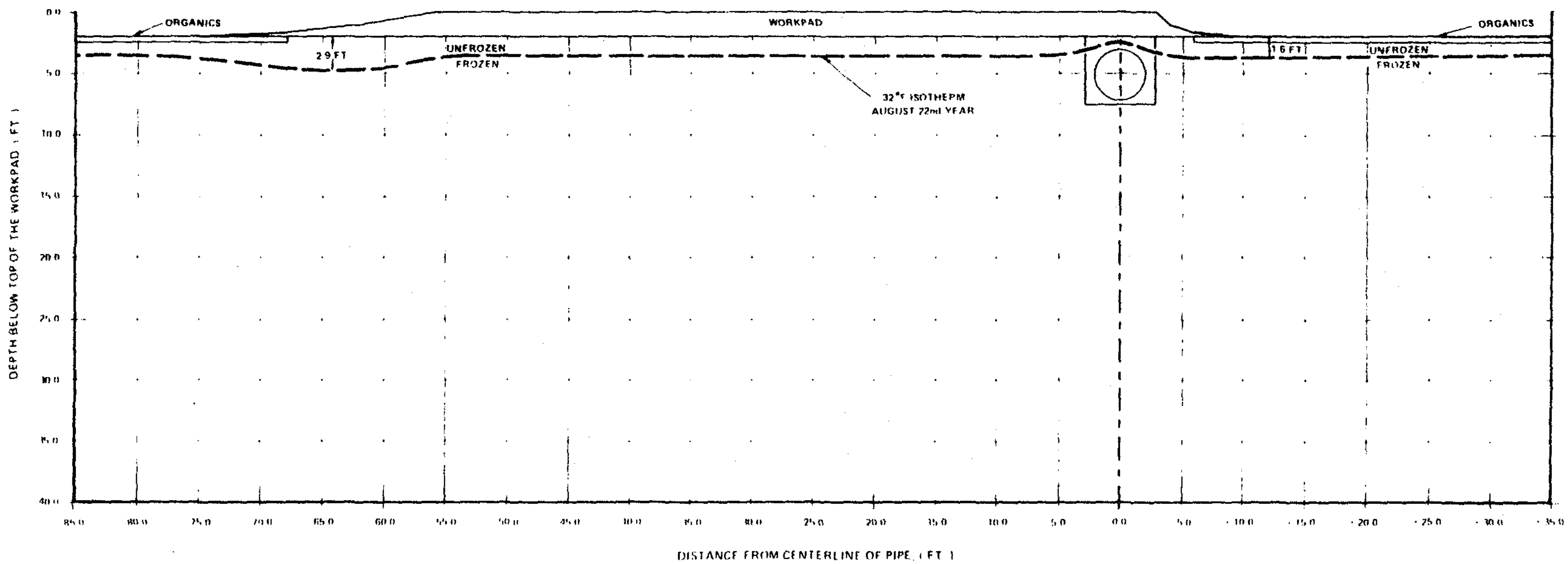
WA

THAW MITIGATION THERMAL

FIGURE 4 - 14

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0643

NORTH OF ATIGUN PASS
SNOW DEPTH 150% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
NO SPOIL AREA
Tgas ~ 28°F BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST



NA

THAW MITIGATION THERMAL

FIGURE 4 - 15

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0653

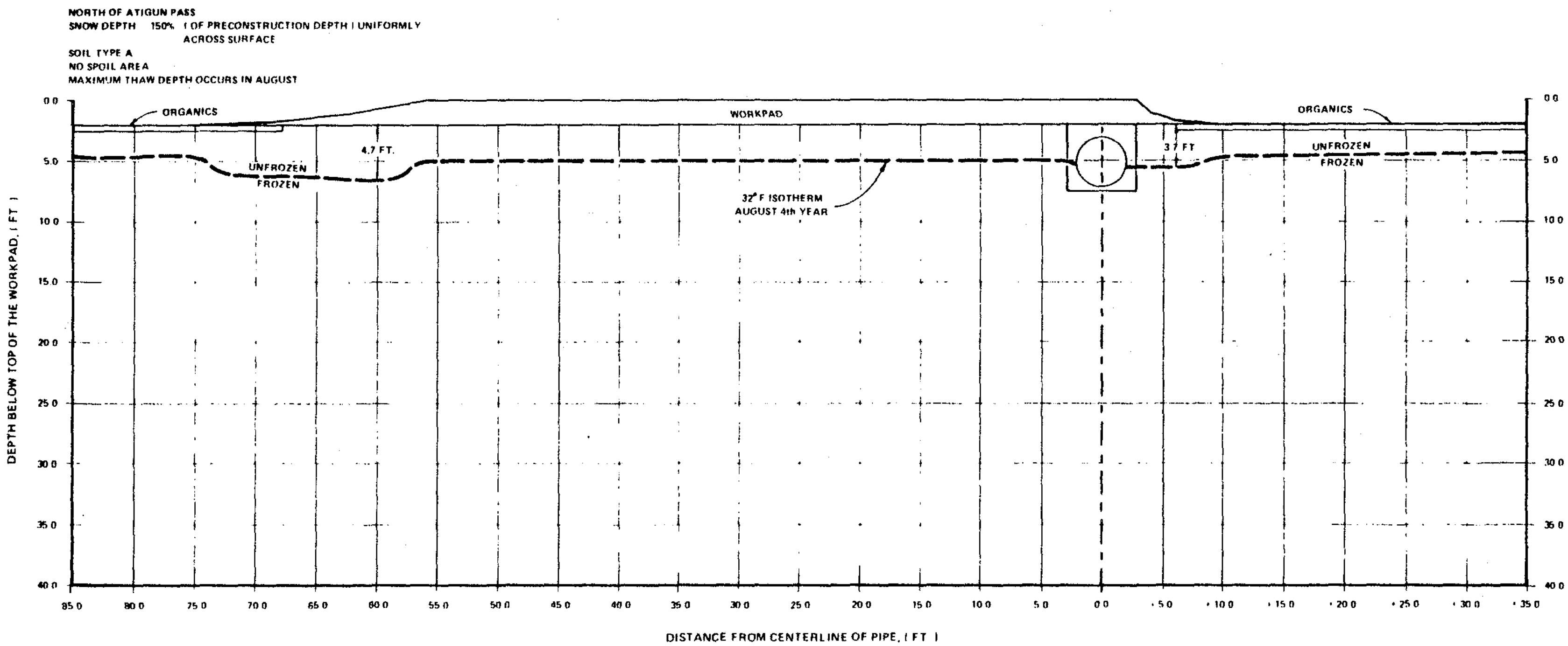
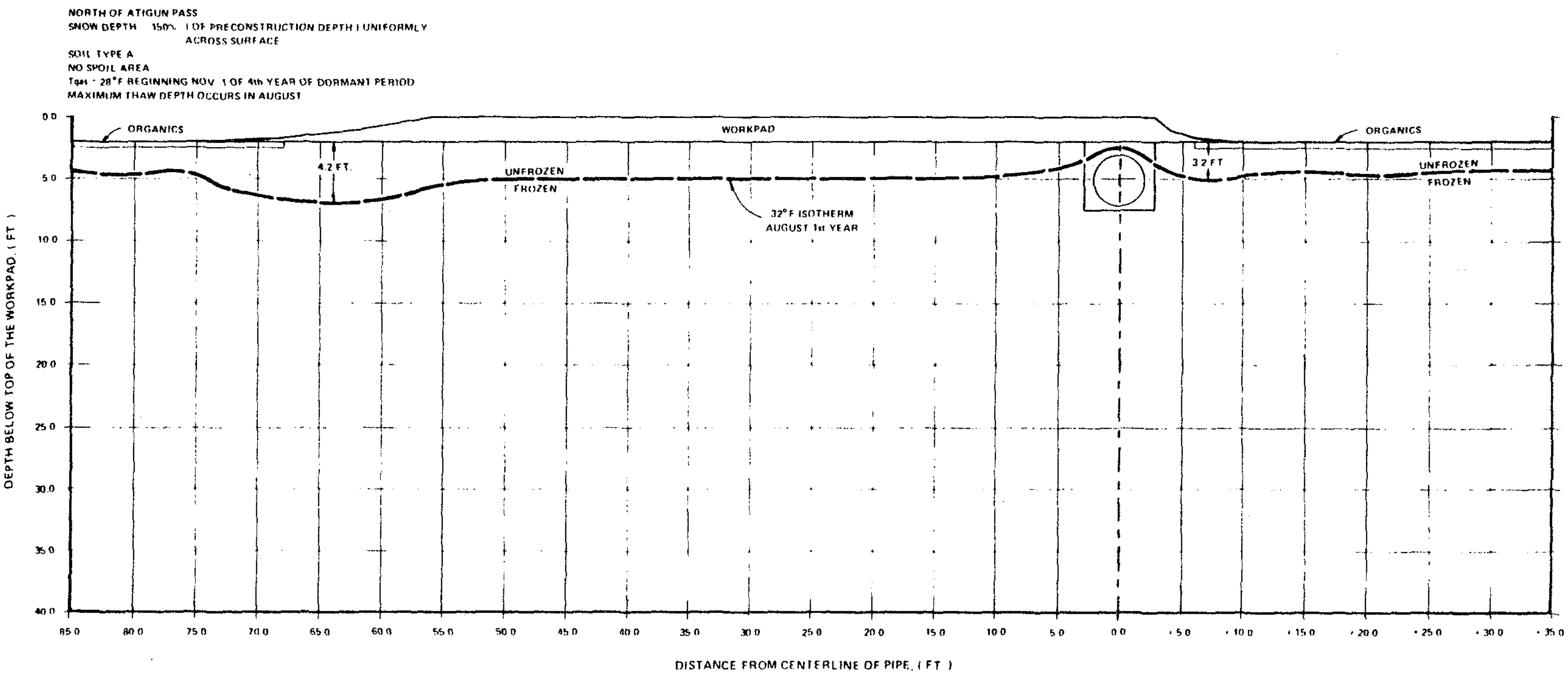


FIGURE 4 - 16

THAW PENETRATION DEPTH
DURING OPERATION PERIOD · RUN NO. JV0653



NA

THAW MITIGATION THERMAL

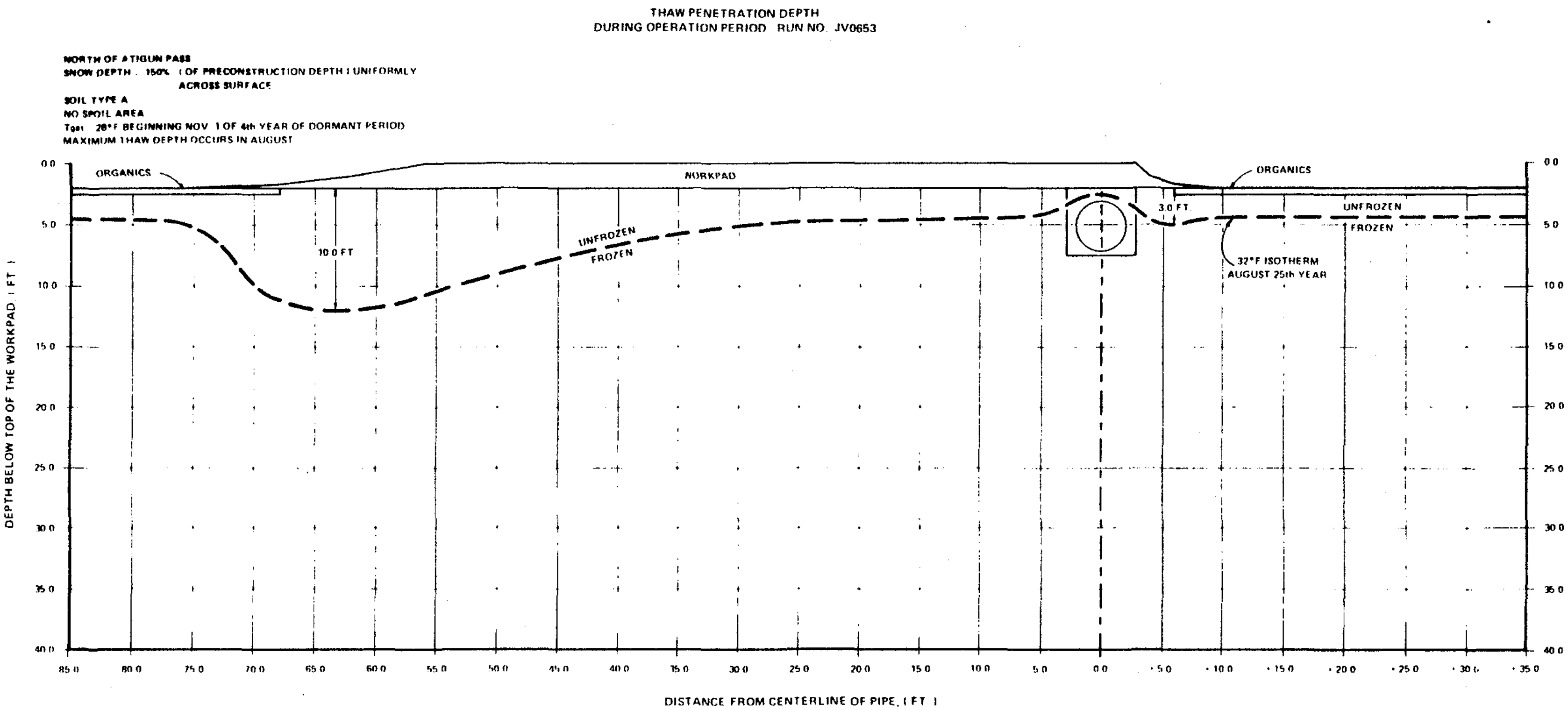


FIGURE 4 - 17

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0651

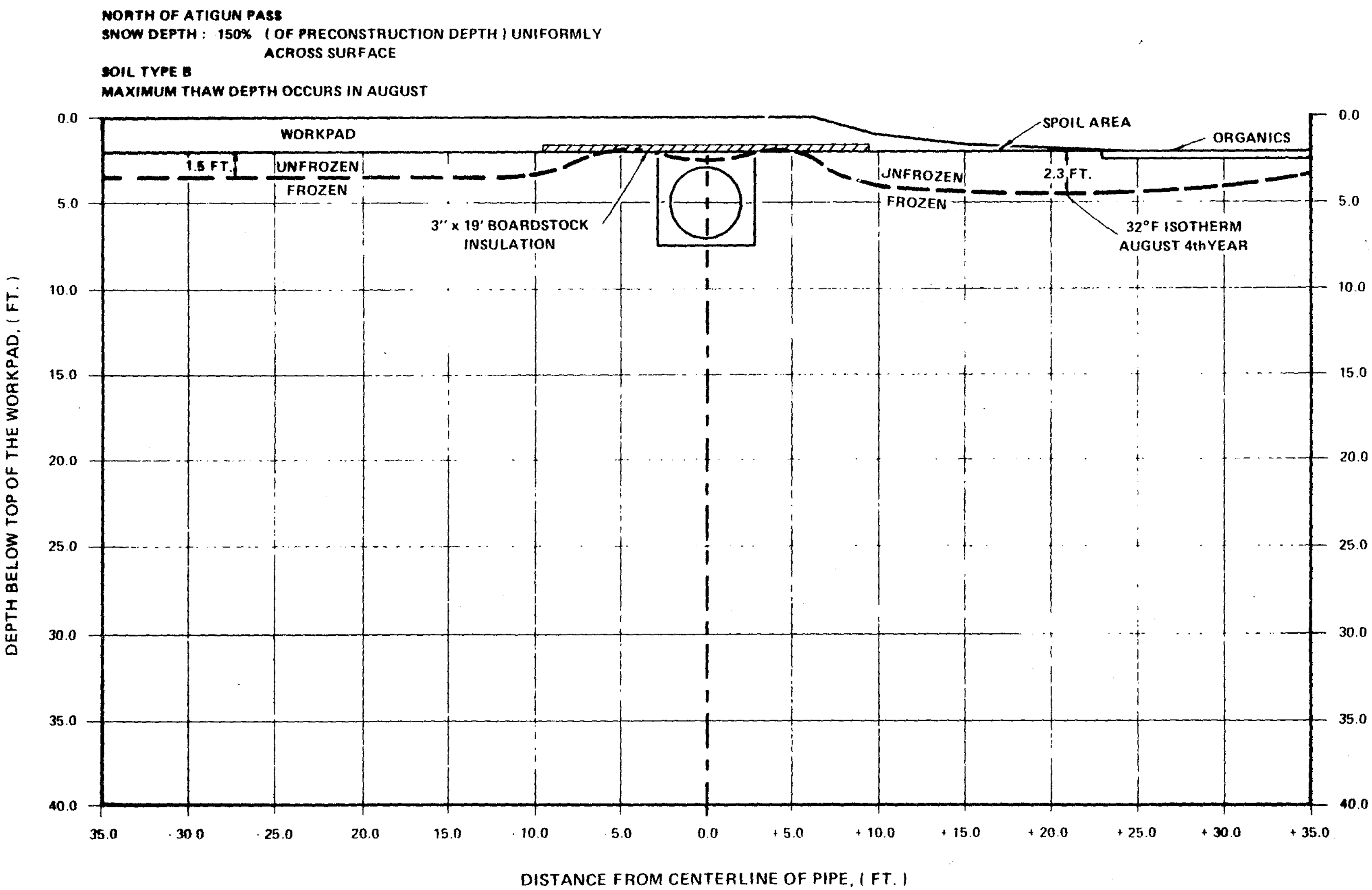
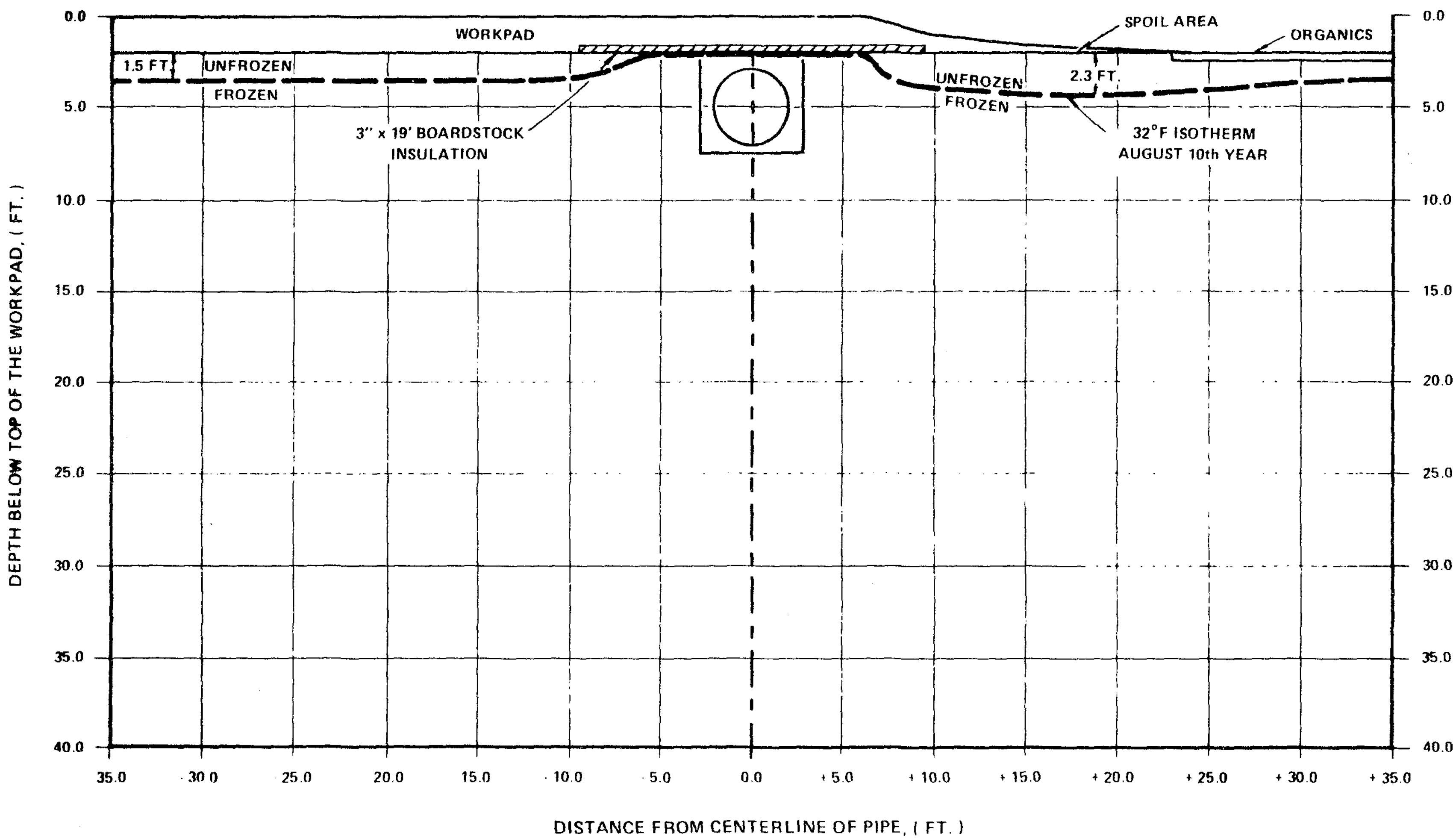


FIGURE 4 - 18

FIGURE 4 - 19

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0651

NORTH OF ATIGUN PASS
SNOW DEPTH : 150% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
Tgas = 28° F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

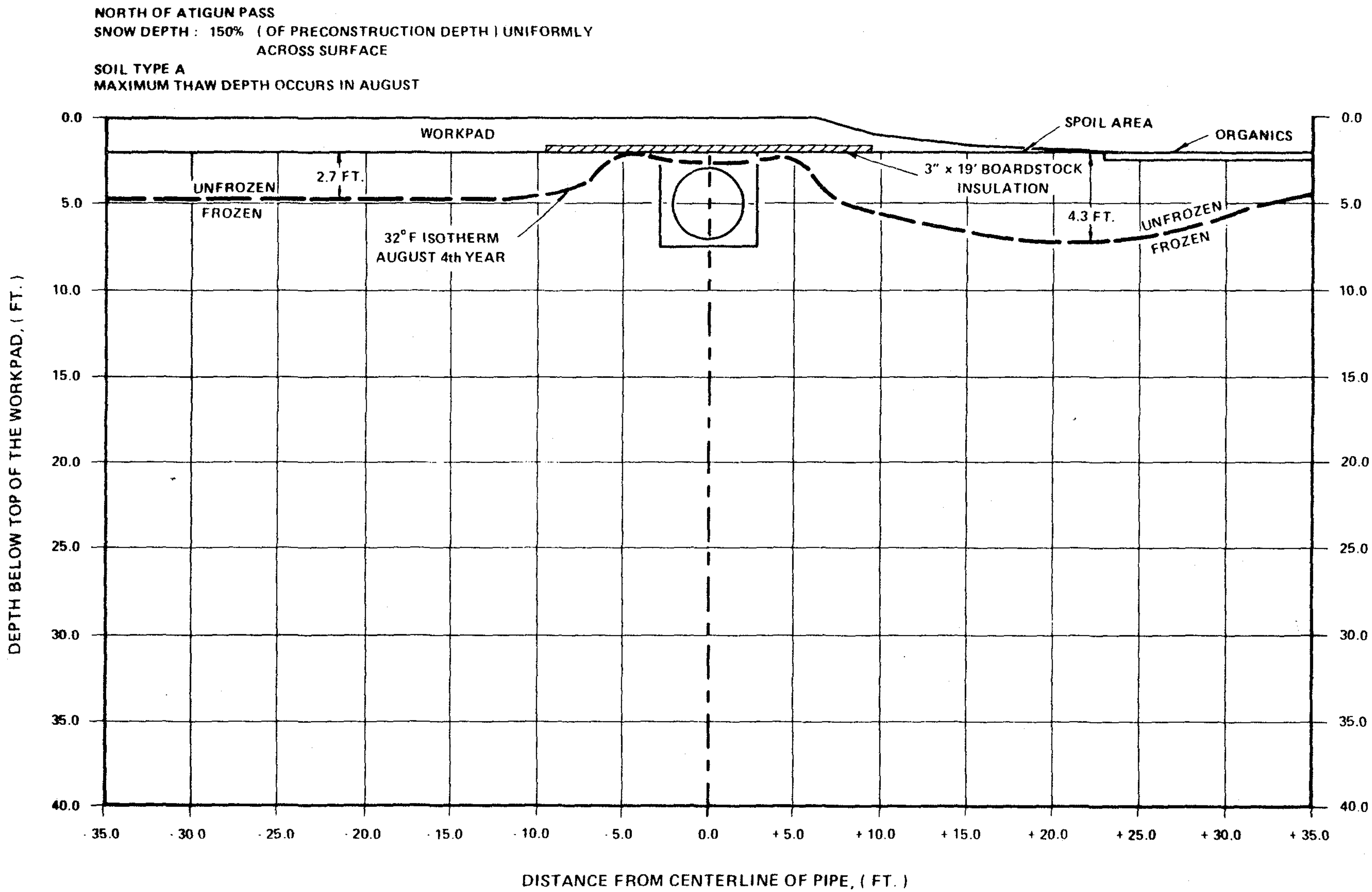


WA

THAW MITIGATION THERMAL

FIGURE 4 - 20

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0657



WA

THAW MITIGATION THERMAL

FIGURE 4 - 21

THAW PENETRATION DEPTH
DURING OPERATION PERIOD · RUN NO. JV0657

NORTH OF ATIGUN PASS
SNOW DEPTH : 150% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
Tgas = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

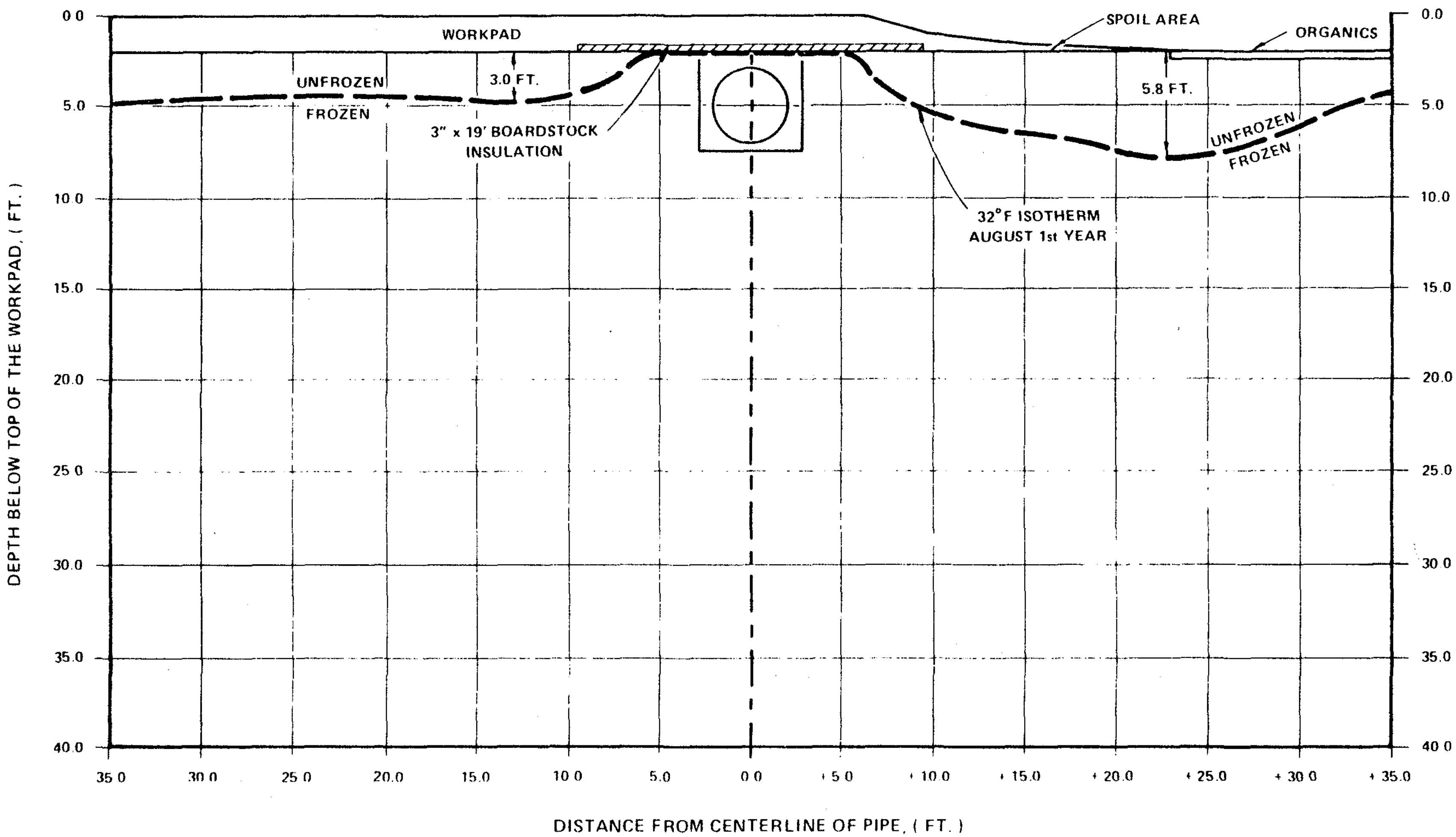
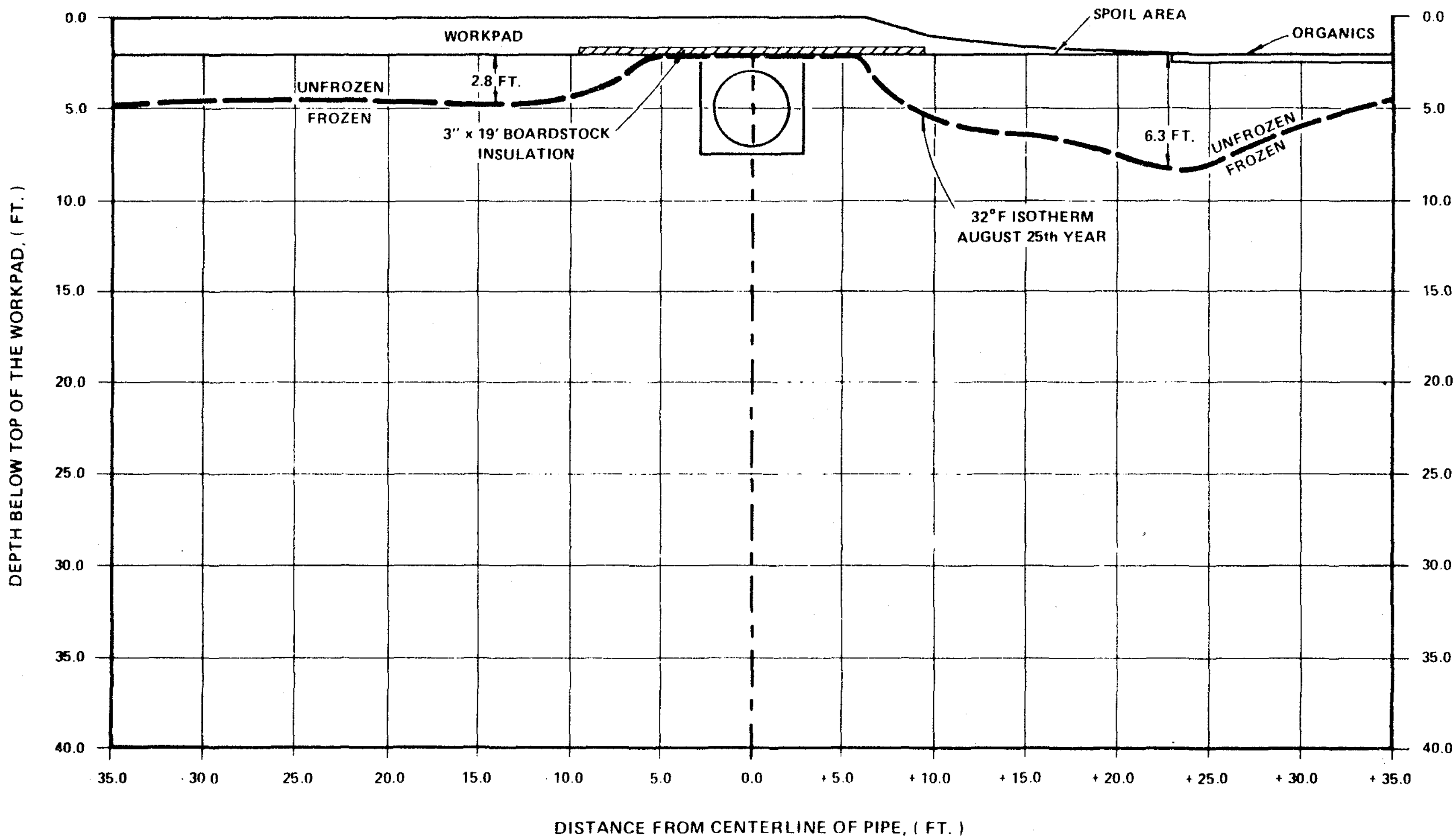


FIGURE 4 - 22

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0657

NORTH OF ATIGUN PASS
SNOW DEPTH : 150% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
T_{gas} = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST



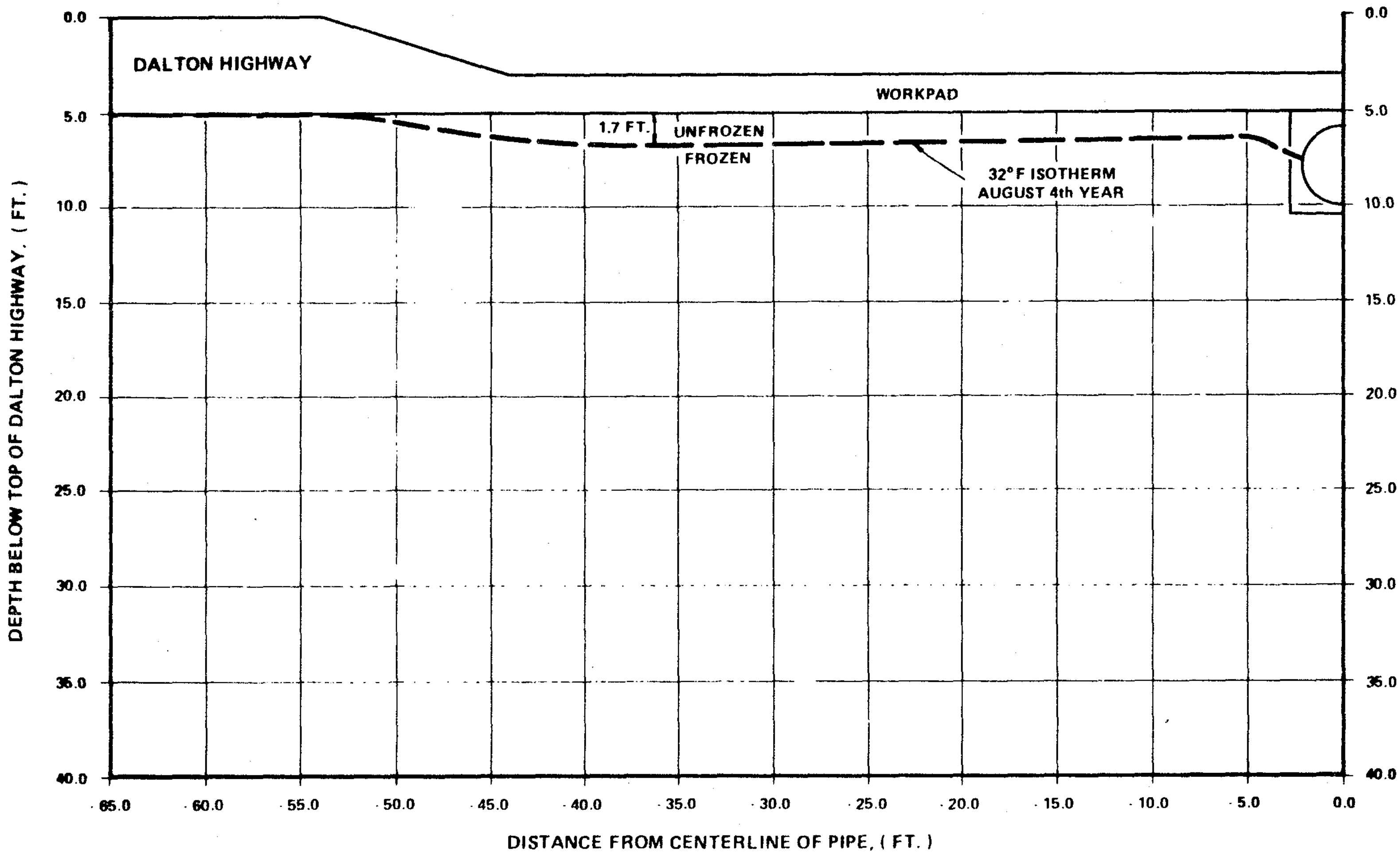
WA

THAW MITIGATION THERMAL

FIGURE 4 - 23

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0649

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD AND OVER DITCH
SOIL TYPE B
MAXIMUM THAW DEPTH OCCURS IN AUGUST



WA

THAW MITIGATION THERMAL

FIGURE 4 - 24

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0649

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD AND OVER DITCH
SOIL TYPE B
Tgas = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

