

# **Palo Verde Nuclear Generating Station**

**Unit 1 Shutdown Cooling Suction Line Elevated Vibration**



**A Presentation on the Physical Modification of  
PVNGS Unit 1 SDC Suction Line to Eliminate  
High-Level Vibration**

**May 11, 2006**

# Introductions

- ◆ **Carl Churchman – Director of Engineering, APS**
- ◆ **Mo Karbassian – Design Engineering Manager, APS**
- ◆ **Craig Seaman – General Manager, Regulatory Affairs - APS**
- ◆ **Bob Yamrus – Bechtel Power Corporation**
- ◆ **Robert Blevins, PhD. – Consultant**
- ◆ **M. K. Au-Yang, PhD. – Consultant**
- ◆ **Frank Ferraraccio – Westinghouse Electric**
- ◆ **Winston Borrero – Sr. Consulting Engineer, APS**
- ◆ **Jeff Brown – Consulting Engineer, APS**



# Presentation Overview

- ◆ **Introductions and meeting objectives – *Carl Churchman***
- ◆ **Technical discussions – *Jeff Brown***
  - **Configuration**
  - **Unit 1 vibration history**
  - **Phenomenological**
  - **Modifications**
  - **Final modification selection and development**
- ◆ **Modification process – *Mo Karbassian***
- ◆ **Open discussion**



# **Presentation Objectives**

## **(continued)**

- ◆ **Communicate to NRC sensitive PVNGS issue**
  - **Present Unit 1 SDC suction line vibration issue and final modification design**
  - **Present Unit 1 restart criteria**
  - **Discuss modification process and licensing considerations**
  - **Address NRC questions**

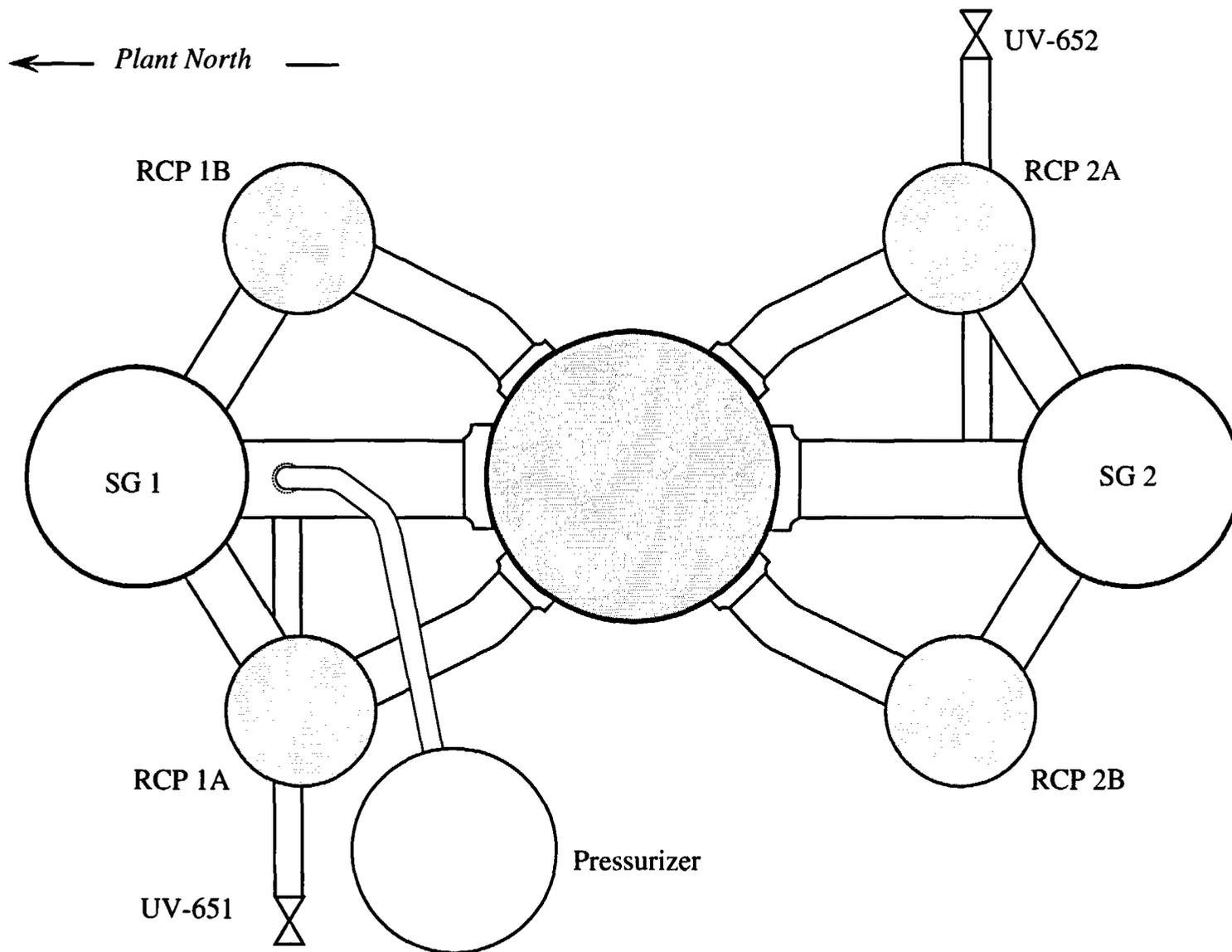
# Configuration

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PVNGS Unit 1 SDC Suction Line Modification



# Configuration

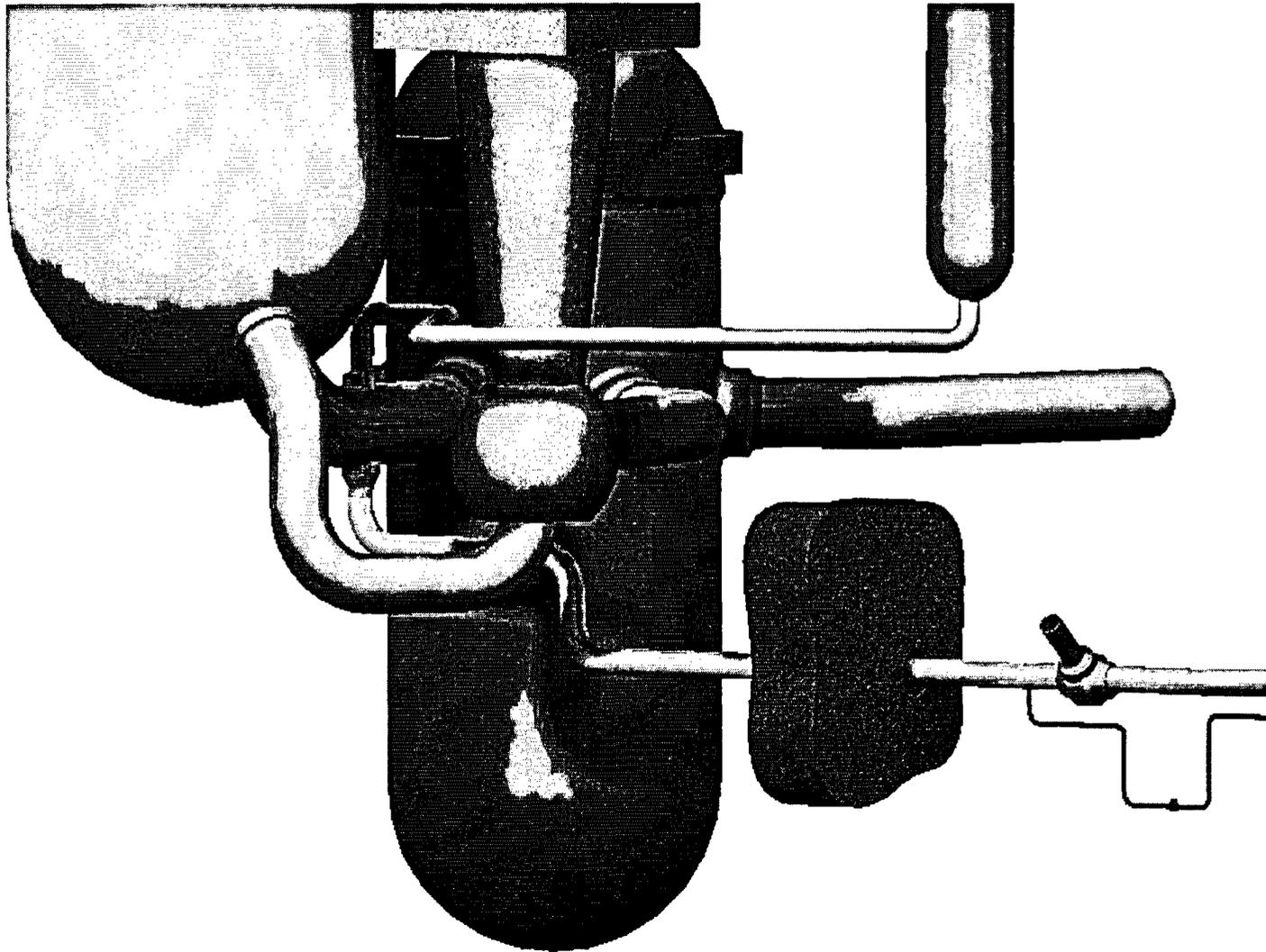


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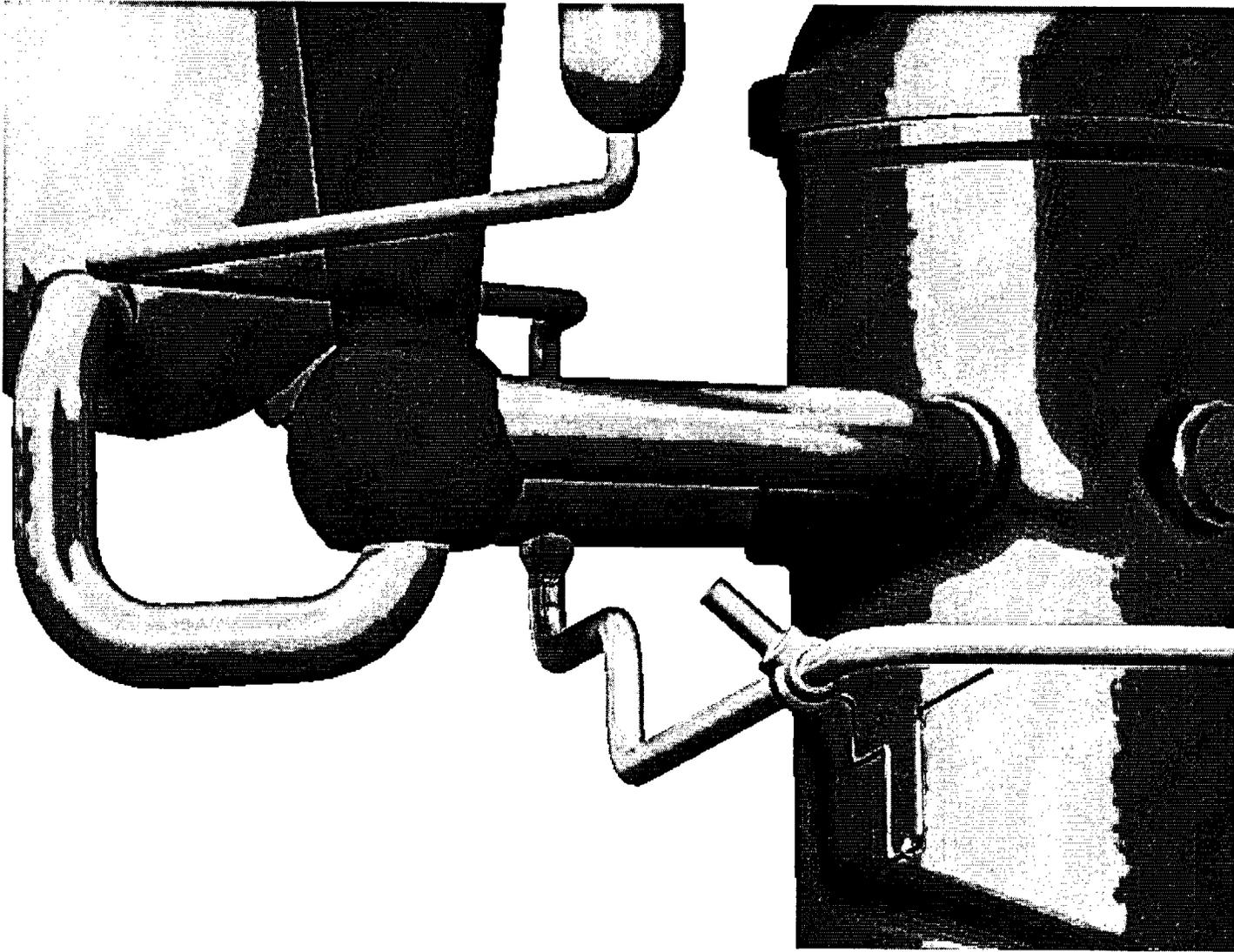


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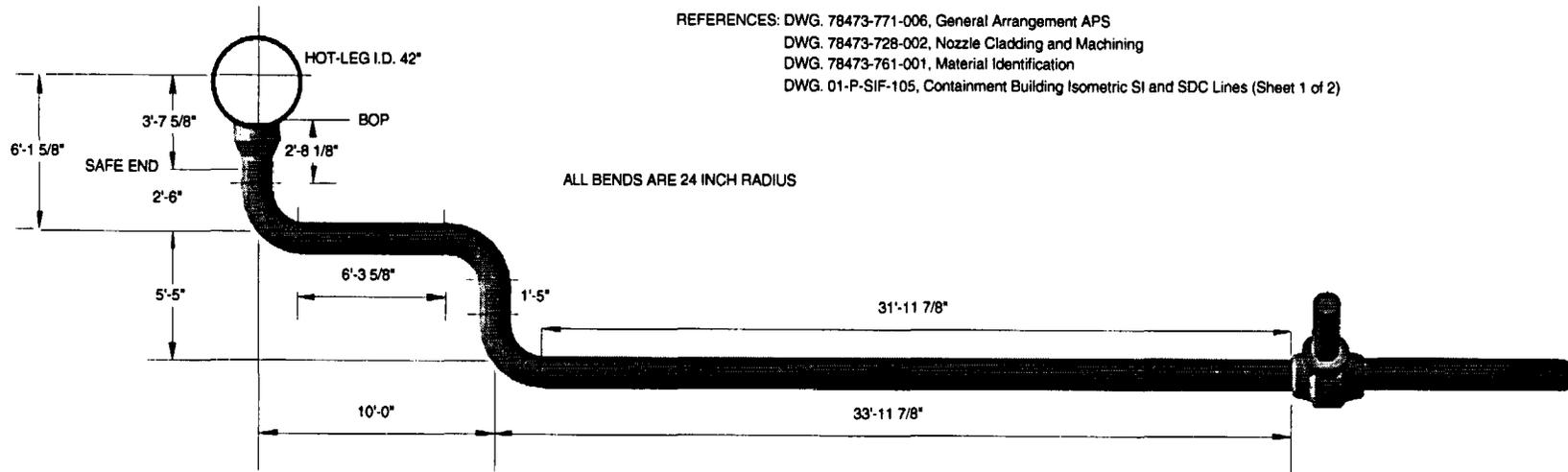


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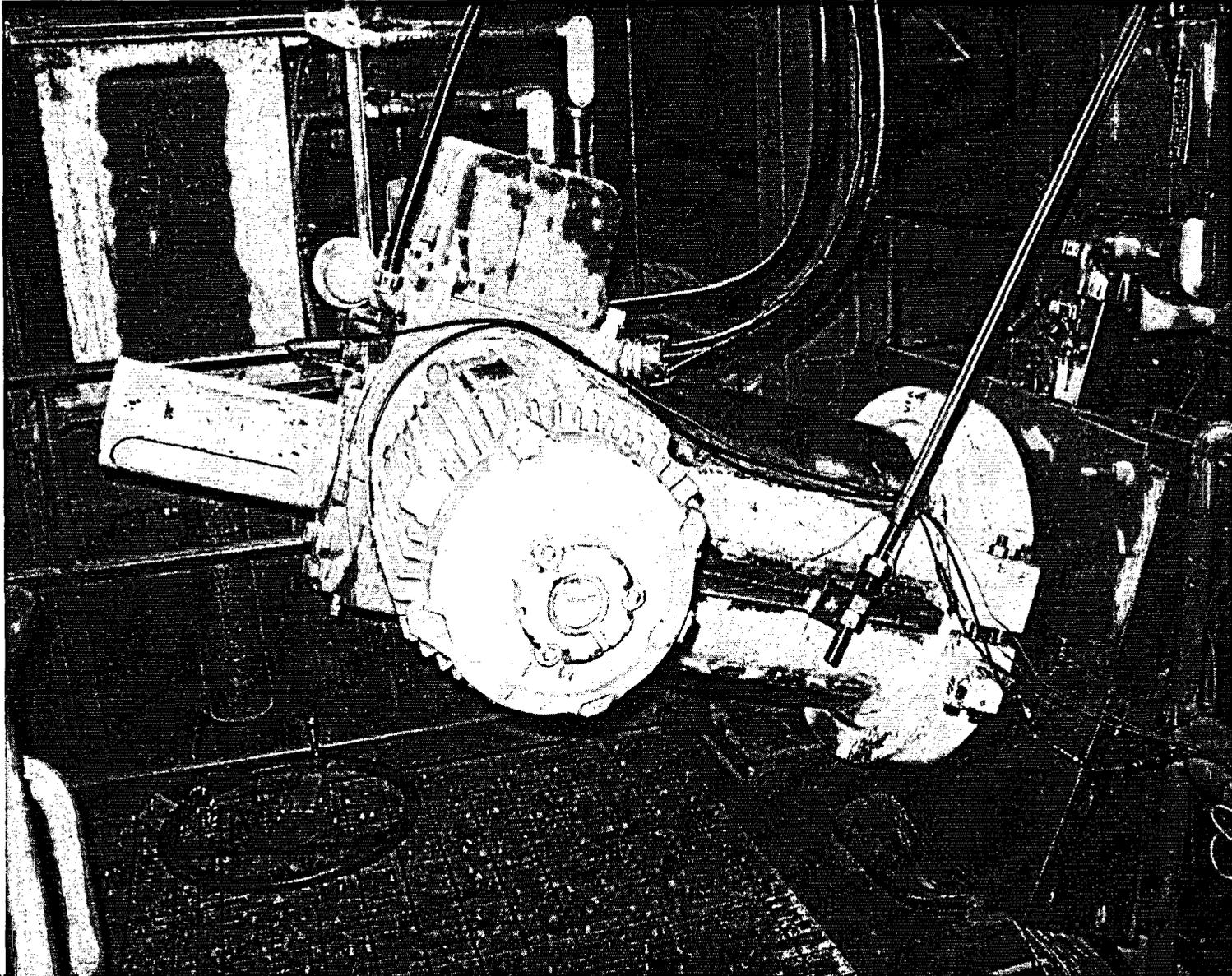