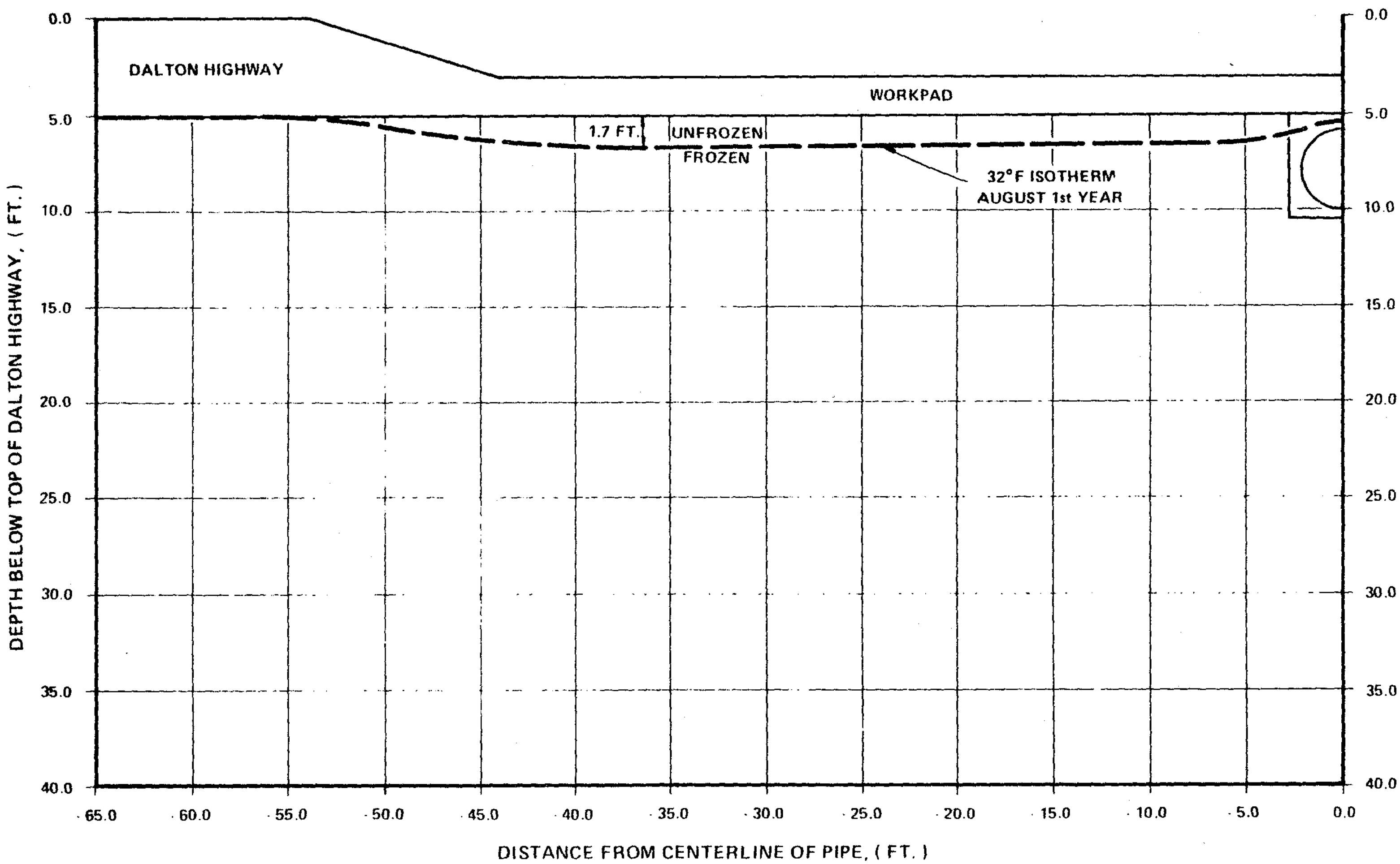


FIGURE 4 - 25

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0649

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD AND OVER DITCH
SOIL TYPE B
T_{gas} = 28° F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

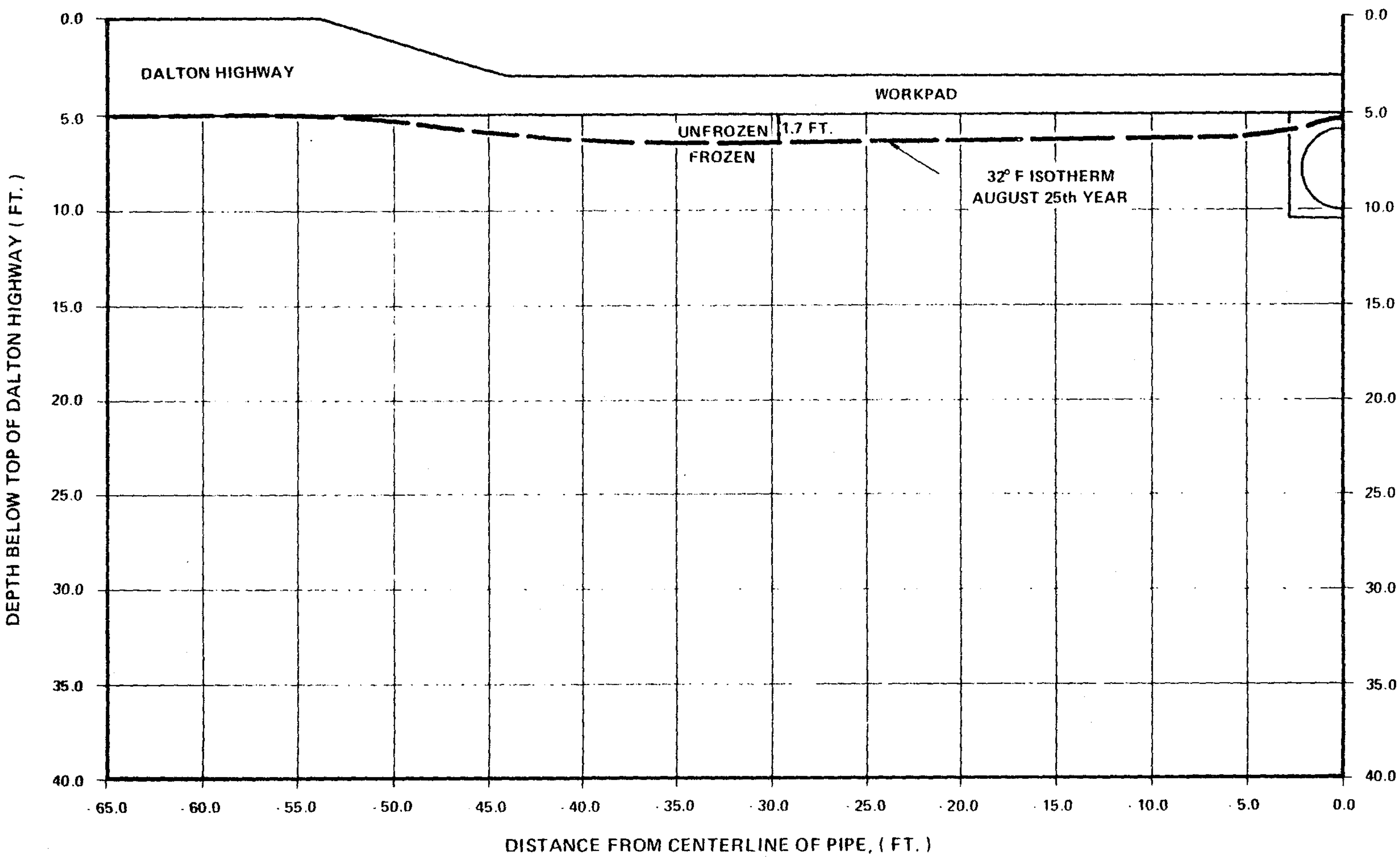


FIGURE 4 - 26

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0671

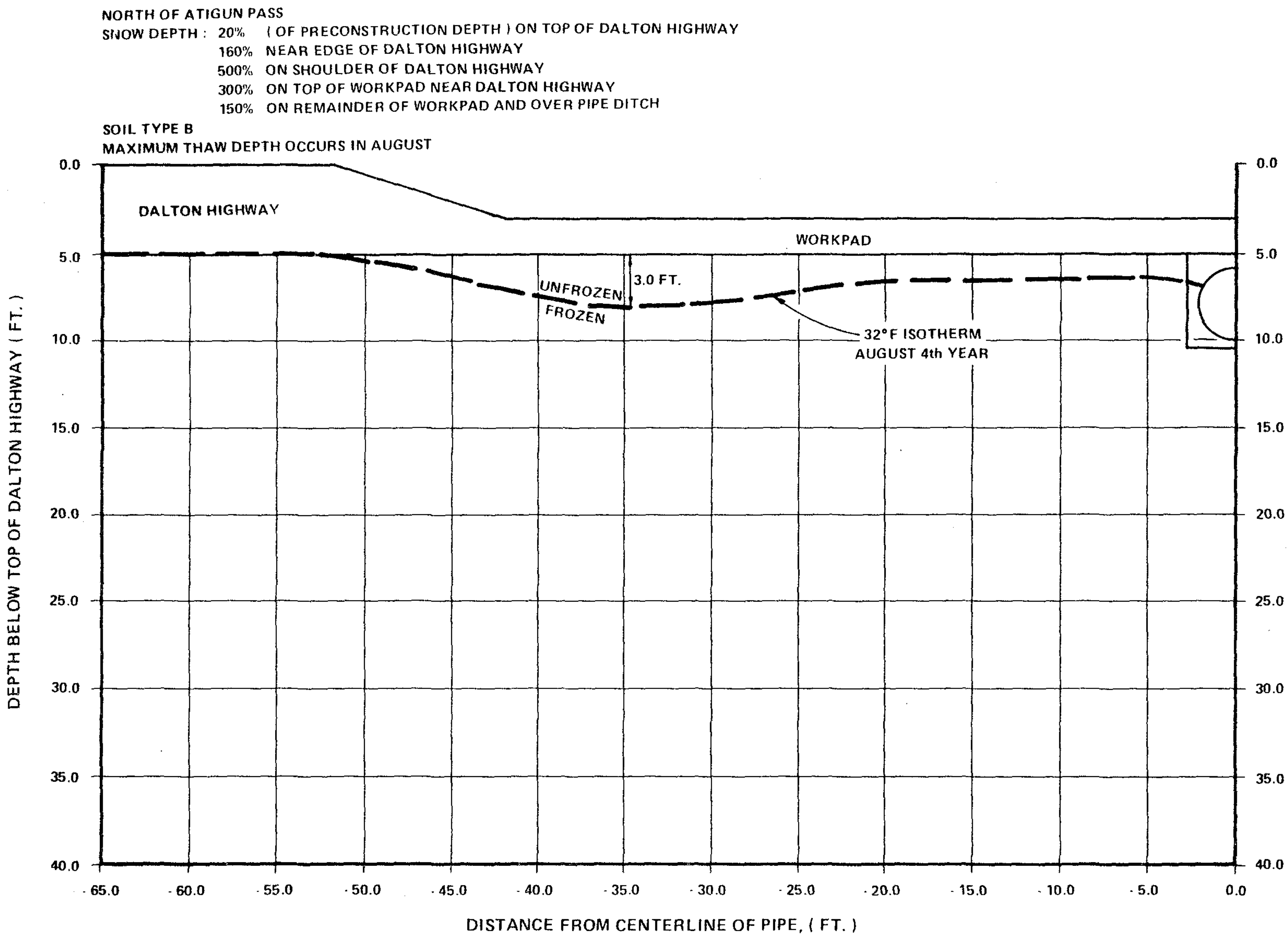


FIGURE 4 - 27

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0671

NORTH OF ATIGUN PASS (MILEPOST 0 - 173)
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE B
T_{gas} = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

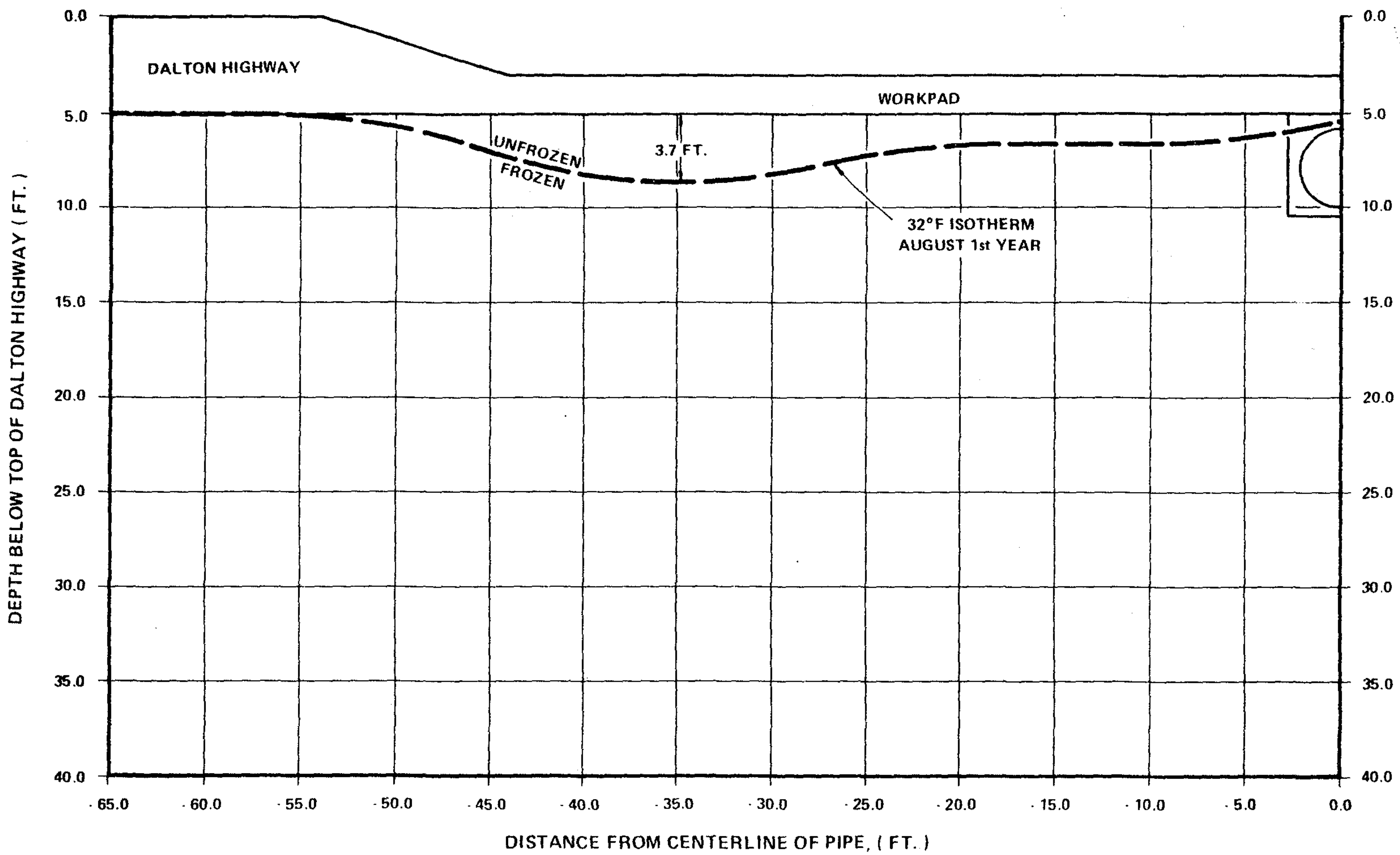


FIGURE 4 - 28

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0671

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
160% AT EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE B
Tgas = 28 F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

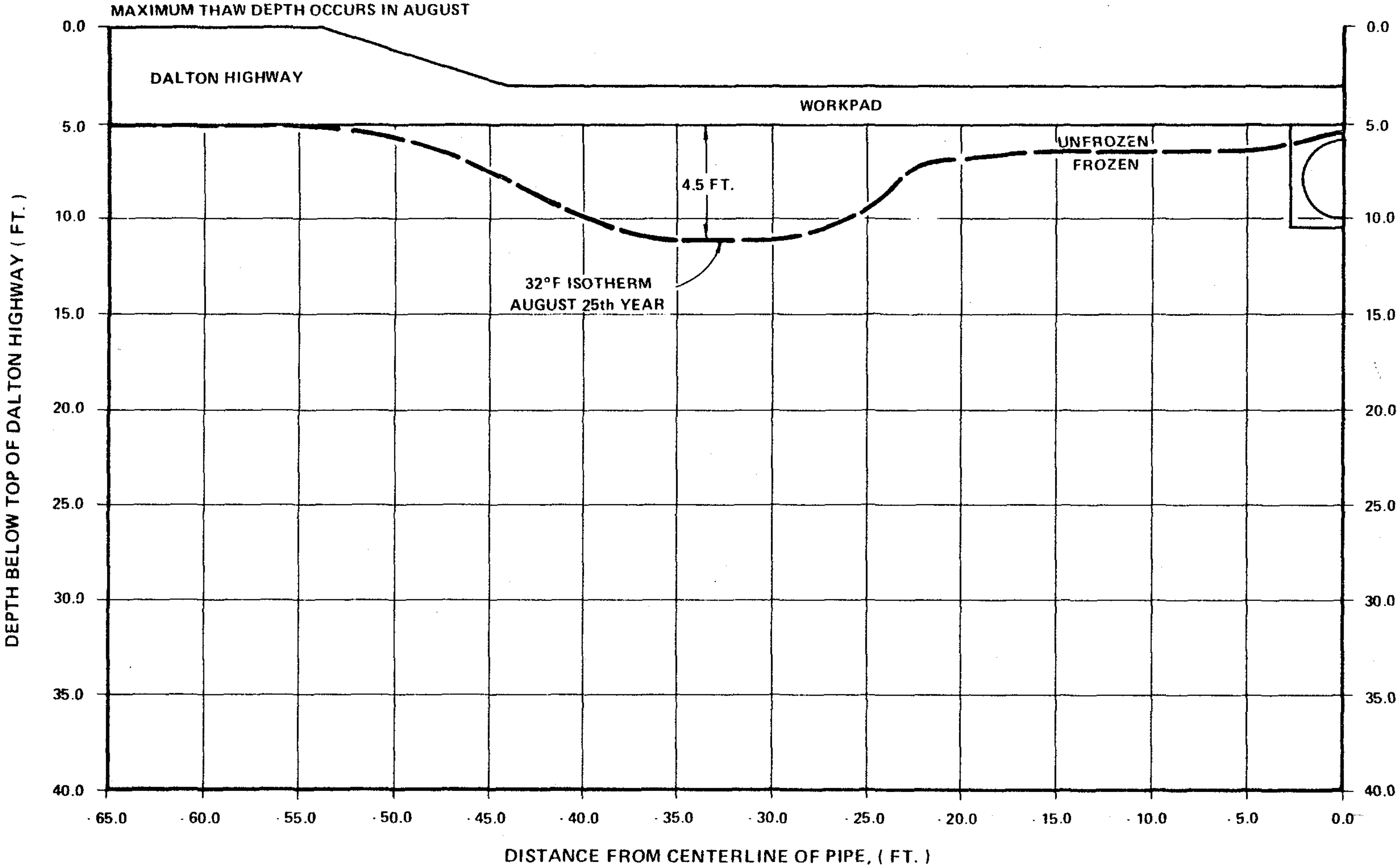
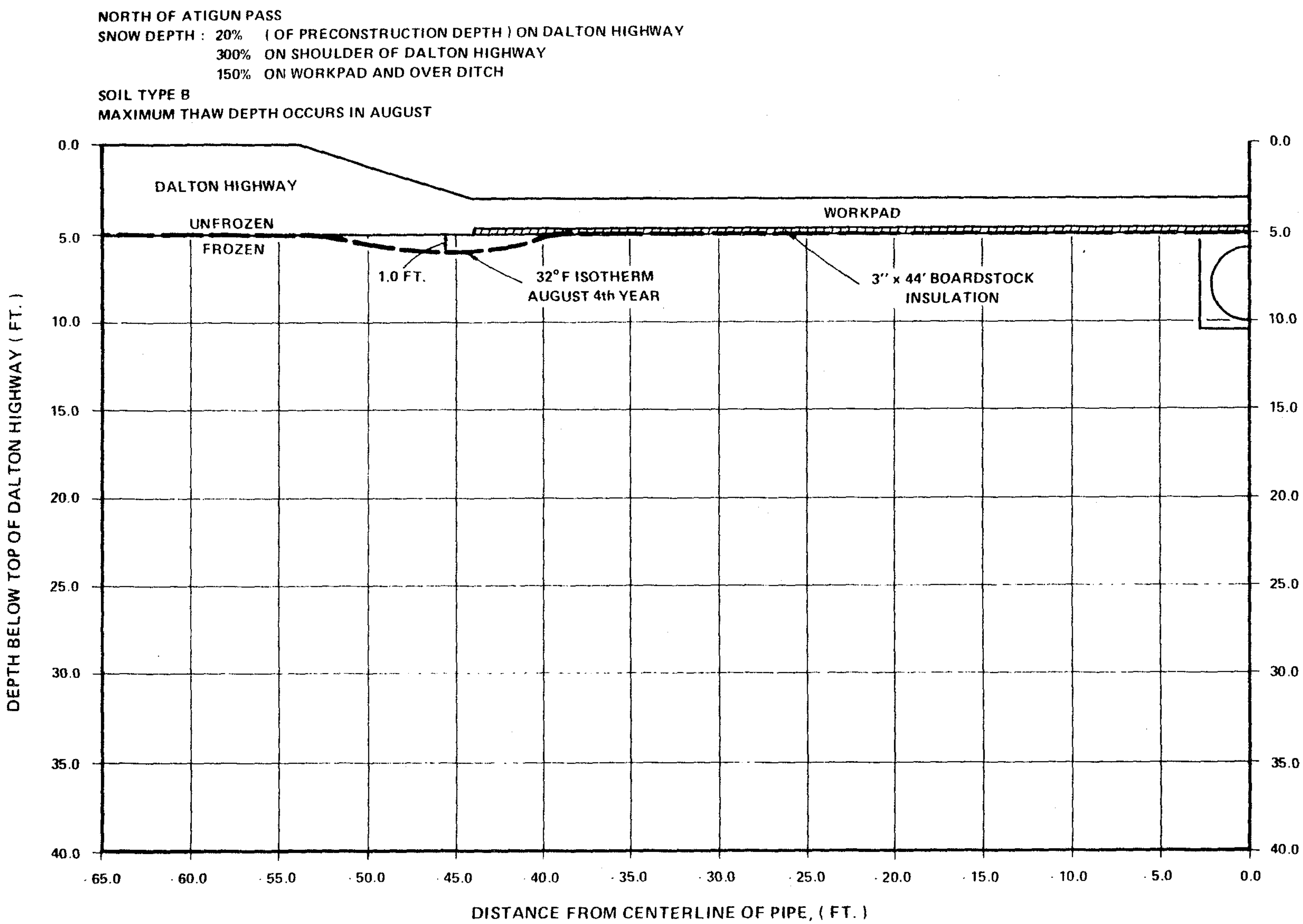


FIGURE 4 - 29

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0654



THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0654

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD AND OVER DITCH
SOIL TYPE B
Tgas = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

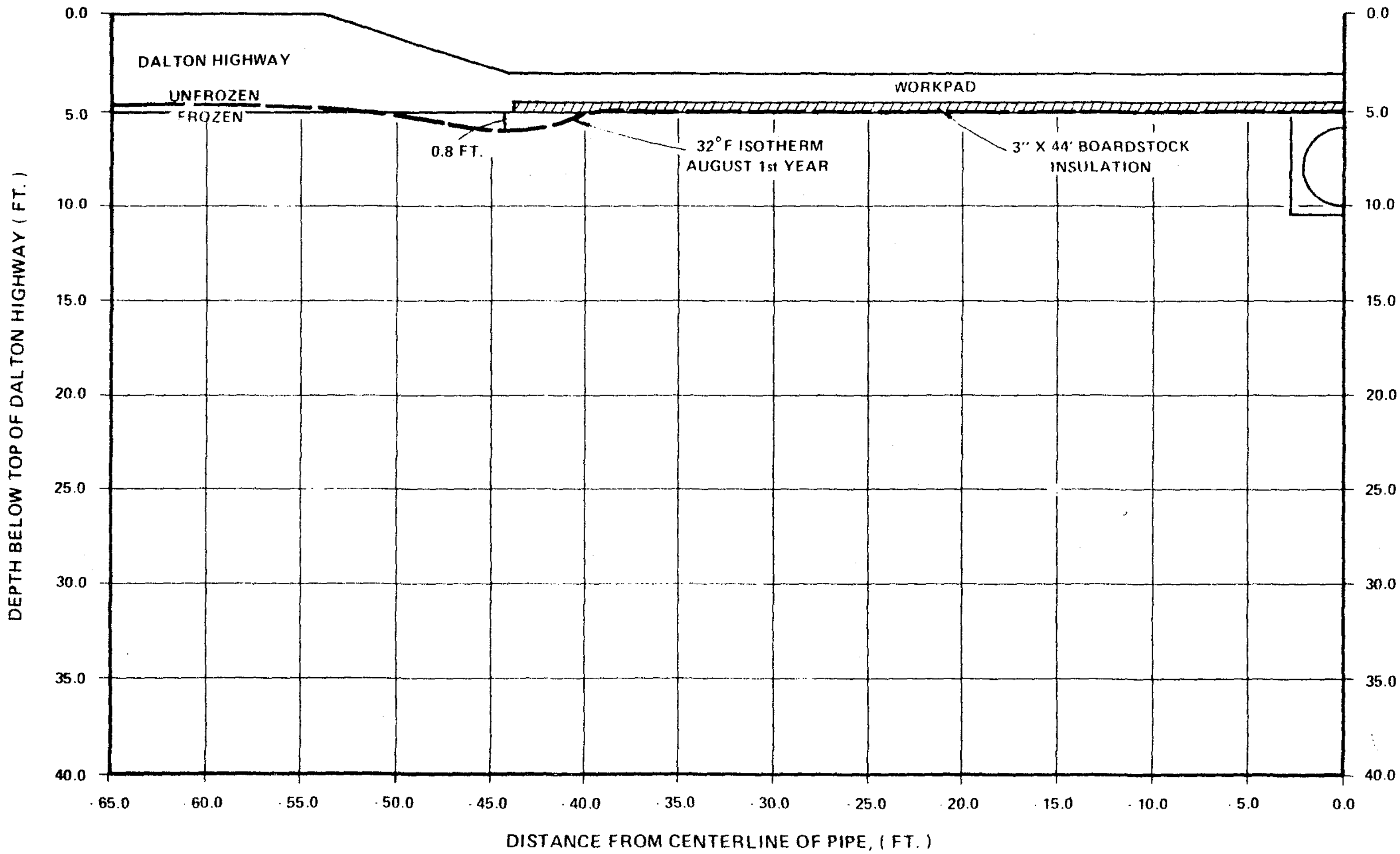


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FIGURE 4 - 30

THAW MITIGATION THERMAL

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THAW MITIGATION THERMAL

FIGURE 4 - 31

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0654

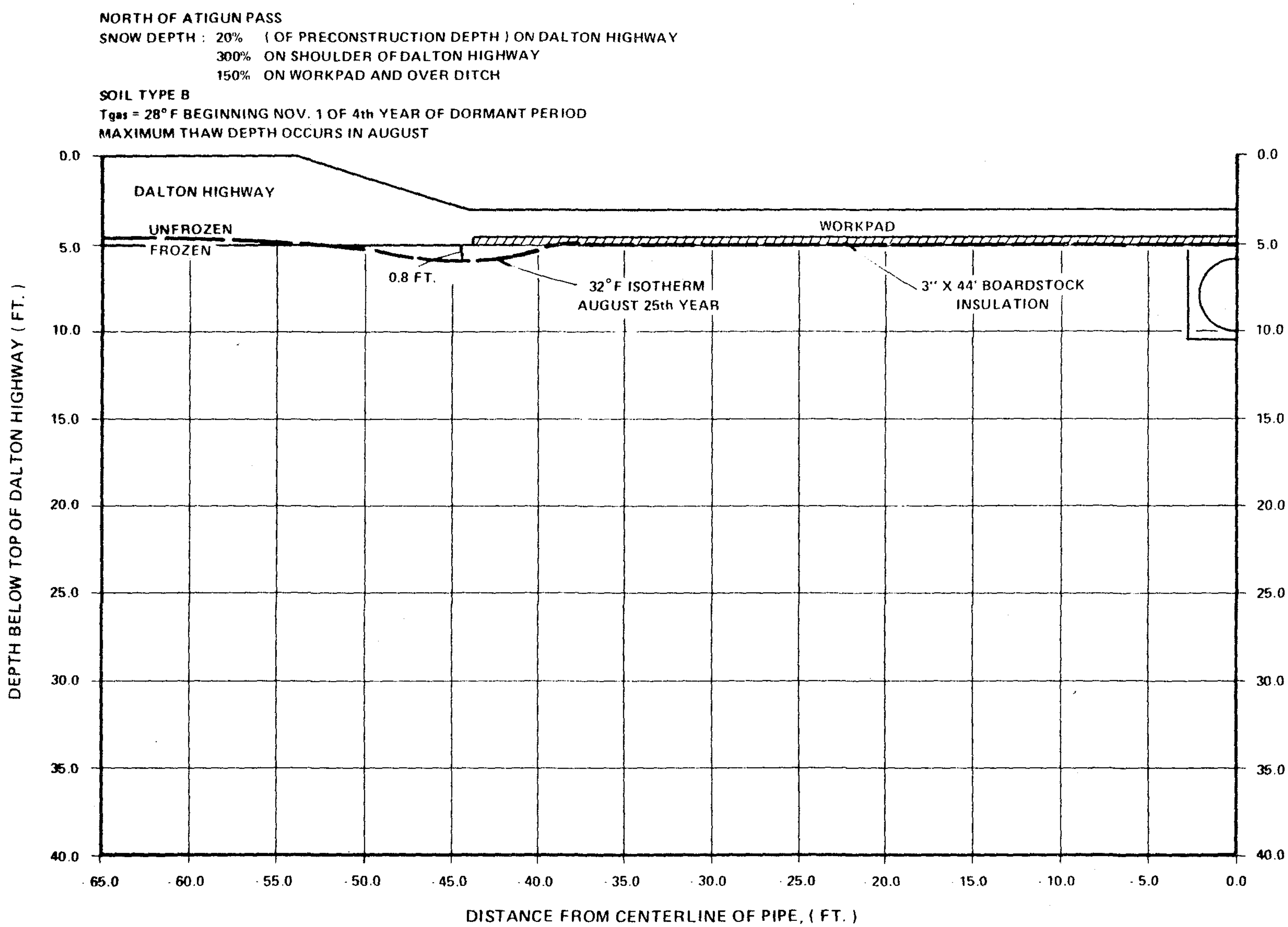
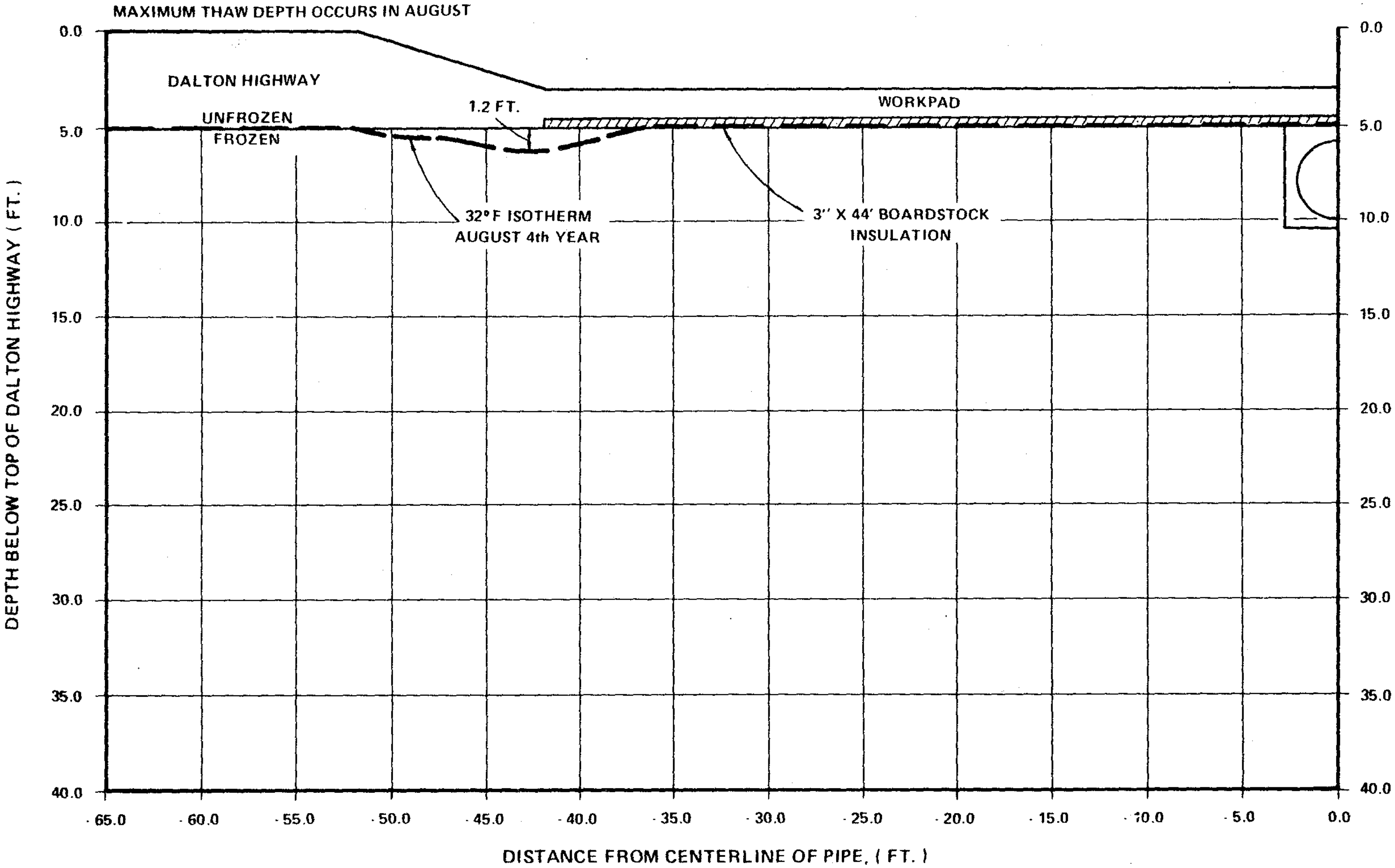


FIGURE 4 - 32

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0697

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE B
MAXIMUM THAW DEPTH OCCURS IN AUGUST



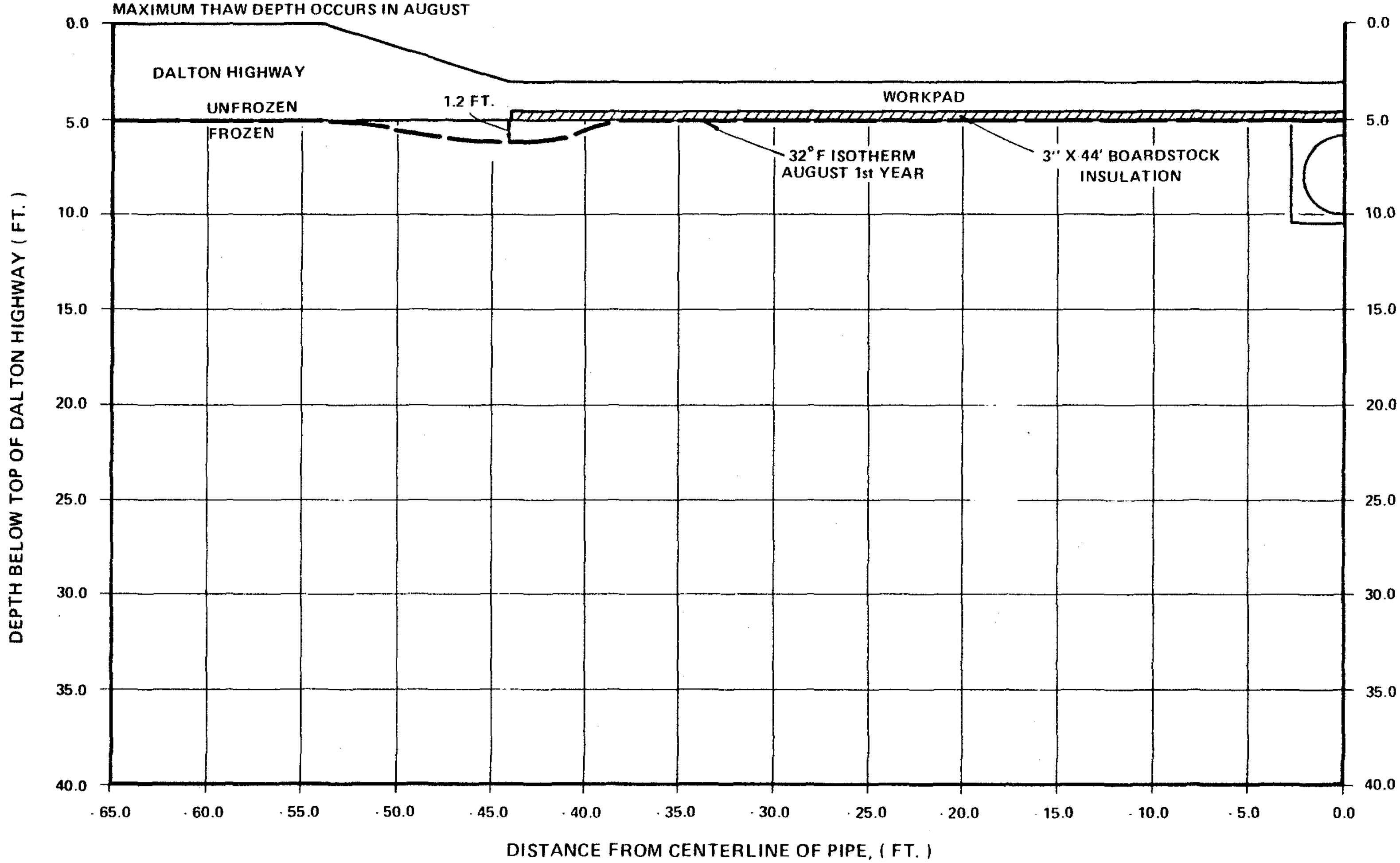
WA

THAW MITIGATION THERMAL

FIGURE 4 - 33

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0697

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE B
Tgas = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST



THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0697

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE B
Tgas = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

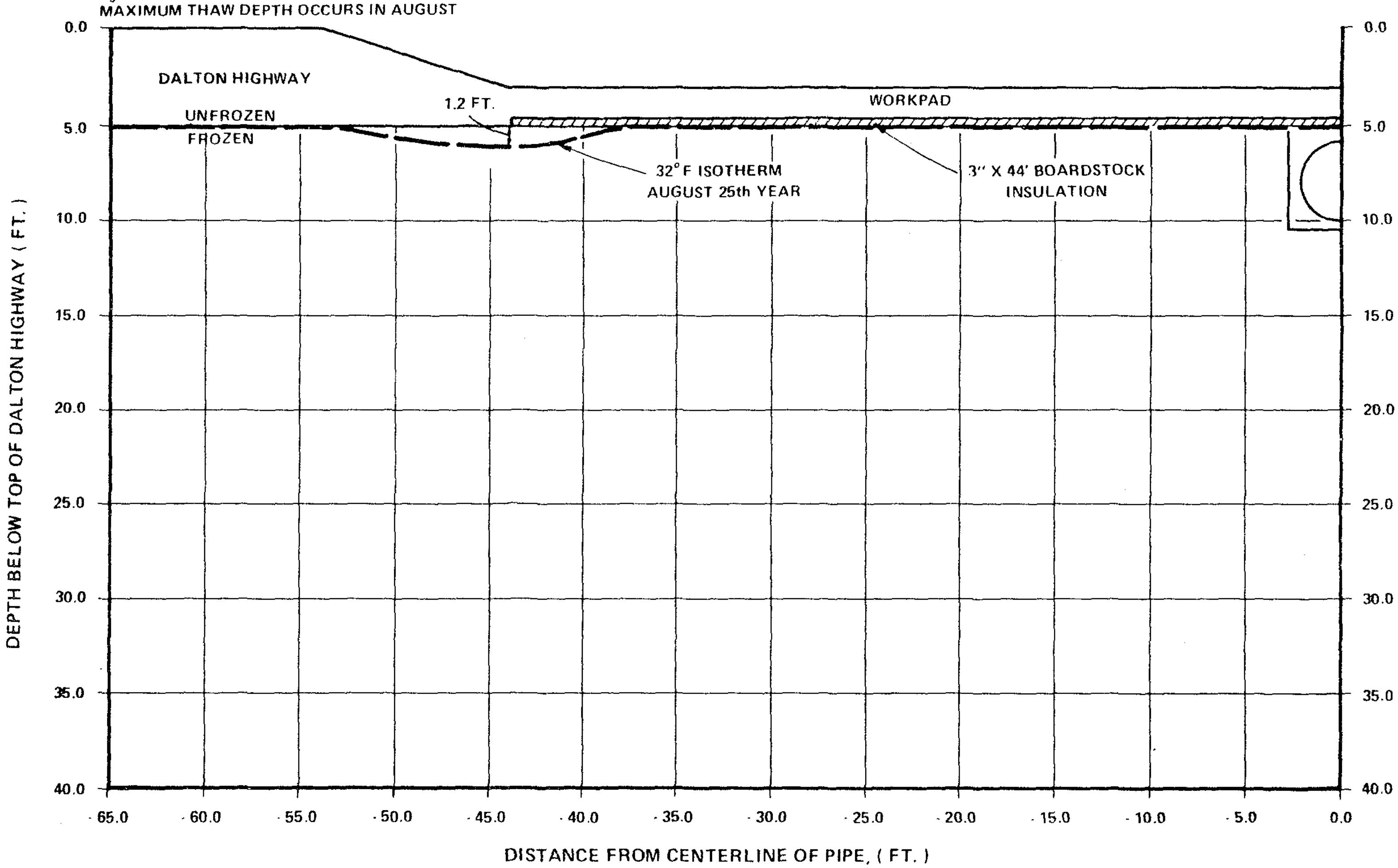


FIGURE 4 - 34

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0656

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD
SOIL TYPE A
MAXIMUM THAW DEPTH OCCURS IN AUGUST

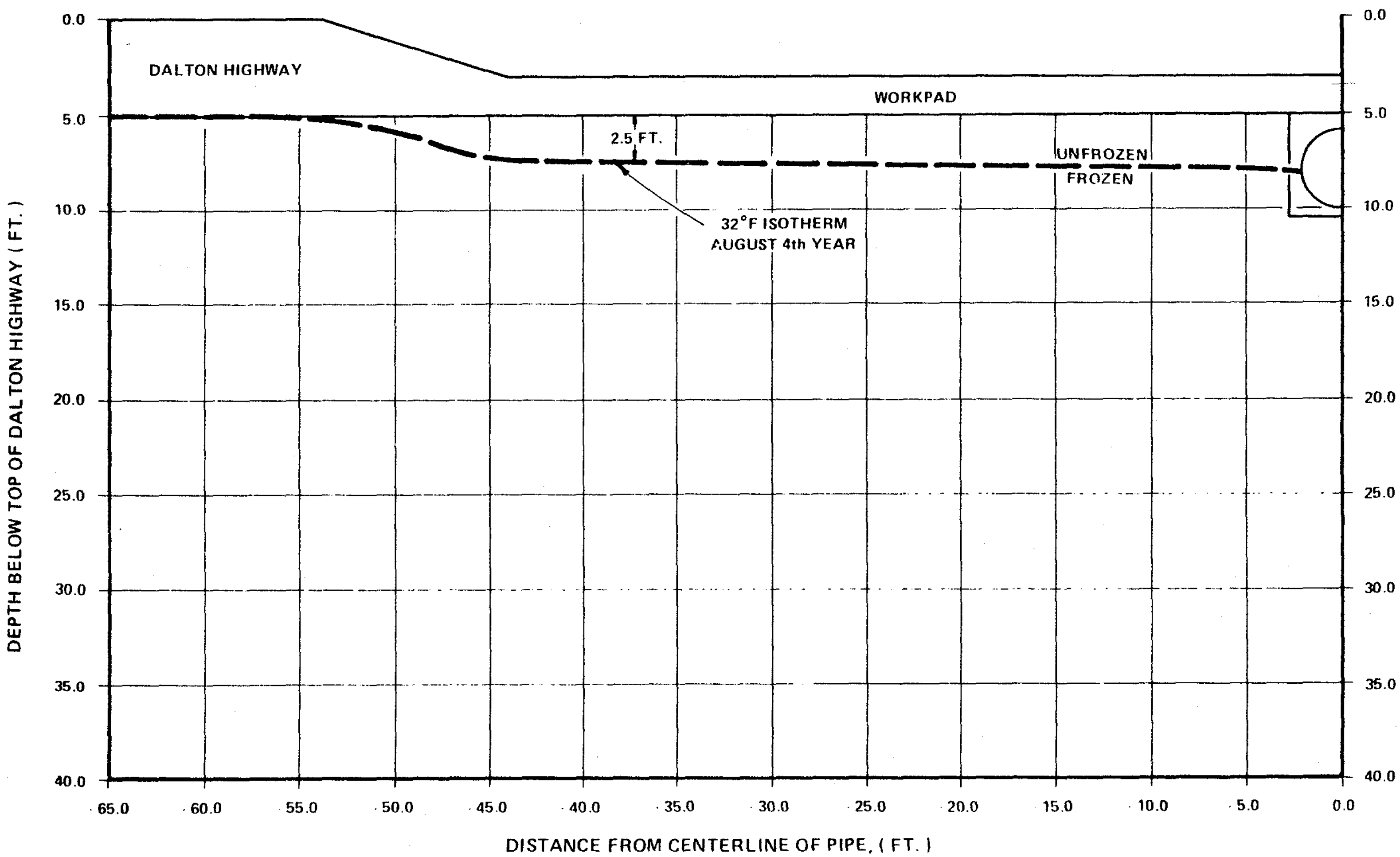


FIGURE 4 - 35

FIGURE 4 - 36

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0656

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD
SOIL TYPE A
Tgas = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

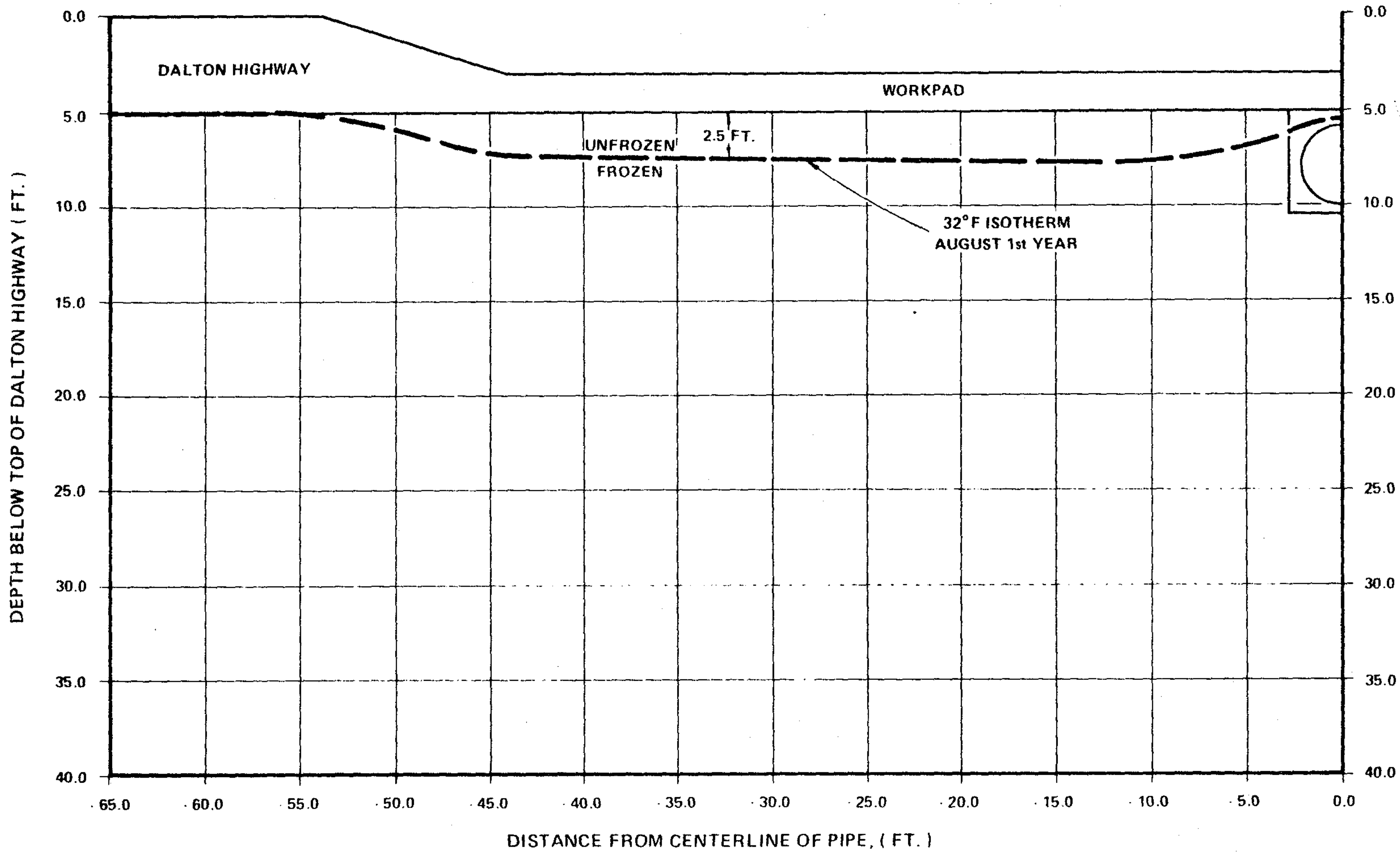


FIGURE 4 - 37

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0656

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD
SOIL TYPE A
T_{gas} = 28° F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

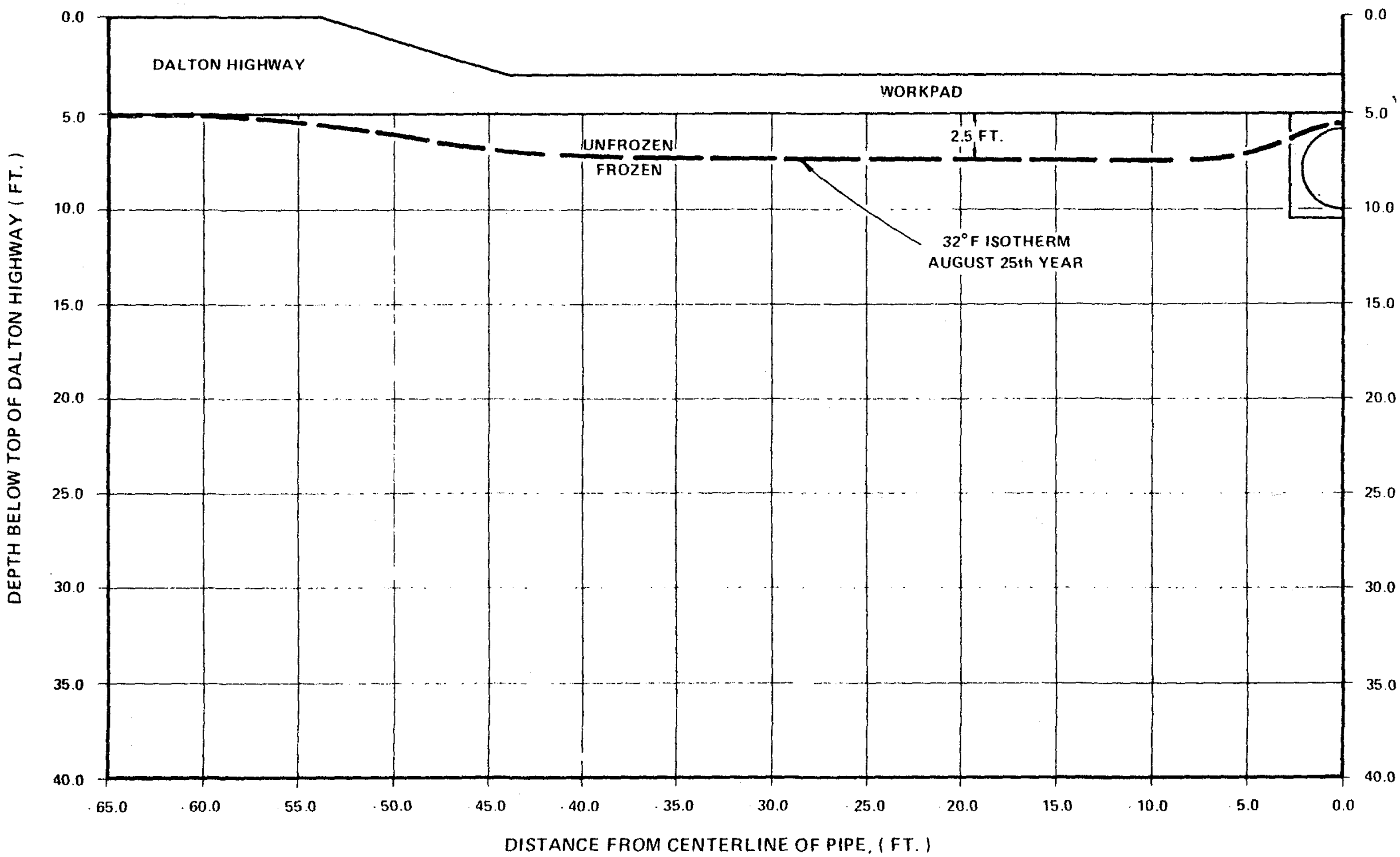
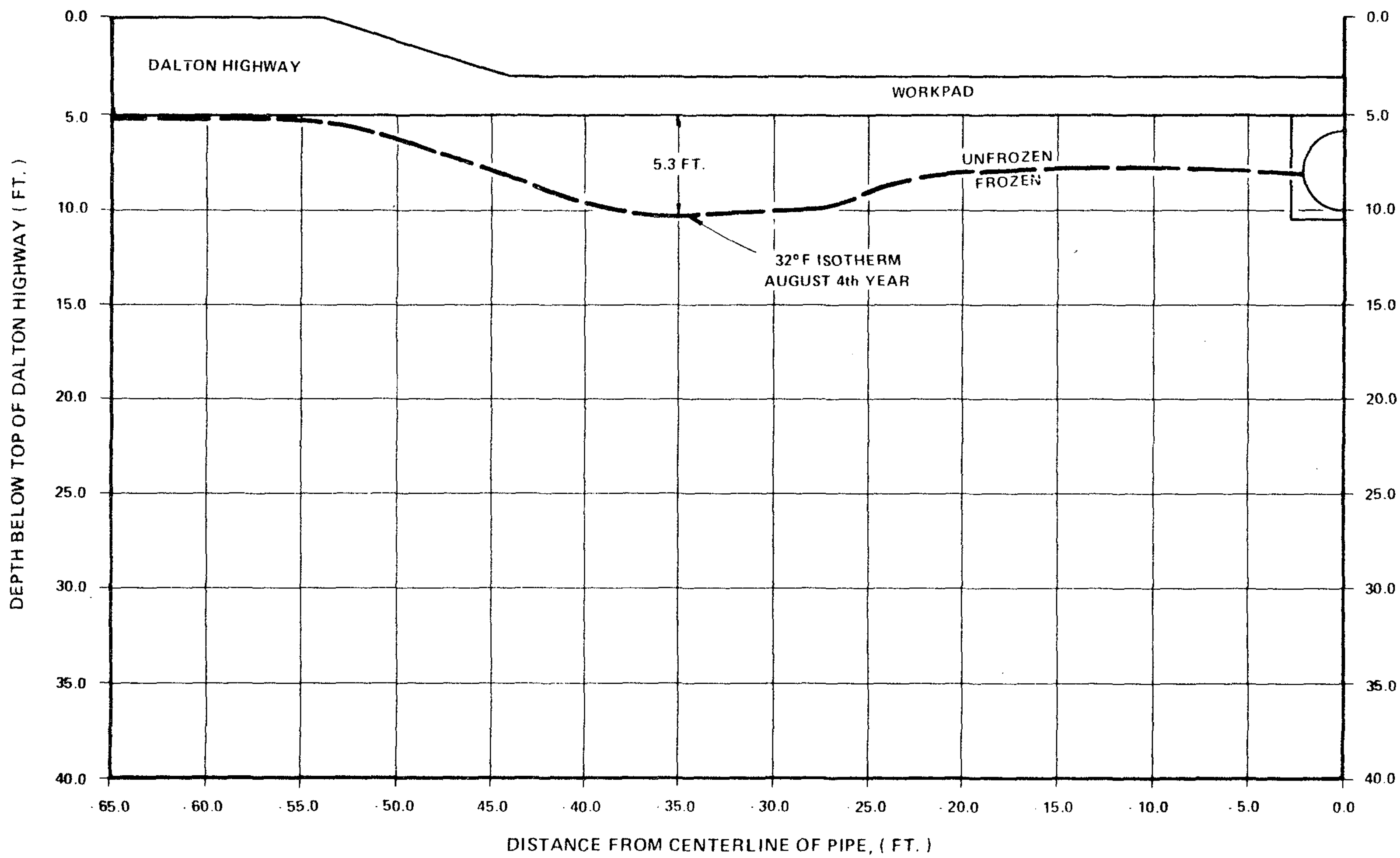


FIGURE 4 - 38

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0699

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE A
MAXIMUM THAW DEPTH OCCURS IN AUGUST



WA

THAW MITIGATION THERMAL

FIGURE 4 - 39

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0699

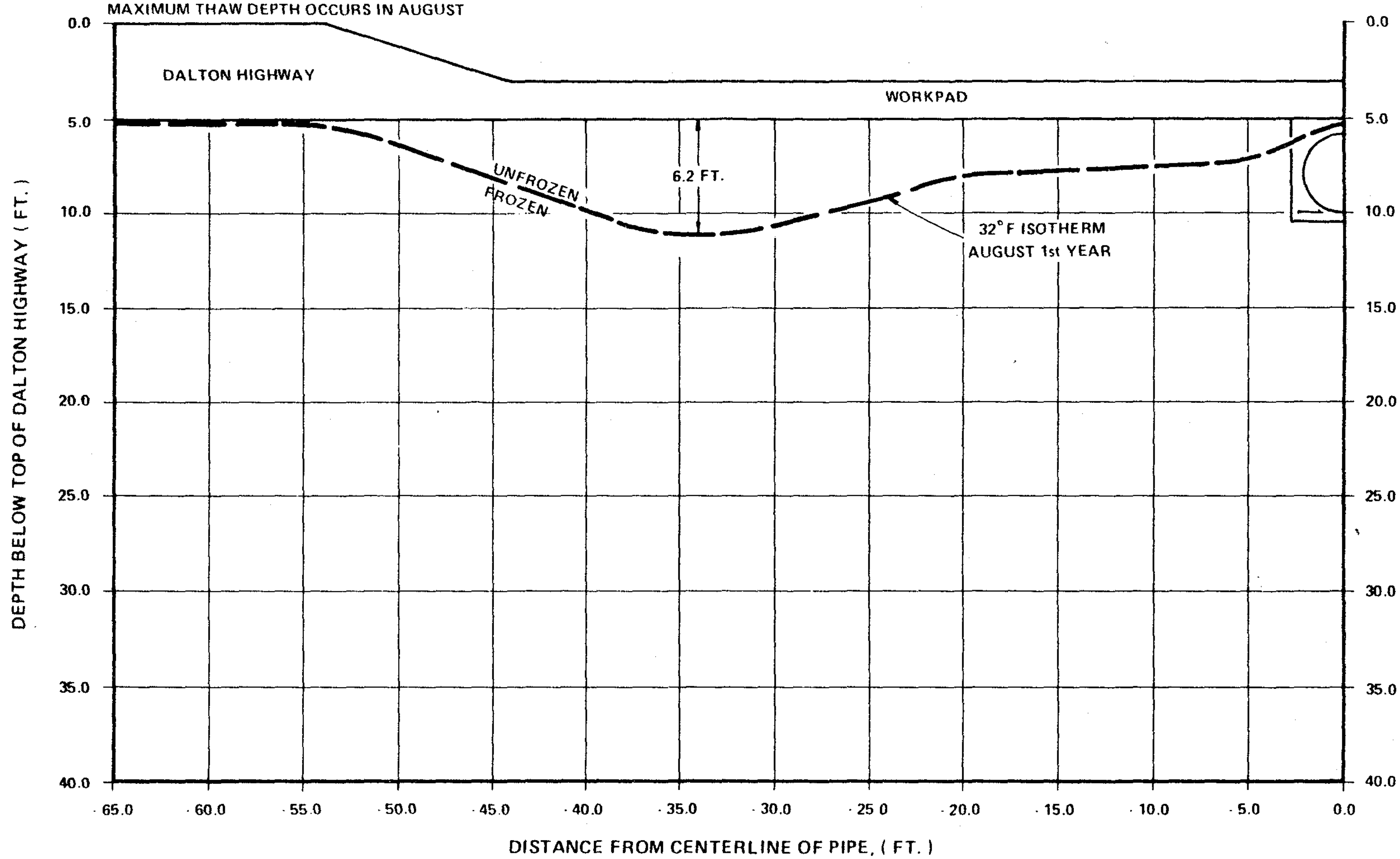
NORTH OF ATIGUN PASS

SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH

SOIL TYPE A

T_{gas} = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD

MAXIMUM THAW DEPTH OCCURS IN AUGUST



VA

THAW MITIGATION THERMAL

FIGURE 4 - 40

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0699

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH

SOIL TYPE A
Tgas = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

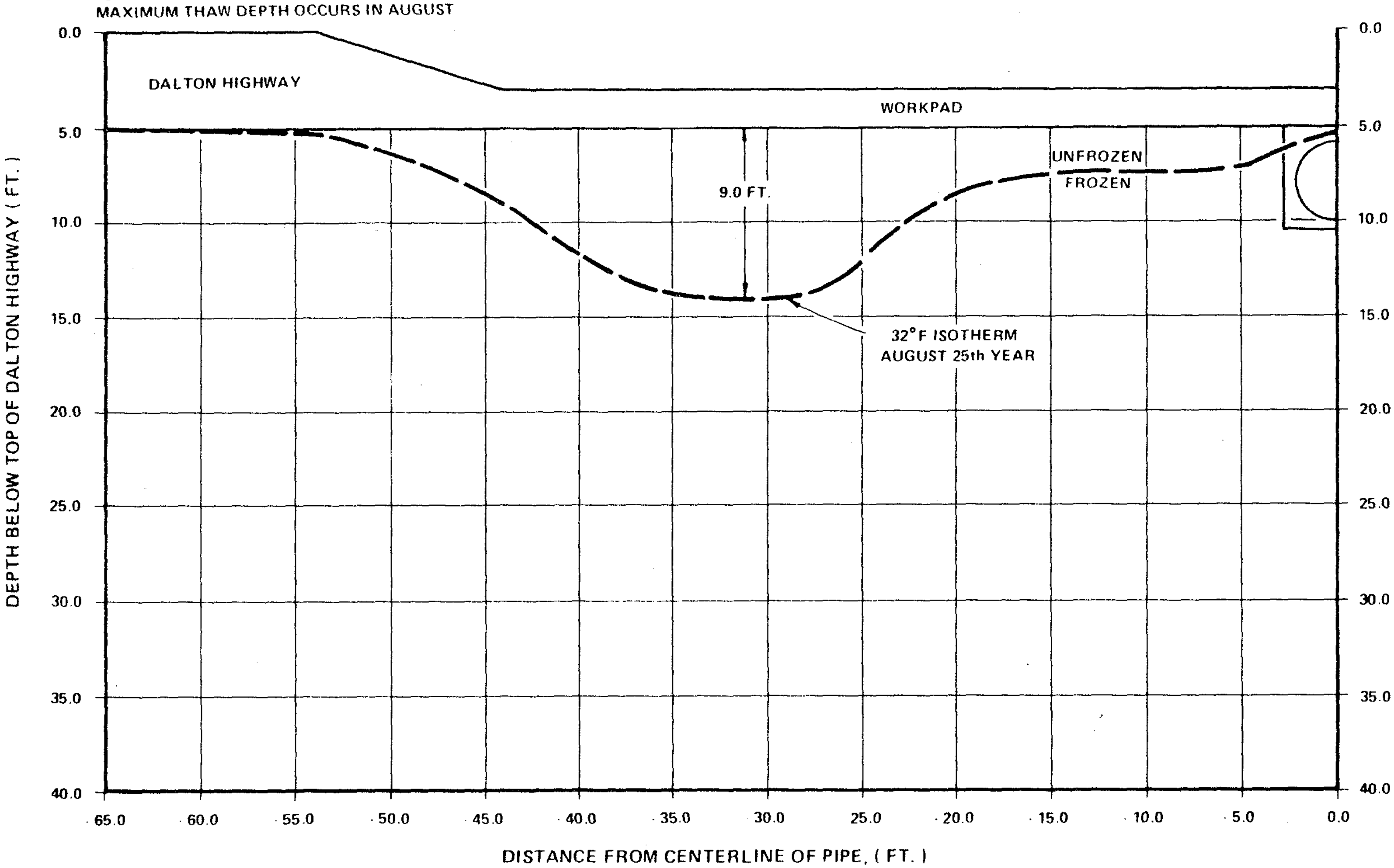


FIGURE 4-41

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0655

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD
SOIL TYPE A
MAXIMUM THAW DEPTH OCCURS IN AUGUST

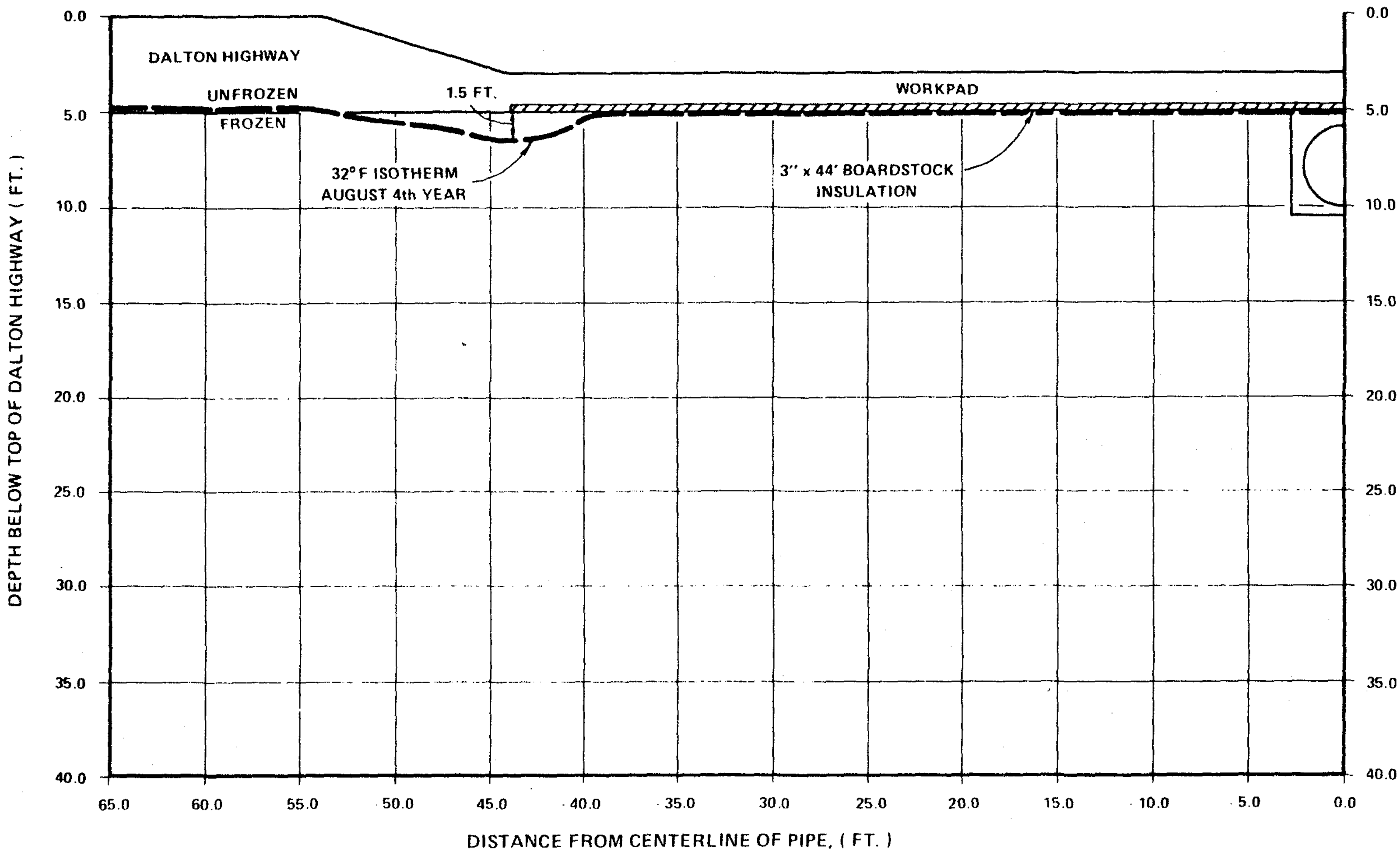
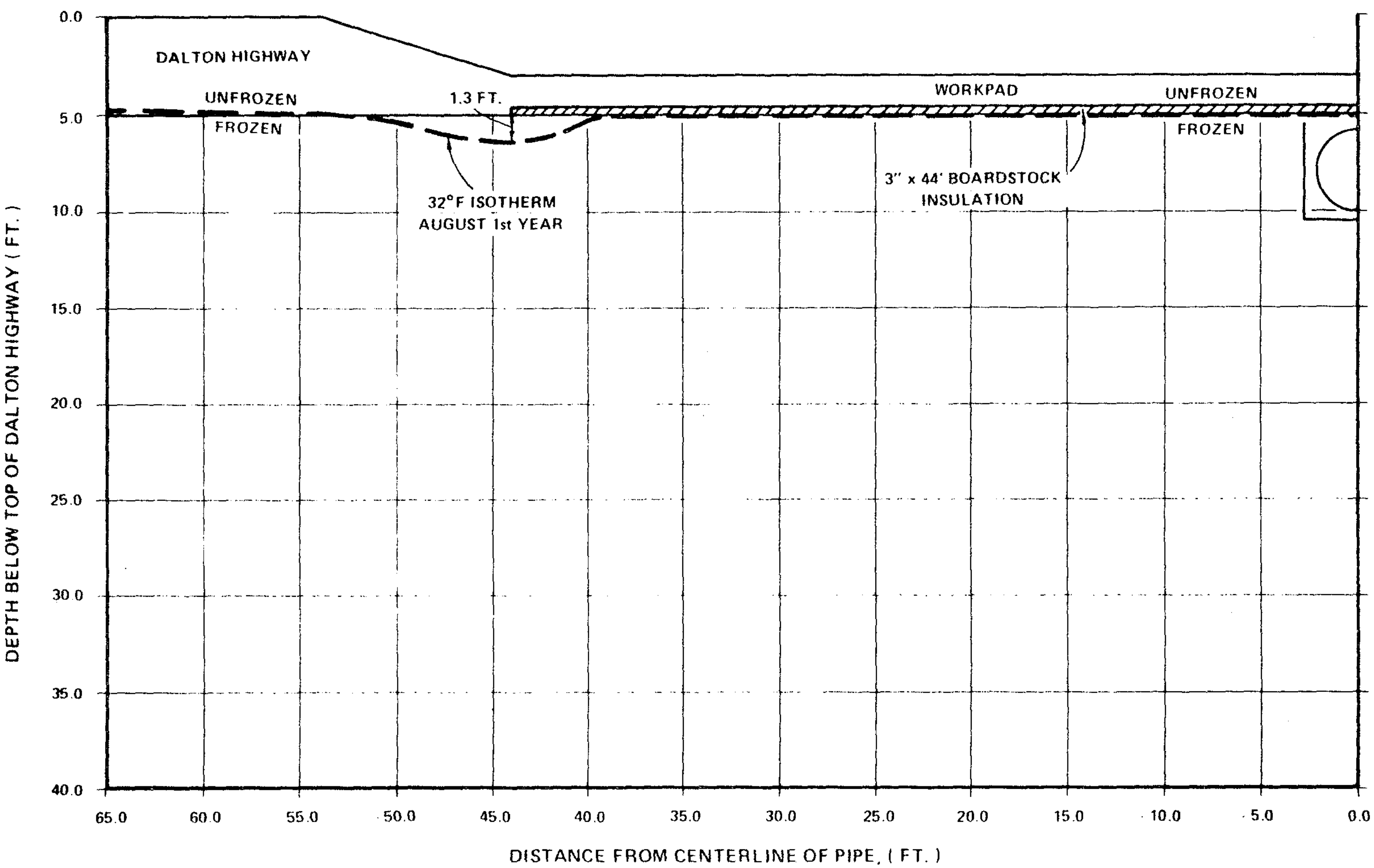


FIGURE 4 - 42

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0655

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD
SOIL TYPE A
T_{gas} = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST



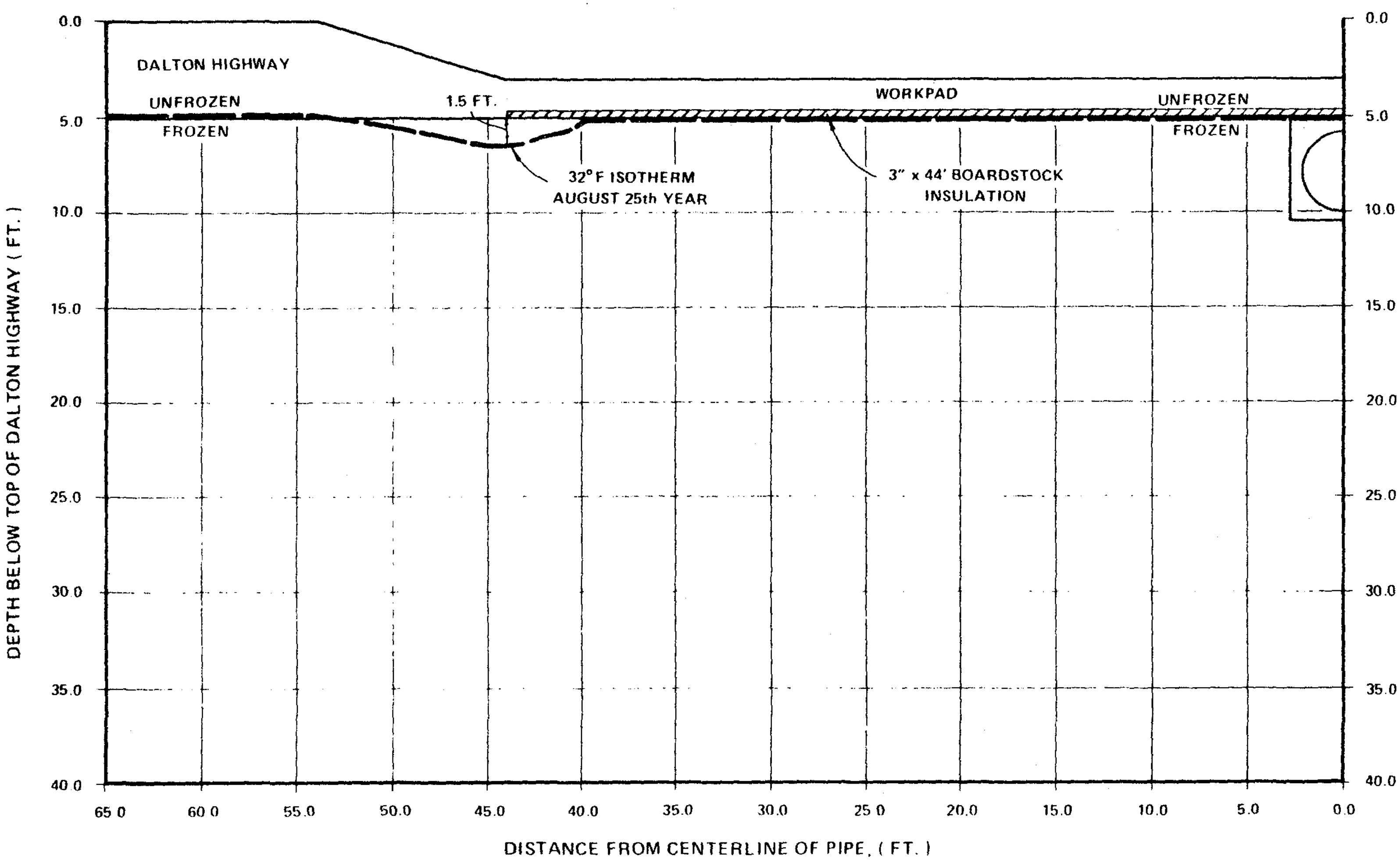
IWA

THAW MITIGATION THERMAL

FIGURE 4 - 43

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0655

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON DALTON HIGHWAY
300% ON SHOULDER OF DALTON HIGHWAY
150% ON WORKPAD
SOIL TYPE A
Tgas = 28° F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST



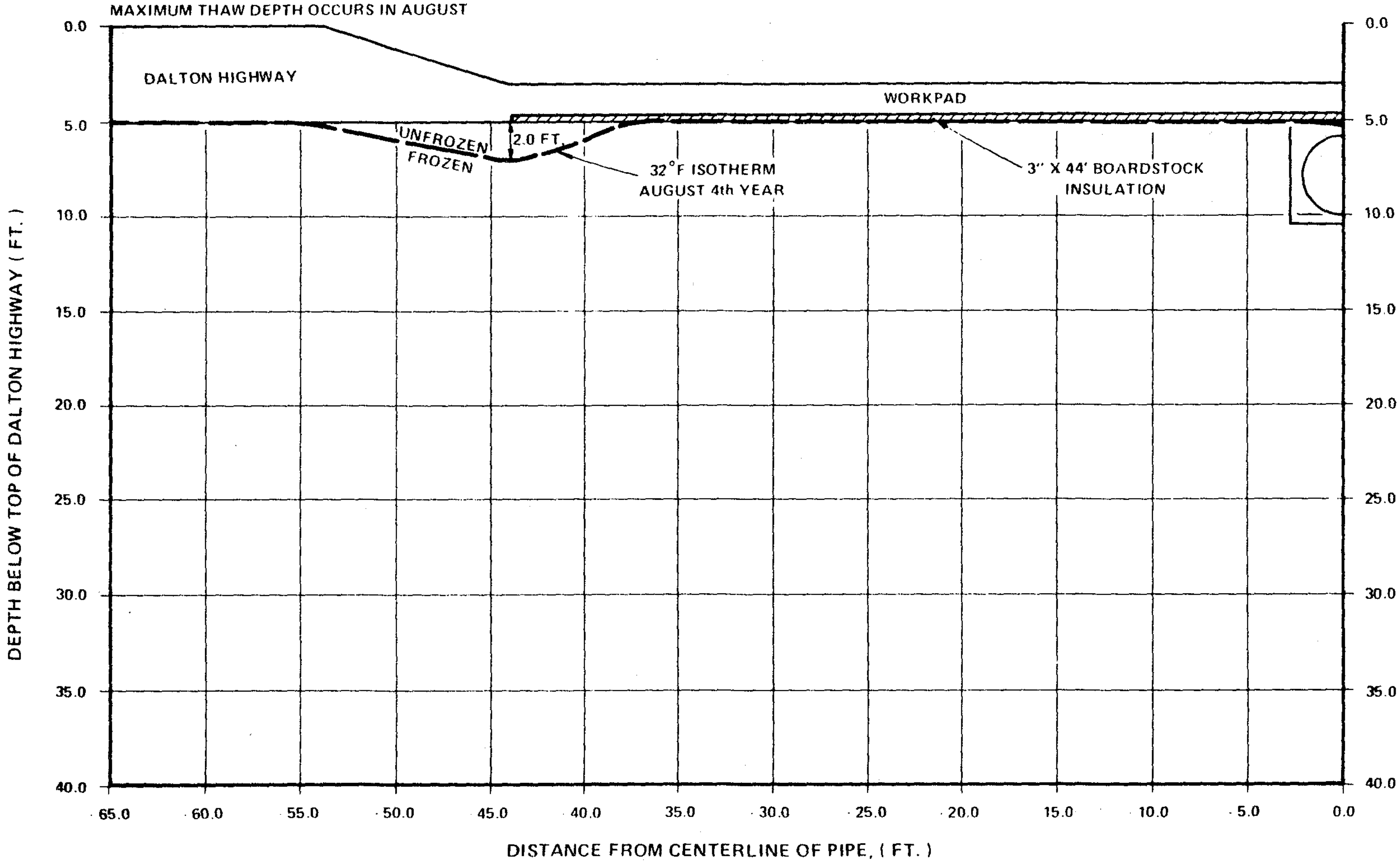
NA

THAW MITIGATION THERMAL

FIGURE 4 - 44

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0698

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE A
MAXIMUM THAW DEPTH OCCURS IN AUGUST



THAW MITIGATION THERMAL

FIGURE 4 - 45

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0698

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE A
T_{gas} = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST

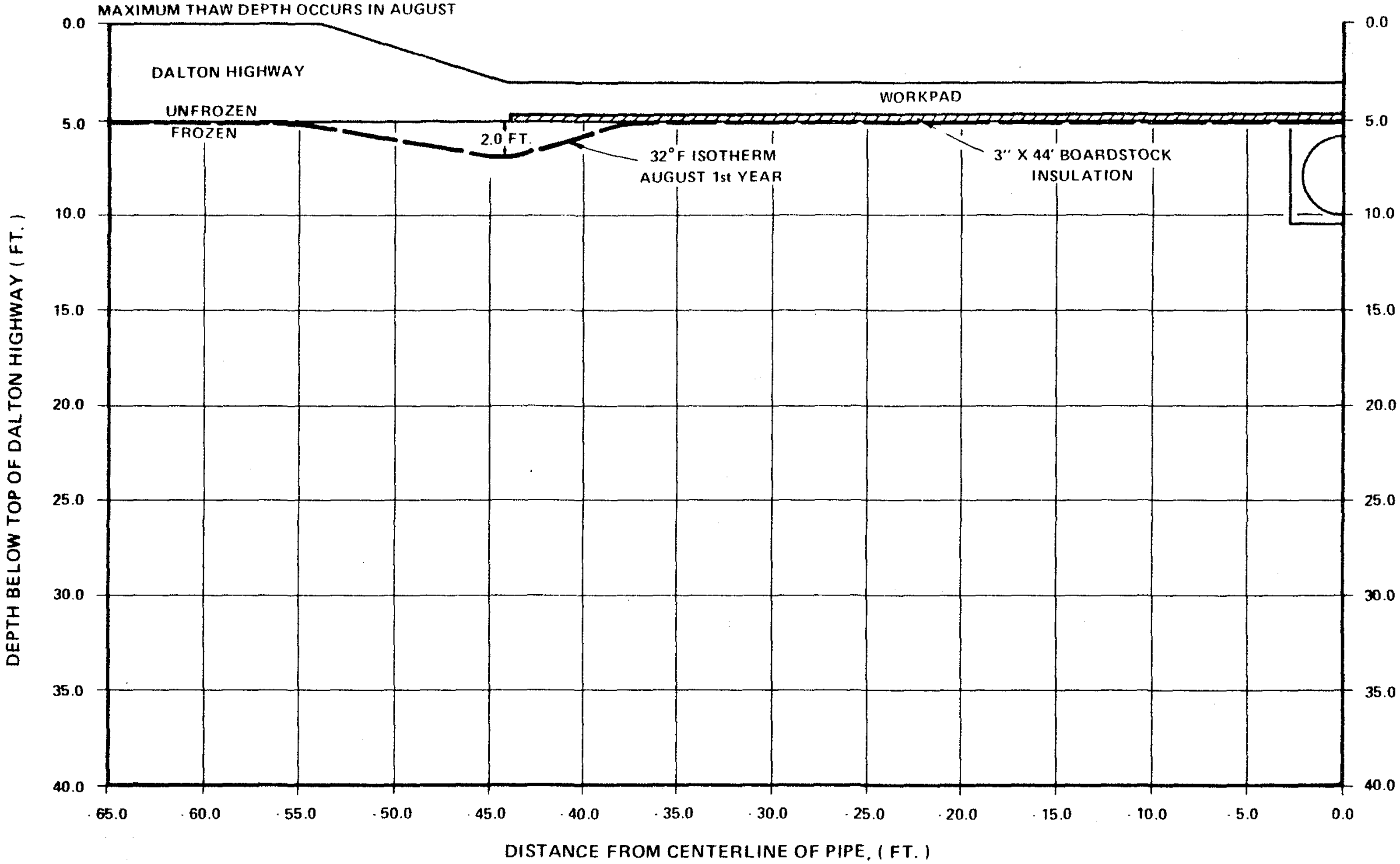
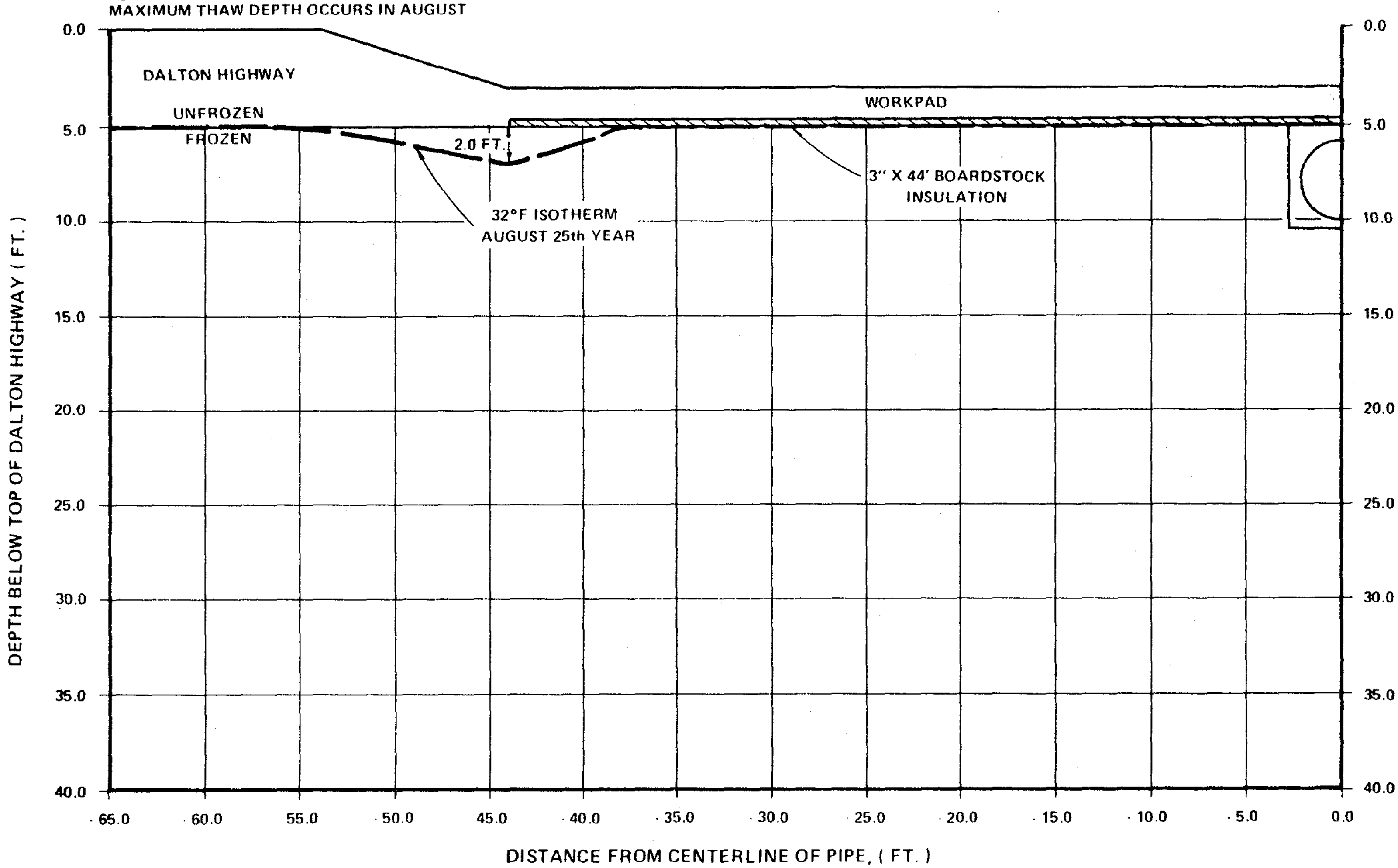


FIGURE 4 - 46

THAW PENETRATION
DURING OPERATION PERIOD - RUN NO. JV0698

NORTH OF ATIGUN PASS
SNOW DEPTH : 20% (OF PRECONSTRUCTION DEPTH) ON TOP OF DALTON HIGHWAY
160% NEAR EDGE OF DALTON HIGHWAY
500% ON SHOULDER OF DALTON HIGHWAY
300% ON TOP OF WORKPAD NEAR DALTON HIGHWAY
150% ON REMAINDER OF WORKPAD AND OVER PIPE DITCH
SOIL TYPE A
Tgas = 28° F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN AUGUST



THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO. JV0311

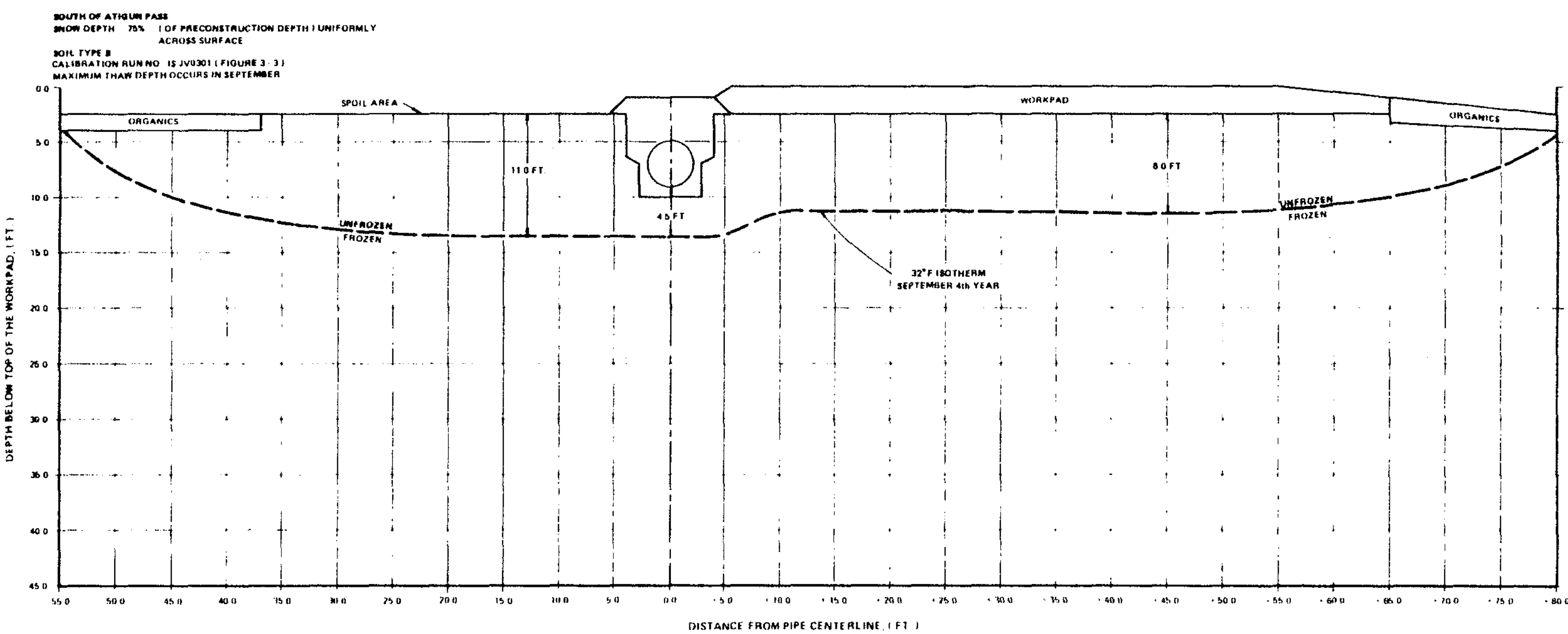
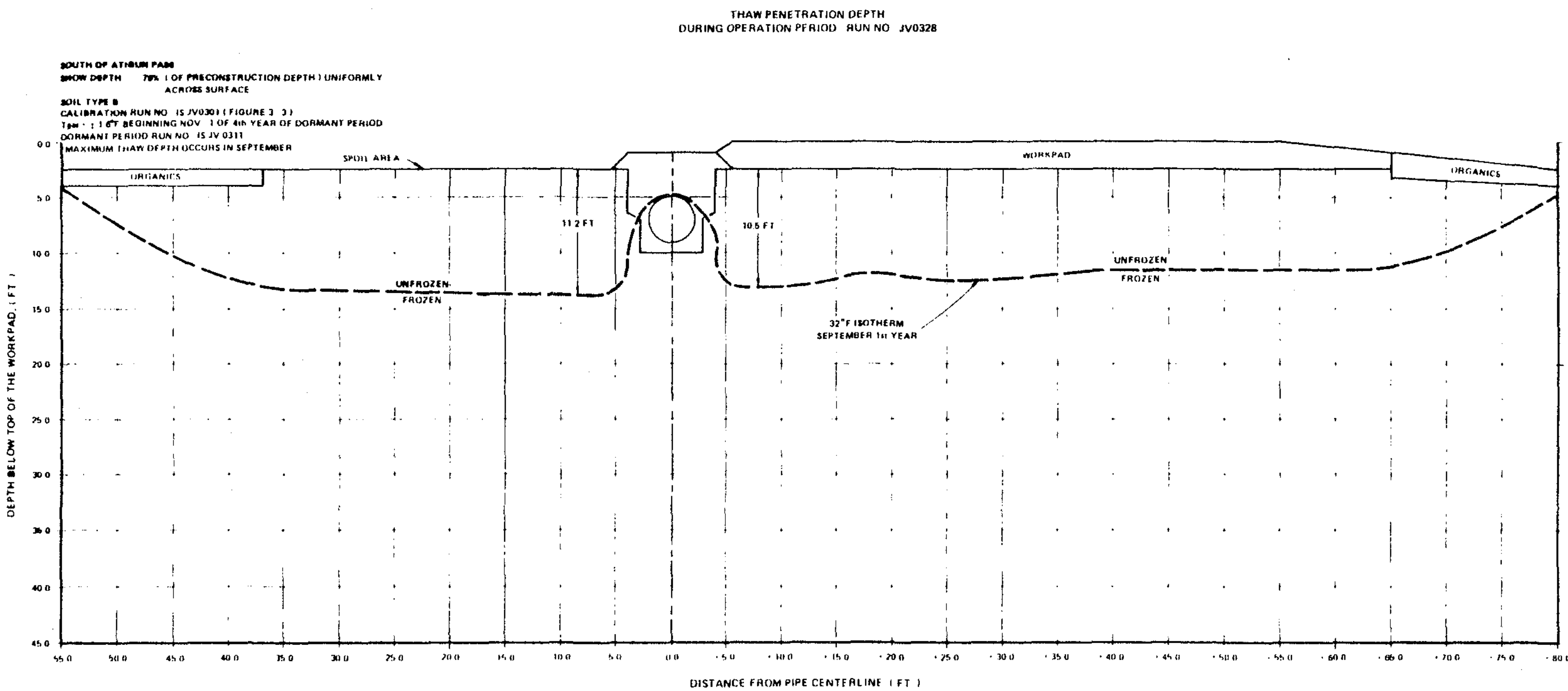


FIGURE 4-47

FIGURE 4 - 48


THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO JV0328
SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
CALIBRATION RUN NO IS JV0301 (FIGURE 3 3)
BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
DORMANT PERIOD RUN NO IS JV 0311
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
ORGANICS
11 2 FT
10 5 FT
UNFROZEN
FROZEN
UNFROZEN
FROZEN
32°F ISOTHERM
SEPTEMBER 1st YEAR
DEPTH BELOW TOP OF THE WORKPAD (FT)
DISTANCE FROM PIPE CENTERLINE (FT)

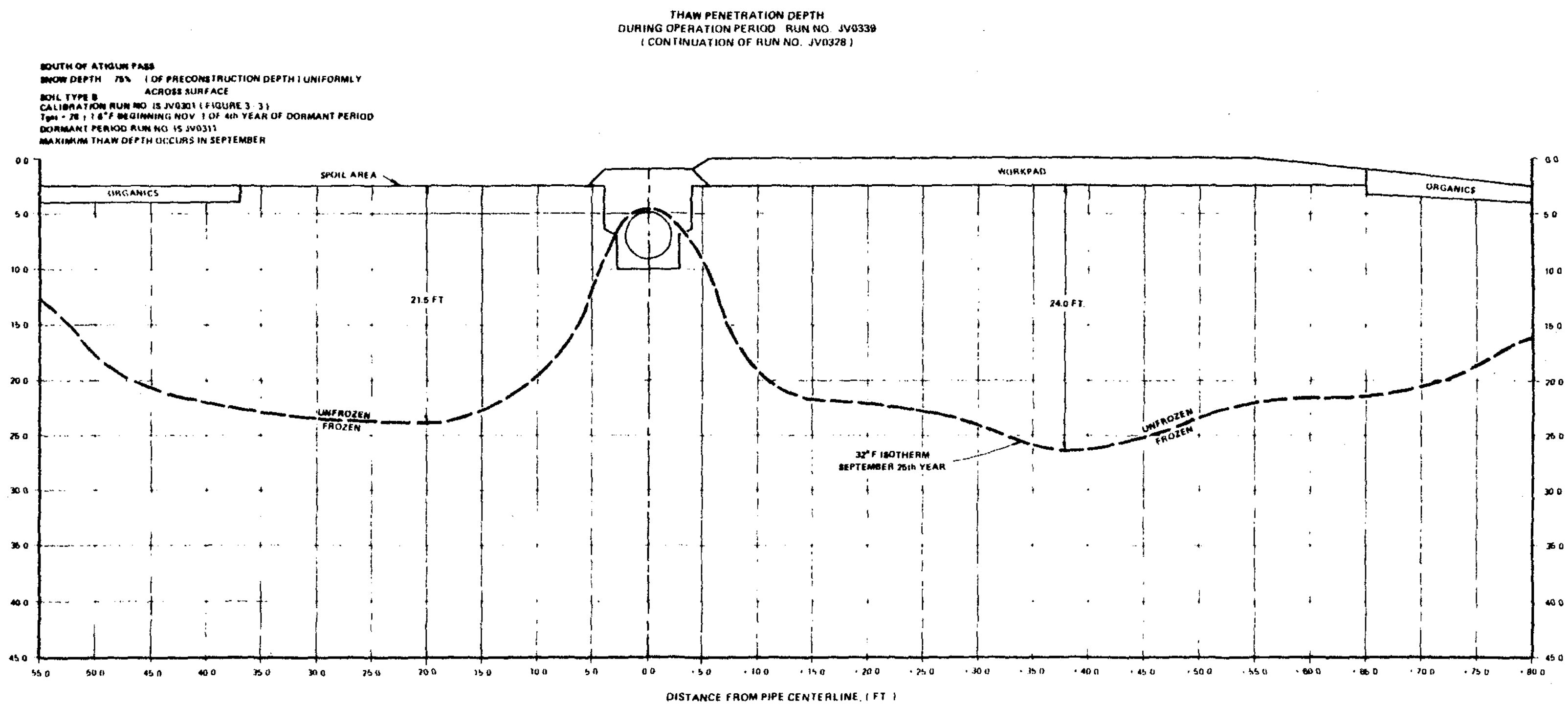

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0339
(CONTINUATION OF RUN NO. JV0328)
SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
CALIBRATION RUN NO. IS JV0301 (FIGURE 3-3)
DORMANT PERIOD RUN NO. IS JV0311
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
ORGANICS
21.5 FT
24.0 FT
UNFROZEN
FROZEN
UNFROZEN
FROZEN
32°F ISOTHERM
SEPTEMBER 25th YEAR
DEPTH BELOW TOP OF THE WORKPAD (FT)
DISTANCE FROM PIPE CENTERLINE (FT)

FIGURE 4-49

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO JV0668

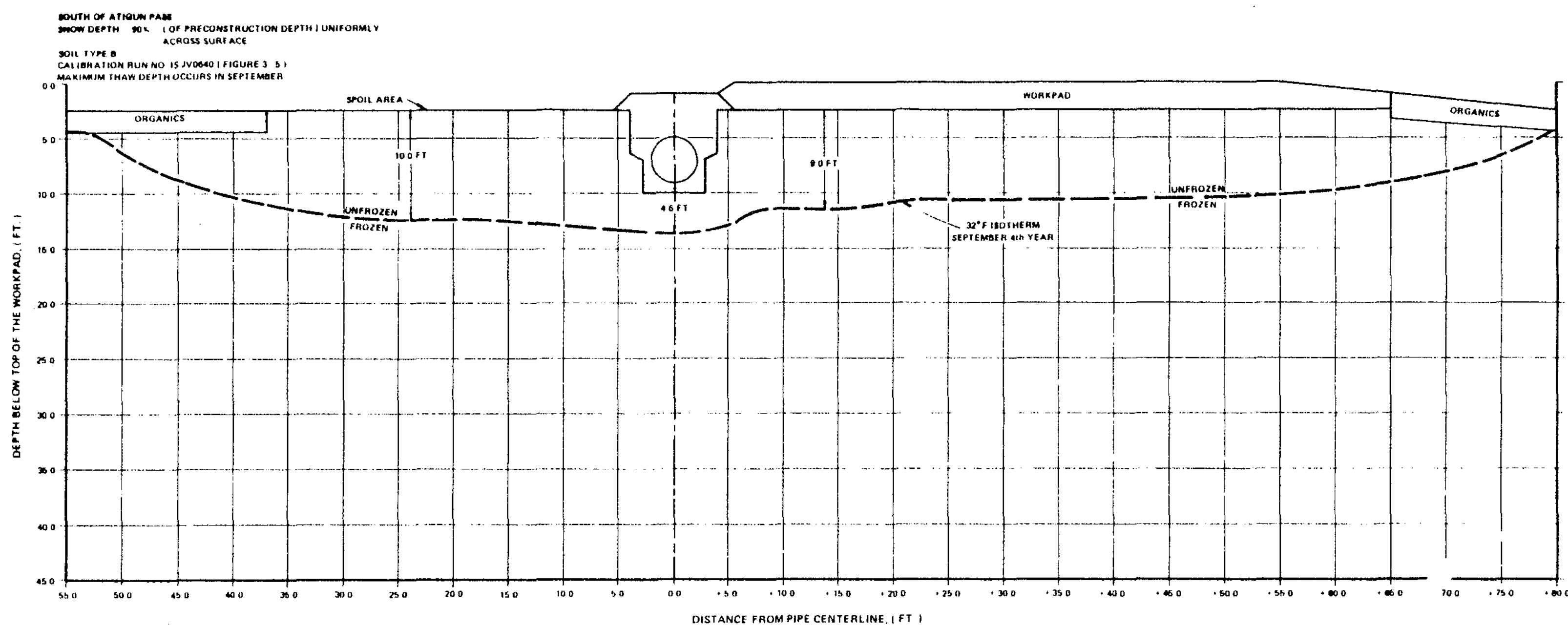


FIGURE 4 - 50

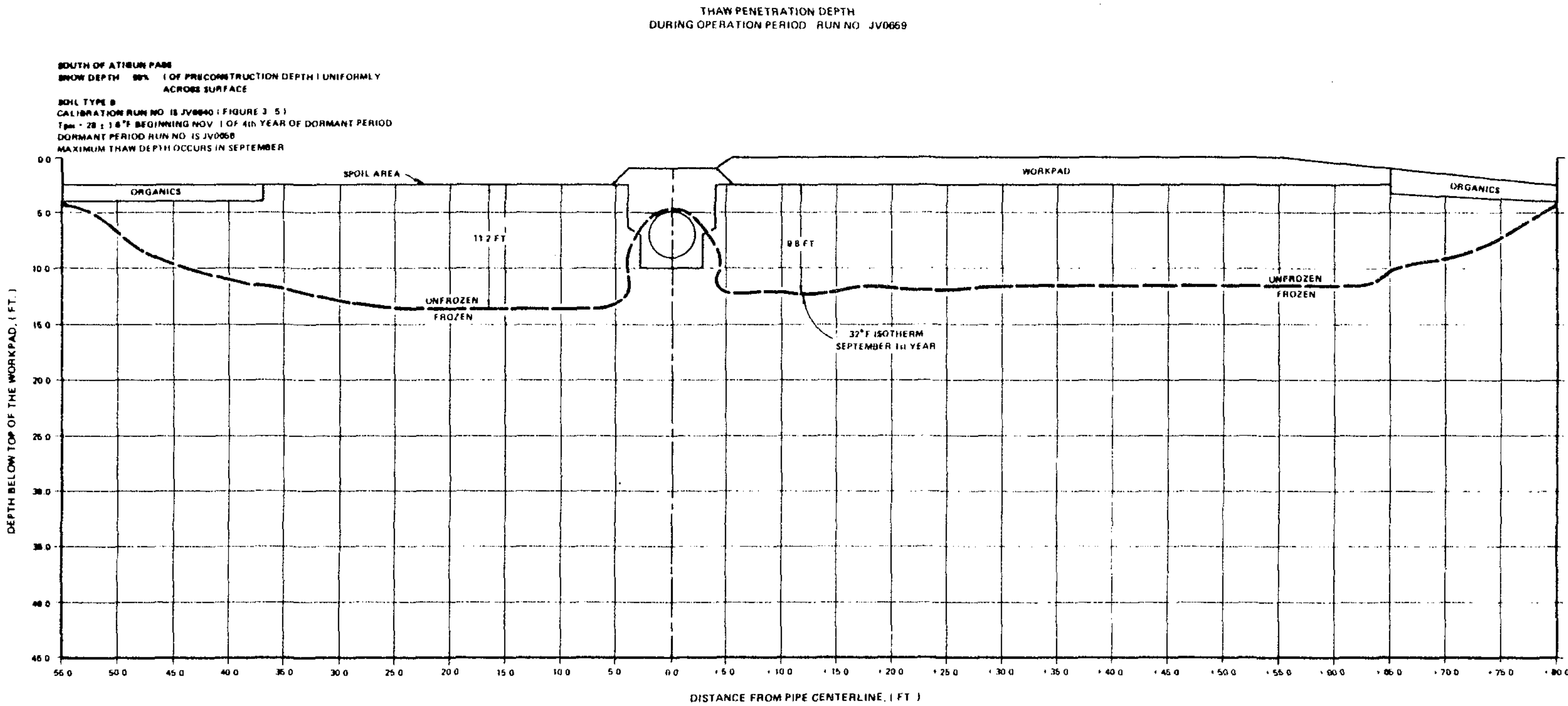

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO JV0659
CALIBRATION RUN NO
(FIGURE 3 5)
BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
DORMANT PERIOD RUN NO IS JV0658
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
ORGANICS
11.2 FT
9.8 FT
UNFROZEN
FROZEN
UNFROZEN
FROZEN
32°F ISOTHERM
SEPTEMBER 1st YEAR
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT)

FIGURE 4-51

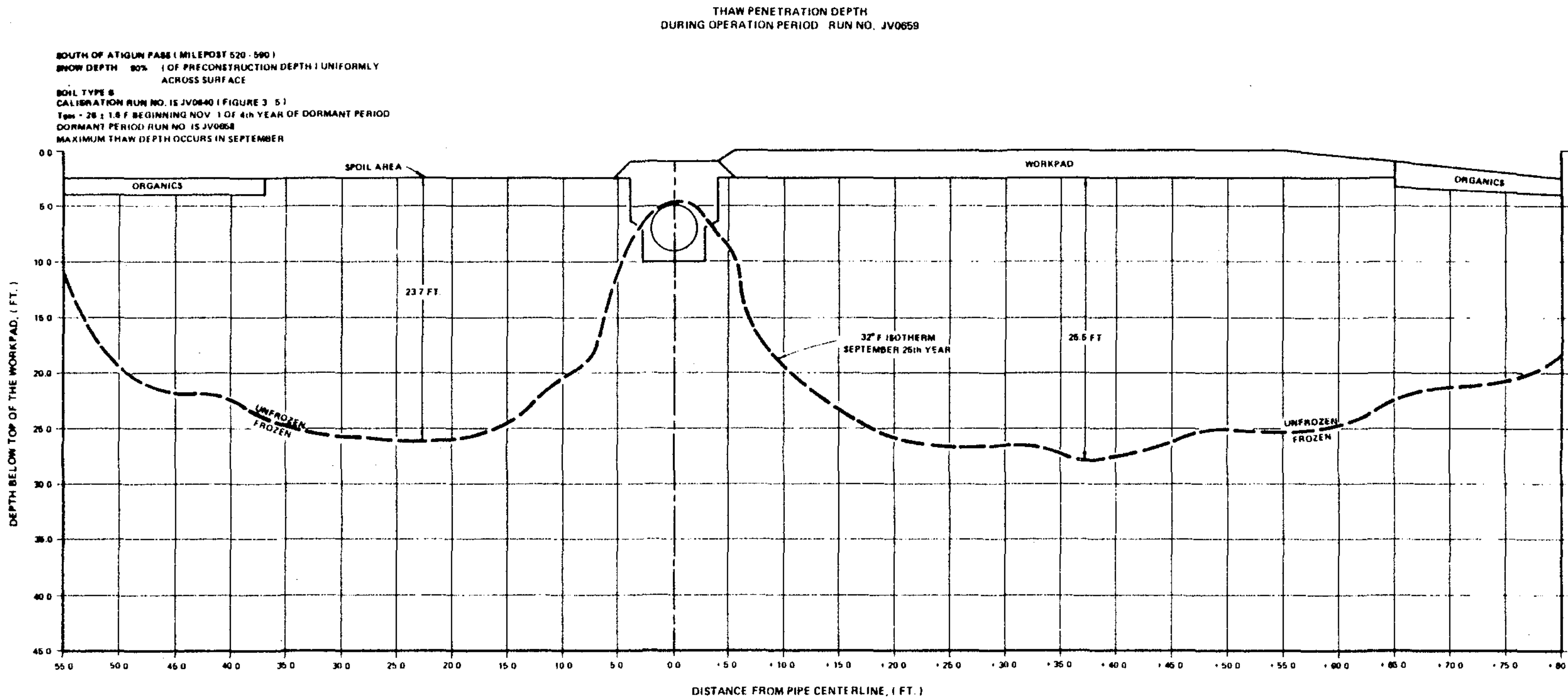
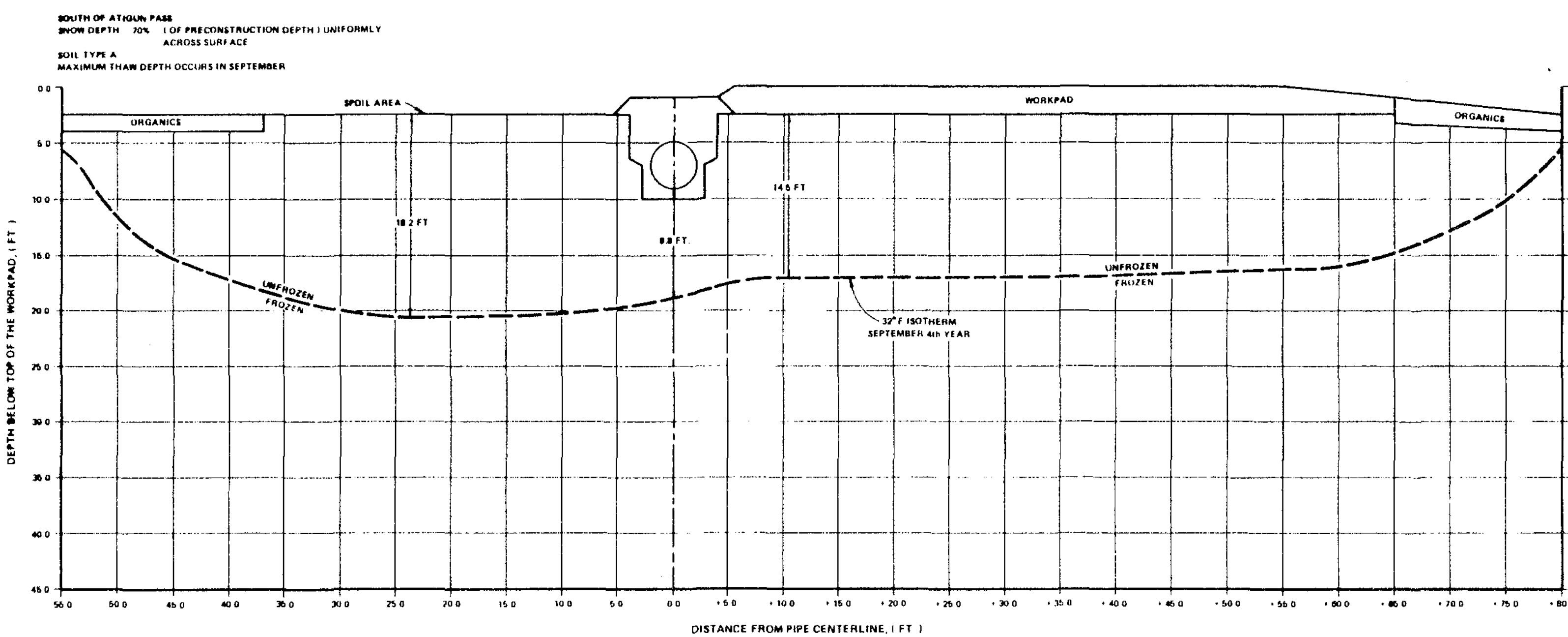

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0659
SOUTH OF ATIGUN PASS (MILEPOST 520 - 590)
SNOW DEPTH 90% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE 6
CALIBRATION RUN NO. IS JV0640 (FIGURE 3 5)
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
ORGANICS
23.7 FT
32° F ISOTHERM
SEPTEMBER 25th YEAR
25.5 FT
UNFROZEN
FROZEN
UNFROZEN
FROZEN
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT.)