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# Configuration



August 19, 2005

PVNS Unit 1 SDC Suction Line Modification



# Configuration

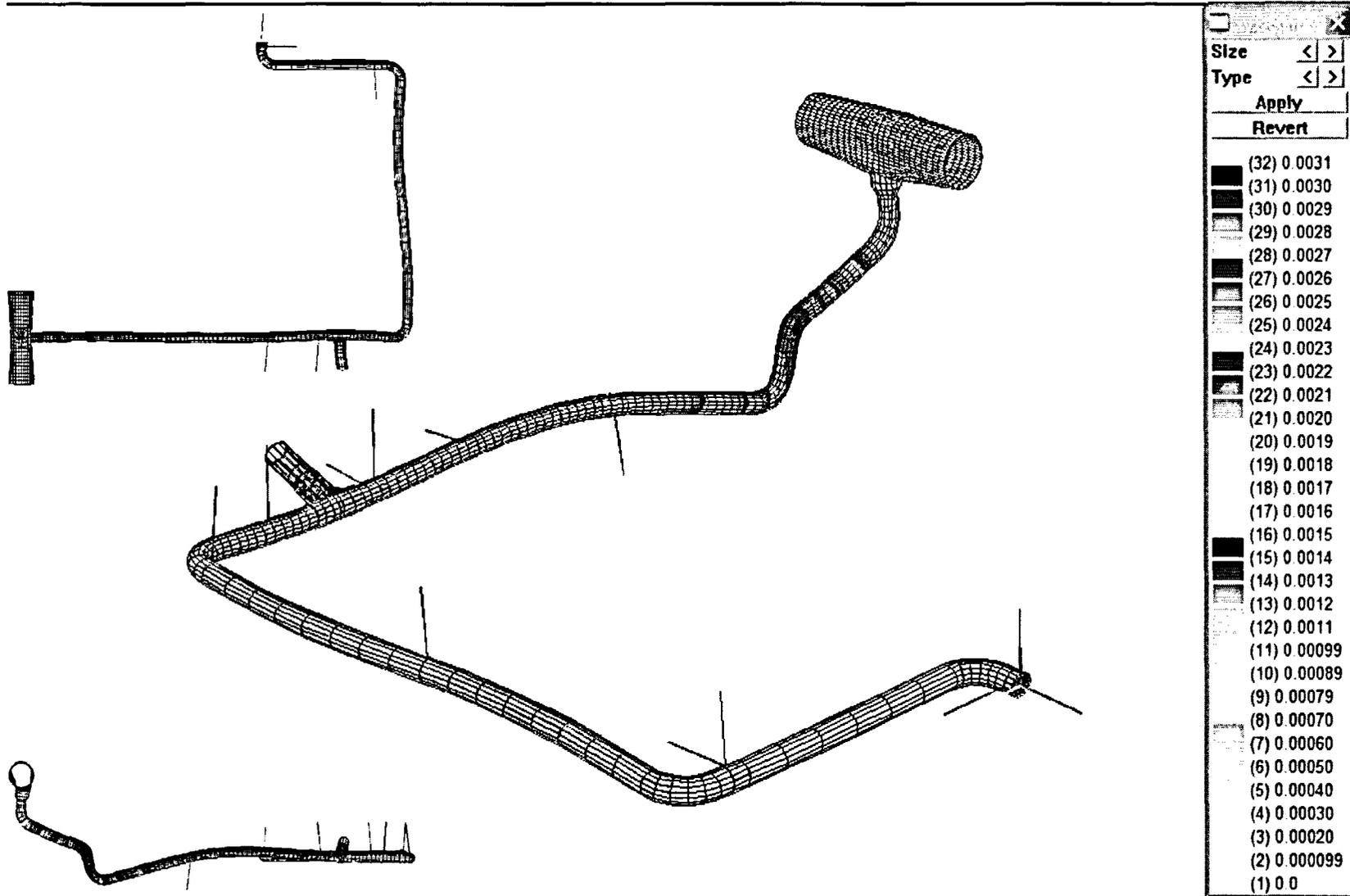
## ◆ Condition

- Unit 1, train 'A' vibration amplitude as high as 2.0 IPS at 24.5 Hz
- Units 2 and 3, train 'A' vibration amplitude approximately 0.2 – 0.3 IPS at 24.0 Hz
- Units 1, 2, and 3 train 'B' has no appreciable vibration – small peaks at approximately 27 Hz.

**Note that 2.0 IPS at 24.5 Hz ~ 13 mils (0-P) and 0.8g**

# Configuration

COMPLEX EIGENVALUE = 0.000000E+00, 1.377998E+02



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# Unit 1 Vibration History

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# Unit 1 Vibration History

- ◆ **U1C9 (March, 2001) – vibration identified**
  - **Monitoring data indicates vibration since beginning of U1C9**
  - **No vibration prior to U1C9**
  - **Possible change during U1R8 – CSB 10 year ISI**
- ◆ **U1R9 Engineering action plan**
  - **Inspection of all susceptible welds**
  - **Vibration and temperature monitoring program**
  - **Inspection of 1JSIAUV0651 valve and actuator**
  - **Periodic on-line inspections of SDC suction line during U1C10**

# Unit 1 Vibration History

## ◆ U1C10

- Continuous breaker to breaker run (May, 01 – September, 02)
- Vibration levels trended upward from 1.0 to 1.2 IPS at 24.8 Hz during final 3 months
- No indication of degradation during on-line inspections

# Unit 1 Vibration History

## ◆ U1R10 (October, 2002)

- **SDC suction isolation valve 1JSIAUV0651 fails to open**
  - Root cause evaluation determined failure due to insufficient actuator fastener tightening during U1R9 reassembly
  - High-level vibration
- **Revised Engineering action plan**
  - All butt and socket welds re-inspected
  - Branch line socket weld build-up
  - Actuator hardened – internal fasteners secured with “Loctite”
  - Inspection ports installed in actuator housing – enhanced inspection program during U1C11
  - Pipe support modification installed to reduce structural resonance with acoustic forcing function



# Unit 1 Vibration History

## ◆ U1C11

- **Significant increase in vibration amplitude with increasing power**
  - Power ascension stopped at 70% RTP – 1.90 IPS at 24 Hz
  - Plant shutdown and new pipe support removed - vibration levels reduced to approximately EOC U1C10
- **Amplitude increased to 1.40 IPS following March 2003 short-notice outage**
- **Amplitude increased to 1.60 IPS following EOC MTC testing**
- **Pin hole leak found in fitting socket weld on branch drain line during preparation for T-Mod in Feb. 2004**
  - Root cause of failure analysis determined that fatigue failure was the result of pipe support not in compliance with design
  - Failure accelerated by high-level vibration
  - Drain line reconfigured to reduce fatigue



# Unit 1 Vibration History

## ◆ U1R11 (March, 2004)

- Performed ISI of all butt and socket welds
- Performed additional weld build-up for all attached small bore pipe
- Implemented an enhanced monitoring program
- Inspected core support barrel (CSB) position
- Installed temporary installation of heat trace along SDC suction line
- Refurbished and inspected actuator
- Installed “heat tracing” on SDC suction line

## ◆ U1C12

- Vibration levels ~1.60 IPS



# Unit 1 Vibration History

## ◆ U1R12 (October, 2005 - SGR)

- Installed “vortex plate”
- Design validation testing demonstrated increase in air entrainment
- Vortex plate removed prior to start-up
- Inspected all butt and socket welds
- Refurbished and inspected actuator

## ◆ U1C13

- Baseline vibration levels at 0% RTP ~1.0 IPS
- Vibration levels at administrative limit (2.0 IPS) at 32% RTP
- Testing identified potential for vibration levels beyond design limit – Unit 1 shut down
  - LER draft in progress
- Testing completed under exigent licensing amendment



# Phenomenological

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# Phenomenological

## ◆ Hypothesis

The *direct cause* of the Unit 1 vibration condition is the development of pressure pulsations in the suction line resulting from coupling between the fundamental (one-quarter wave length) acoustic frequency of the SDC suction line and the shear layer instability (vortex shedding) due to RCS flow over the SDC suction nozzle

### ■ “Coke bottle” analogy

# Phenomenological

## ◆ Supporting Facts

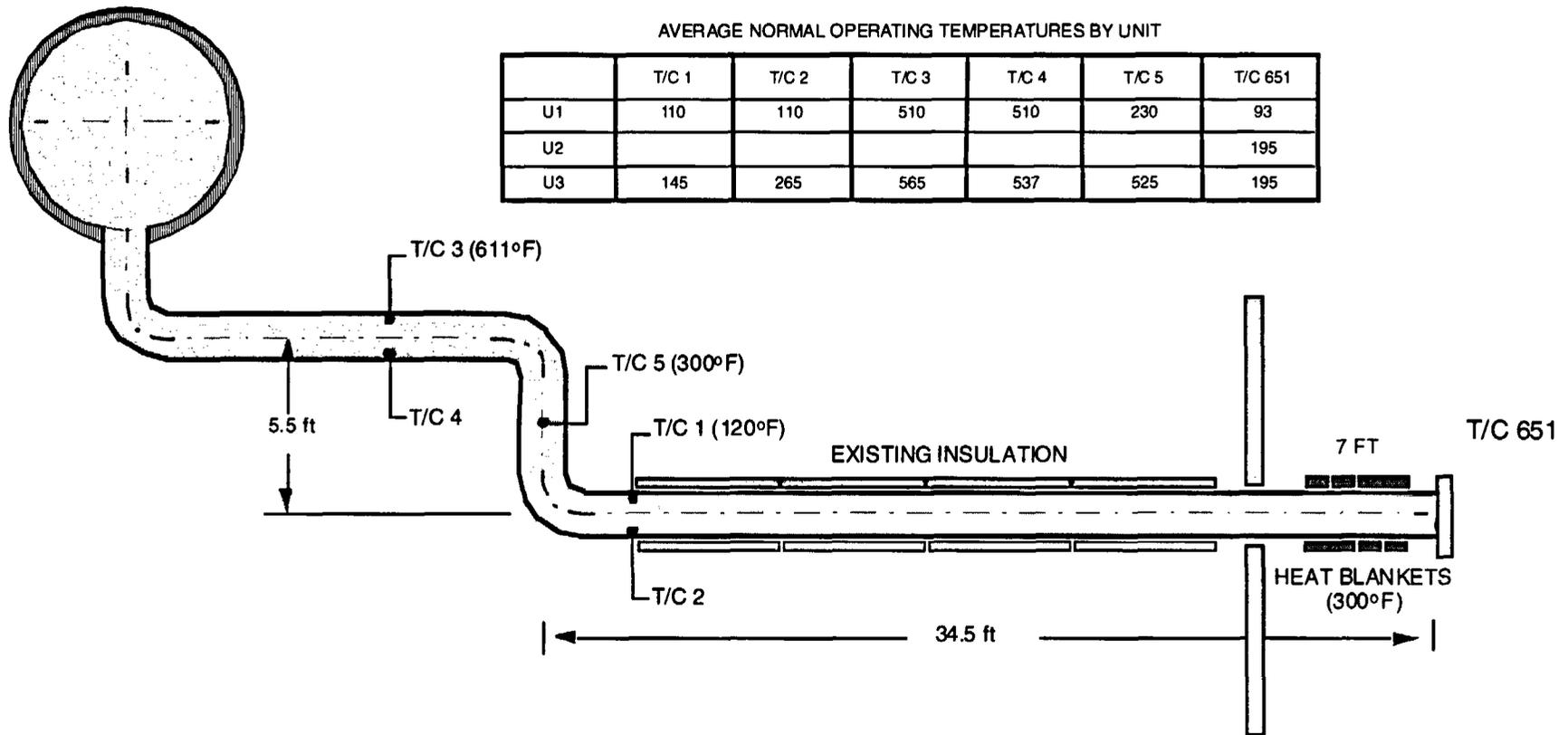
- **Unit 1 vibration amplitude proportional to RCS flow rate**
  - **Correlated to RCS temperature (density) – Proportional change in amplitude with changes in RCS temperature**
  - **Demonstrated during phenomenological testing**
- **Vibration frequency proportional to SDC suction line temperature**
  - **Unit 1 SDC line temperature and vibration different that Units 2 and 3**
- **Vibration amplitude dependent on frequency**

# Phenomenological

U1 LOOP 1 HOT LEG - 42" ID

AVERAGE NORMAL OPERATING TEMPERATURES BY UNIT

	T/C 1	T/C 2	T/C 3	T/C 4	T/C 5	T/C 651
U1	110	110	510	510	230	93
U2						195
U3	145	265	565	537	525	195



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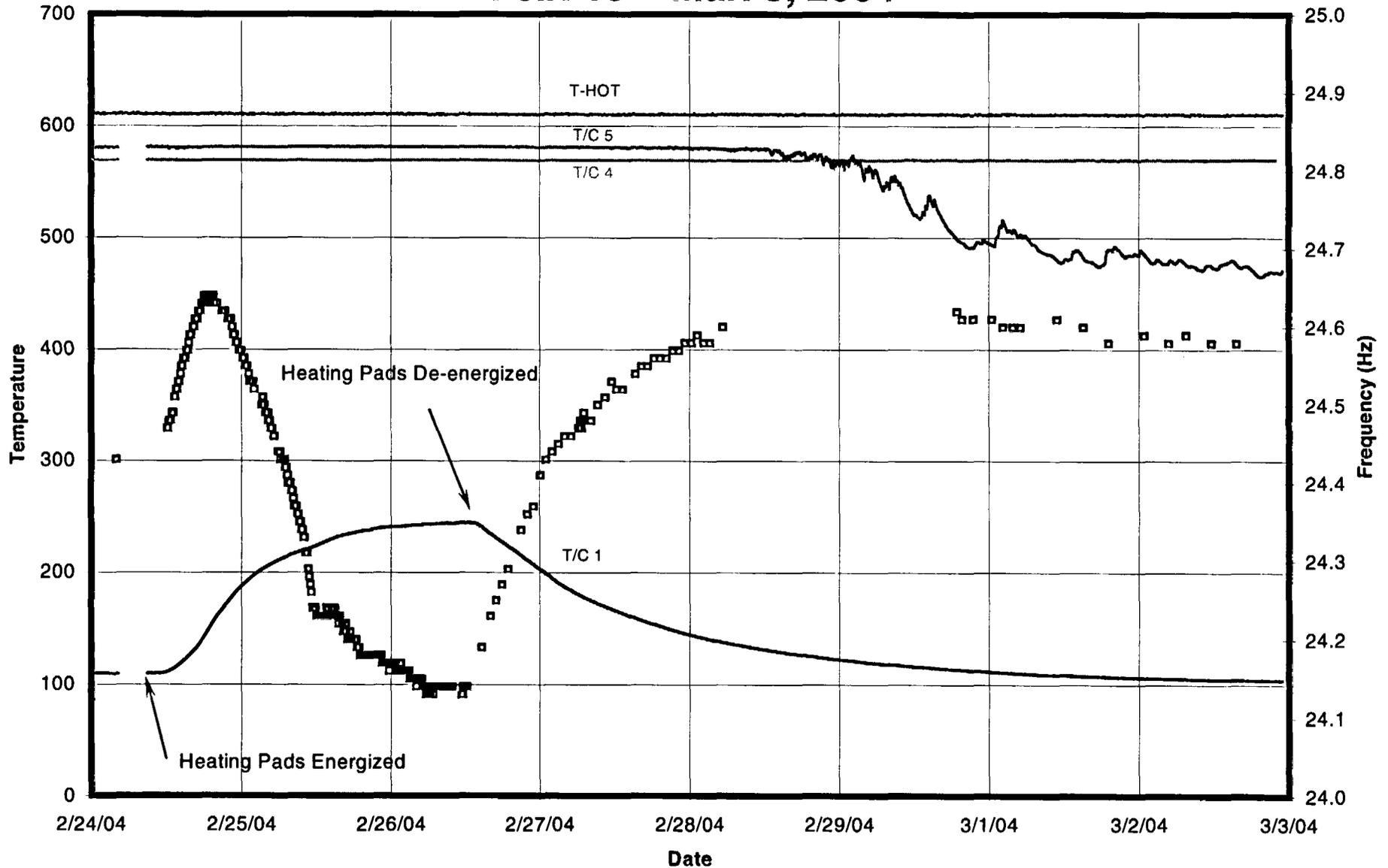
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# Phenomenological