FIGURE 4-52

THAW MITIGATION THERMAL
EVALUATION AND SENSITIVITY STUDY

FIGURE 4-53

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO JV0667



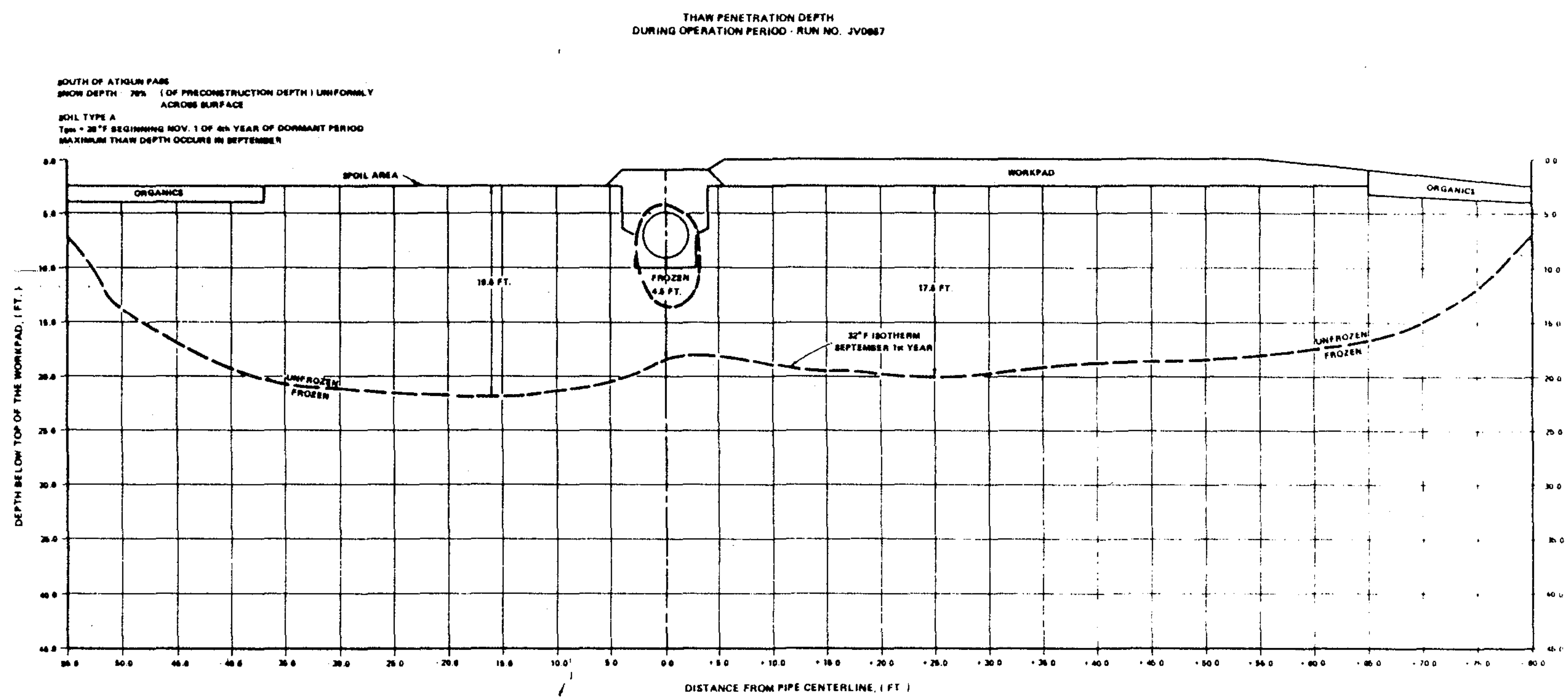

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0867
SOUTH OF ATIGUN PASS
SNOW DEPTH 70% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
Tgm = 28°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
ORGANICS
19.6 FT.
FROZEN
4.6 FT.
17.8 FT.
32°F ISOTHERM
SEPTEMBER 1st YEAR
UNFROZEN
FROZEN
UNFROZEN
FROZEN
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT)

FIGURE 4 - 54

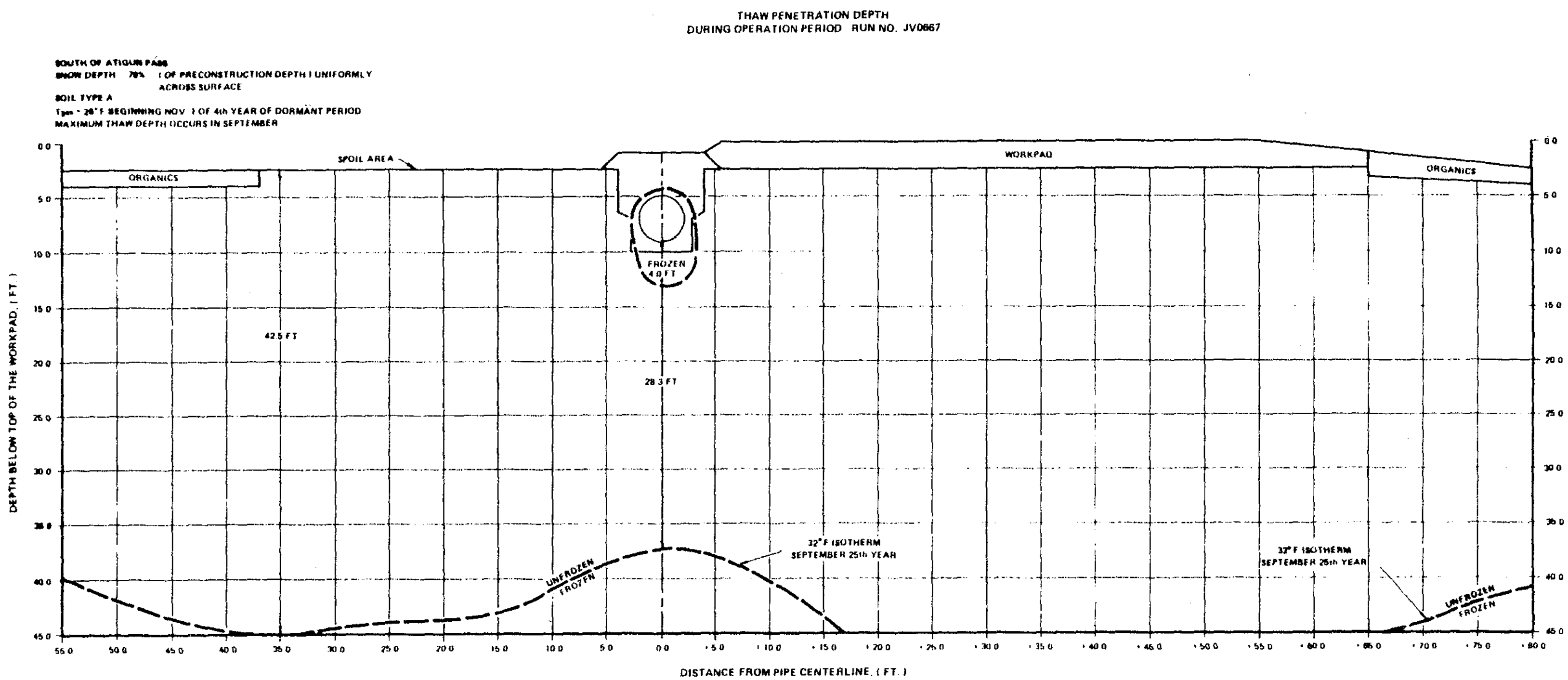

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0667
SOUTH OF ATIGUN PASS
SNOW DEPTH 70% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
Tpm - 20°F BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
ORGANICS
FROZEN
4.0 FT
42.5 FT
28.3 FT
32°F ISOTHERM
SEPTEMBER 25th YEAR
32°F ISOTHERM
SEPTEMBER 25th YEAR
UNFROZEN
FROZEN
UNFROZEN
FROZEN
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT.)

FIGURE 4-55

FIGURE 4 - 57

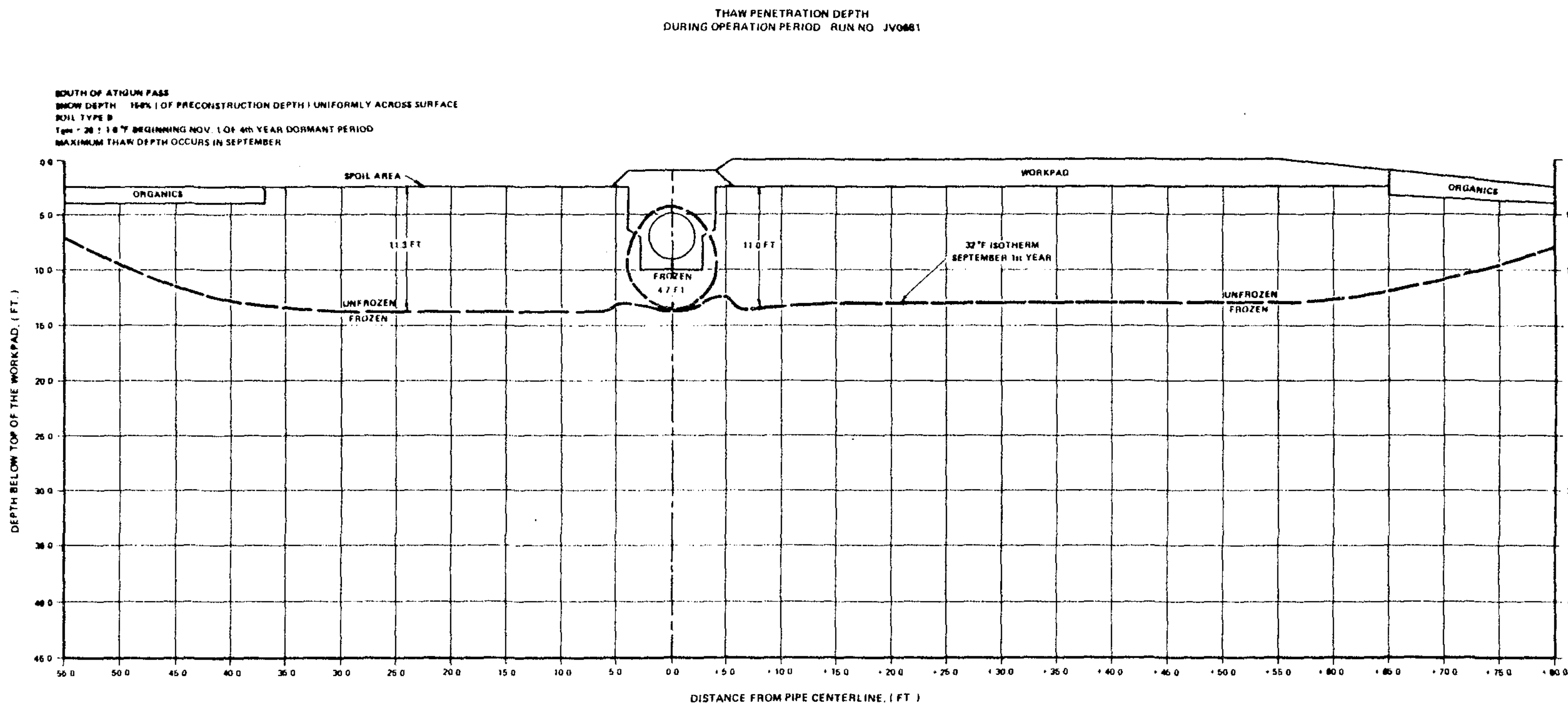
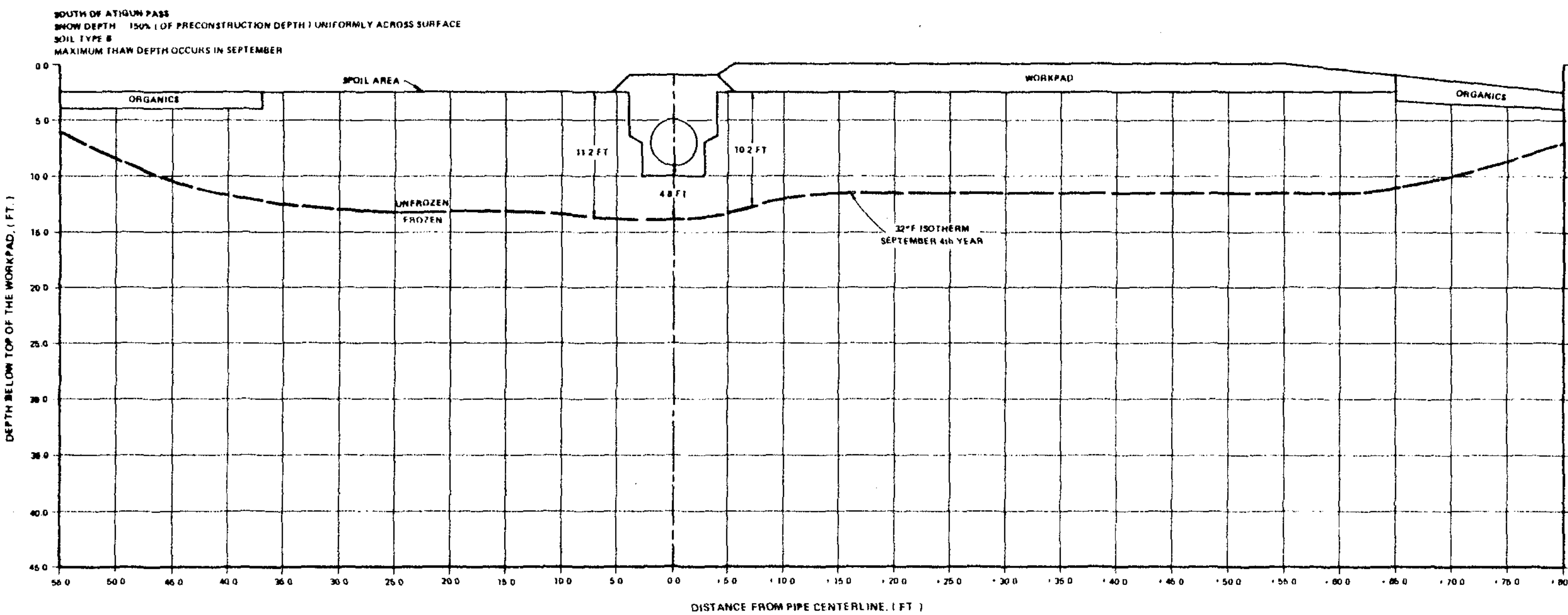

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO JV0681
SOUTH OF ATIGUN PASS
SNOW DEPTH 150% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
11.3 FT
11.0 FT
FROZEN
4.7 FT
32°F ISOTHERM
SEPTEMBER 1st YEAR
UNFROZEN
FROZEN
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT)

FIGURE 4 - 56

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO. JV0681



THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0681

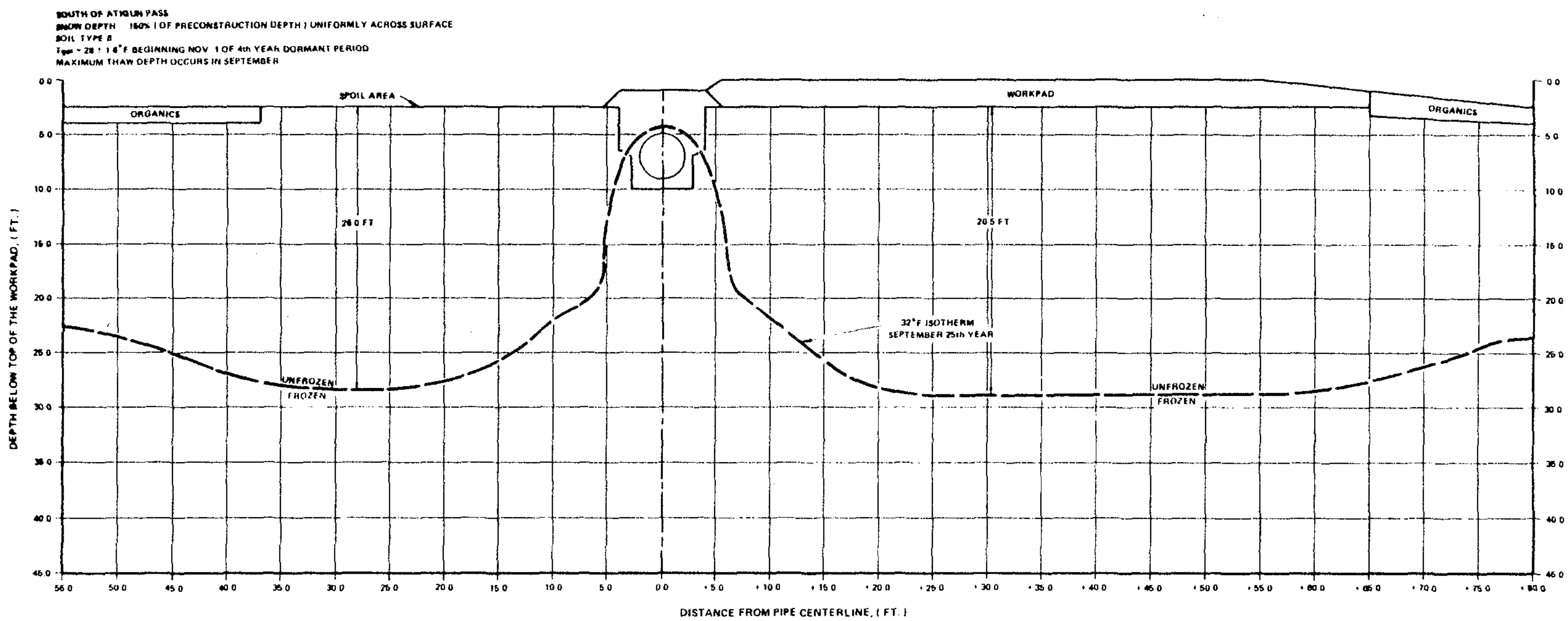
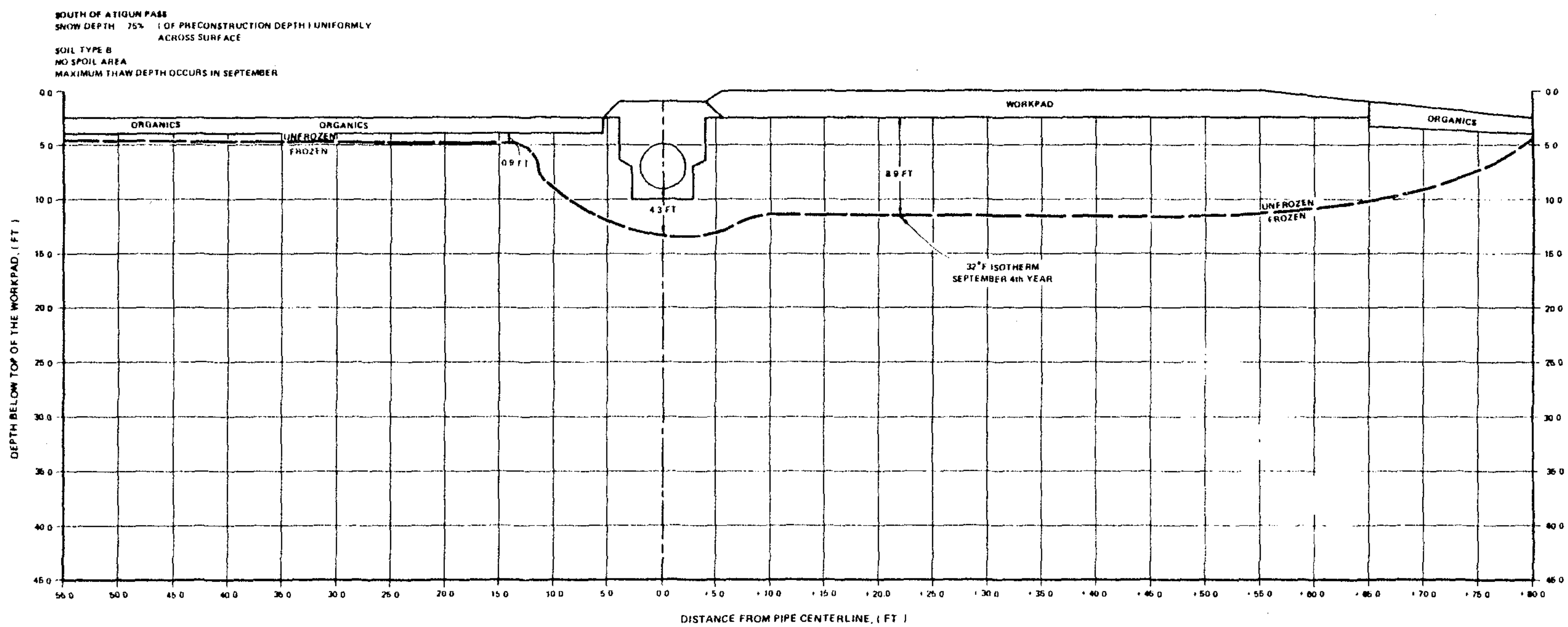


FIGURE 4-58

FIGURE 4 - 59

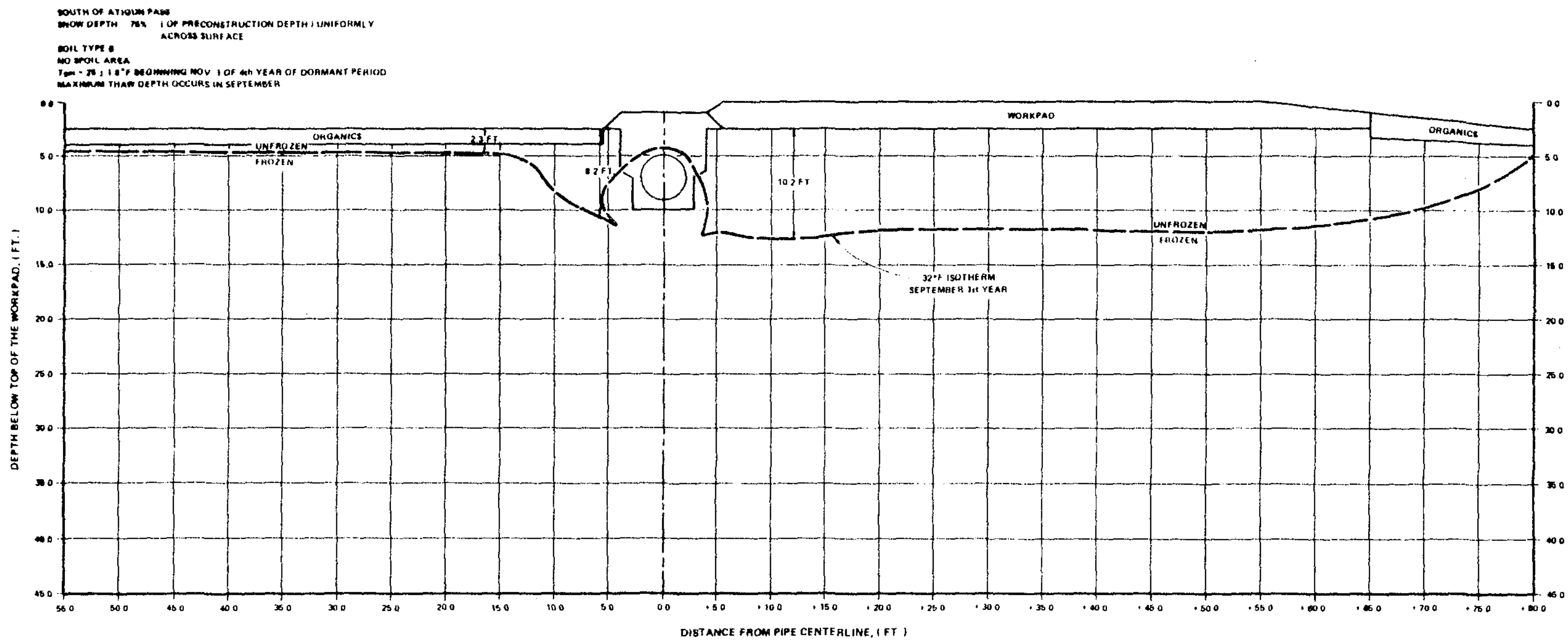
THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO JV0677



THAW MITIGATION THERMAL EVALUATION AND SENSITIVITY STUDY

FIGURE 4 - 60

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0677



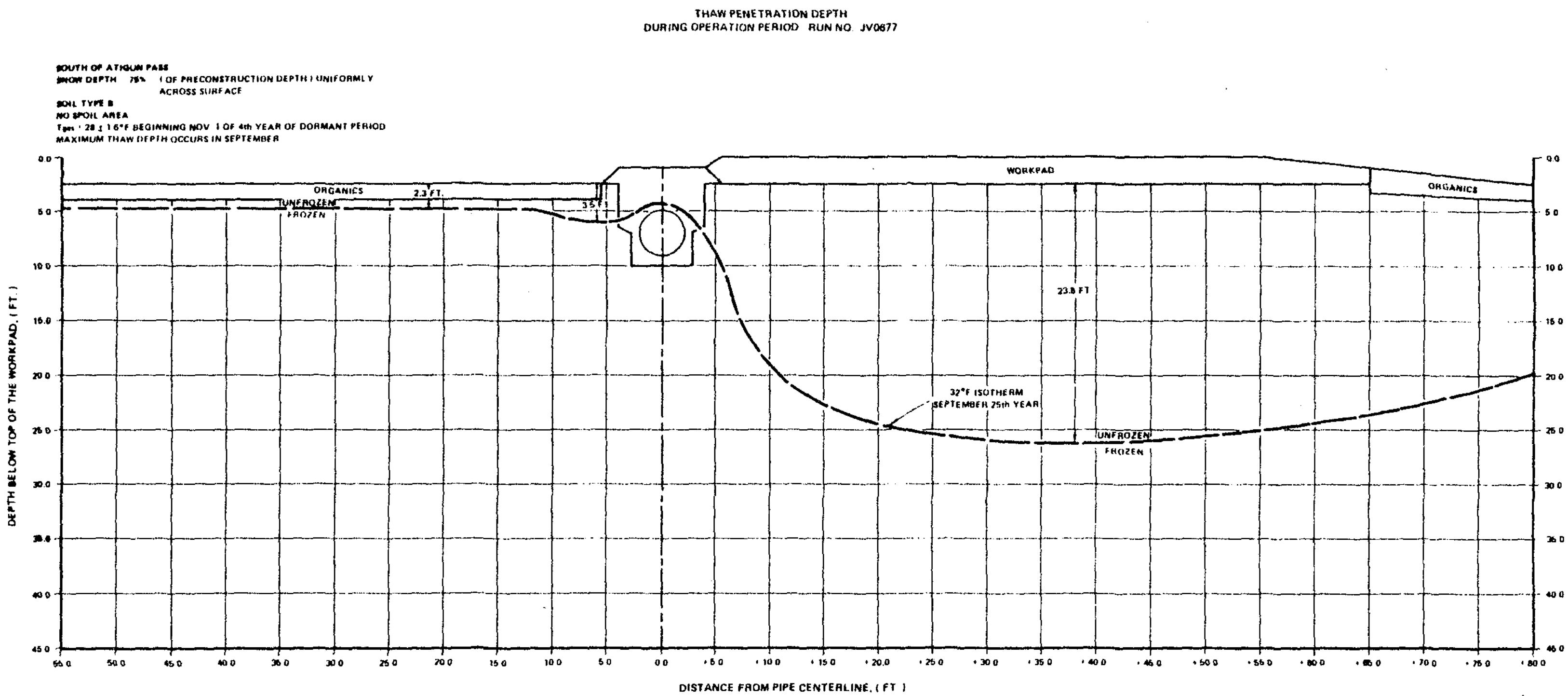
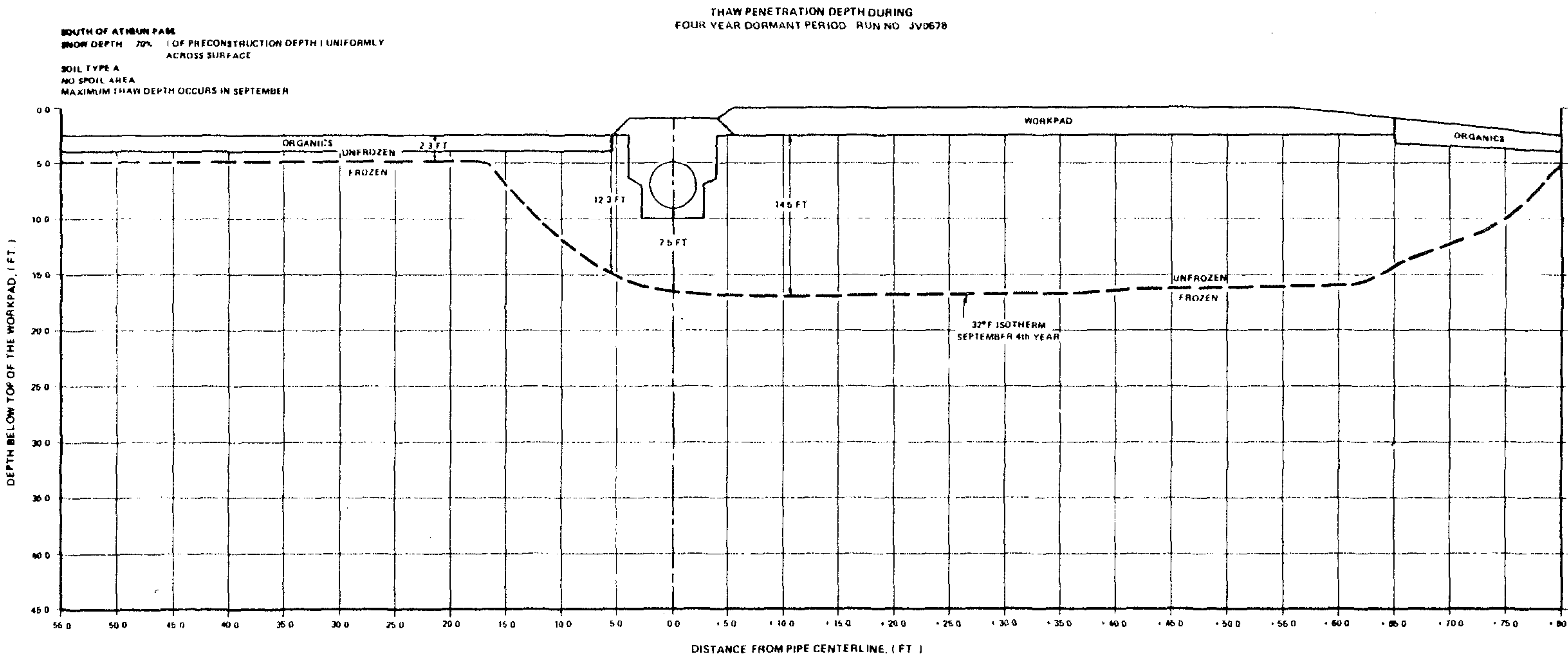

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0677
SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
NO SPOIL AREA
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
WORKPAD
ORGANICS
2.3 FT.
UNFROZEN
FROZEN
23.8 FT
32°F ISOTHERM
SEPTEMBER 25th YEAR
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT.)

FIGURE 4-61

FIGURE 4-62


THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO JV0678
SOUTH OF ATIGUN PASS
SNOW DEPTH 70% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
NO SPOIL AREA
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
ORGANICS
UNFROZEN
FROZEN
2.3 FT
12.3 FT
7.5 FT
14.5 FT
WORKPAD
32°F ISOTHERM
SEPTEMBER 4th YEAR
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT.)

THAW MITIGATION THERMAL EVALUATION AND SENSITIVITY STUDY

FIGURE 4-63

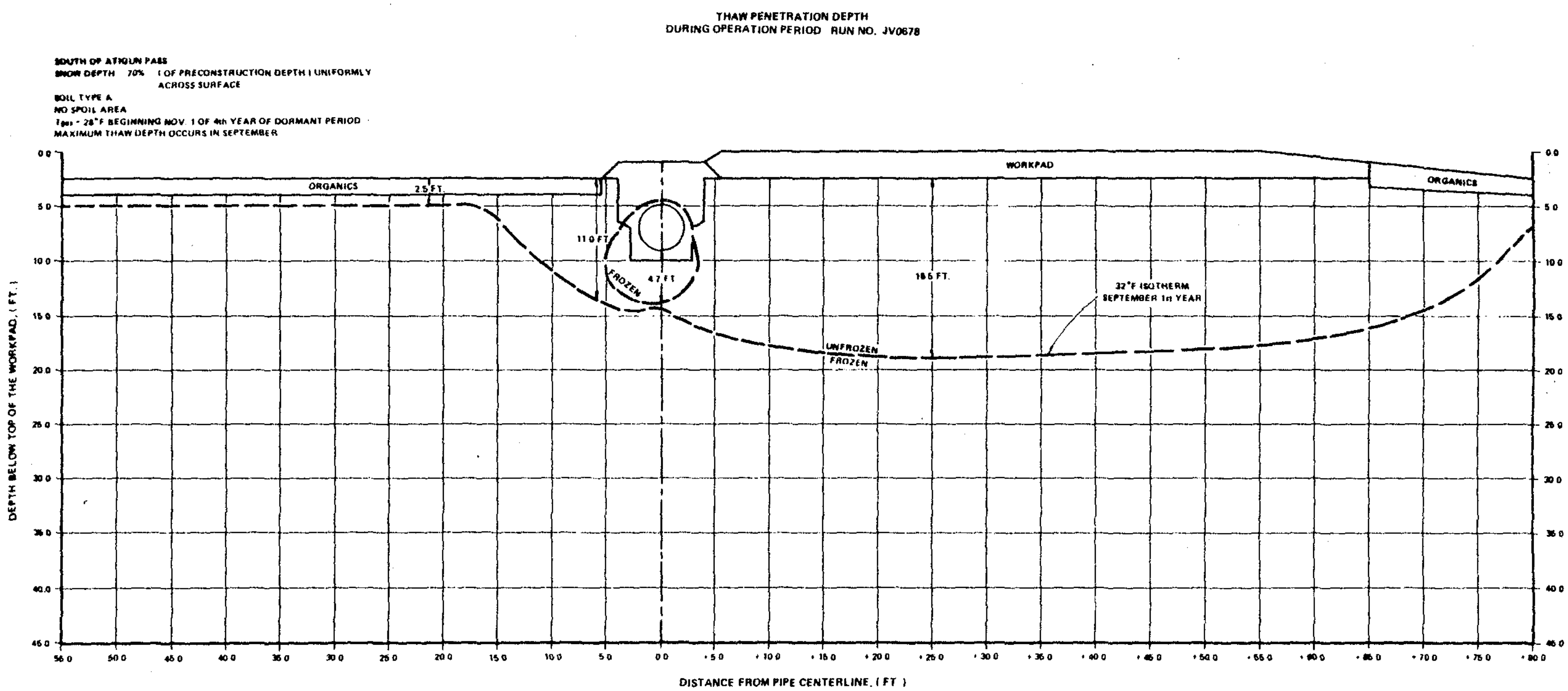


FIGURE 4 - 64

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0678

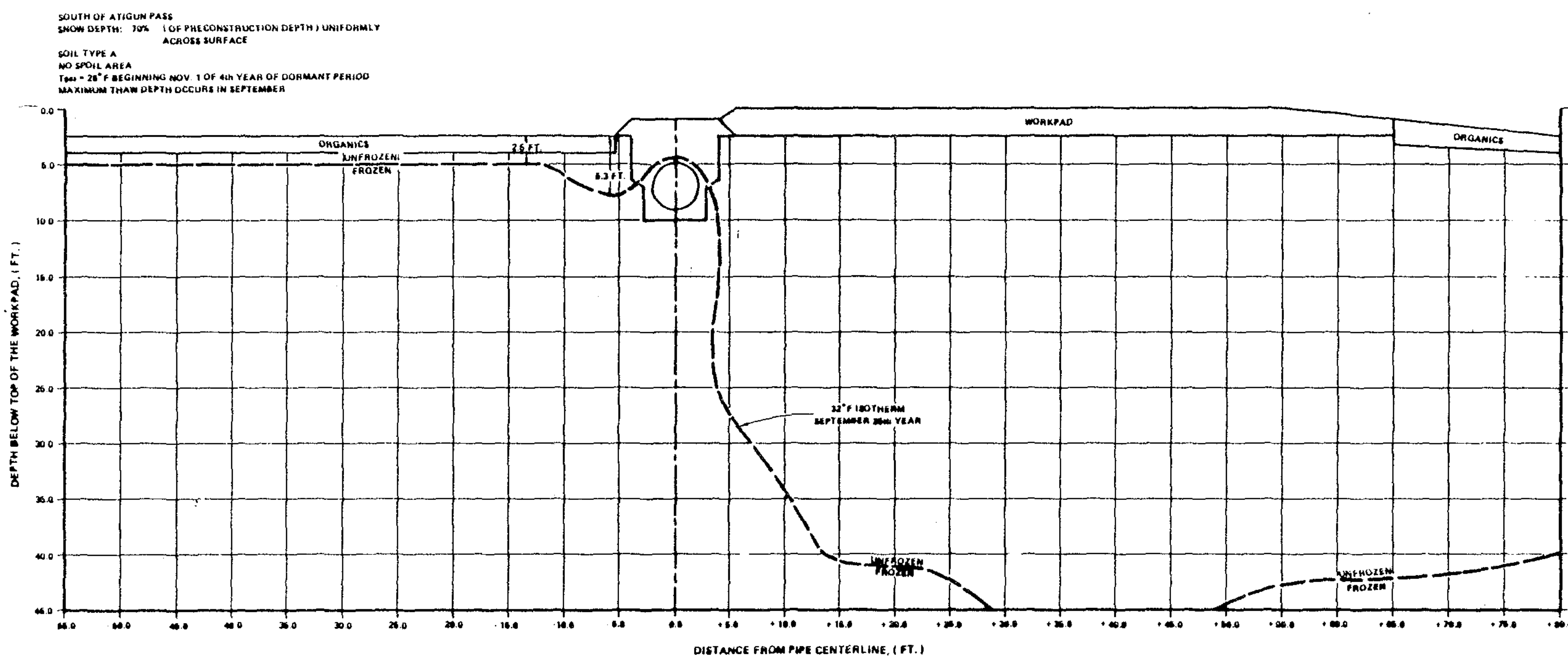


FIGURE 4 - 65

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO JV0679

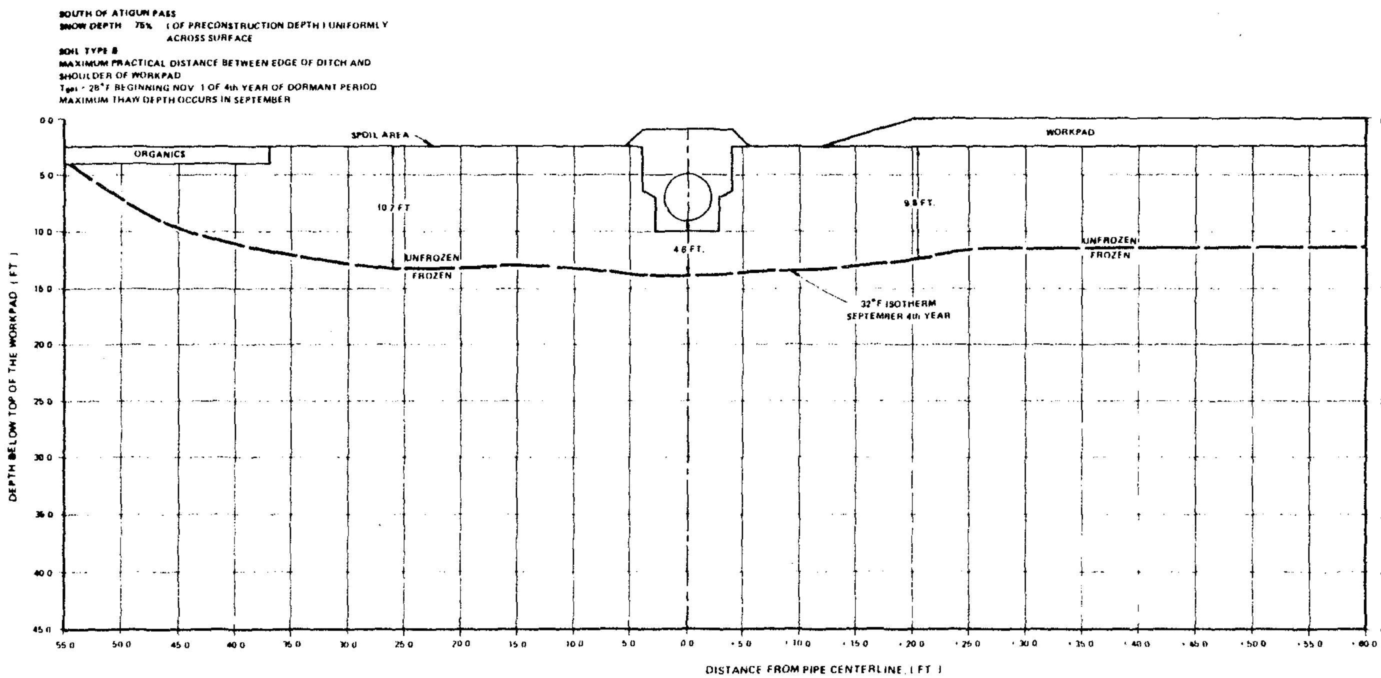


FIGURE 4 - 66

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0679

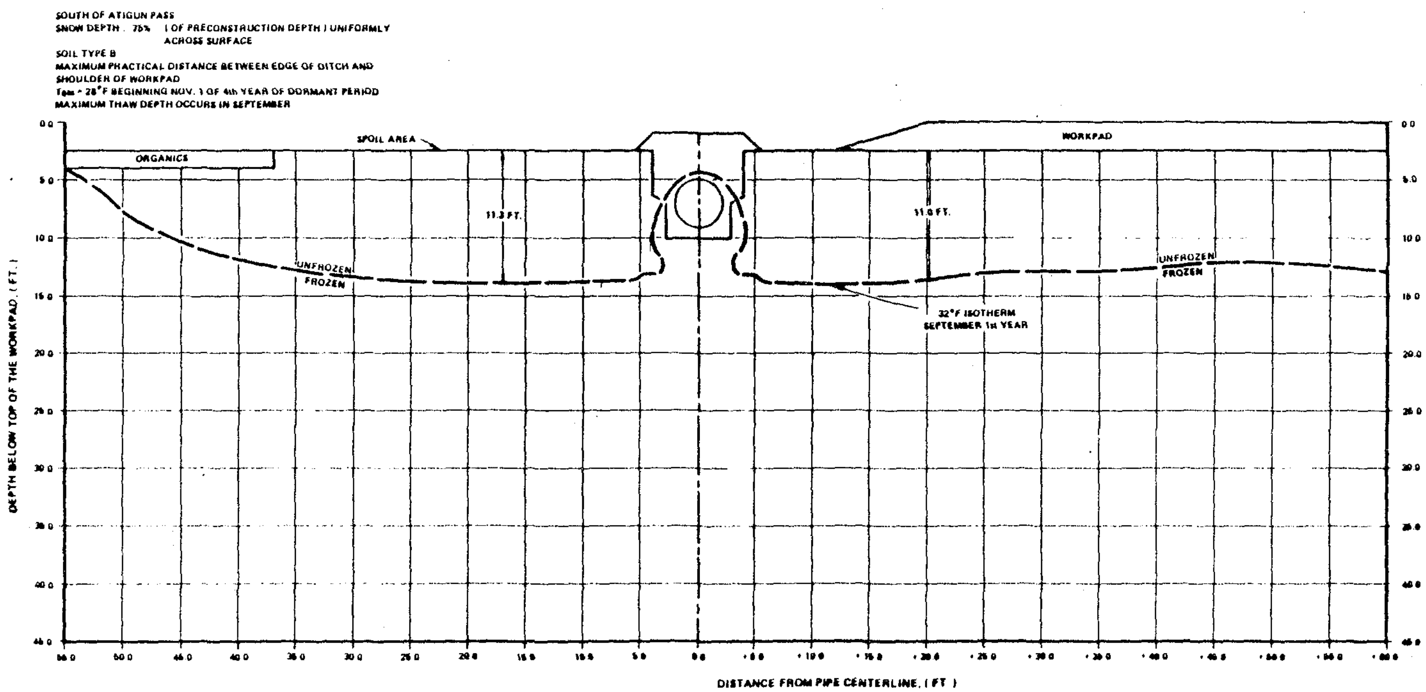


FIGURE 4 - 67

THAW PENETRATION DEPTH
DURING OPERATION PERIOD - RUN NO. JV0679

SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
MAXIMUM PRACTICAL DISTANCE BETWEEN EDGE OF DITCH AND SHOULDER OF WORKPAD
T_{gas} = 78°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER

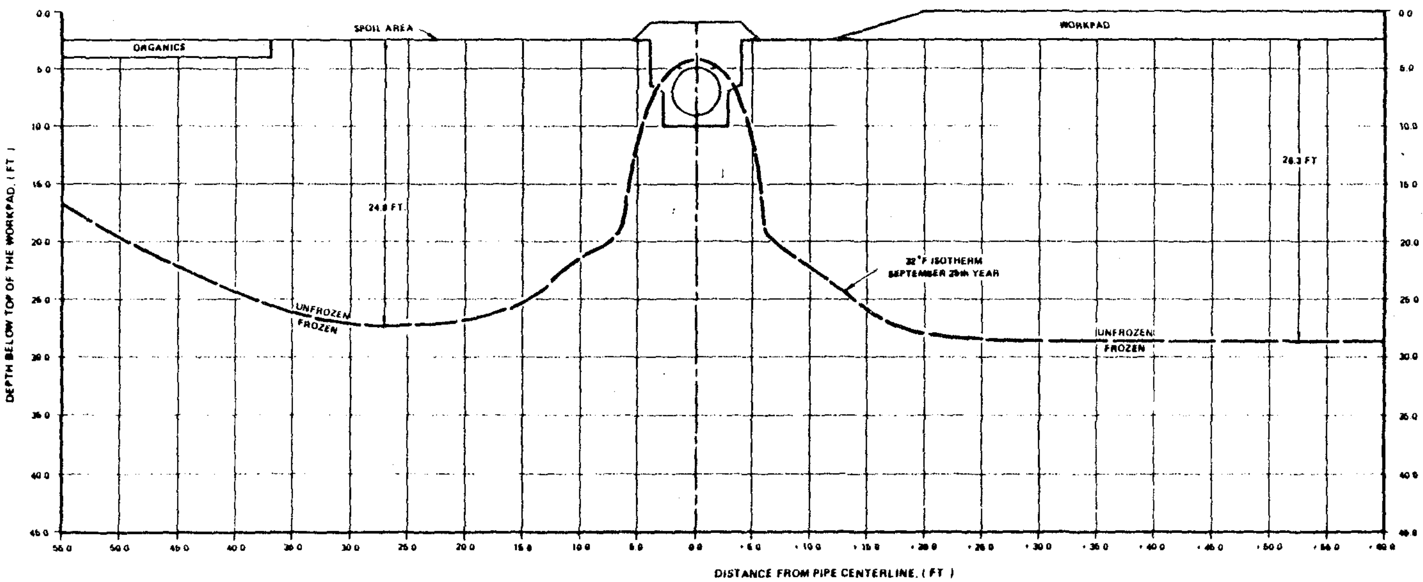
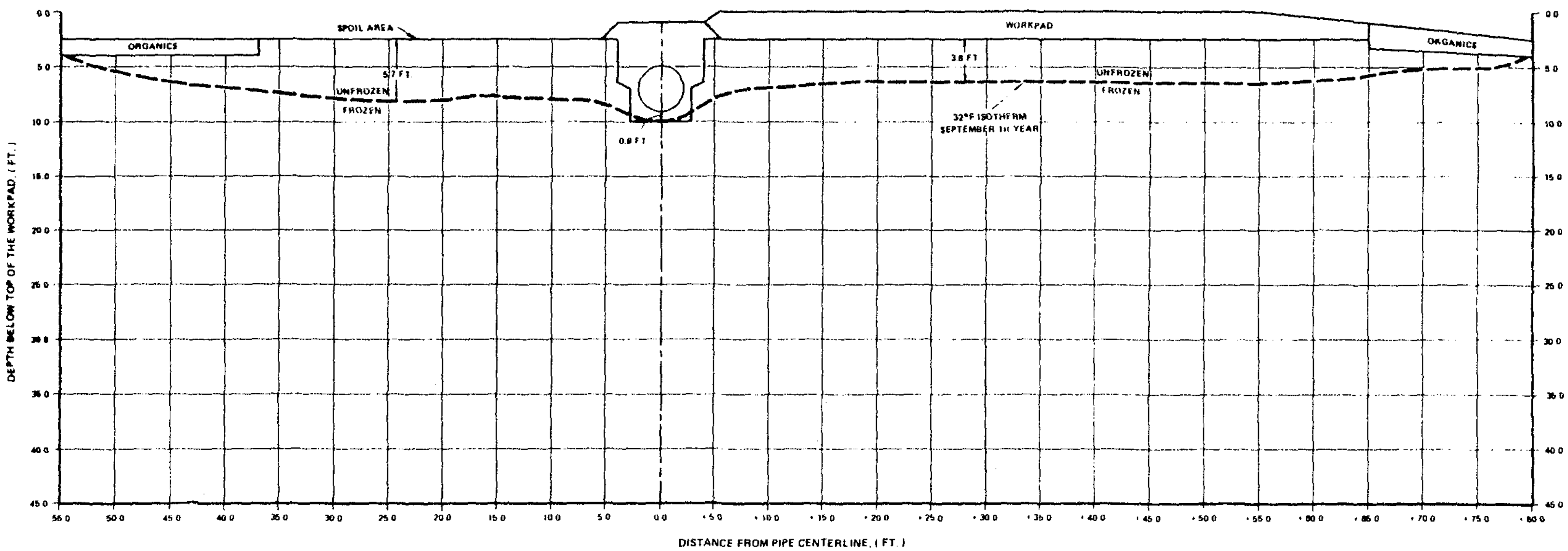


FIGURE 4 - 68

THAW PENETRATION DEPTH DURING
ONE YEAR DORMANT PERIOD RUN NO JV0680

SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER



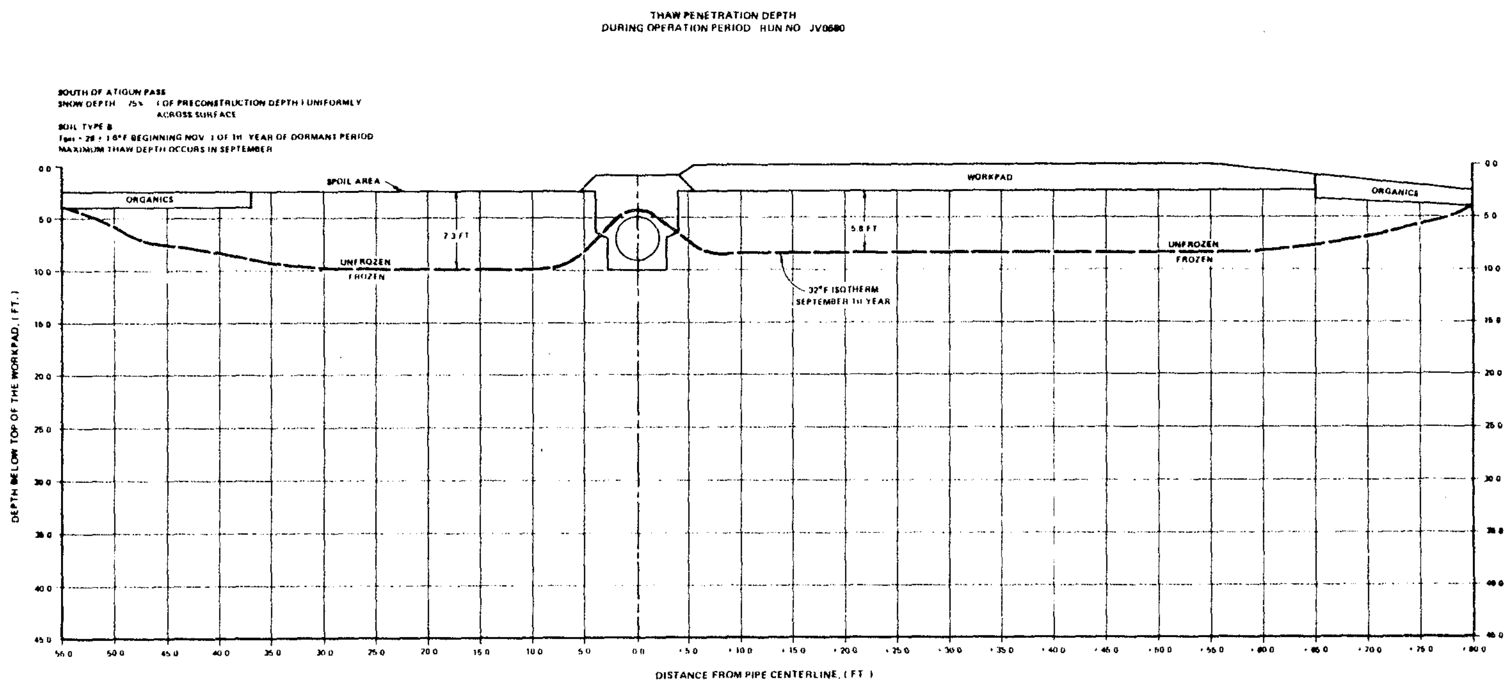

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO JV0680
SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
ORGANICS
WORKPAD
ORGANICS
7.3 FT
5.8 FT
UNFROZEN
FROZEN
UNFROZEN
FROZEN
32°F ISOTHERM SEPTEMBER 1ST YEAR
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT.)

FIGURE 4 - 69

FIGURE 4-70

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO JV0680

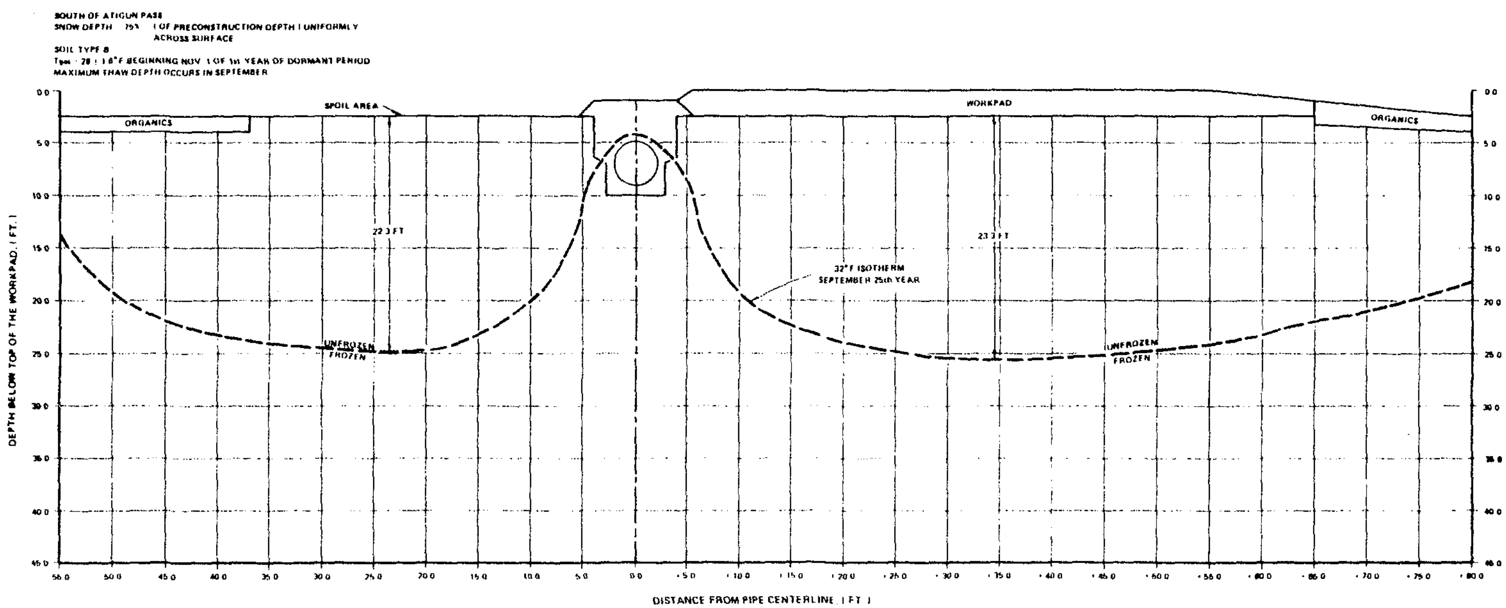
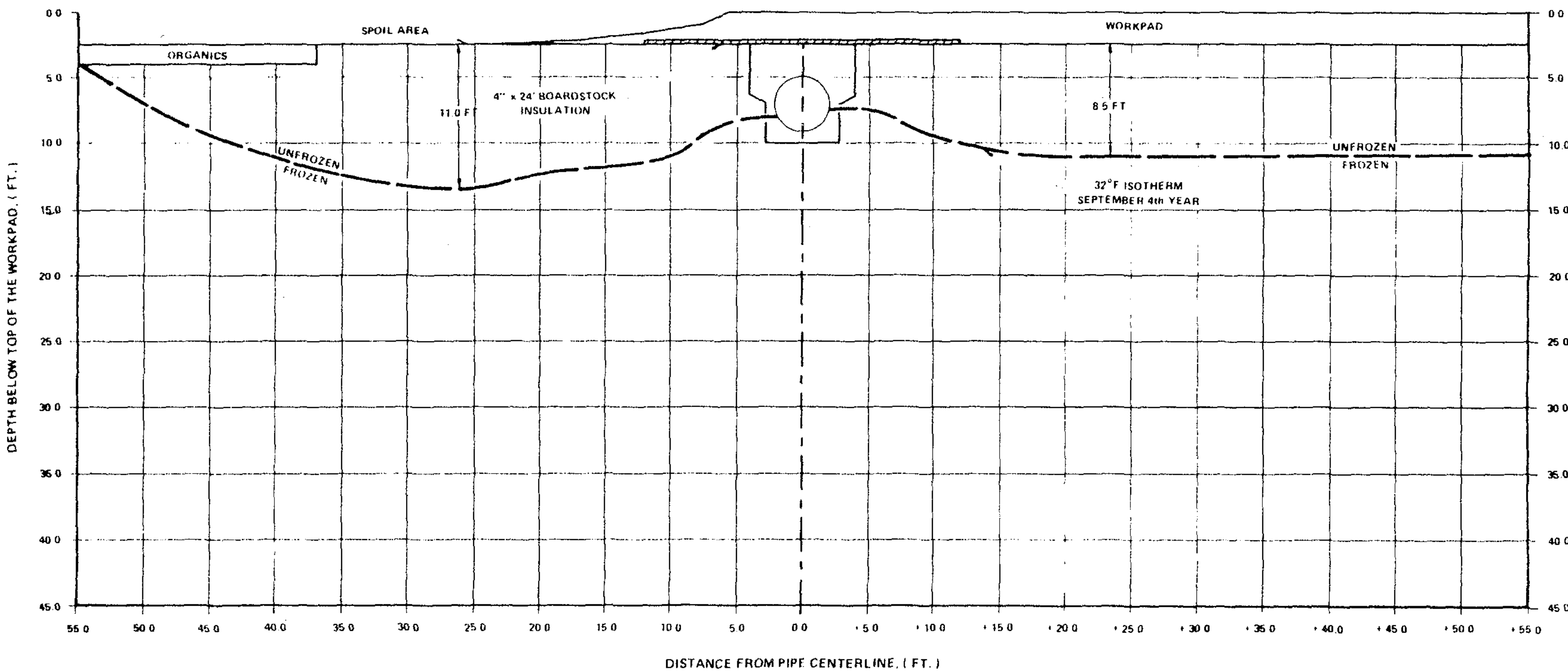


FIGURE 4 - 71

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO JV0325

SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER



THAW MITIGATION THERMAL
EVALUATION AND SENSITIVITY STUDY

FIGURE 4-72

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0342

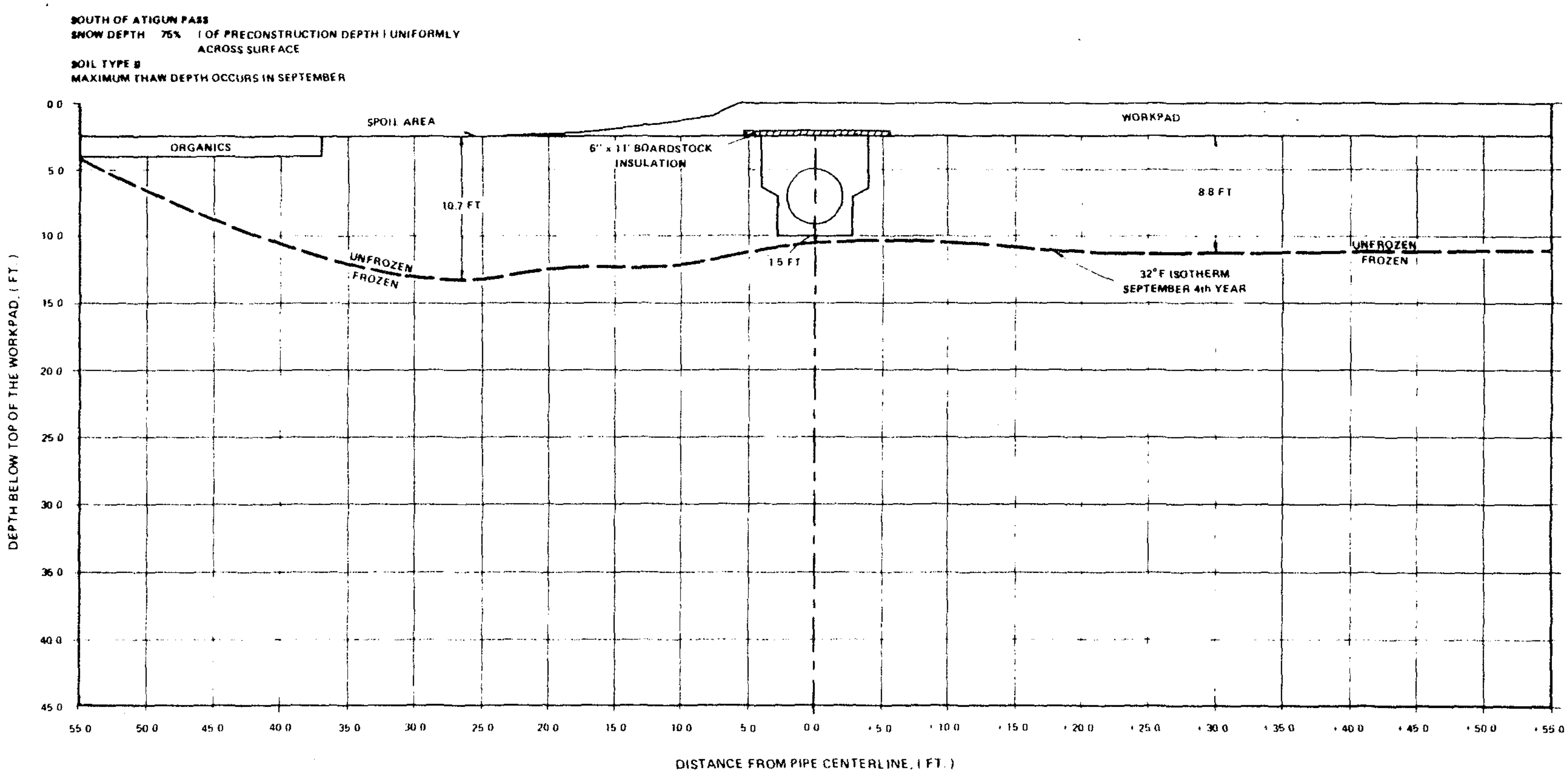


FIGURE 4-73

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. SJV0353

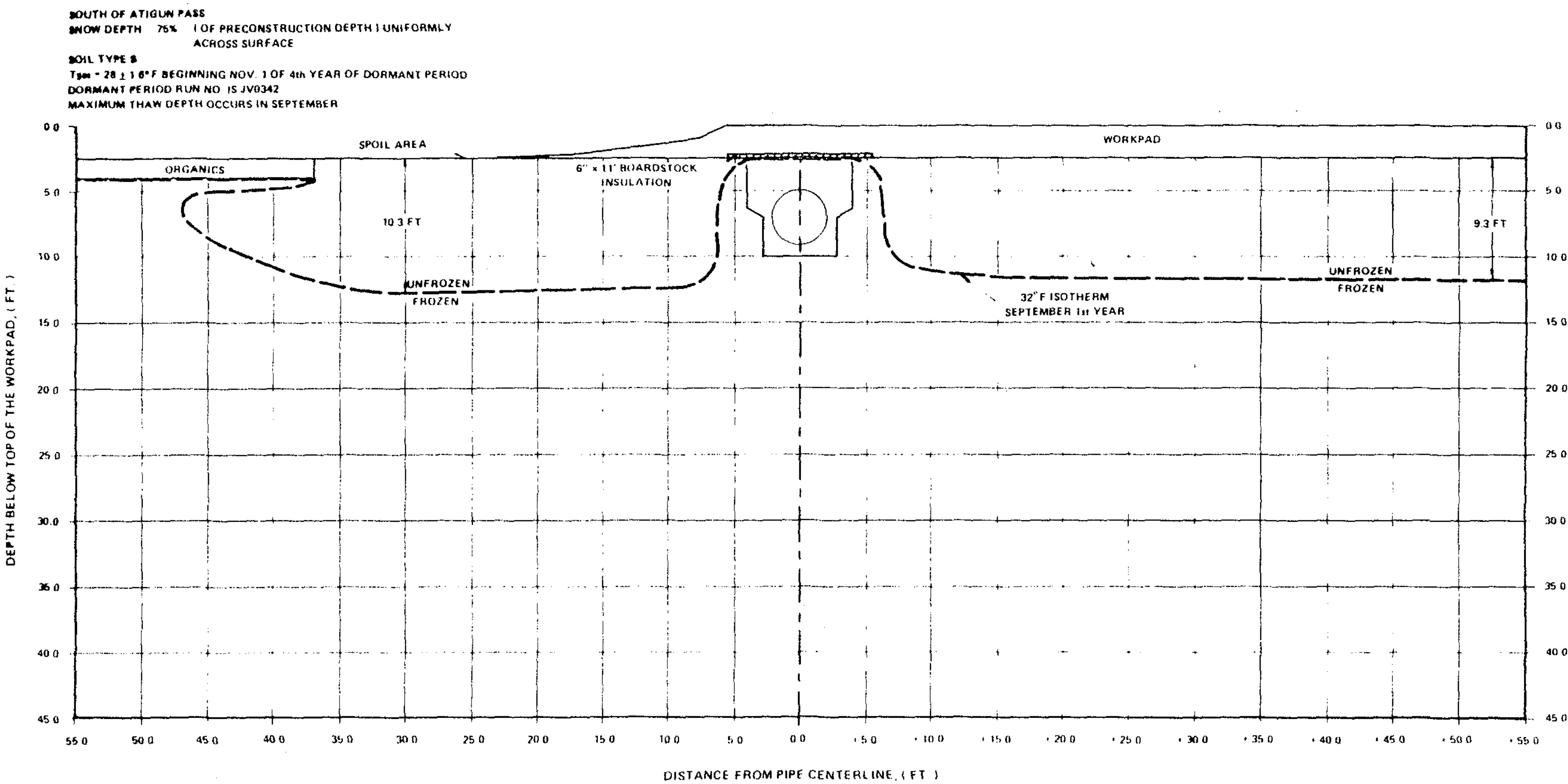


FIGURE 4-74

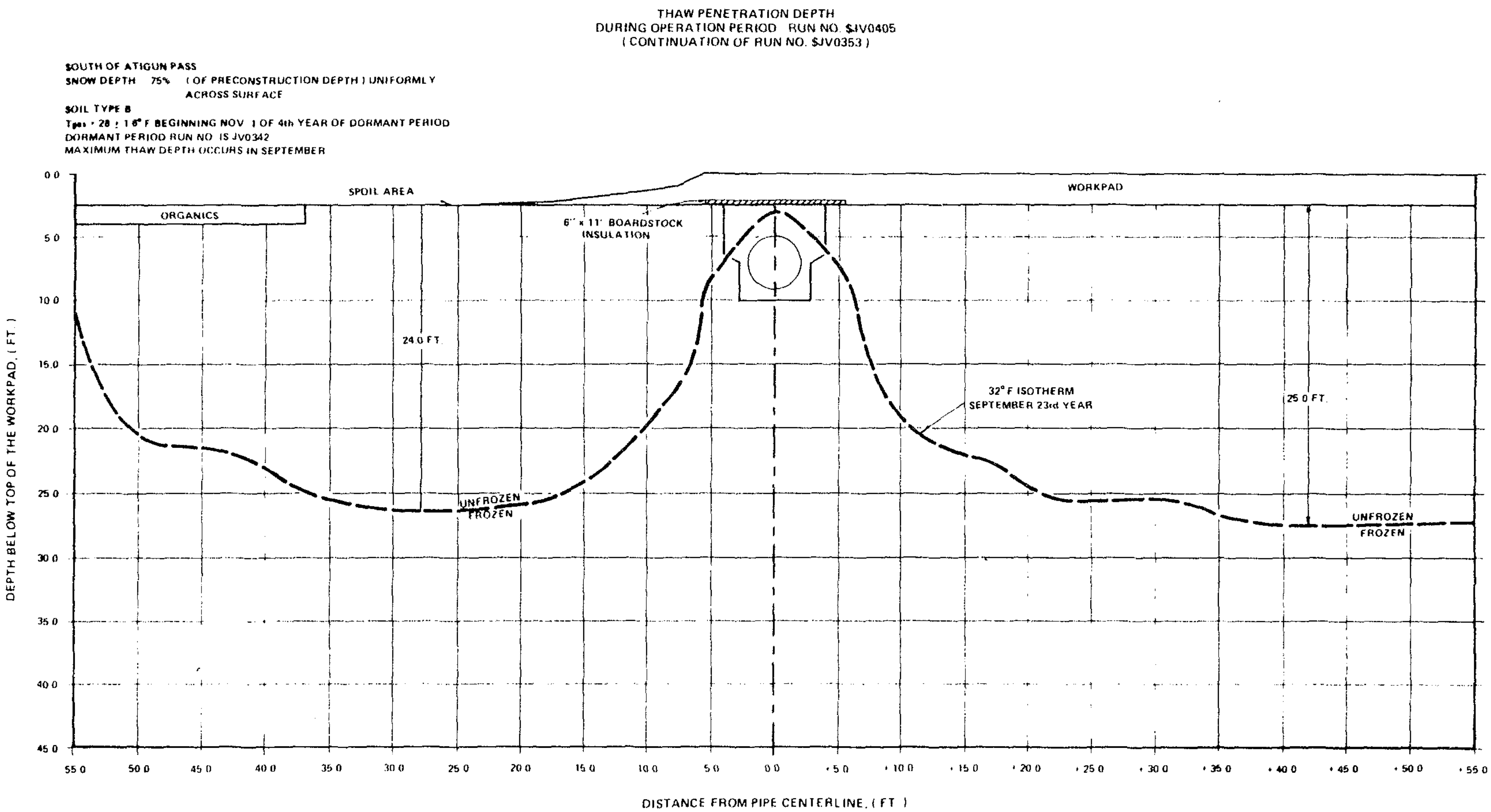

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. SJV0405
(CONTINUATION OF RUN NO. SJV0353)
SOUTH OF ATIGUN PASS
SNOW DEPTH 75% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
Tgas = 28 ± 1.6° F BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
DORMANT PERIOD RUN NO IS JV0342
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
WORKPAD
ORGANICS
6" x 11' BOARDSTOCK INSULATION
24.0 FT.
25.0 FT.
32° F ISOTHERM SEPTEMBER 23rd YEAR
UNFROZEN
FROZEN
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT.)