## Unit 1 SDC Suction Line Temperature and Vibration Frequency

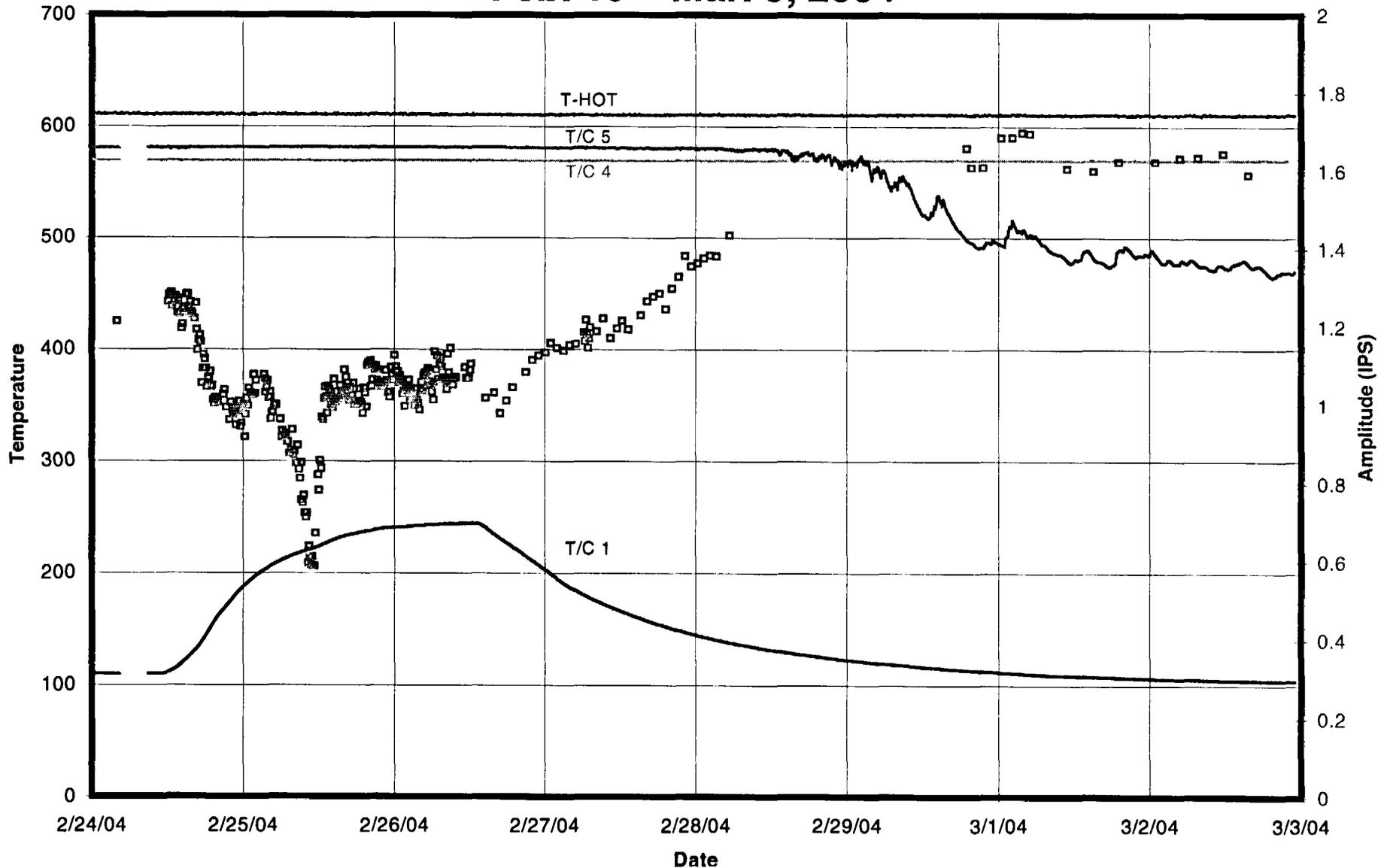
Feb. 19 – Mar. 3, 2004



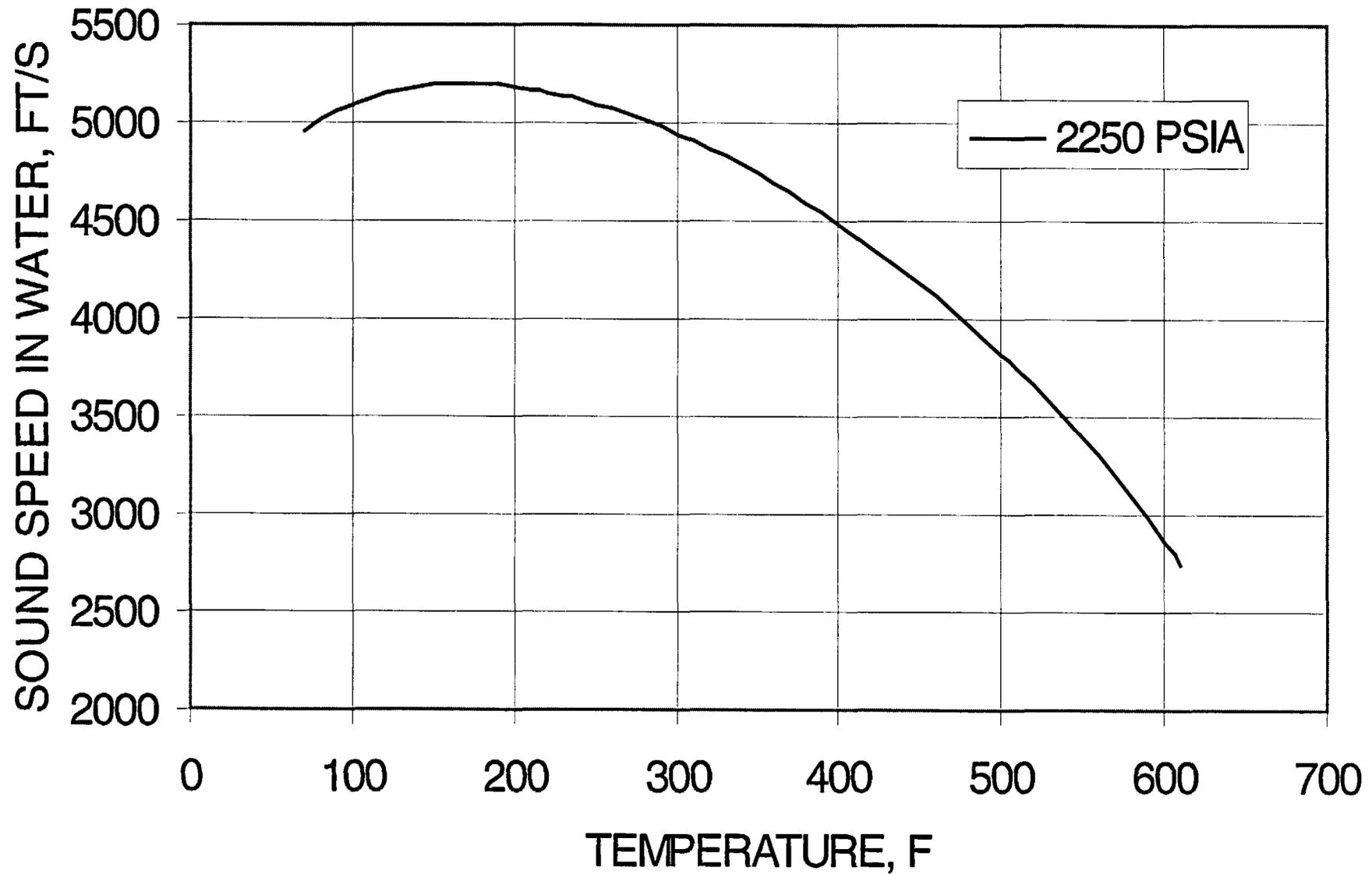
# Phenomenological

## Unit 1 SDC Suction Line Temperature and Vibration Amplitude

Feb. 19 – Mar. 3, 2004

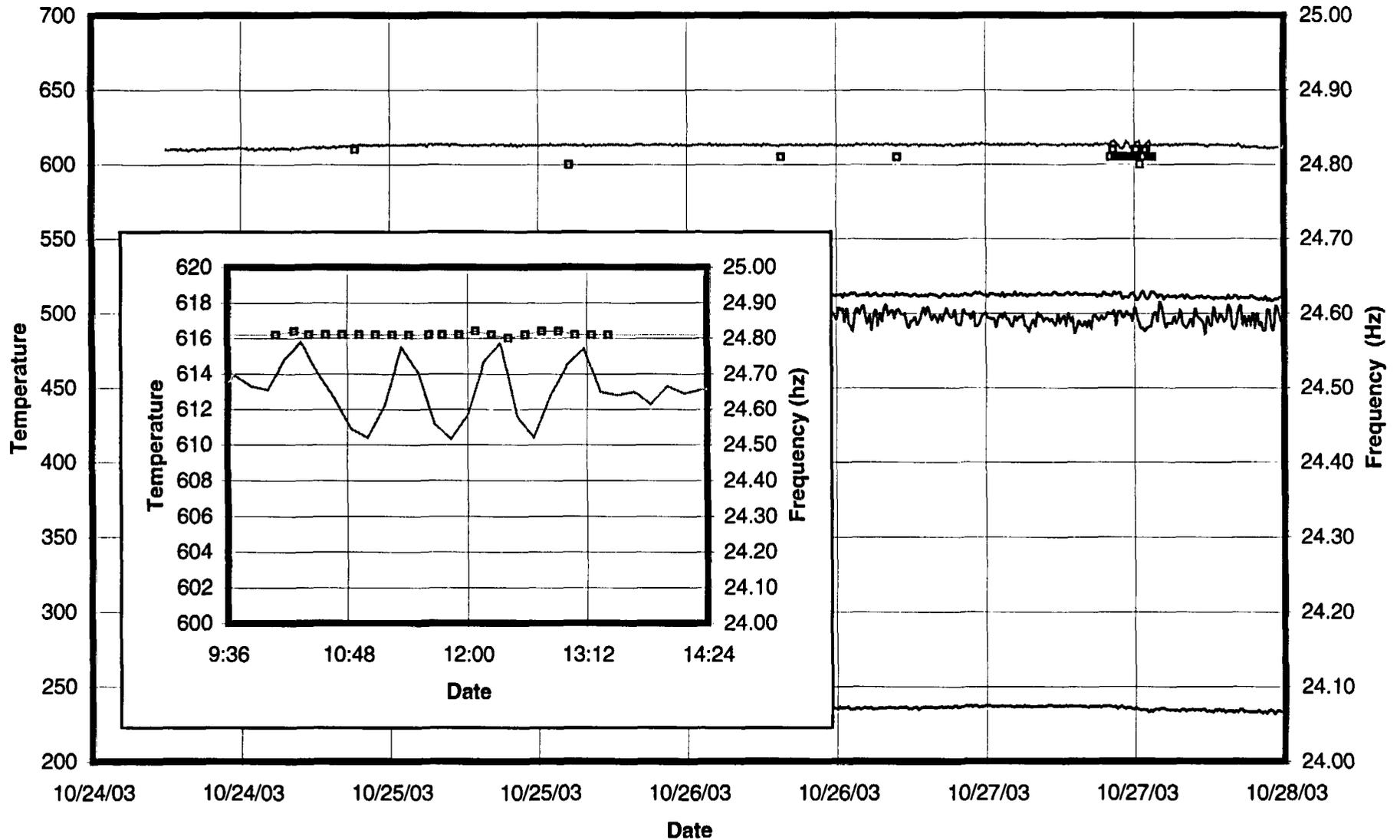


# Phenomenological



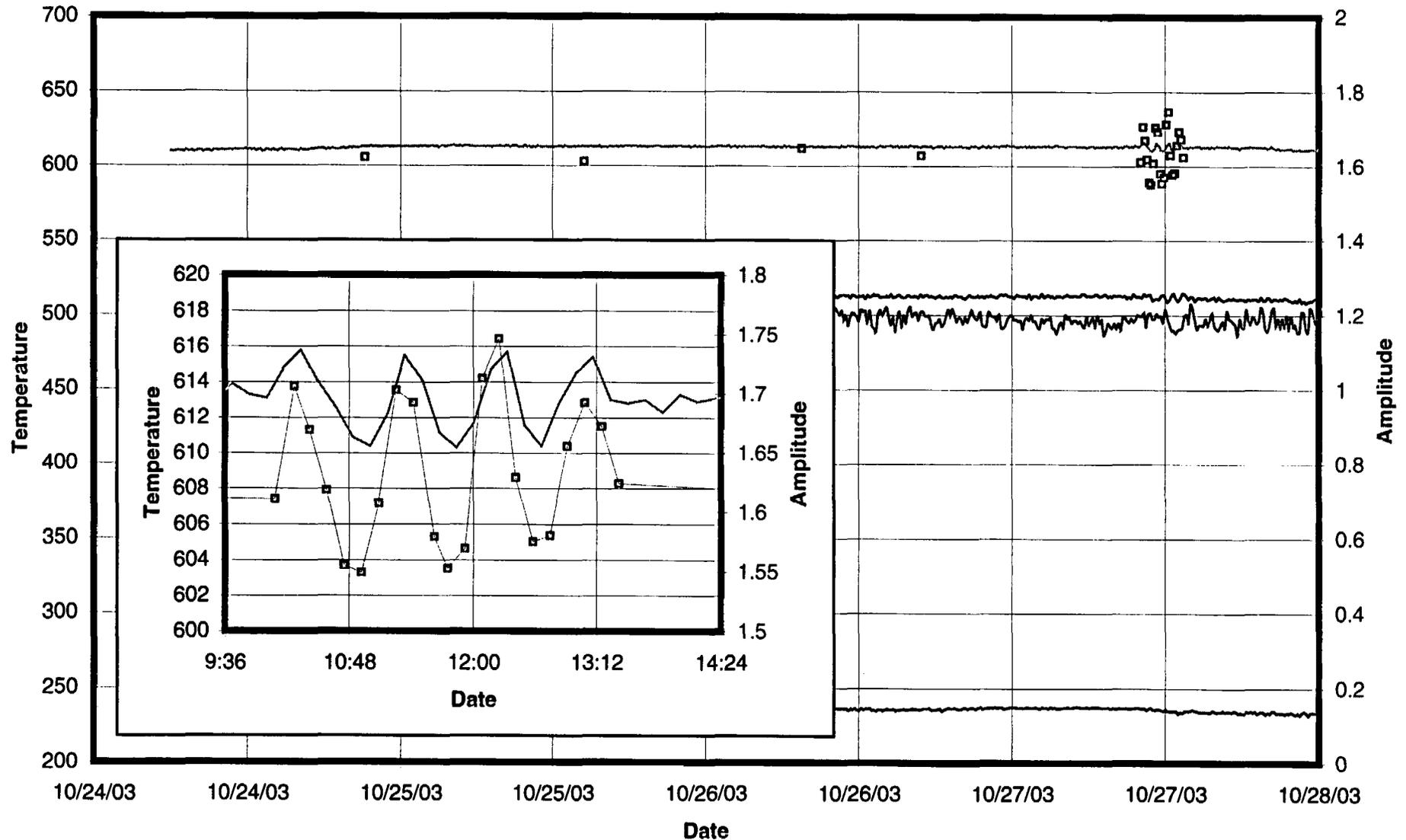
# Phenomenological

## Unit 1 SDC Suction Line Temperature and Vibration Frequency MTC Testing, Oct. 23 – 27, 2003



# Phenomenological

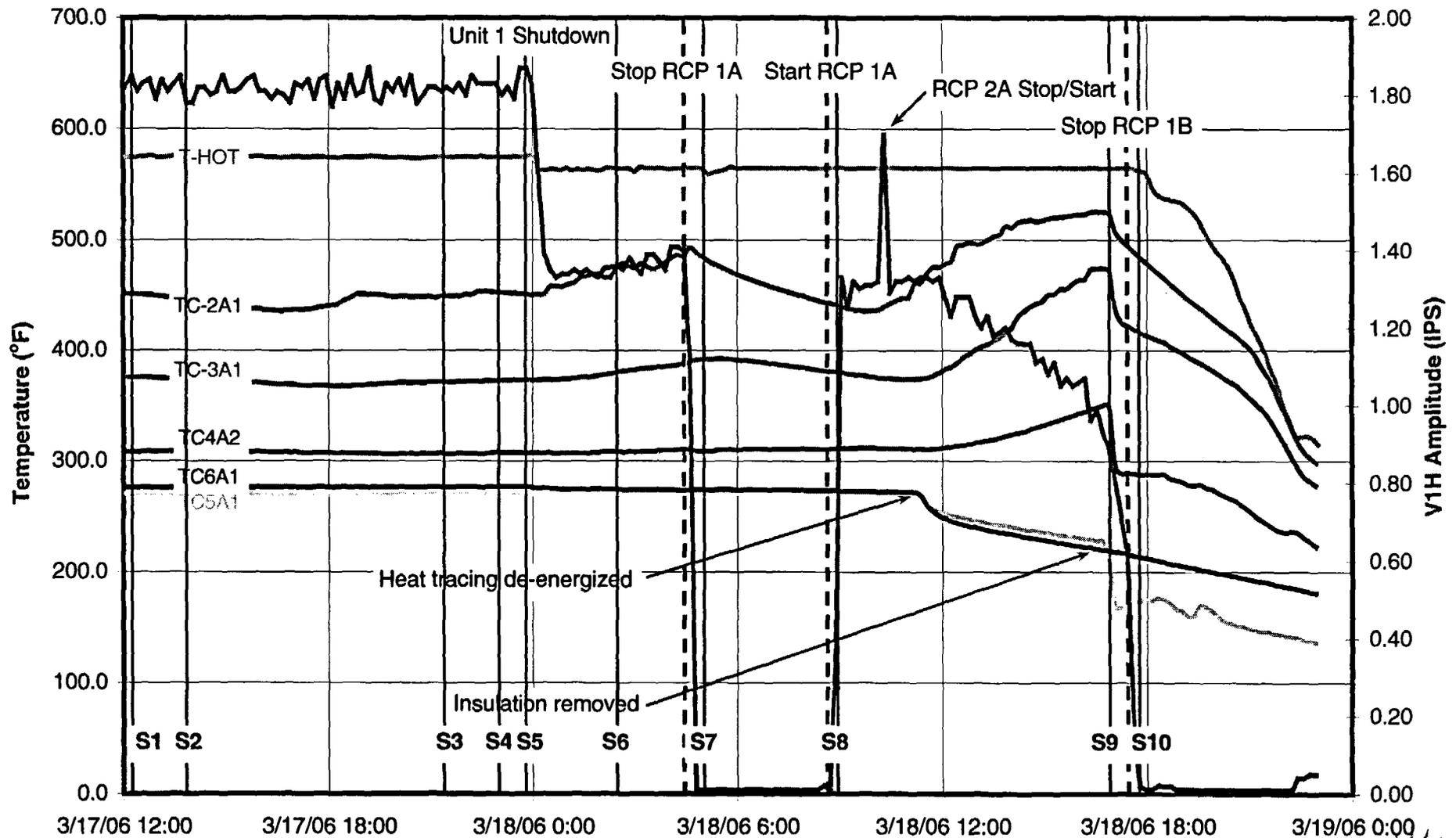
## Unit 1 SDC Suction Line Temperature and Vibration Amplitude MTC Testing, Oct. 23 – 27, 2003



# Phenomenological

## Unit 1 SDC Suction Line Vibration

March 17 - 18, 2006 (SNOW)



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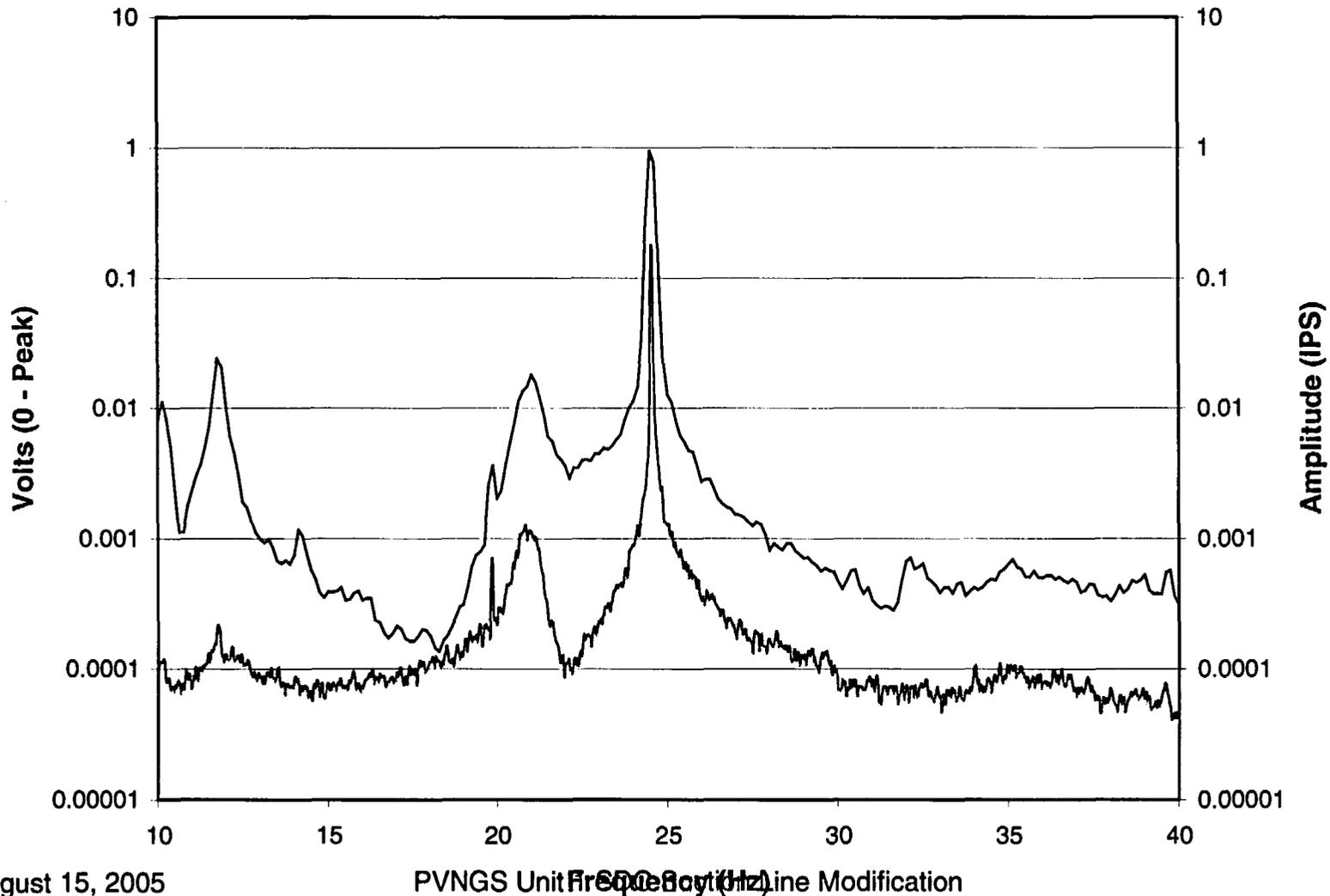
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# Phenomenological

## Unit 1 SDC Suction Line Pressure and Vibration Measurements

April 6, 2006



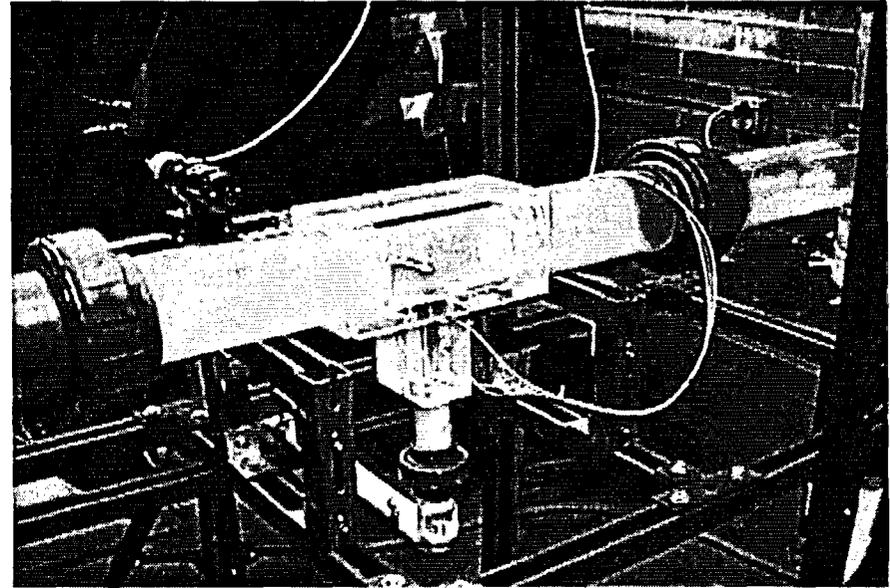
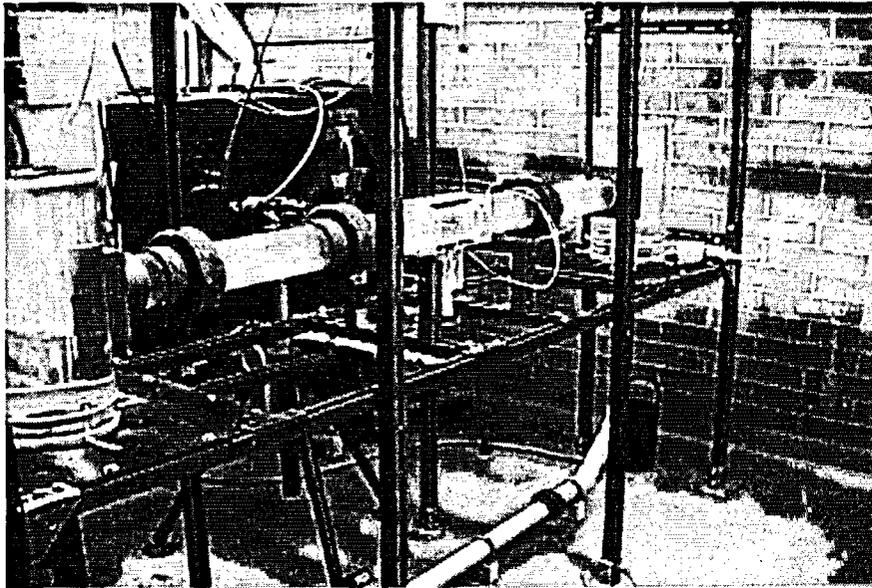
# Phenomenological

## ◆ Research programs

- ASU Phase I – vortex shedding characterization and turbulence penetration depth parametric assessment
- ASU Phase II – scaled acoustic coupling experimentation and quantification of modification effects



# Phenomenological ASU – Phase I

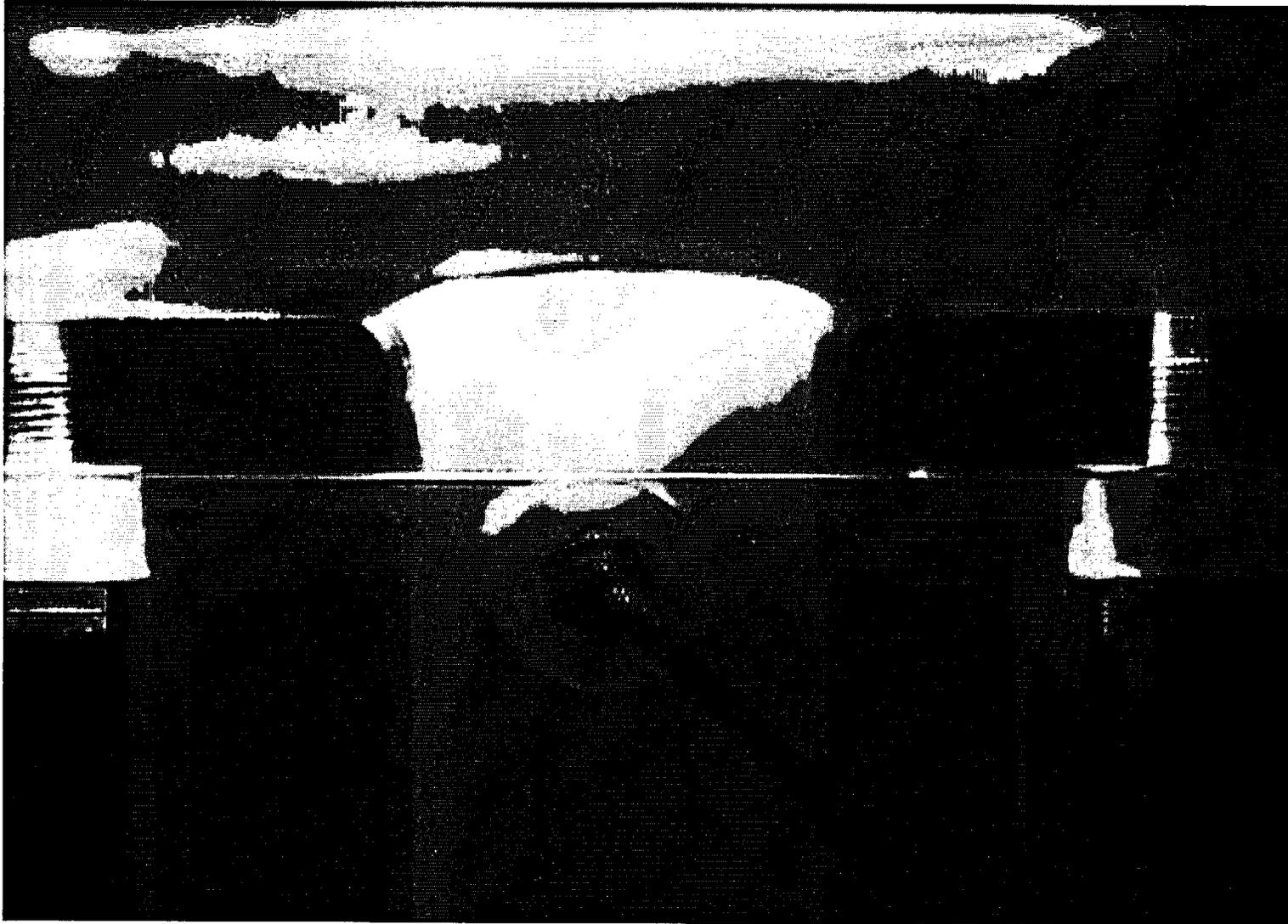


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# Phenomenological ASU – Phase I

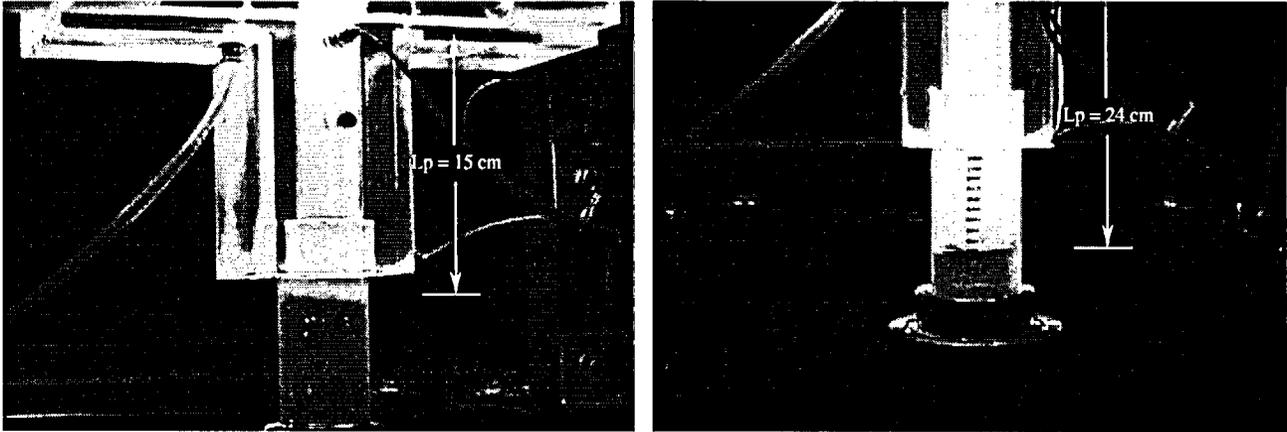


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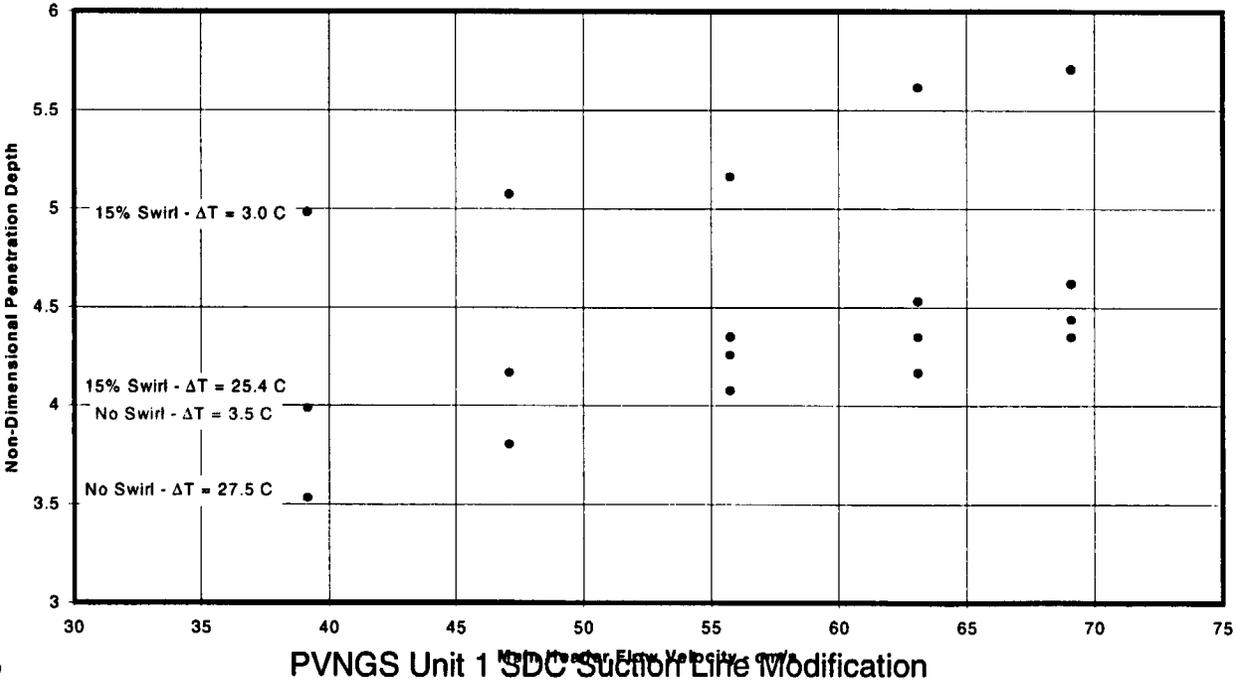
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# Phenomenological ASU – Phase I