FIGURE 4-75

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO. JV0340

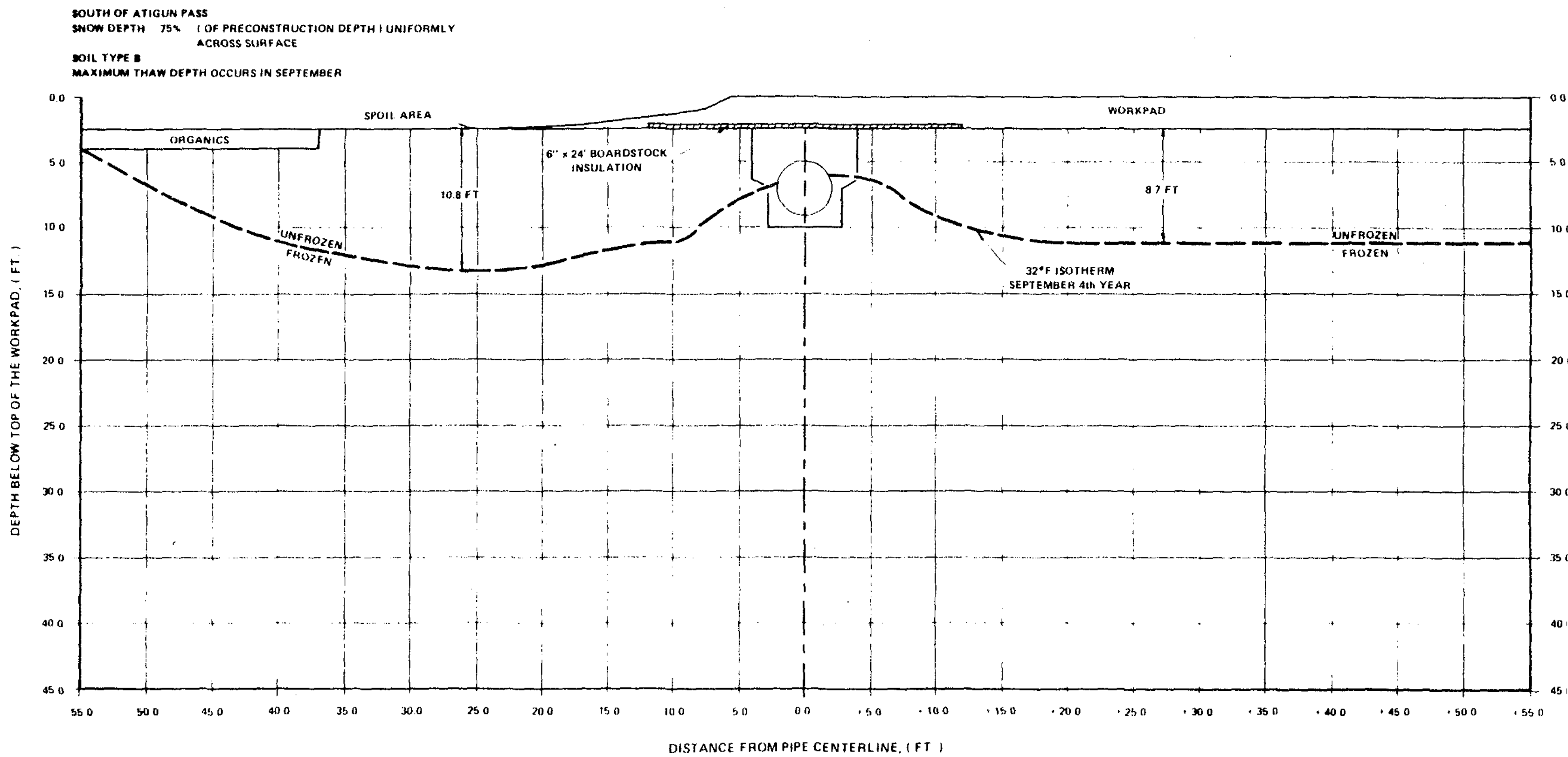


FIGURE 4-76

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. SJV0403

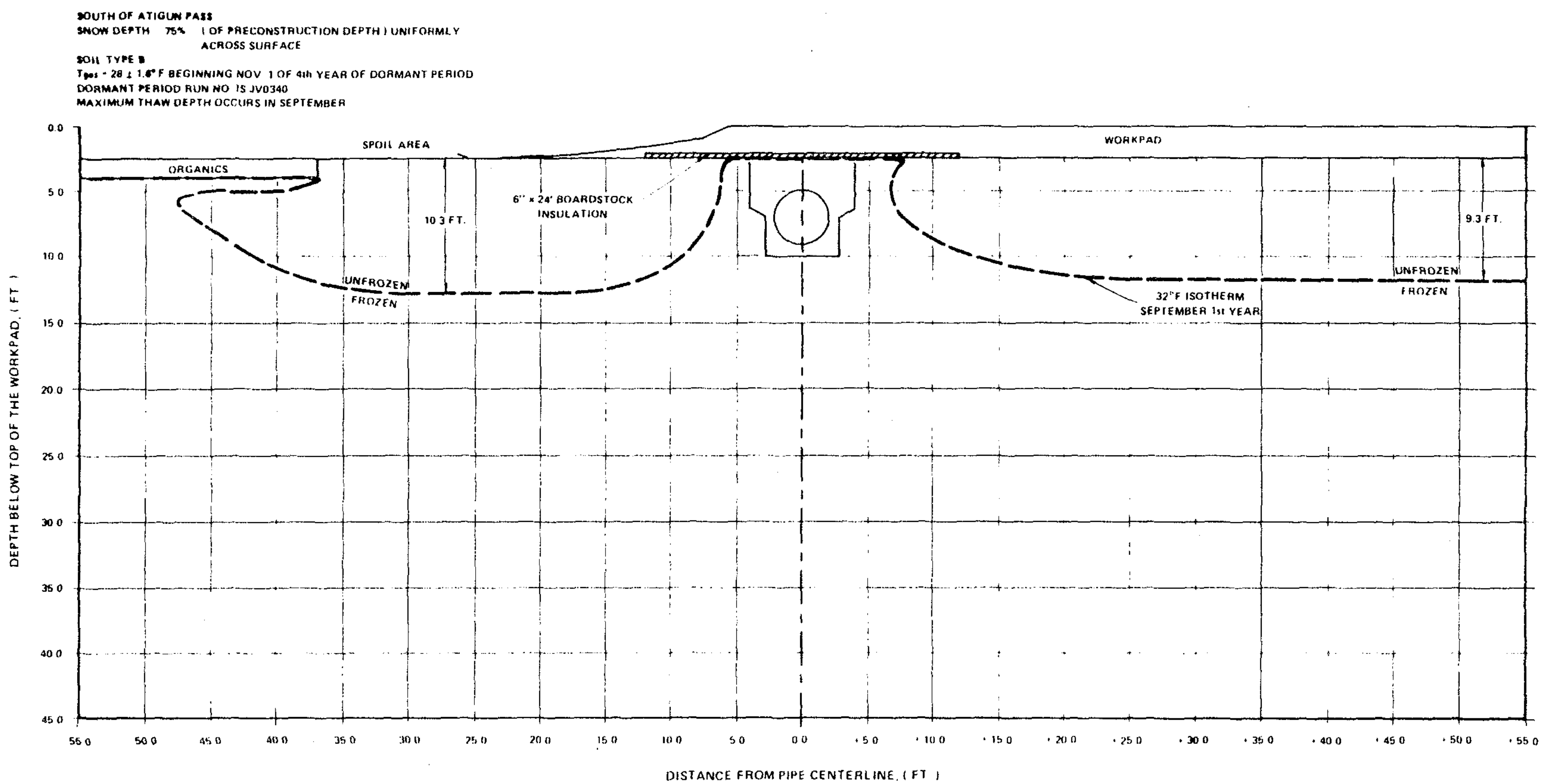
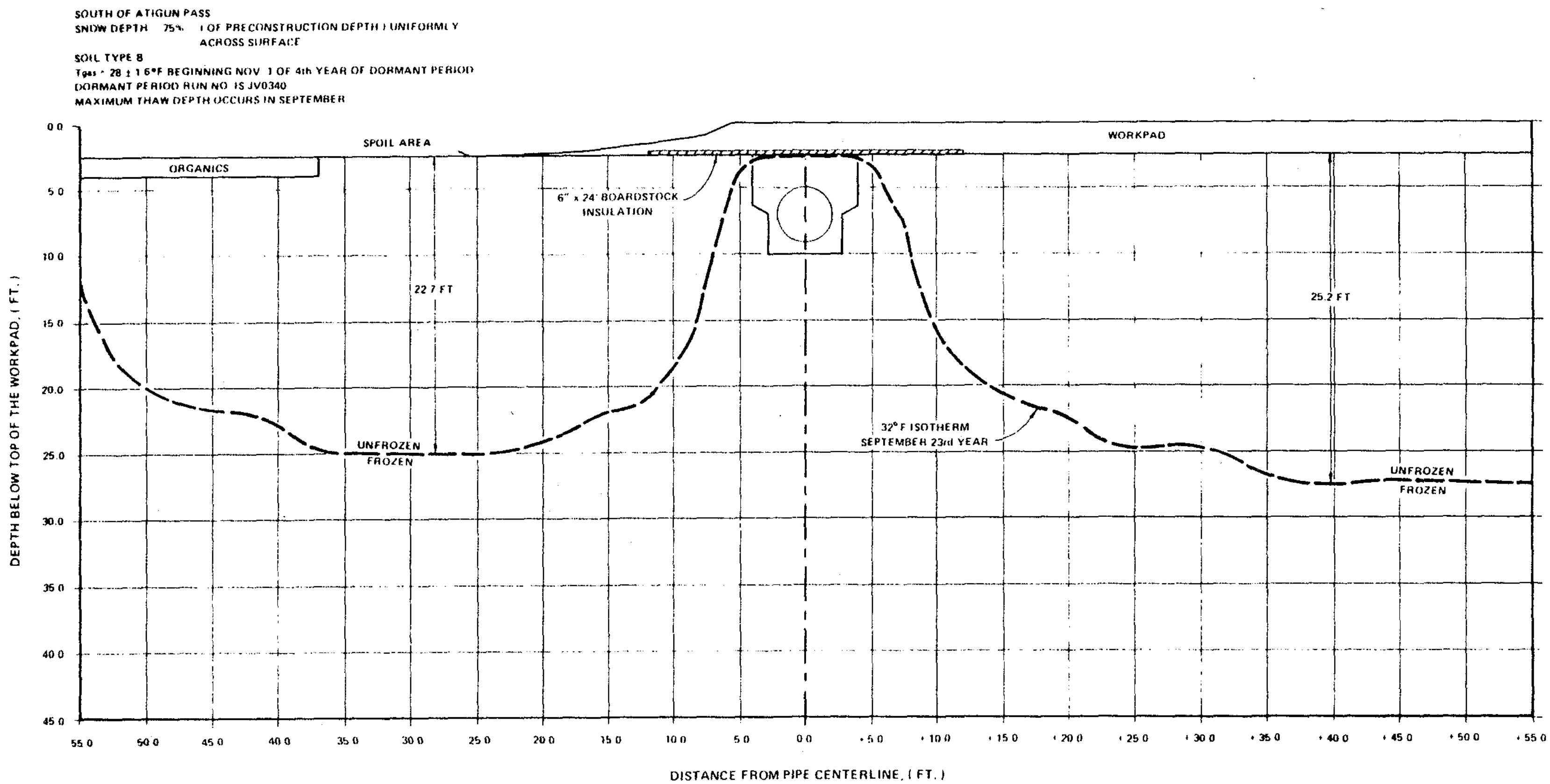


FIGURE 4-77

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO JV0420
(CONTINUATION OF RUN NO SJV0403)



THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO. JV0682

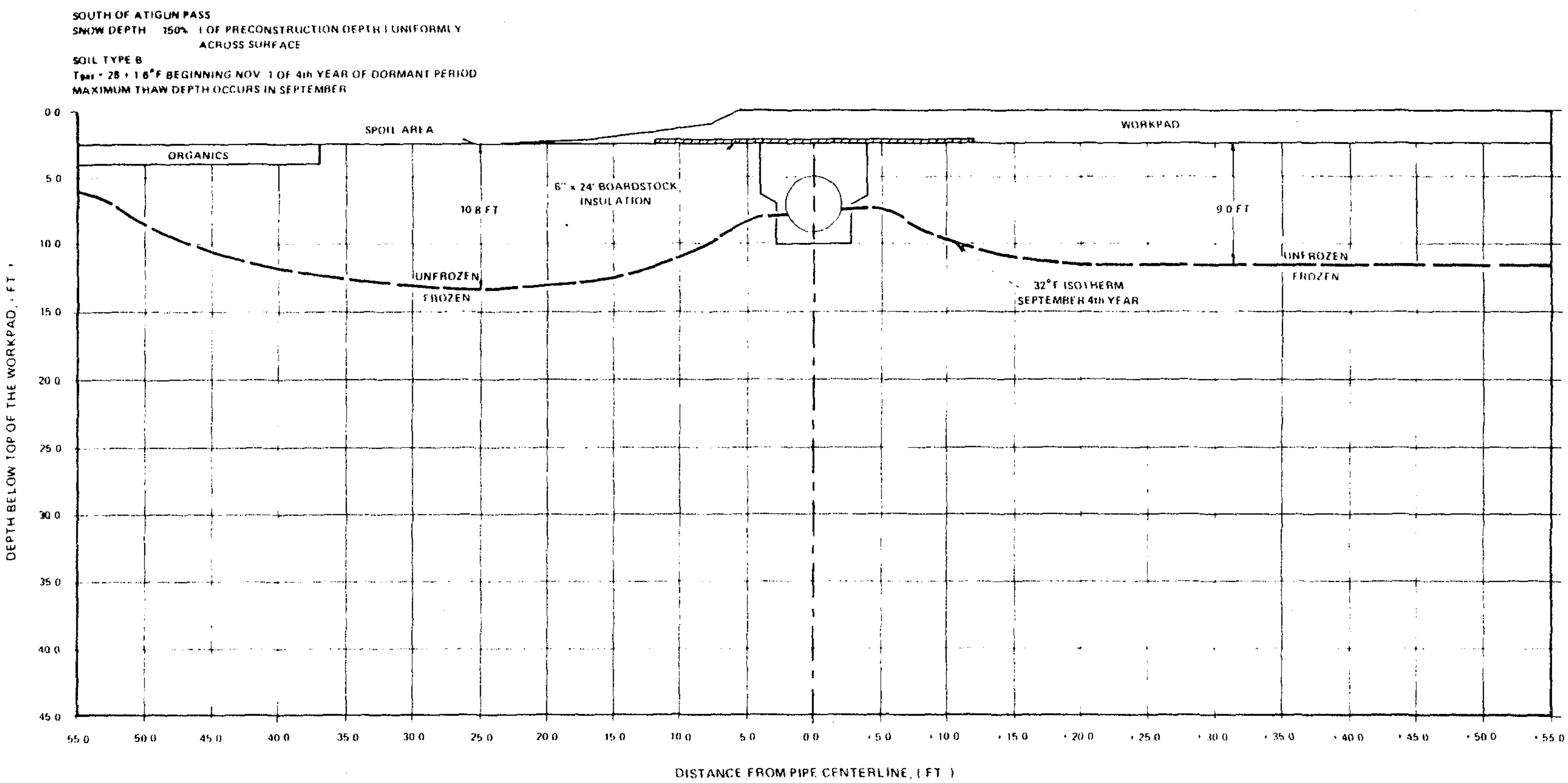


FIGURE 4-78

NWA

THAW MITIGATION THERMAL
EVALUATION AND SENSITIVITY STUDY

FIGURE 4 - 79

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0682

SOUTH OF ATIGUN PASS
SNOW DEPTH 150% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE 8
Tgas = 28 ± 1.6°F BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER

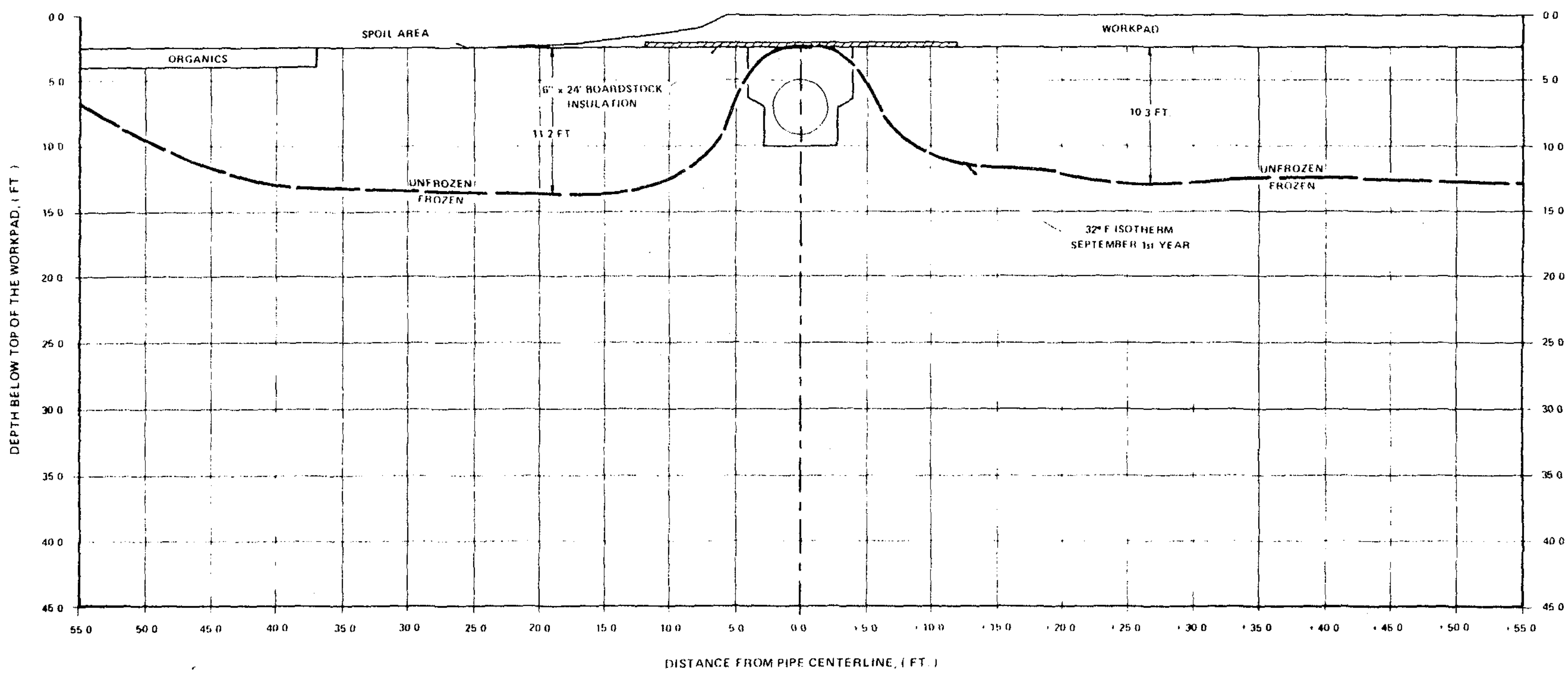


FIGURE 4-80

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0682

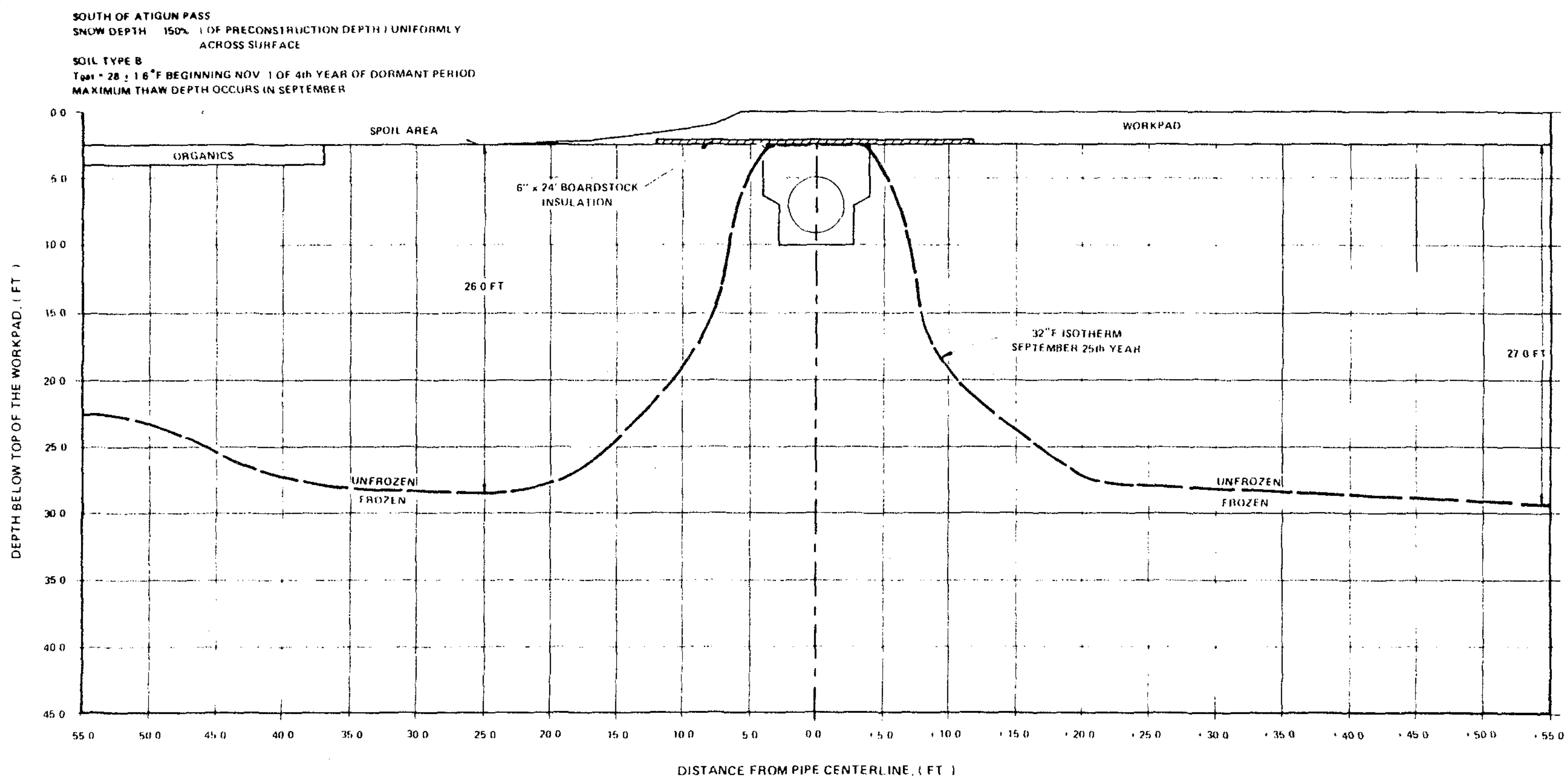
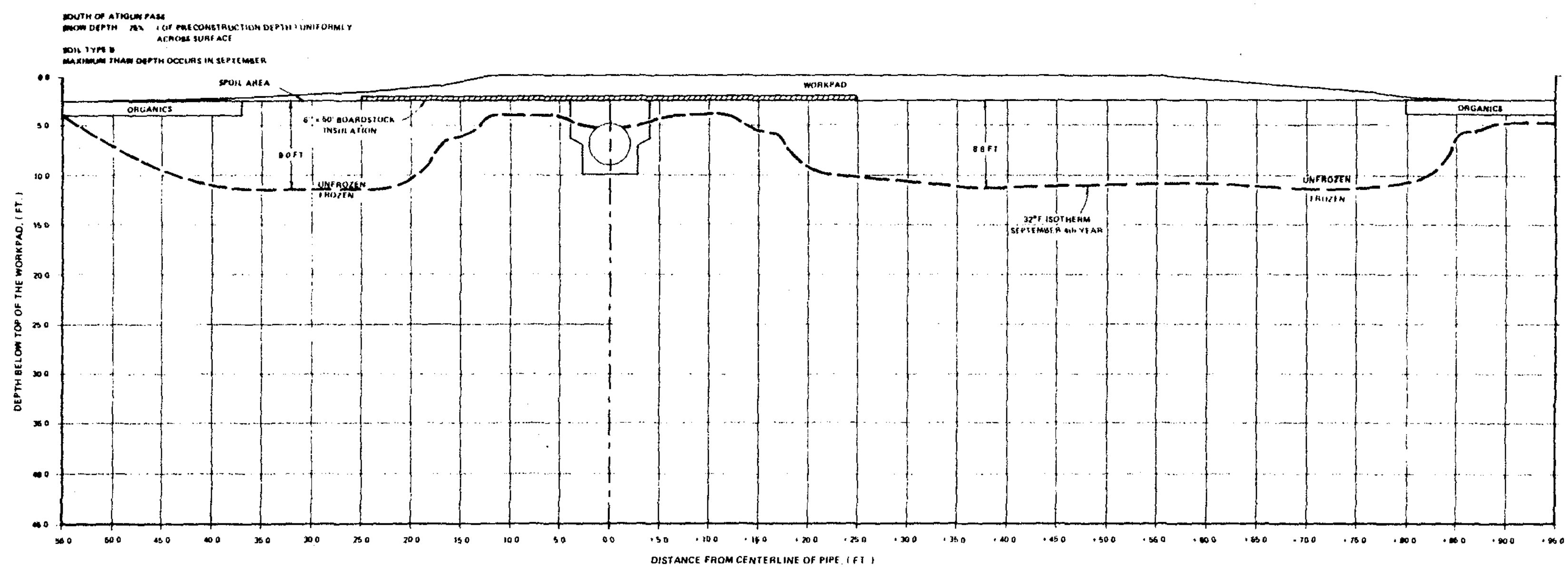


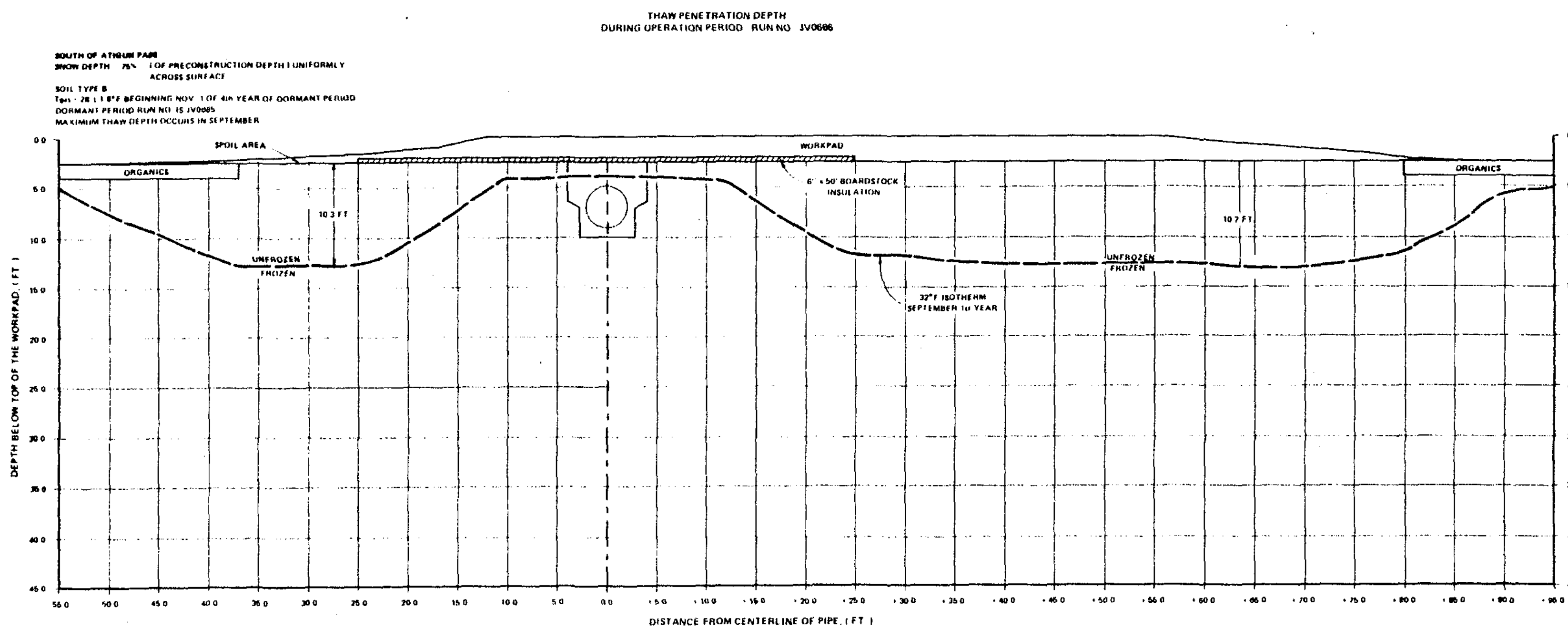
FIGURE 4-81

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD RUN NO. JV0665



THAW MITIGATION THERMAL
EVALUATION AND SENSITIVITY STUDY

FIGURE 4 - 82



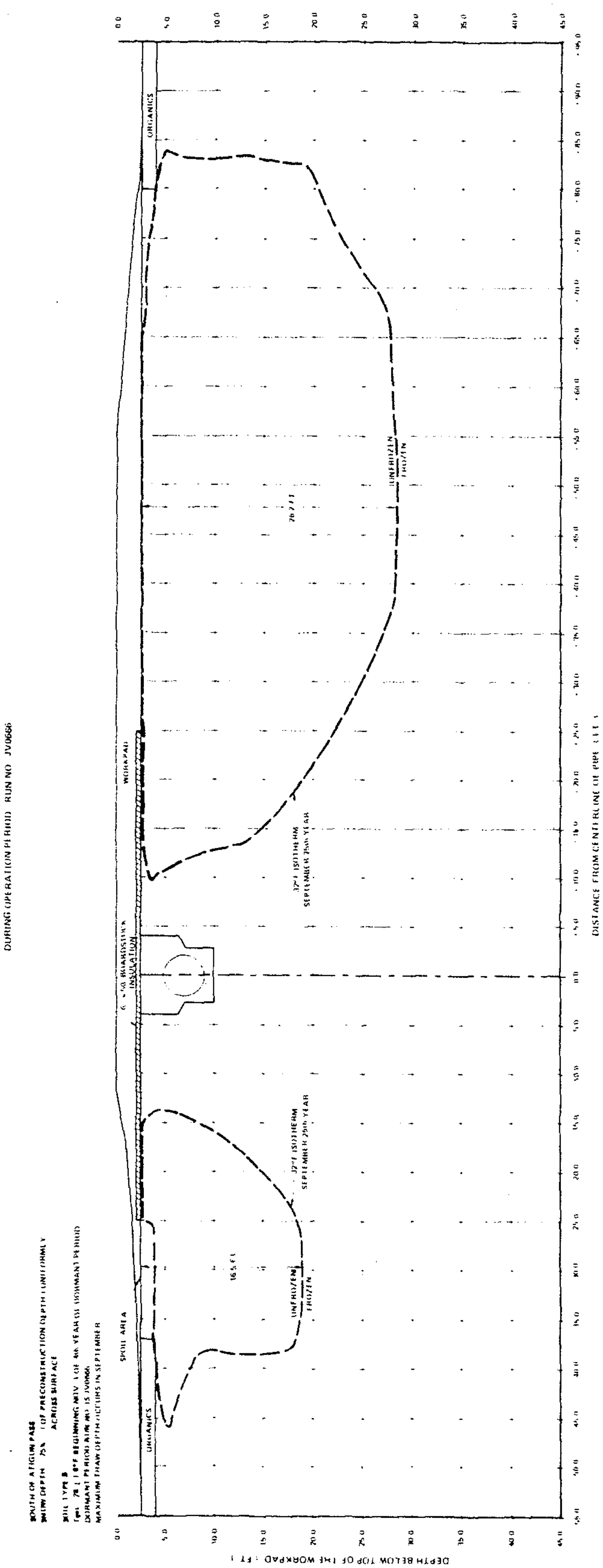
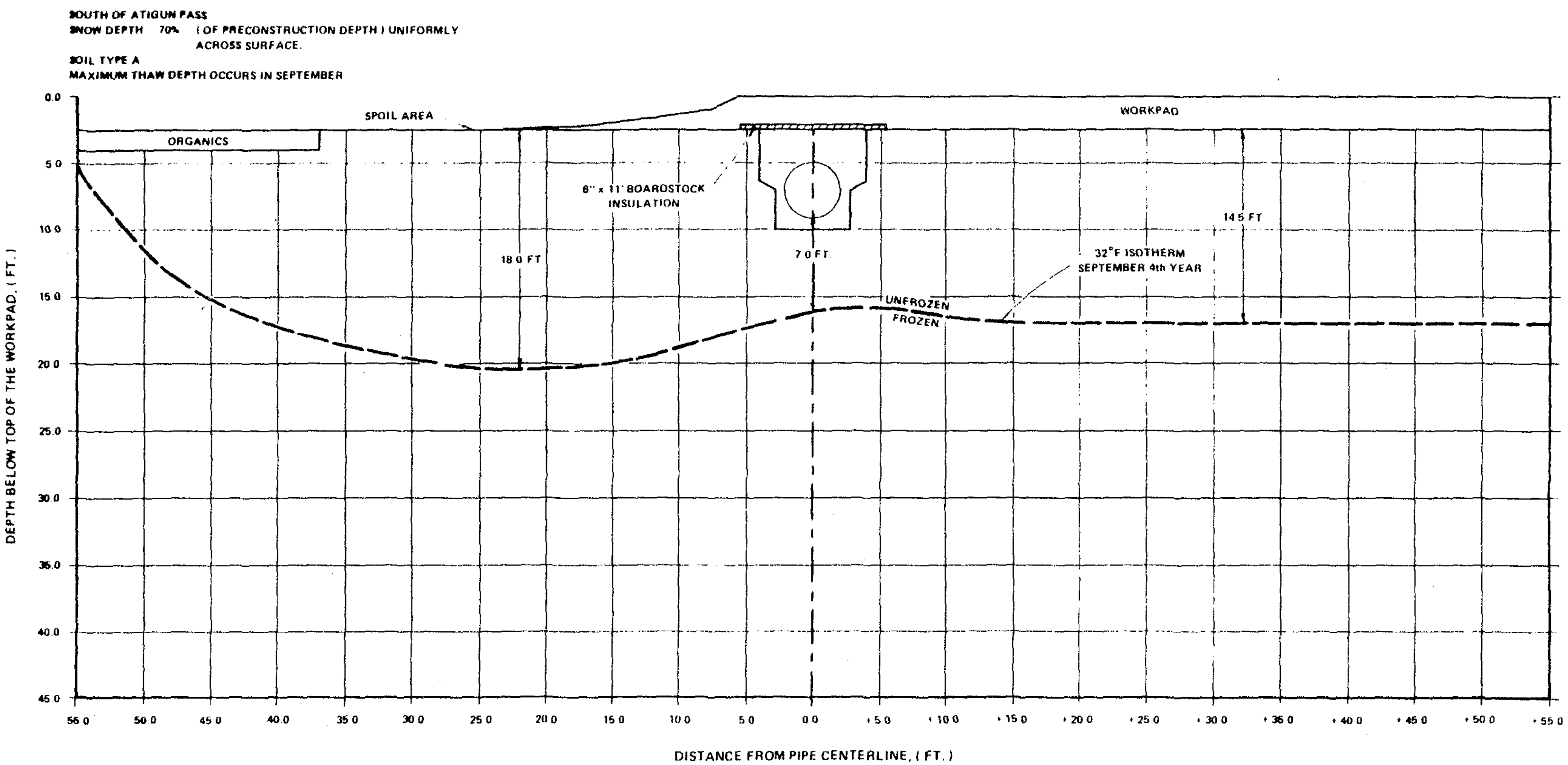
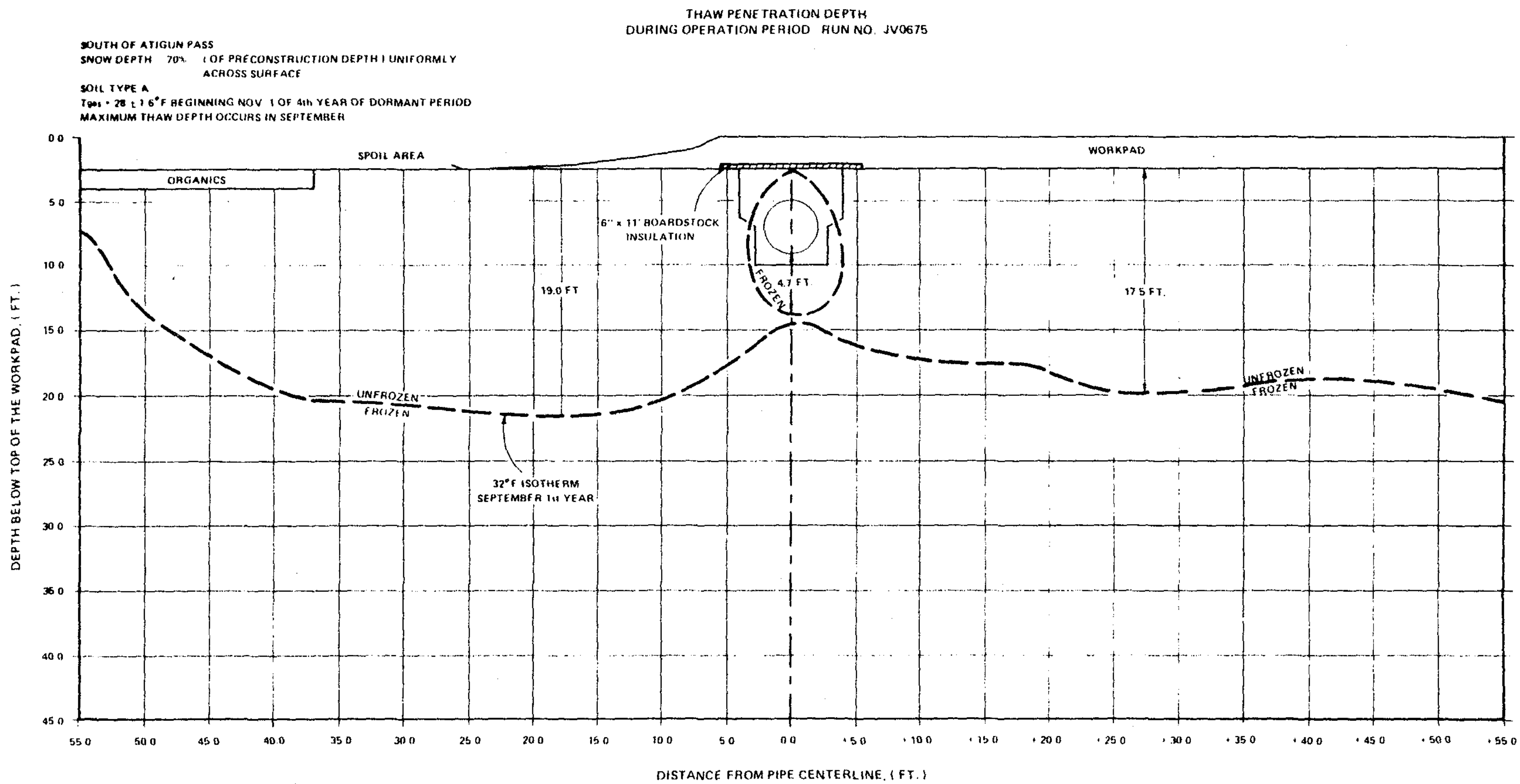


FIGURE 4 - 83

FIGURE 4-84

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0675





THAW MITIGATION THERMAL
EVALUATION AND SENSITIVITY STUDY

FIGURE 4-85

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0675

SOUTH OF ATIGUN PASS
SNOW DEPTH - 70% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE.
SOIL TYPE A
T_{gas} = 28 ± 1.6°F BEGINNING NOV. 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER

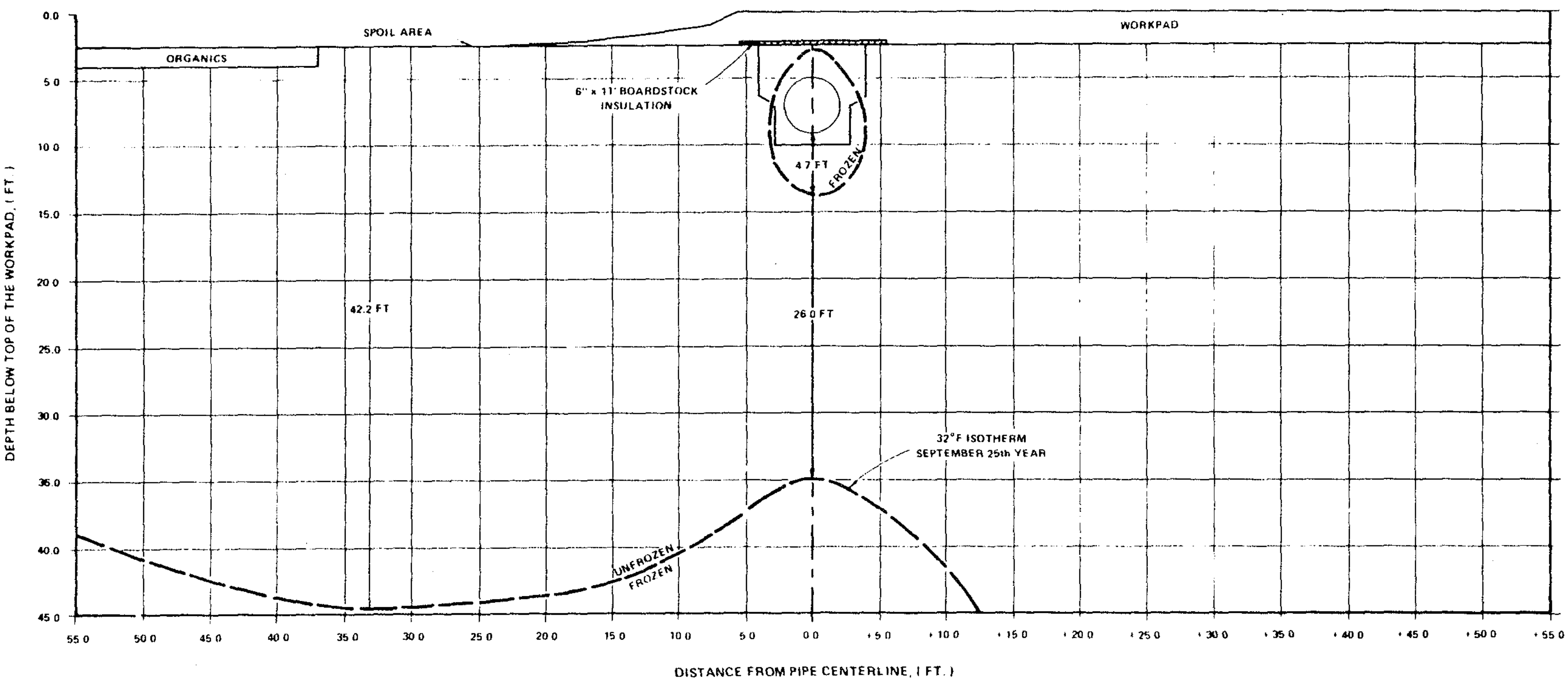


FIGURE 4-86

THAW PENETRATION DEPTH DURING
FOUR YEAR DORMANT PERIOD - RUN NO. JV0707

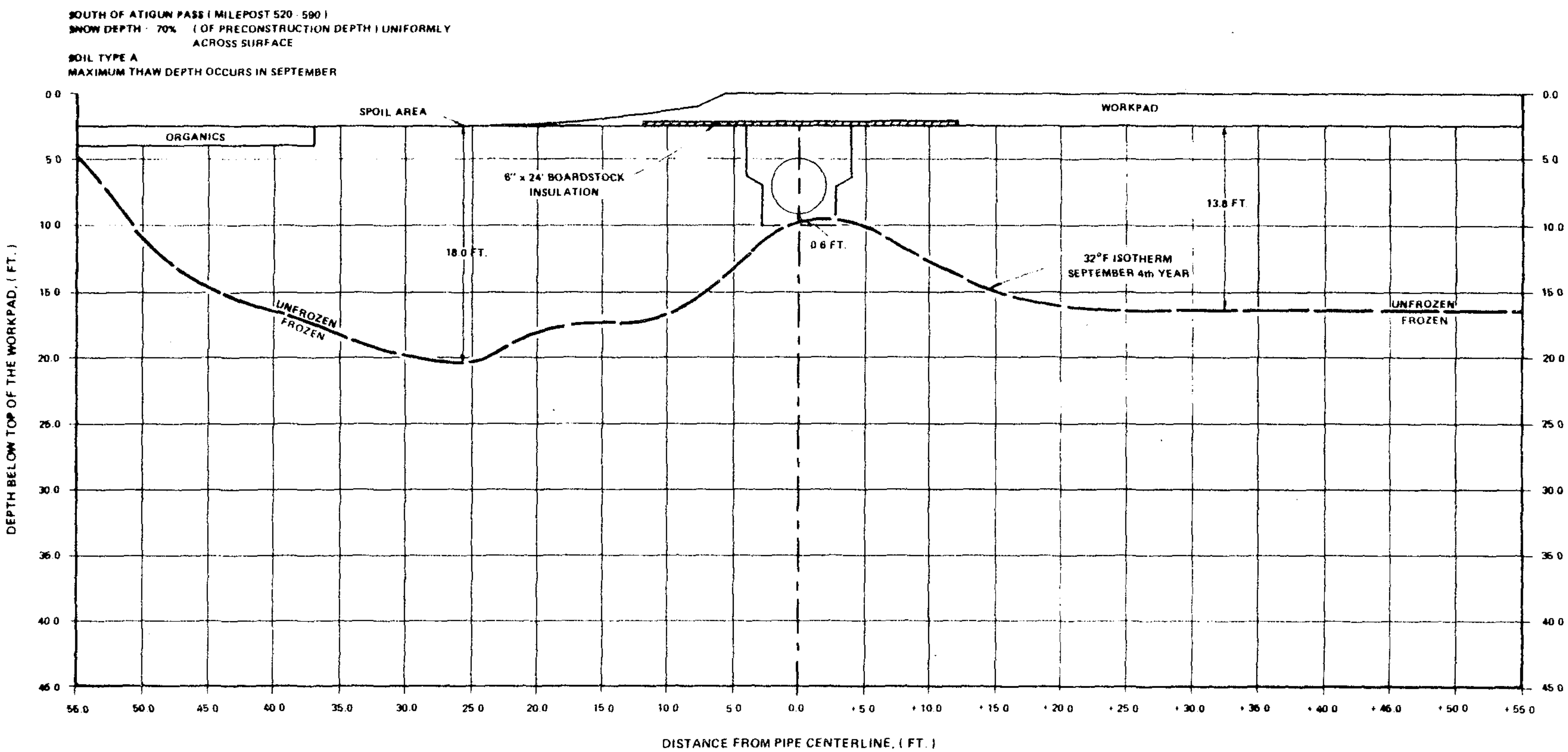


FIGURE 4-87

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0707

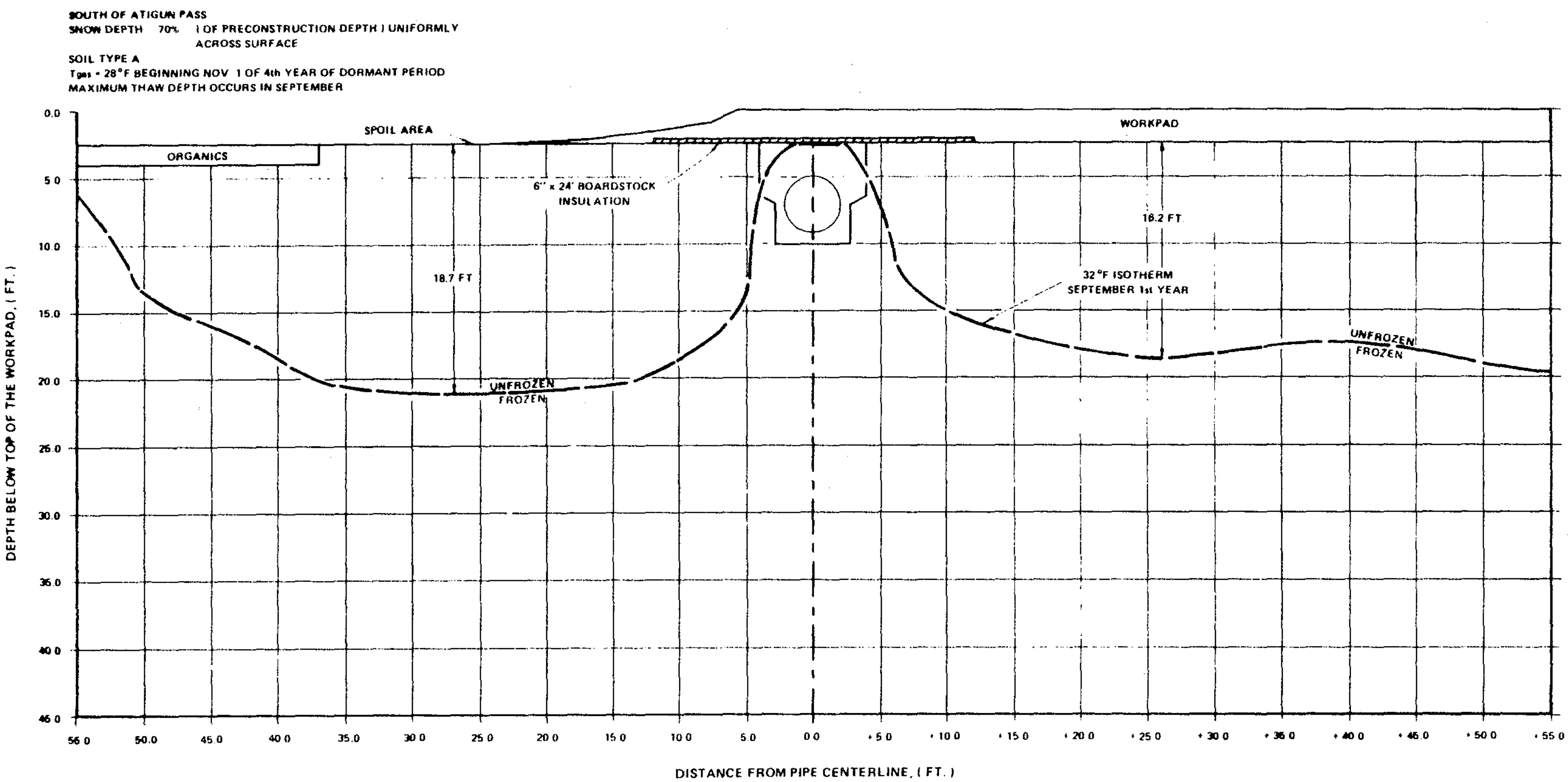


FIGURE 4-88

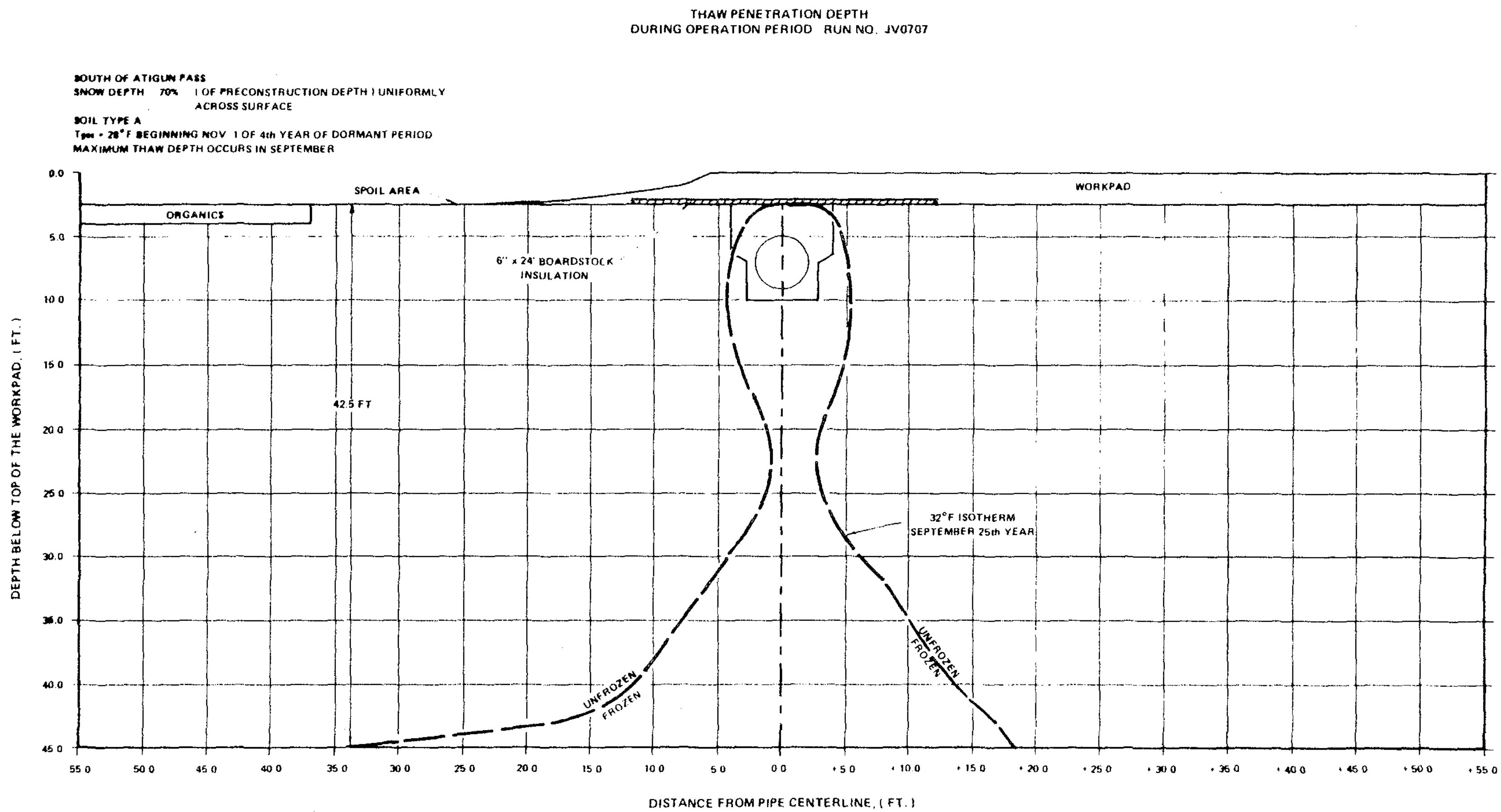

THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO. JV0707
SOUTH OF ATIGUN PASS
SNOW DEPTH 70% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
Tgas = 28°F BEGINNING NOV 1 OF 4th YEAR OF DORMANT PERIOD
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
WORKPAD
ORGANICS
6" x 24' BOARDSTOCK INSULATION
42.5 FT
32°F ISOTHERM SEPTEMBER 25th YEAR
UNFROZEN
FROZEN
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM PIPE CENTERLINE, (FT.)

FIGURE 4-89

FIGURE 4 - 90

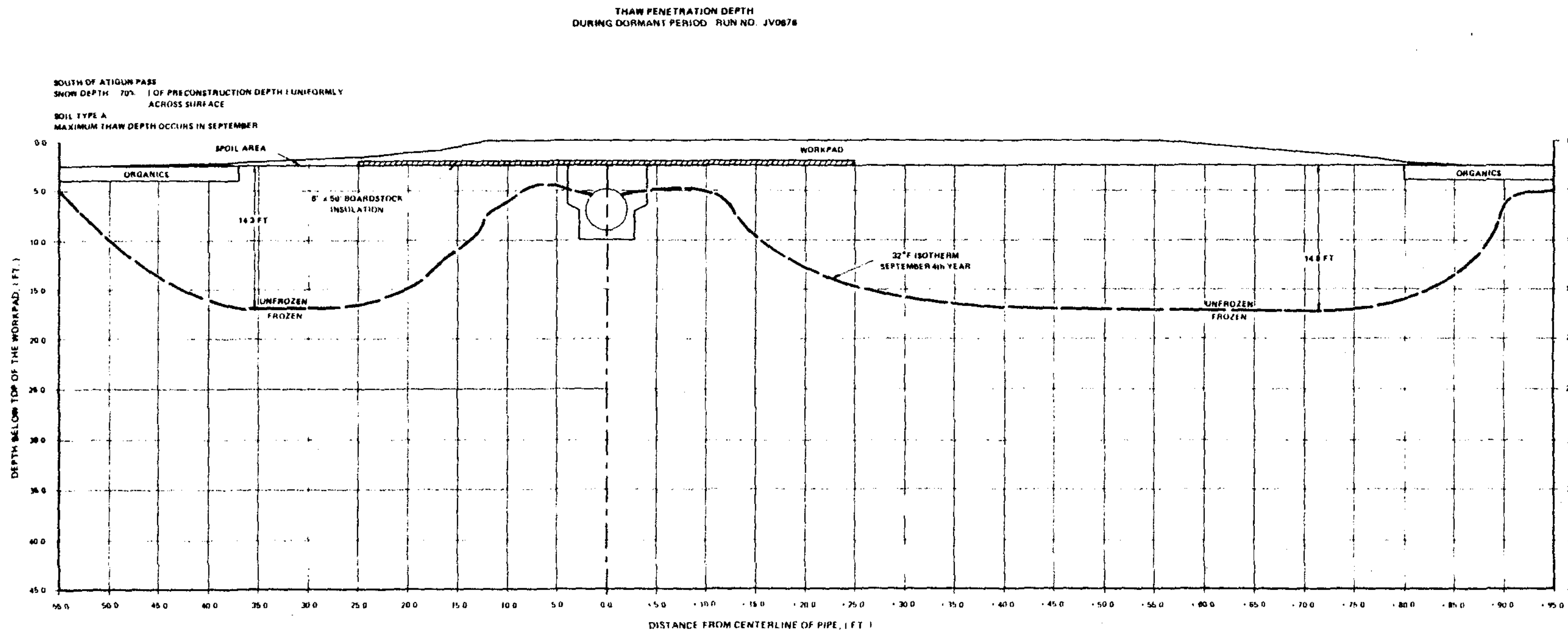
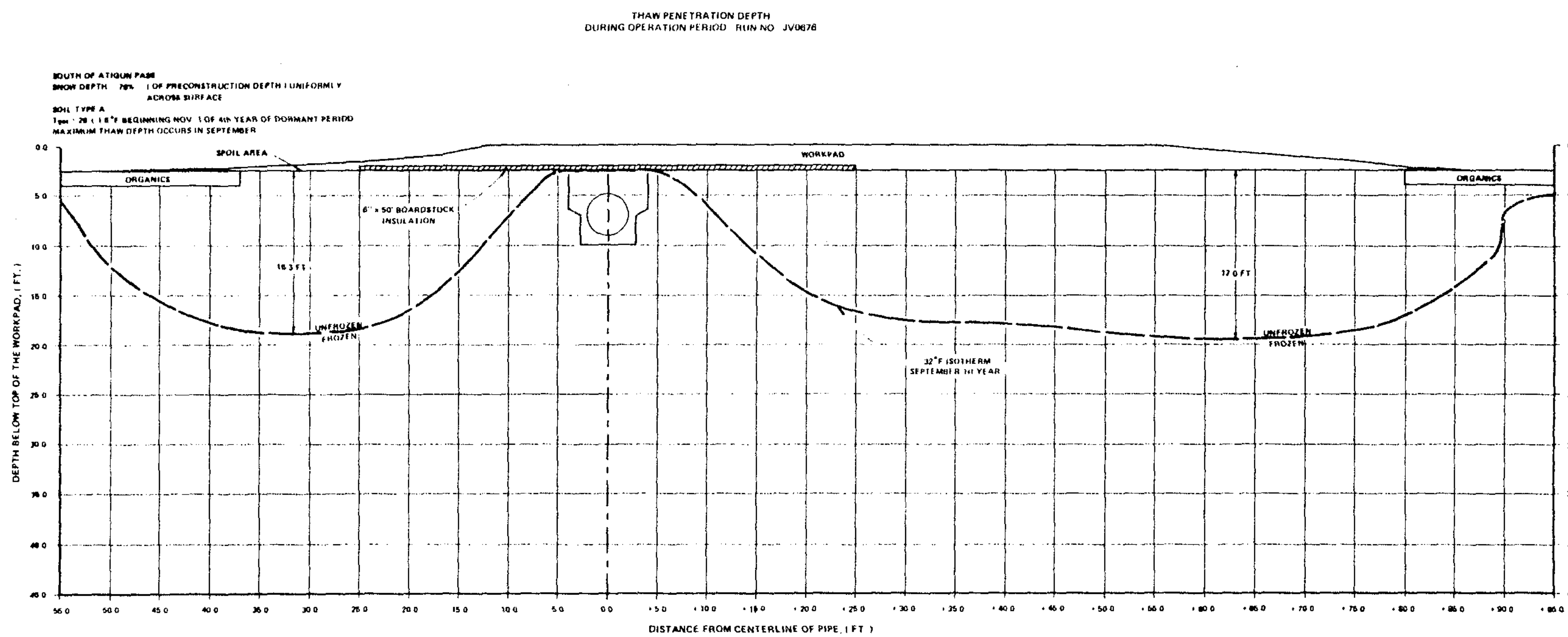

THAW PENETRATION DEPTH
DURING DORMANT PERIOD RUN NO. JV0876
SOUTH OF ATIGUN PASS
SNOW DEPTH 70% (OF PRECONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE A
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
WORKPAD
ORGANICS
ORGANICS
8" x 50' BOARDSTOCK INSULATION
32°F ISOTHERM SEPTEMBER 4th YEAR
UNFROZEN
FROZEN
UNFROZEN
FROZEN
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM CENTERLINE OF PIPE, (FT.)

FIGURE 4 - 91


THAW PENETRATION DEPTH
DURING OPERATION PERIOD RUN NO JV0878
SOUTH OF ATIGUN PASS
SOIL TYPE A
MAXIMUM THAW DEPTH OCCURS IN SEPTEMBER
SPOIL AREA
WORKPAD
ORGANICS
6" x 50' BOARDSTOCK INSULATION
UNFROZEN
FROZEN
32°F ISOTHERM
DEPTH BELOW TOP OF THE WORKPAD, (FT.)
DISTANCE FROM CENTERLINE OF PIPE, (FT.)

NWA

THAW MITIGATION THERMAL EVALUATION AND SENSITIVITY STUDY

FIGURE 4 - 92

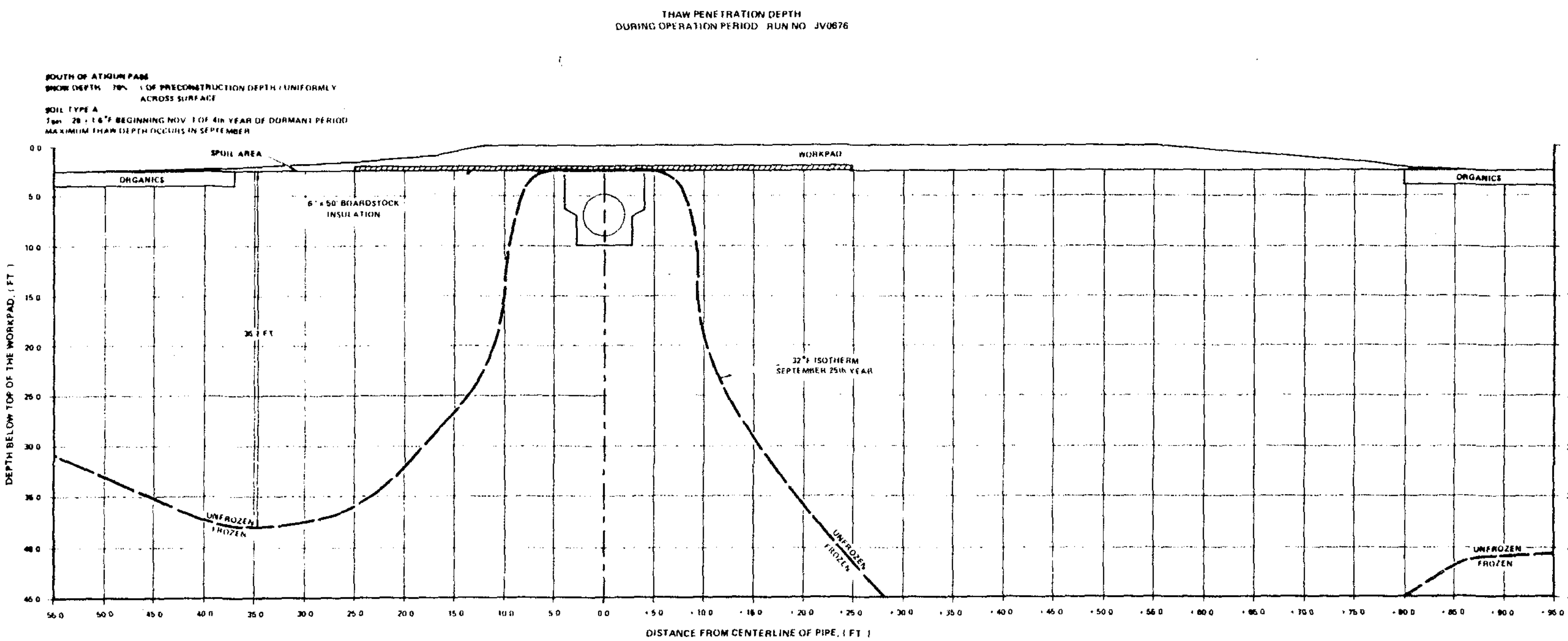


FIGURE 4 - 93

THAW PENETRATION DEPTHS
DURING DORMANT AND OPERATION PERIODS

SOUTH OF ATIGUN PASS
SNOW DEPTH: 75% (OF PRE - CONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
Tgas = 31.7° F & 28 ± 1.6° F BEGINNING NOV. 1 of 4th YEAR OF DORMANT PERIOD

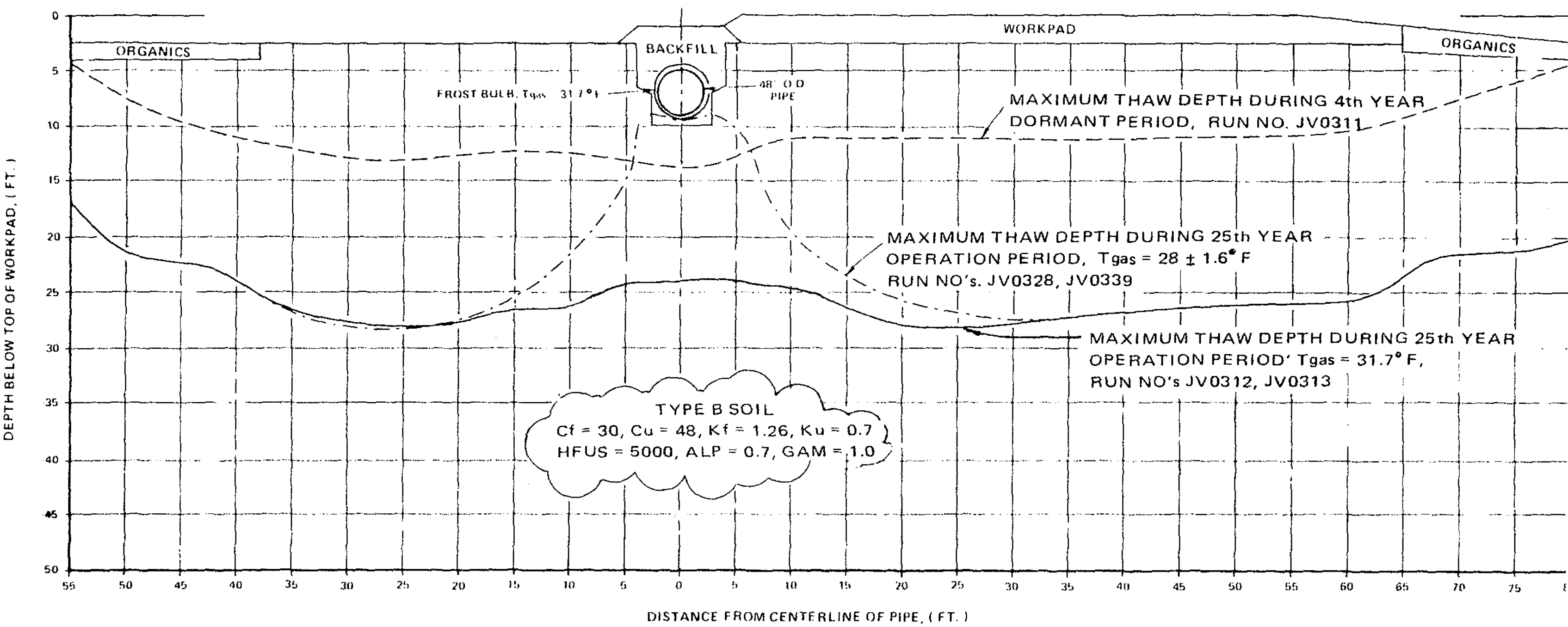
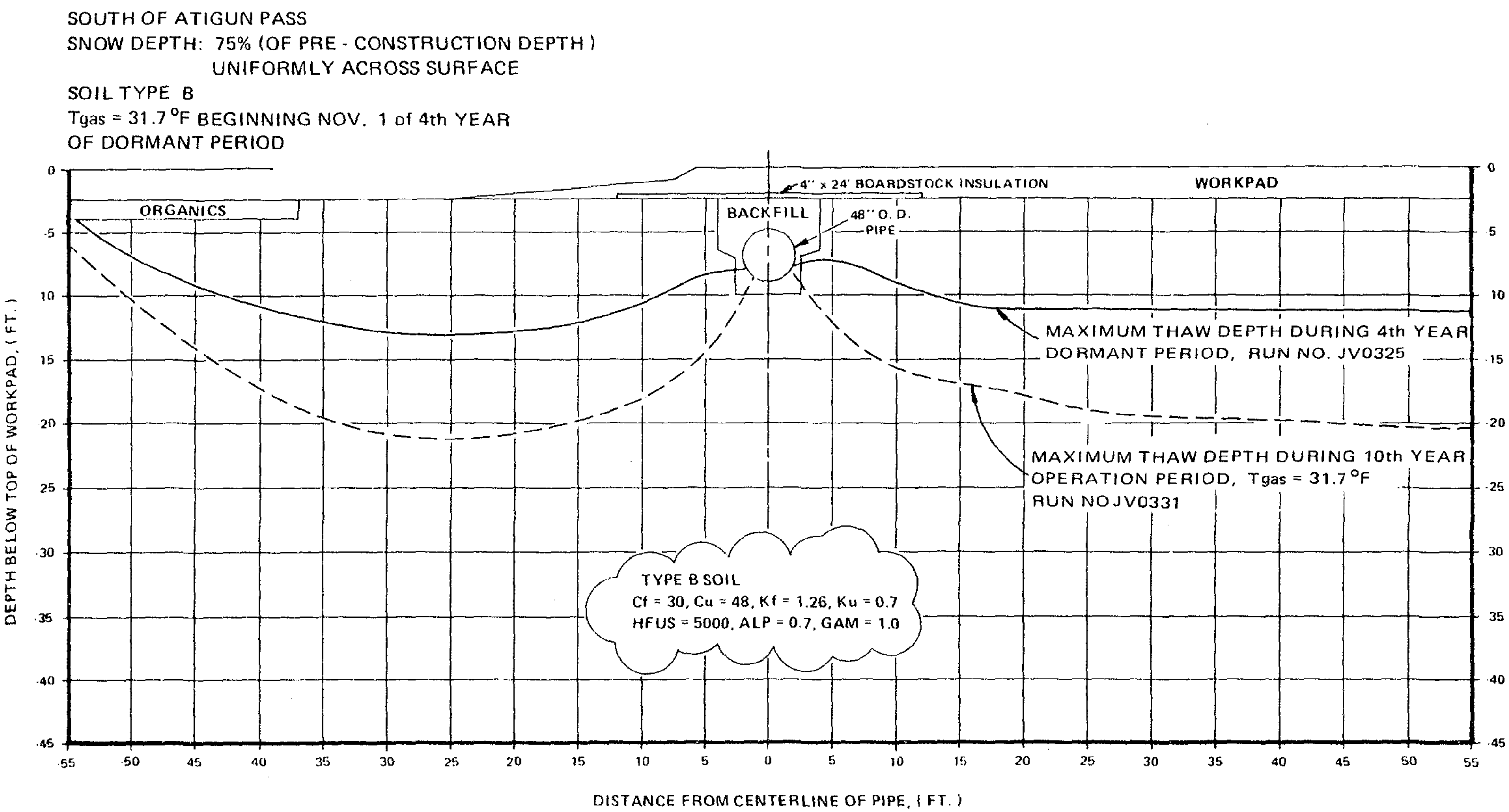


FIGURE 4 - 94

THAW PENETRATION DEPTHS DURING DORMANT AND OPERATION PERIODS



THAW PENETRATION DEPTHS DURING DORMANT AND OPERATION PERIODS

SOUTH OF ATIGUN PASS
SNOW DEPTH: 75% (OF PRE - CONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
Tgas = 31.7°F & 28 ± 1.6°F BEGINNING NOV. 1 of 4th YEAR OF DORMANT PERIOD

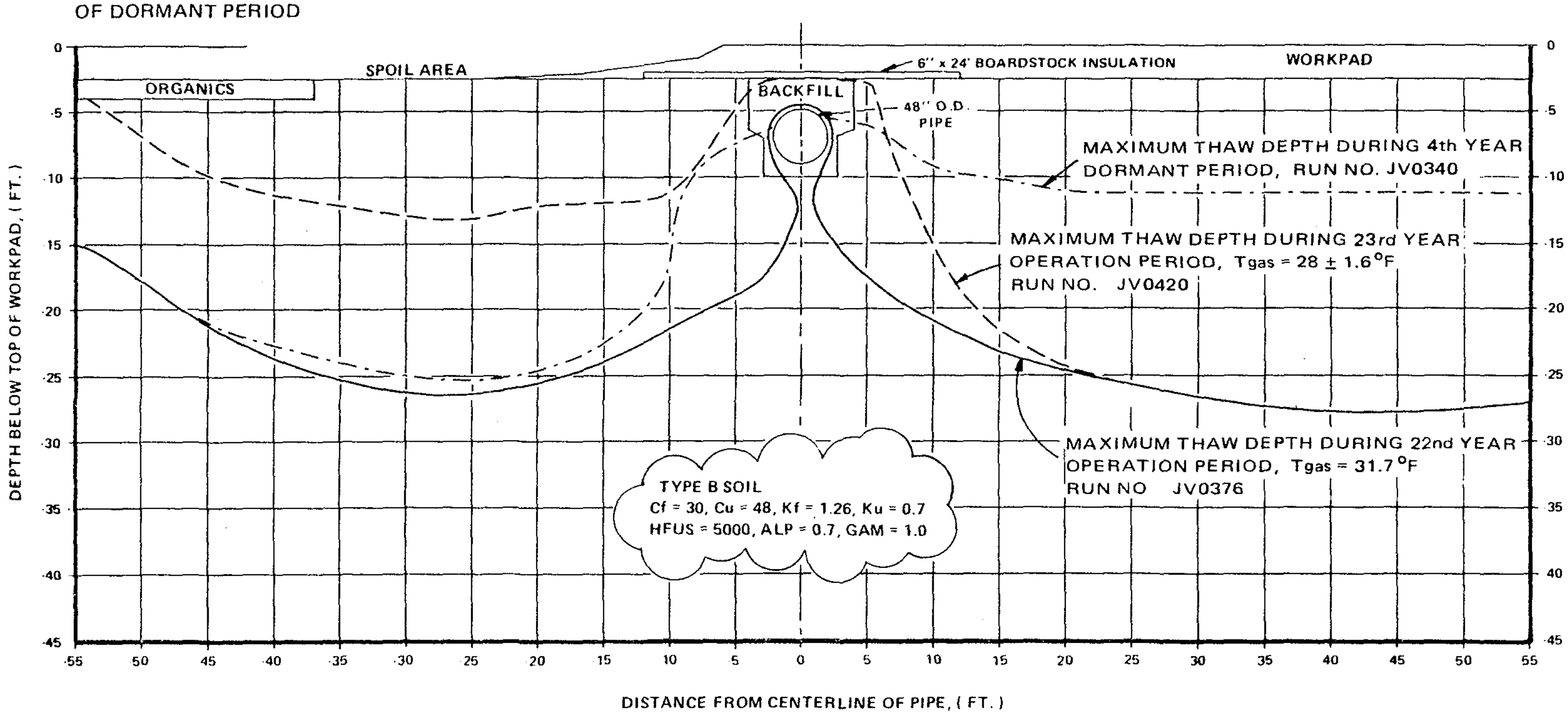


FIGURE 4 - 95

MAXIMUM THAW PENETRATION DEPTHS DURING DORMANT AND OPERATION PERIODS

SOUTH OF ATIGUN PASS
SNOW DEPTH: 75% (OF PRE - CONSTRUCTION DEPTH) UNIFORMLY ACROSS SURFACE
SOIL TYPE B
Tgas = 31.7°F BEGINNING NOV. 1 of 4th YEAR OF DORMANT PERIOD

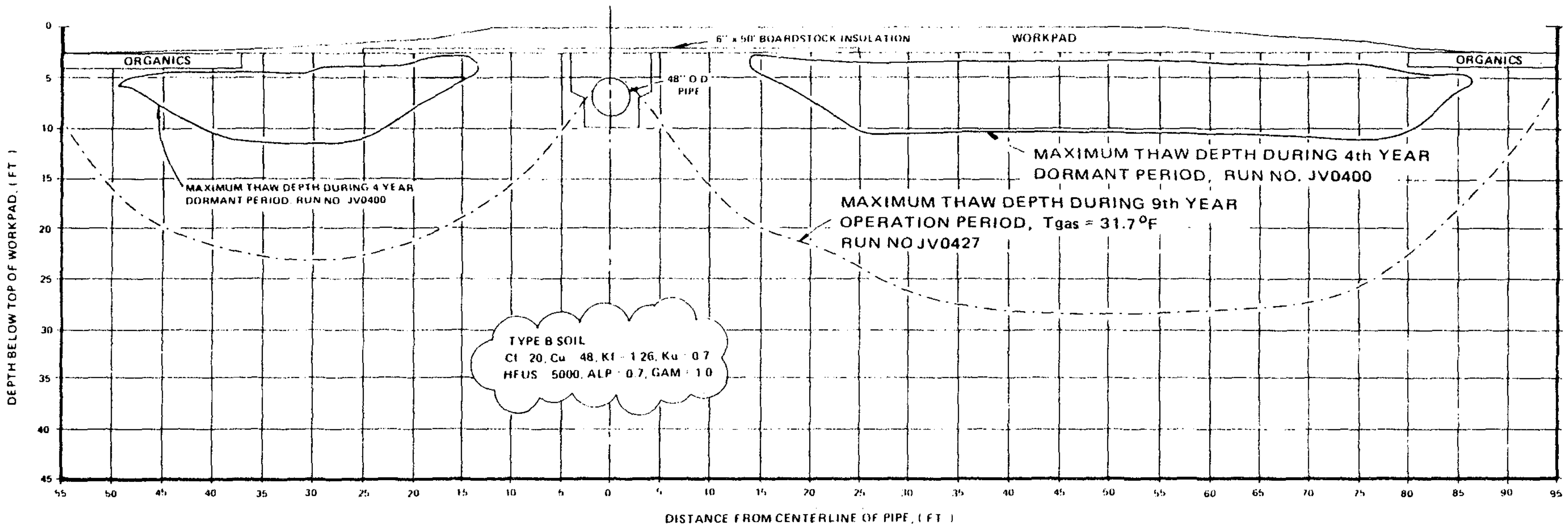


FIGURE 4 - 96