Penetration Depth Correlation

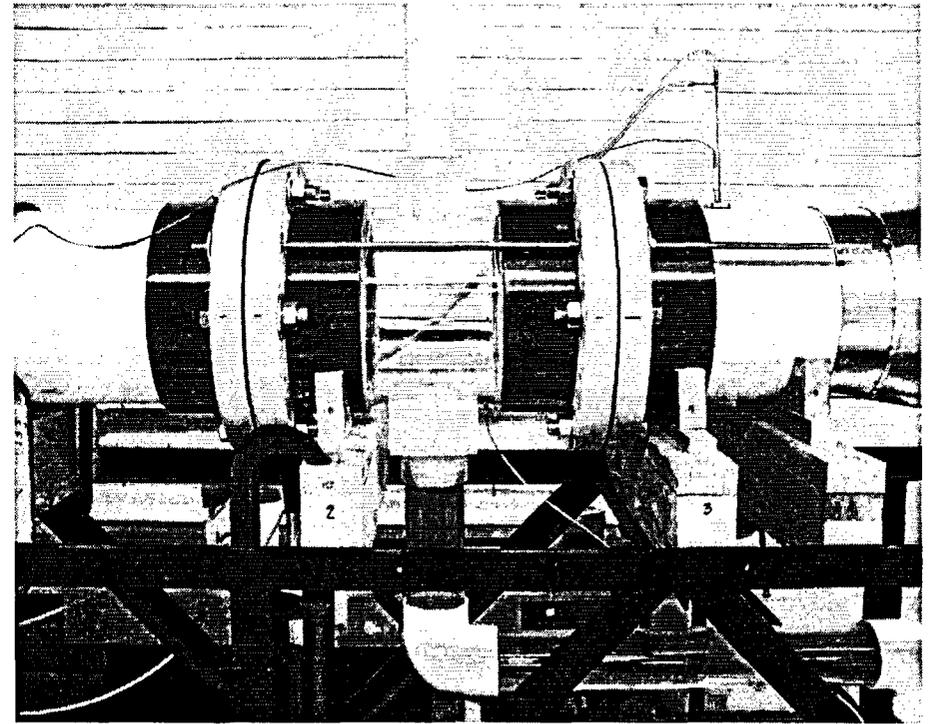
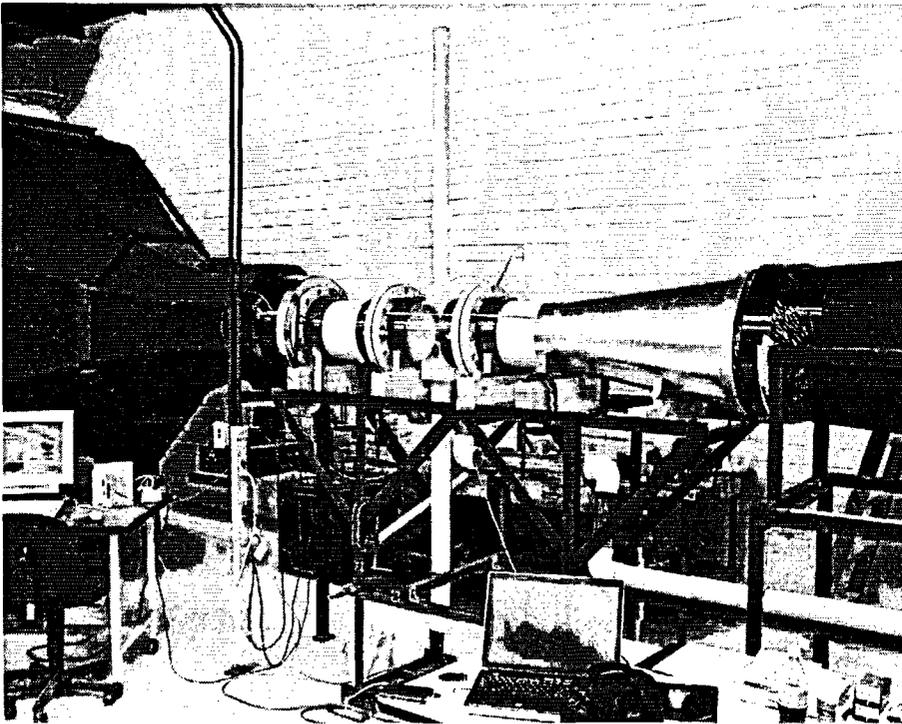


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# Phenomenological ASU – Phase II



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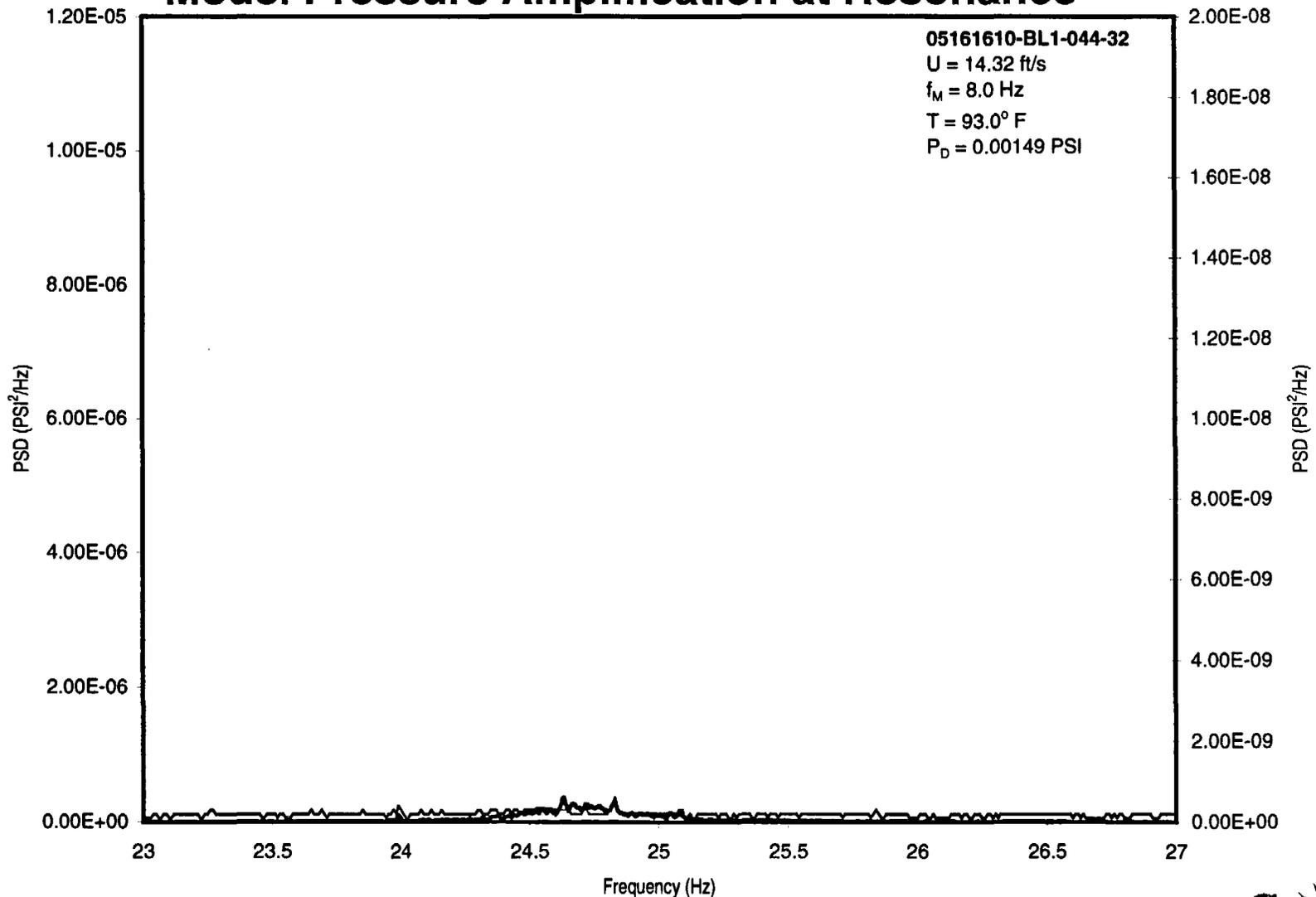
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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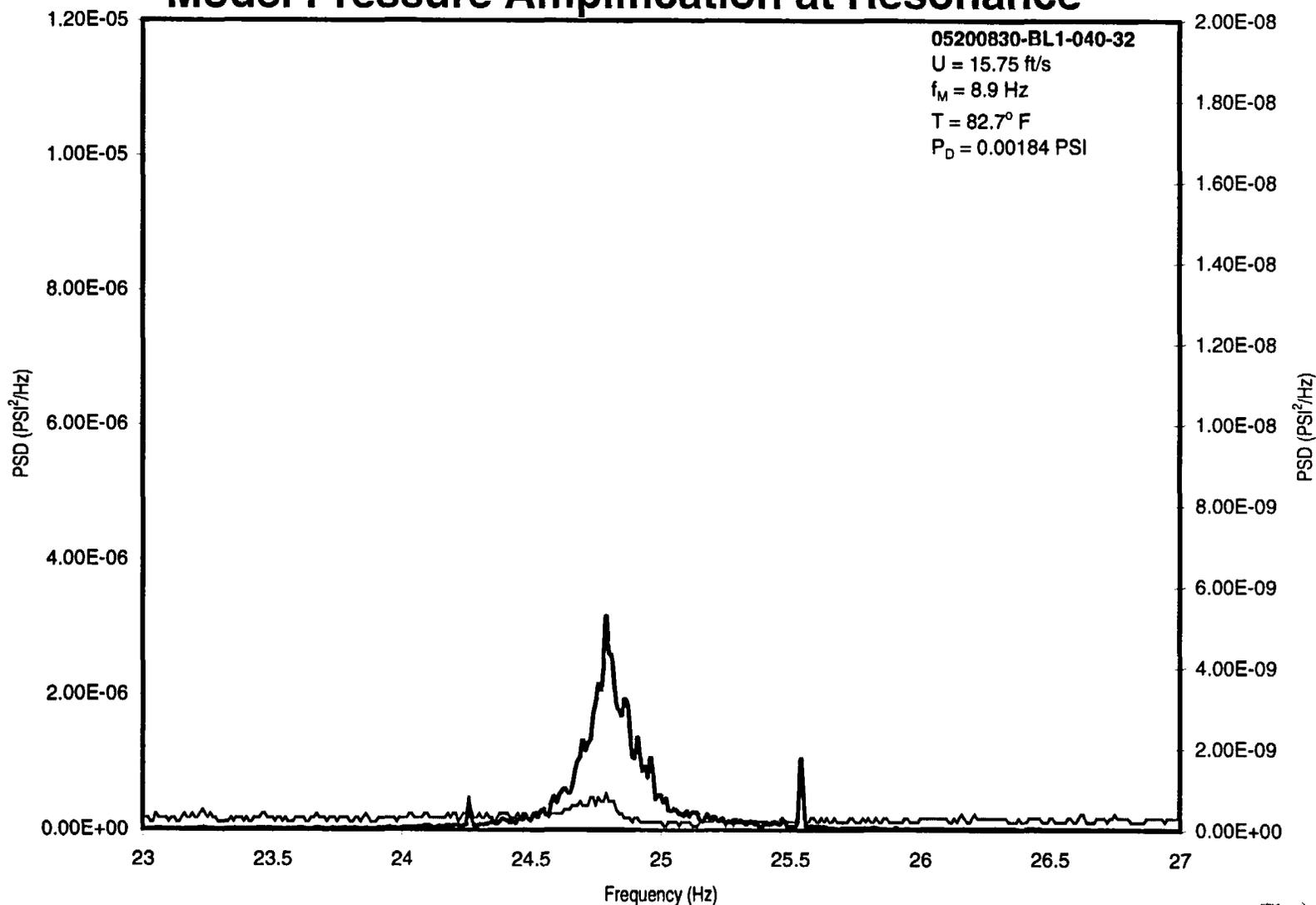
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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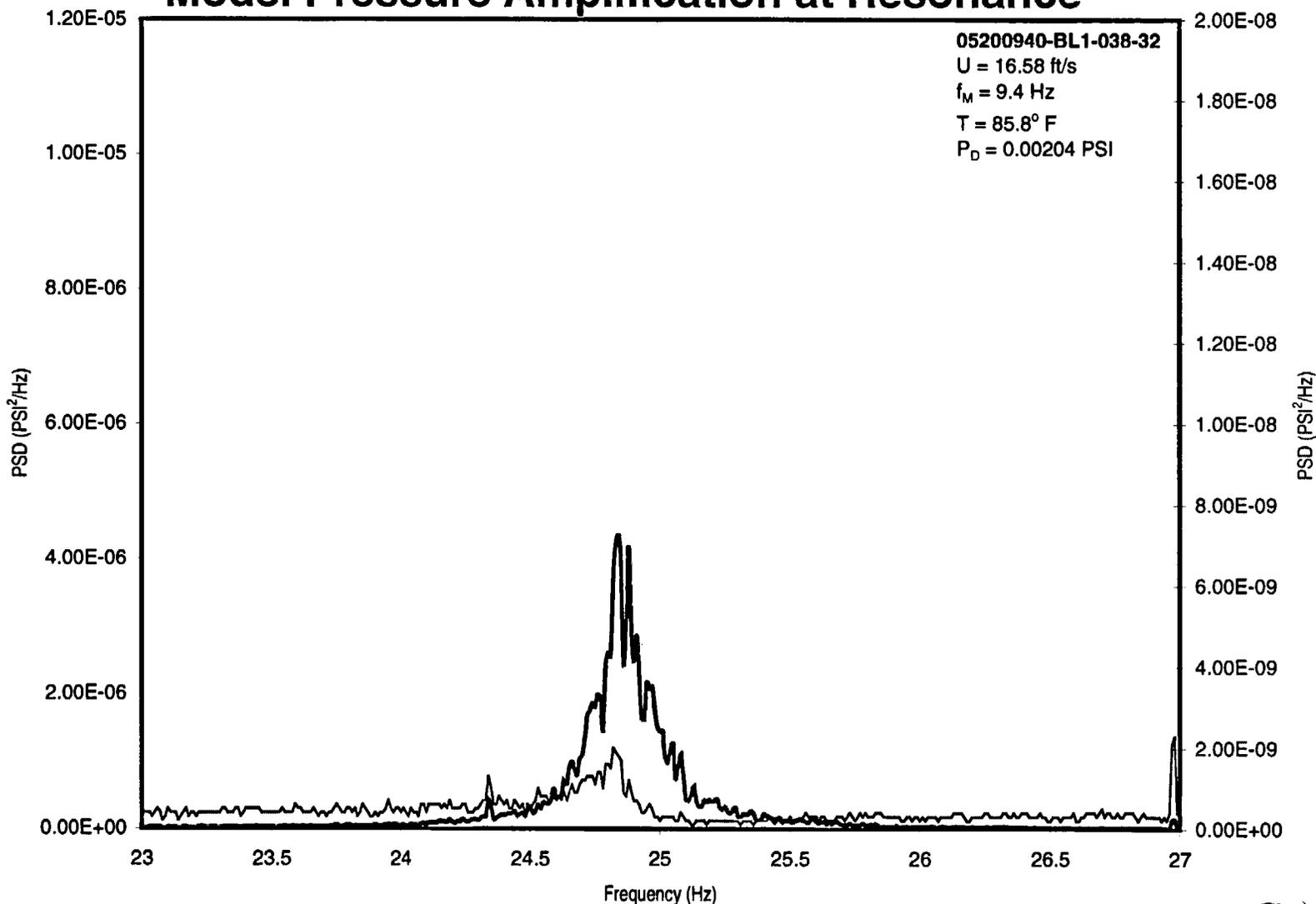
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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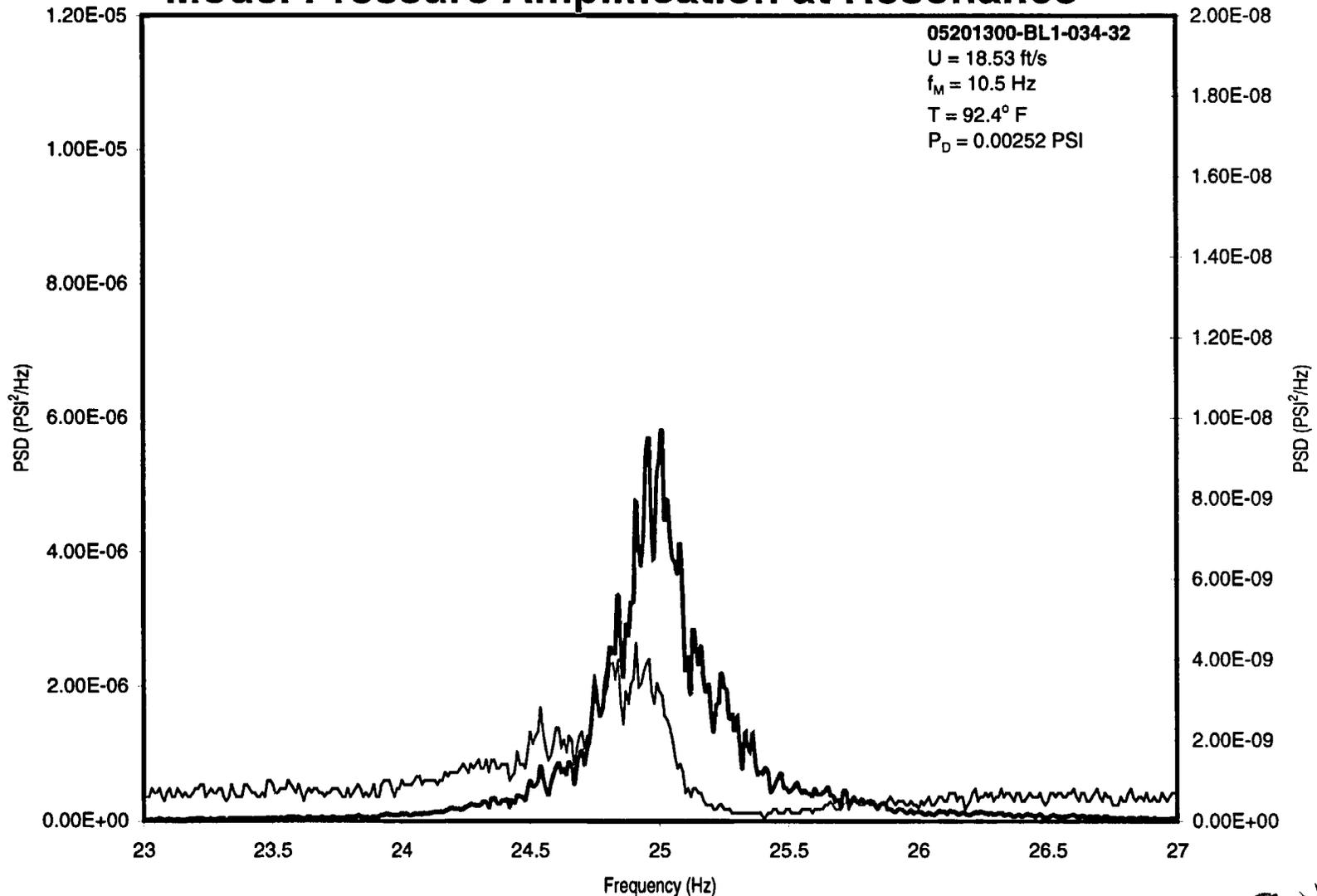
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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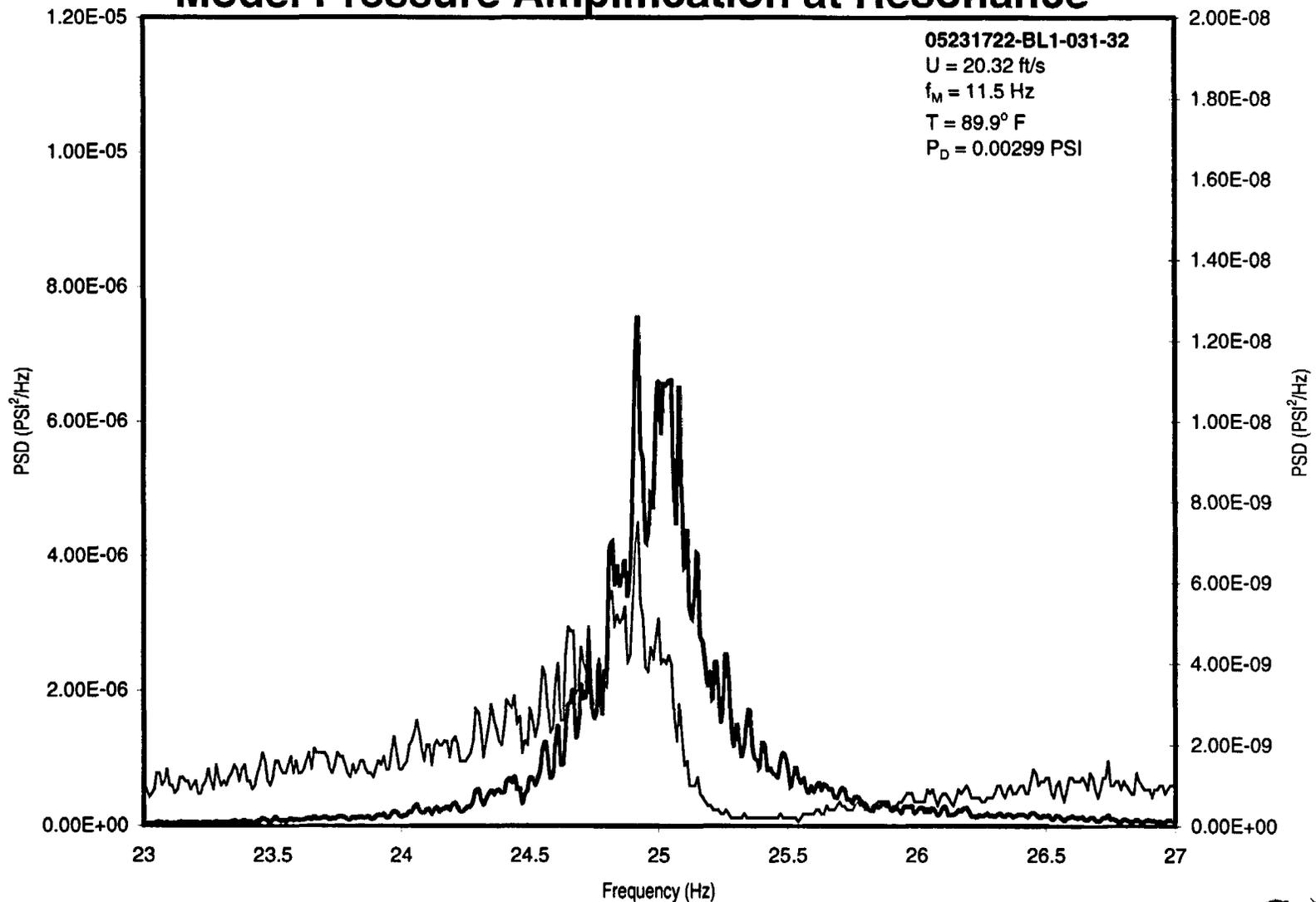
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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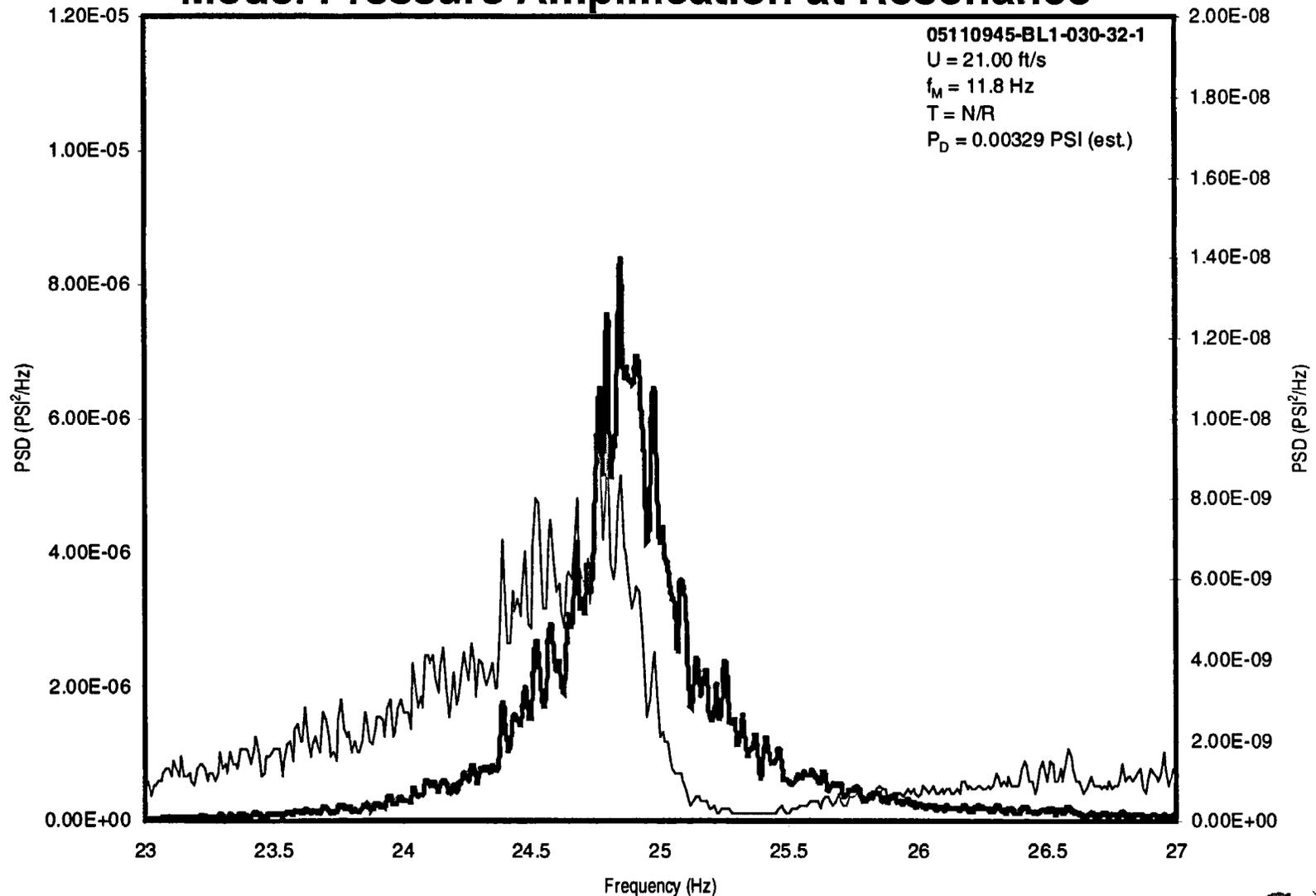
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



August 15, 2005

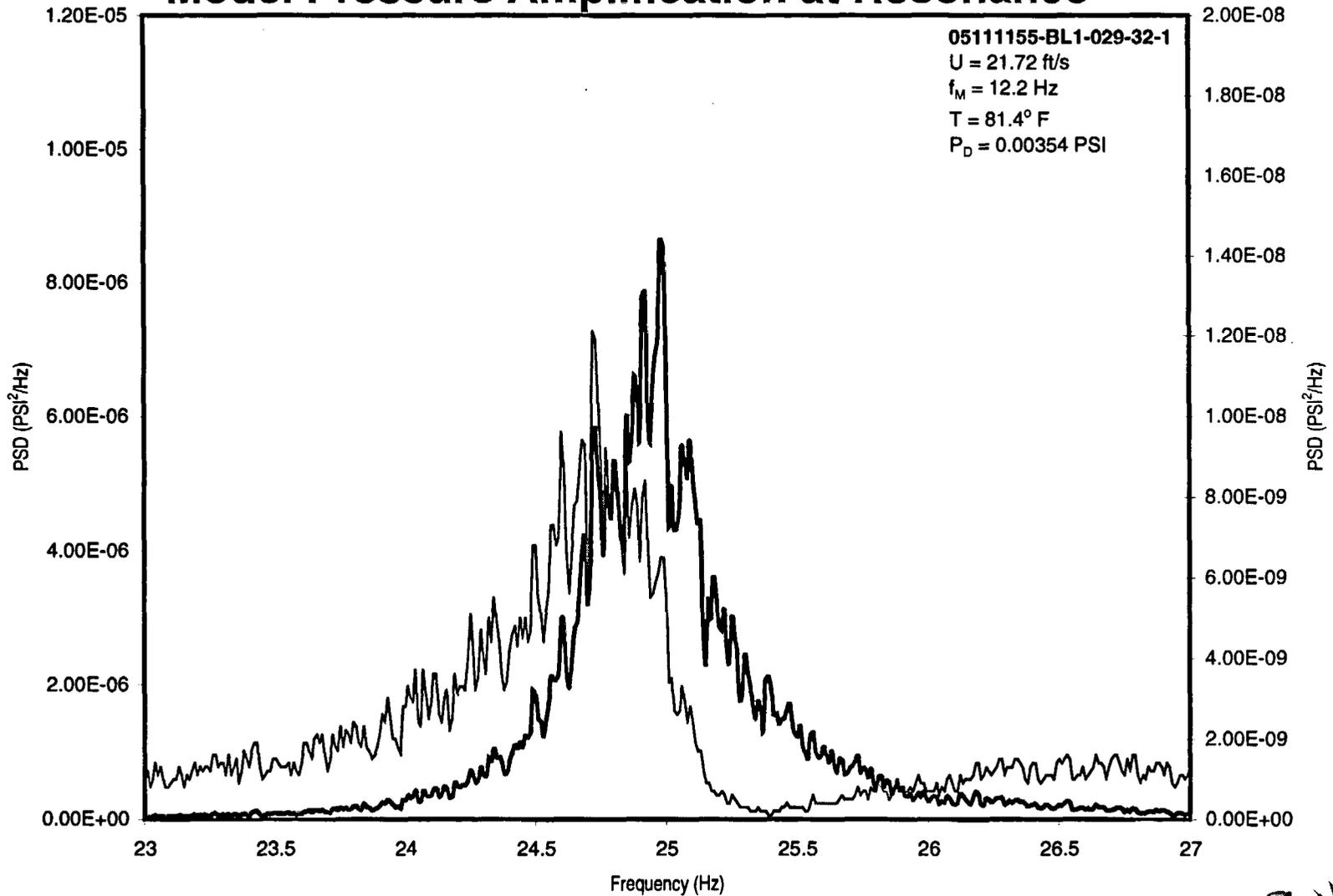
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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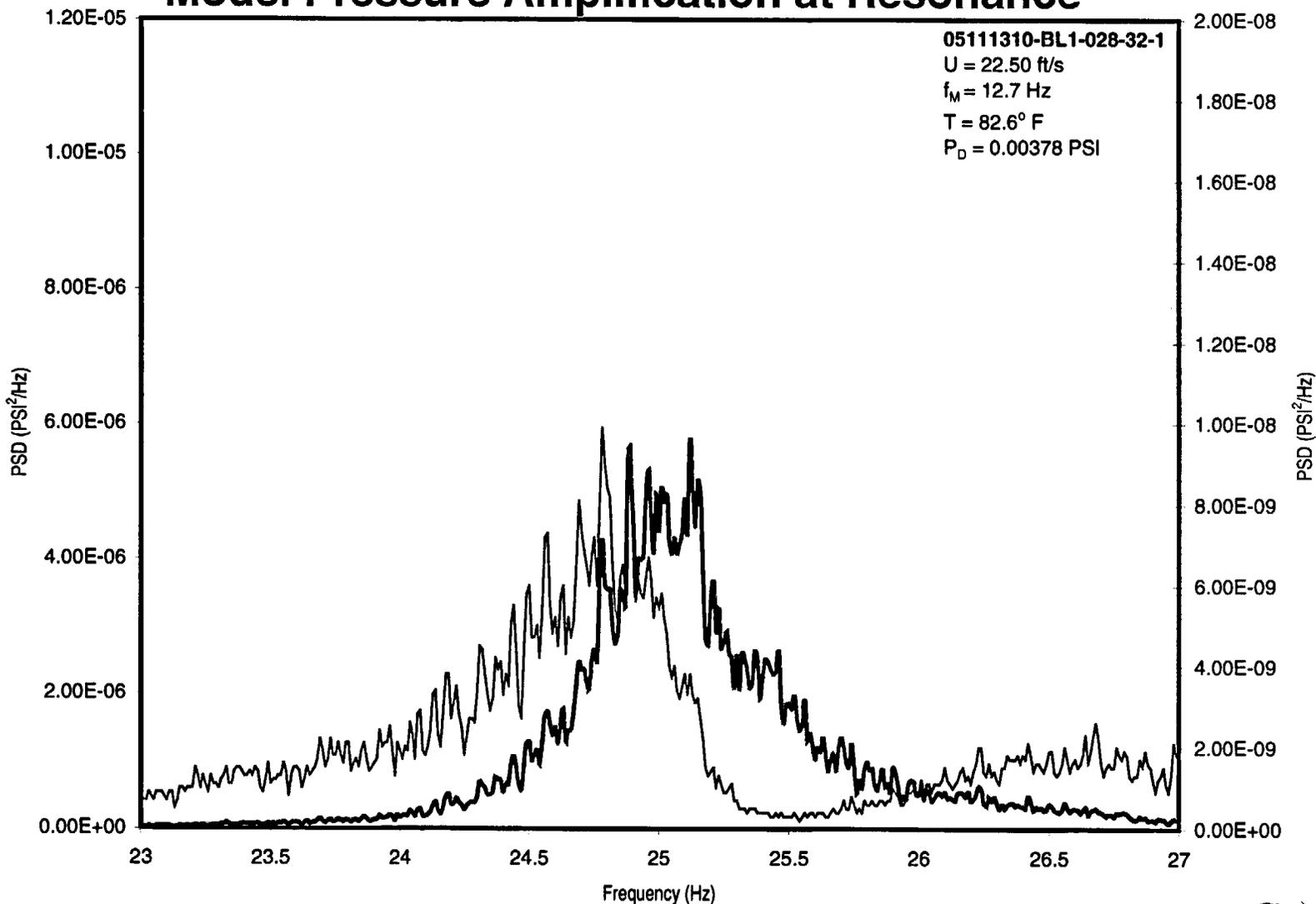
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# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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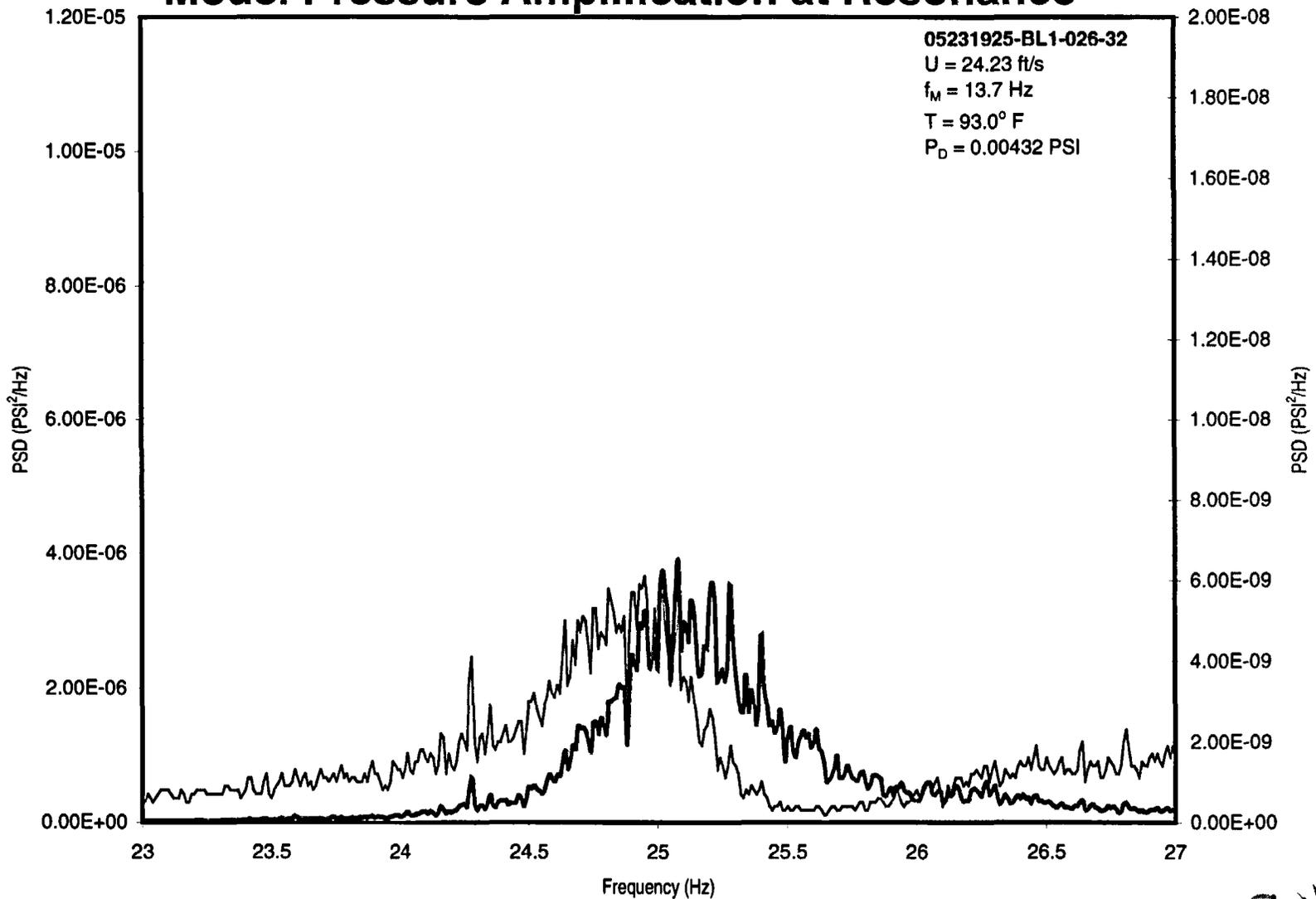
PVNGS Unit 1 SDC Suction Line Modification



# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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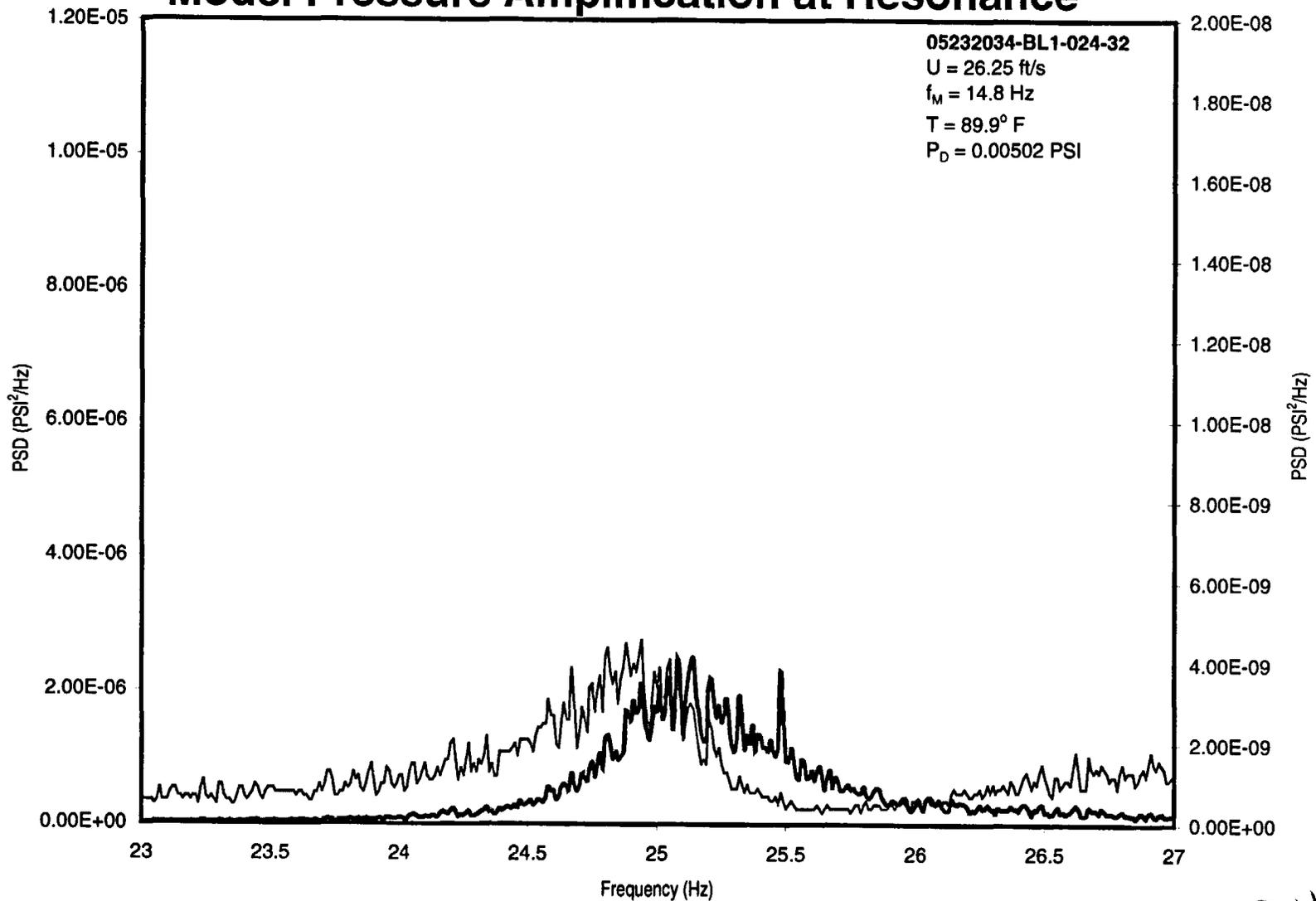
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# Phenomenological

## ASU Phase II

### Model Pressure Amplification at Resonance



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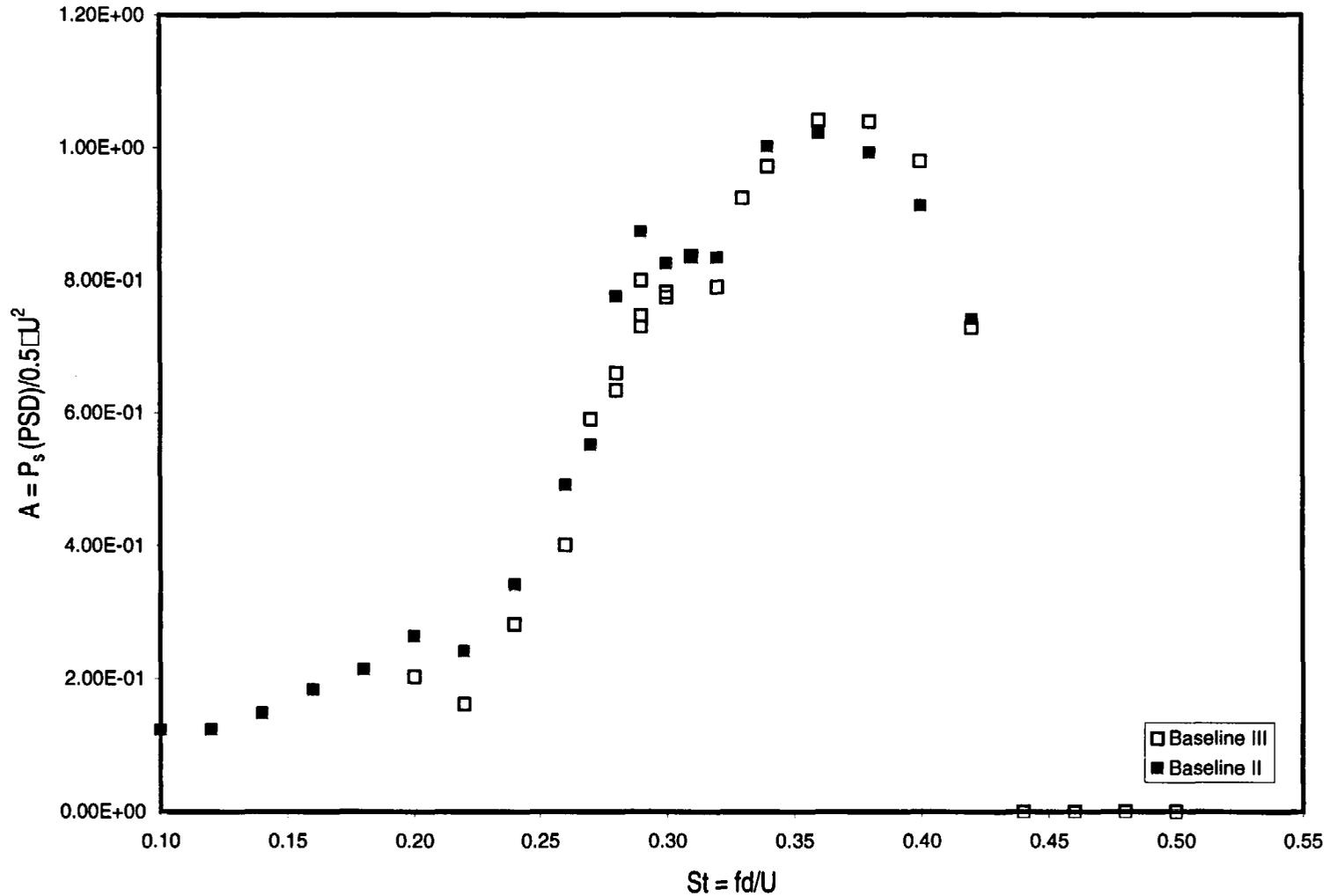
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# Phenomenological

## ASU – Phase II

### Normalized Model Acoustic Amplification



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# Modifications

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# Modification Development and Selection

- ◆ **Consultant and EPRI expert panel recommendations**
- ◆ **Approach predicated on flow-induced vibration hypothesis**
- ◆ **Modifications designed to de-couple acoustic process**
  - **Shift shedding frequency**
  - **Shift acoustic frequency**
  - **Modification of nozzle geometry is typical approach**
    - **Unable to quantify affects and approach requires re-cladding of nozzle and or hot-leg**
- ◆ **Modifications to affect structural resonance not considered**

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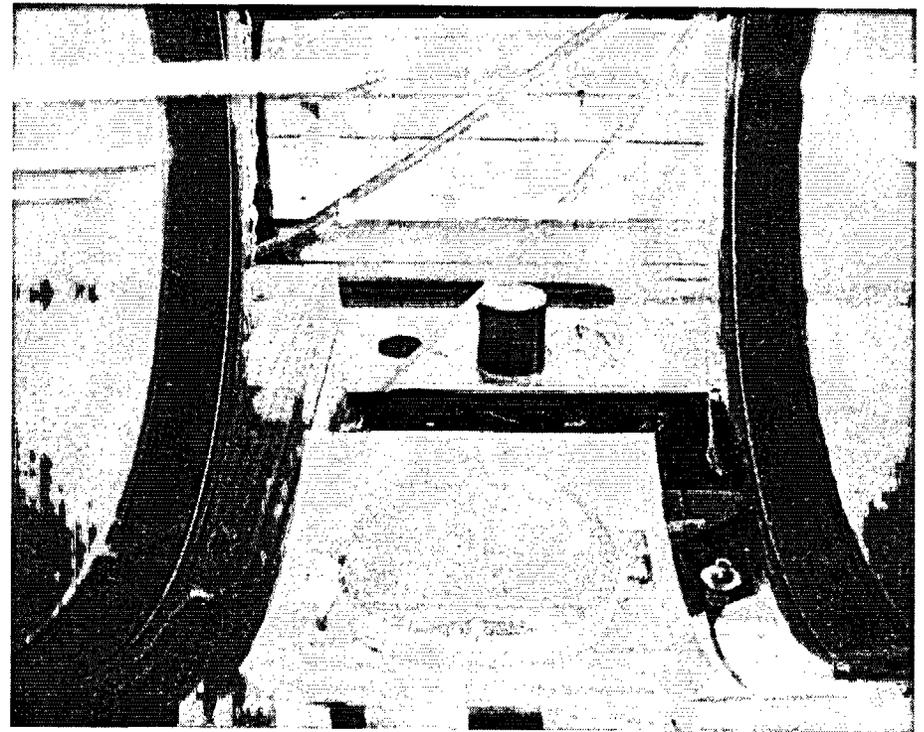
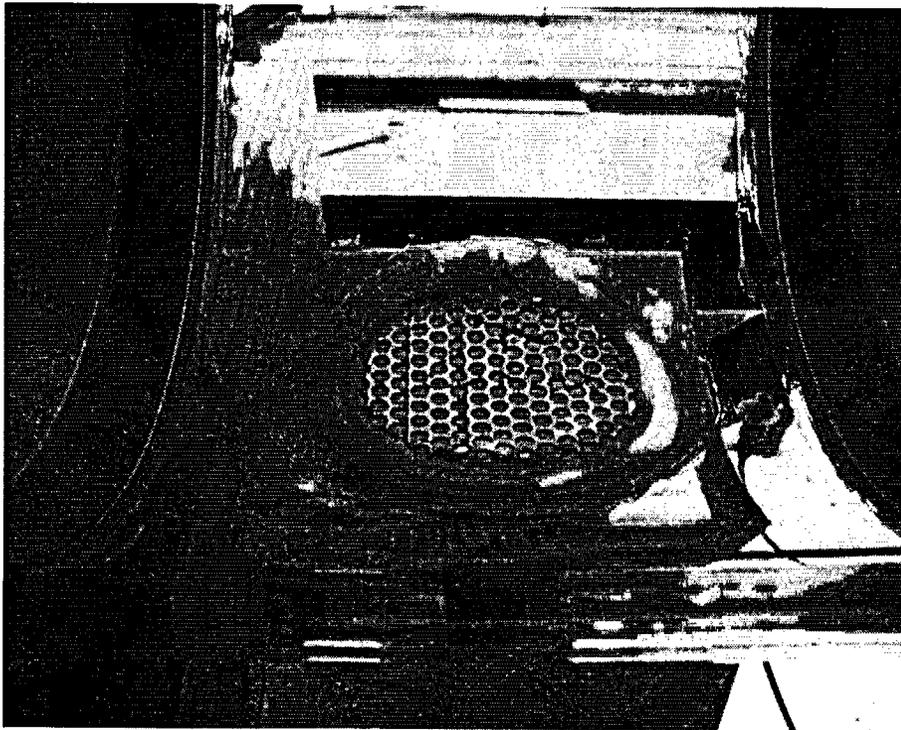
PVNGS Unit 1 SDC Suction Line Modification



# Modification Development and Selection

- ◆ **Modifications to affect shedding and acoustic frequency evaluated by scaled model testing**
  - **One-quarter scale model of hot-leg and SDC suction nozzle**
  - **Tests performed in air with Mach number similarity**
  - **Testing objective is to baseline SDC suction line acoustic pressure force and to qualitatively assess effects of various modifications on the acoustic pressure**
  - **11 variations of nozzle modification tested**
  - **Effects of valve relocation quantified**

# Modification Mock-Up Testing



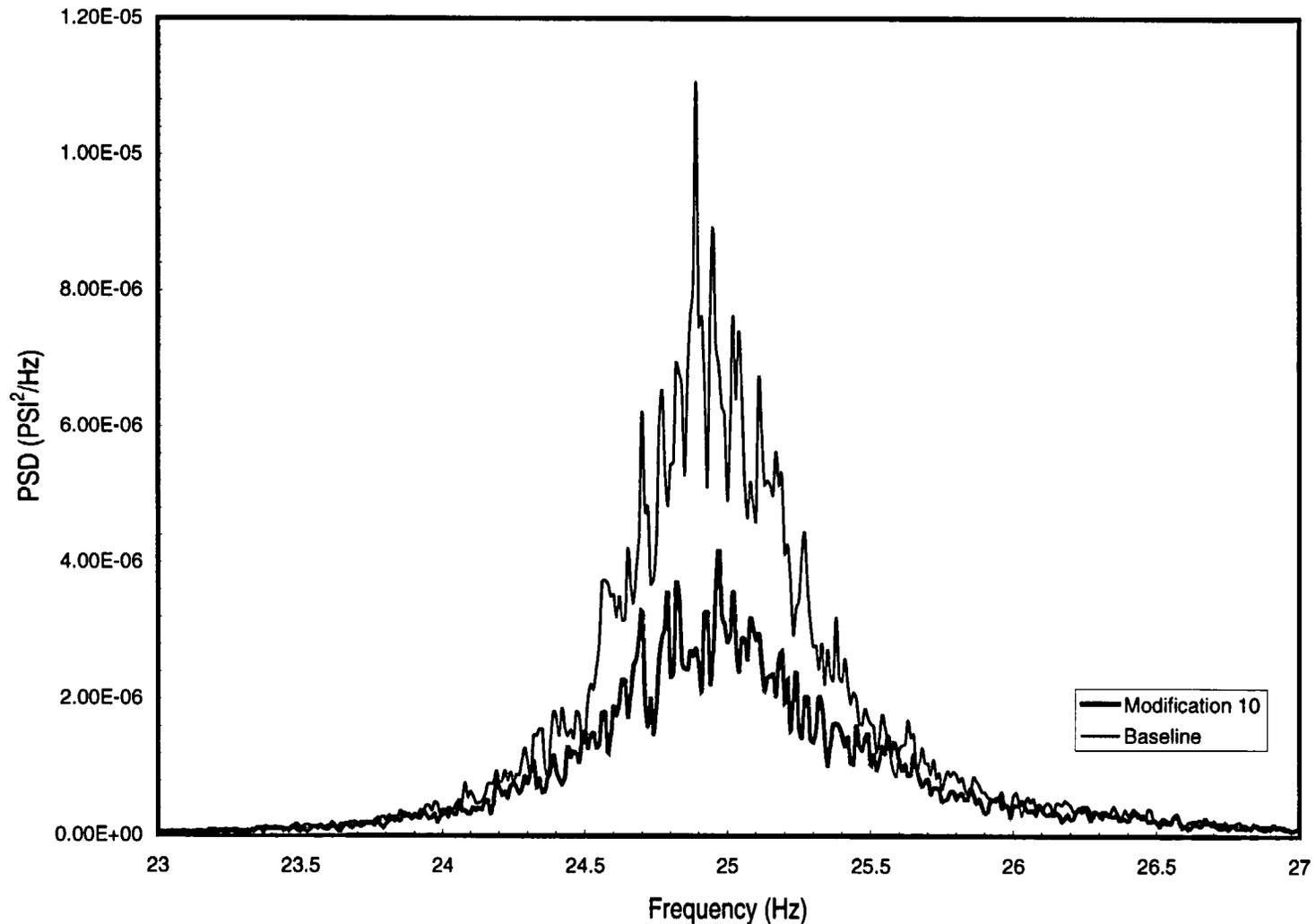
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# Vortex Plate Modification

## Reduction in Acoustic Pressure with Vortex Plate Model



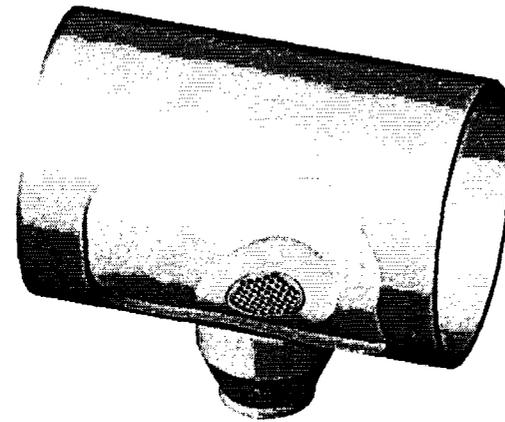
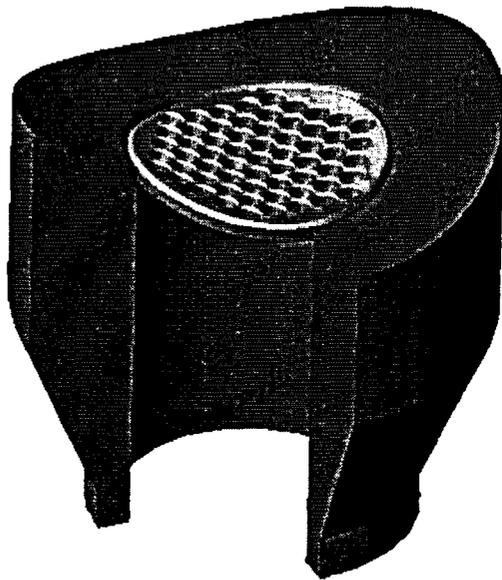
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# Vortex Plate Modification

- ◆ U1R12 final modification – grid plate



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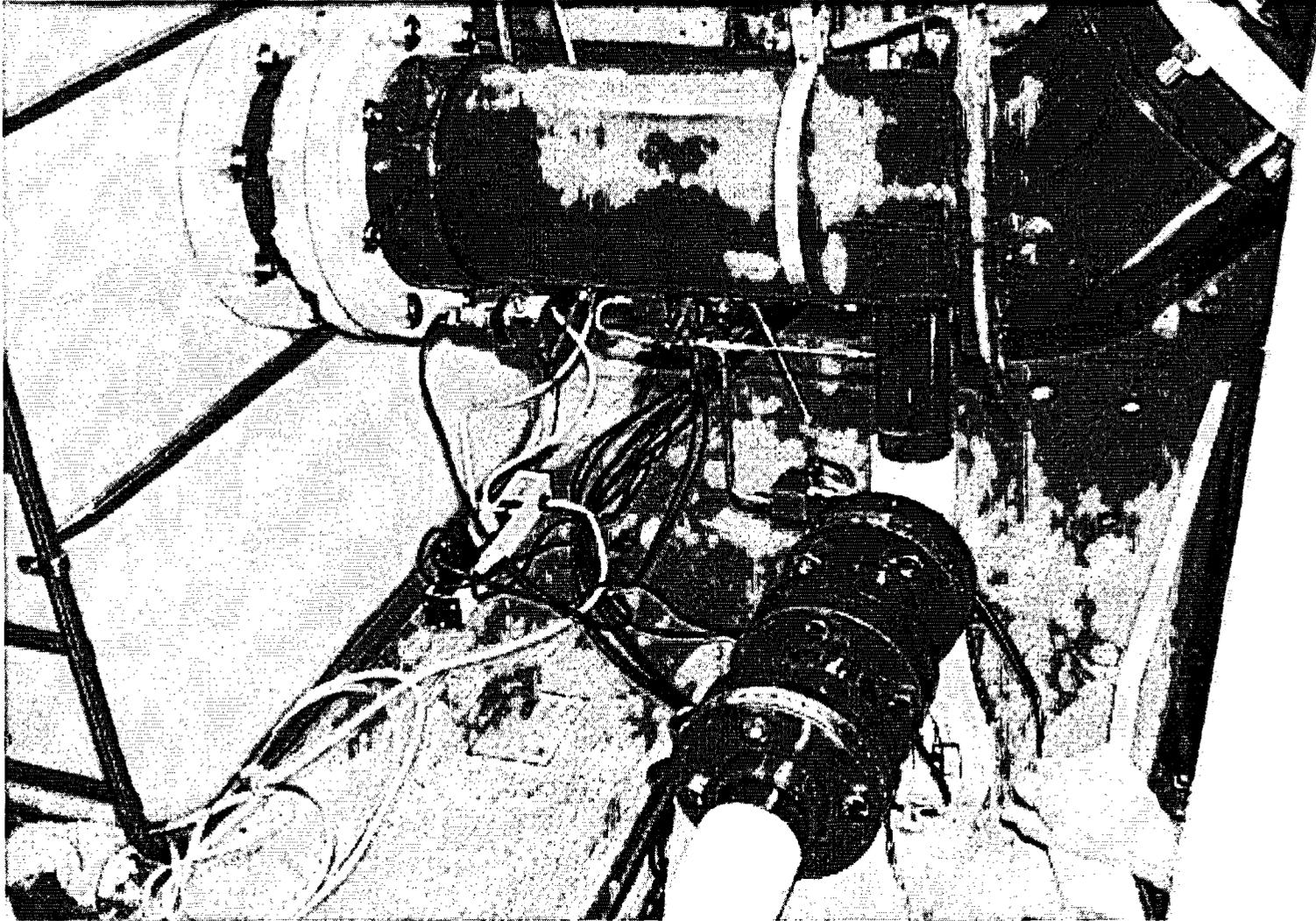
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# Vortex Plate Modification

- ◆ **U1R12 restart – vortex plate validation testing**
  - **Testing demonstrated significant increases in surface vortexing and air entrainment**
  - **Mid-loop operational impacts**
  - **Plate removed**

# Vortex Plate Modification



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# **Final Modification – Isolation Valve Relocation**

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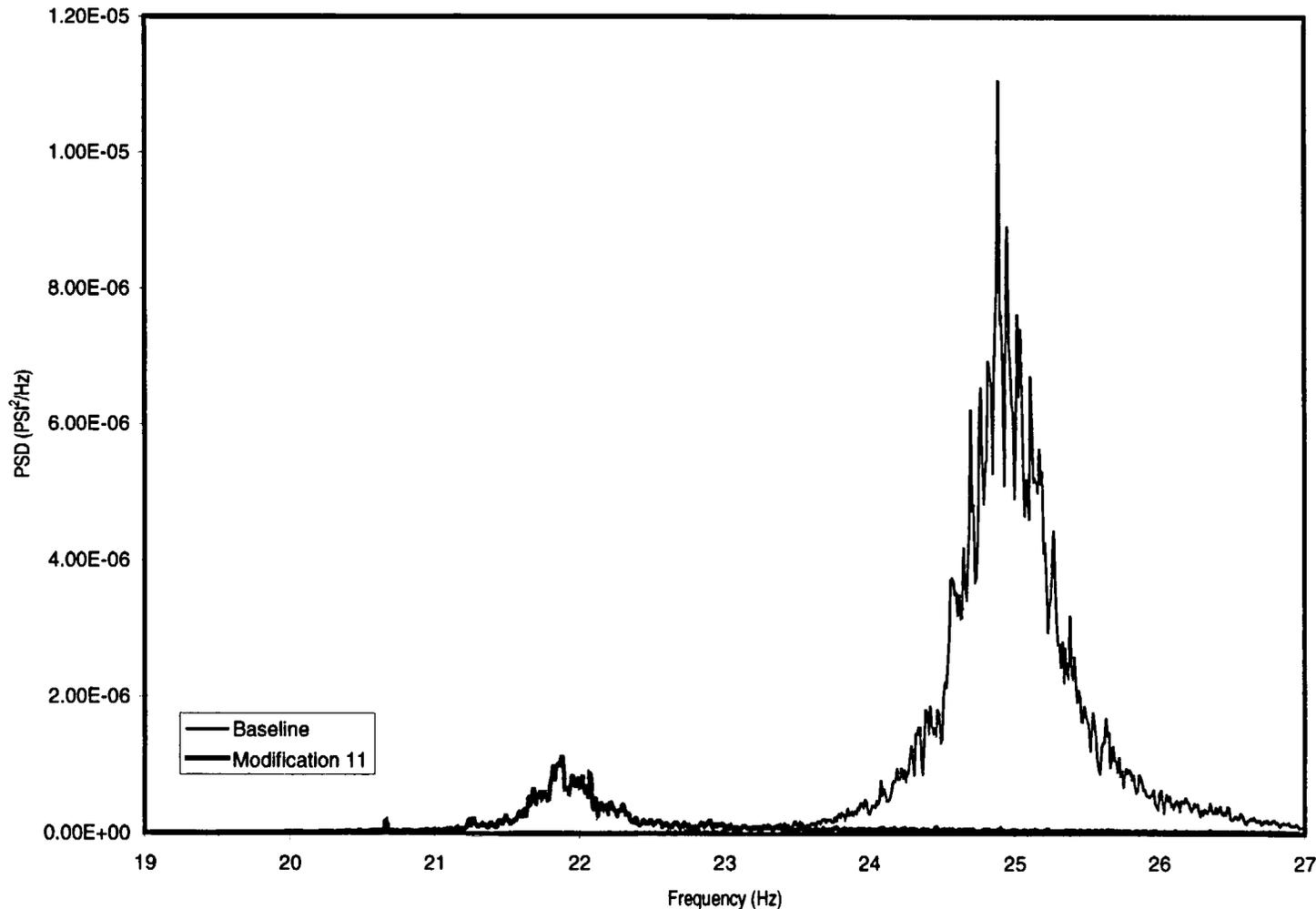
# **Final Modification – Isolation Valve Relocation**

- ◆ **Modification proposed by consultants and EPRI expert panel**
- ◆ **Arizona State University testing demonstrated significant reduction in pressure amplitude**
- ◆ **Valve relocation towards RCS to increase acoustic frequency away from shedding modes and pipe modes**



# Final Modification – Isolation Valve Relocation

## Model Suction Pressure Amplification with Relocated Valve

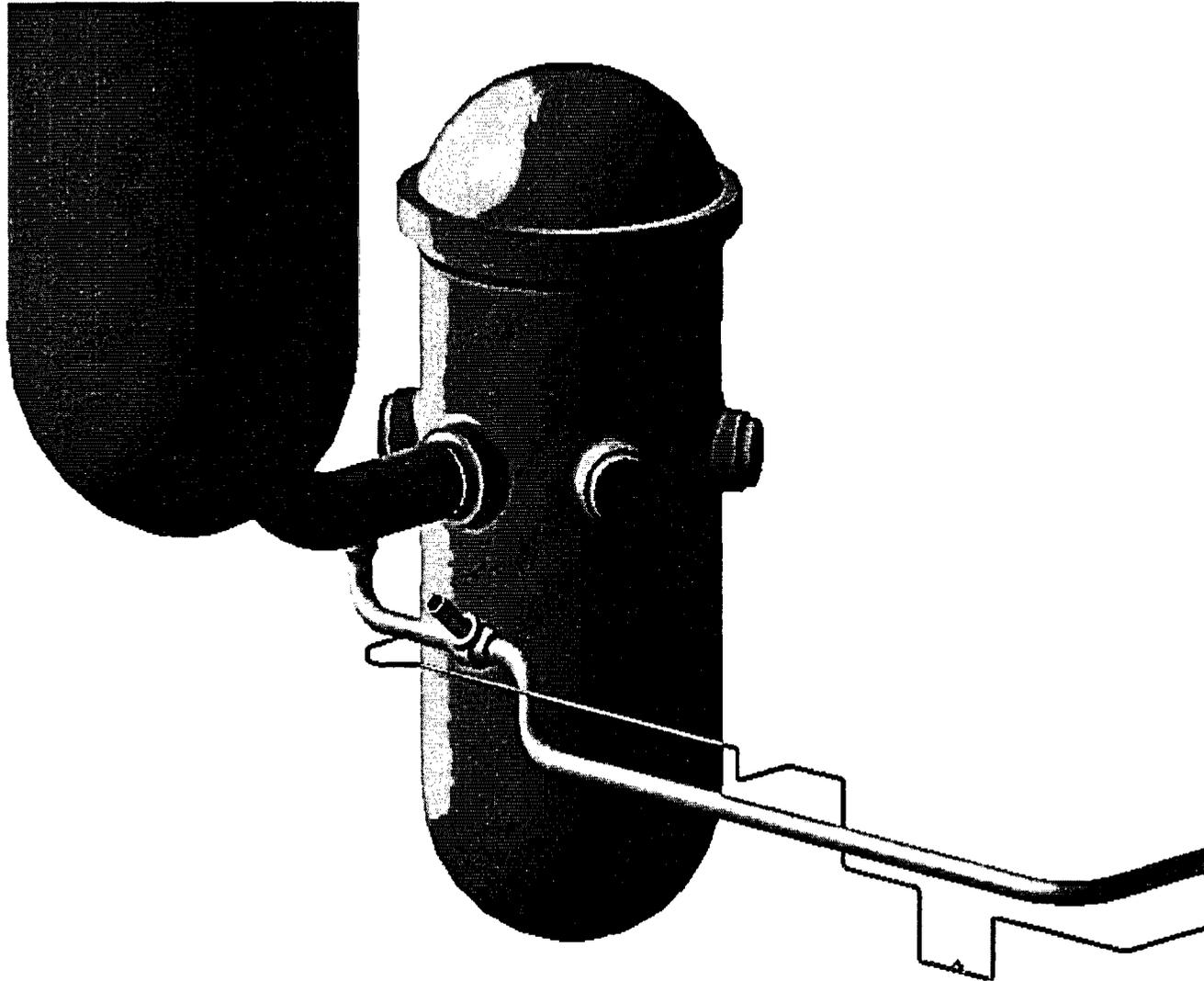


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# Final Modification – Isolation Valve Relocation



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# Final Modification - Isolation Valve Relocation

- ◆ **New location at 11 feet from RCS nozzle**
- ◆ **Higher acoustic frequency (61 Hz)**
- ◆ **No significant coupling with vortex shedding modes**
- ◆ **No evidence of other significant excitation sources**
- ◆ **Location consistent with some Korean System 80 plants**
  - **No vibration issues identified**

# Modification Activities

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# Modification Activities

- ◆ SI-V651 Modification Details
  - Status
  - Design Considerations
  
- ◆ Core Support Barrel Inspection

# Status

**Palo Verde 1**

**De-Fueled/PCV 118 Closed**

**RCS**

**Empty**

**Modification**

**Scaffolding**

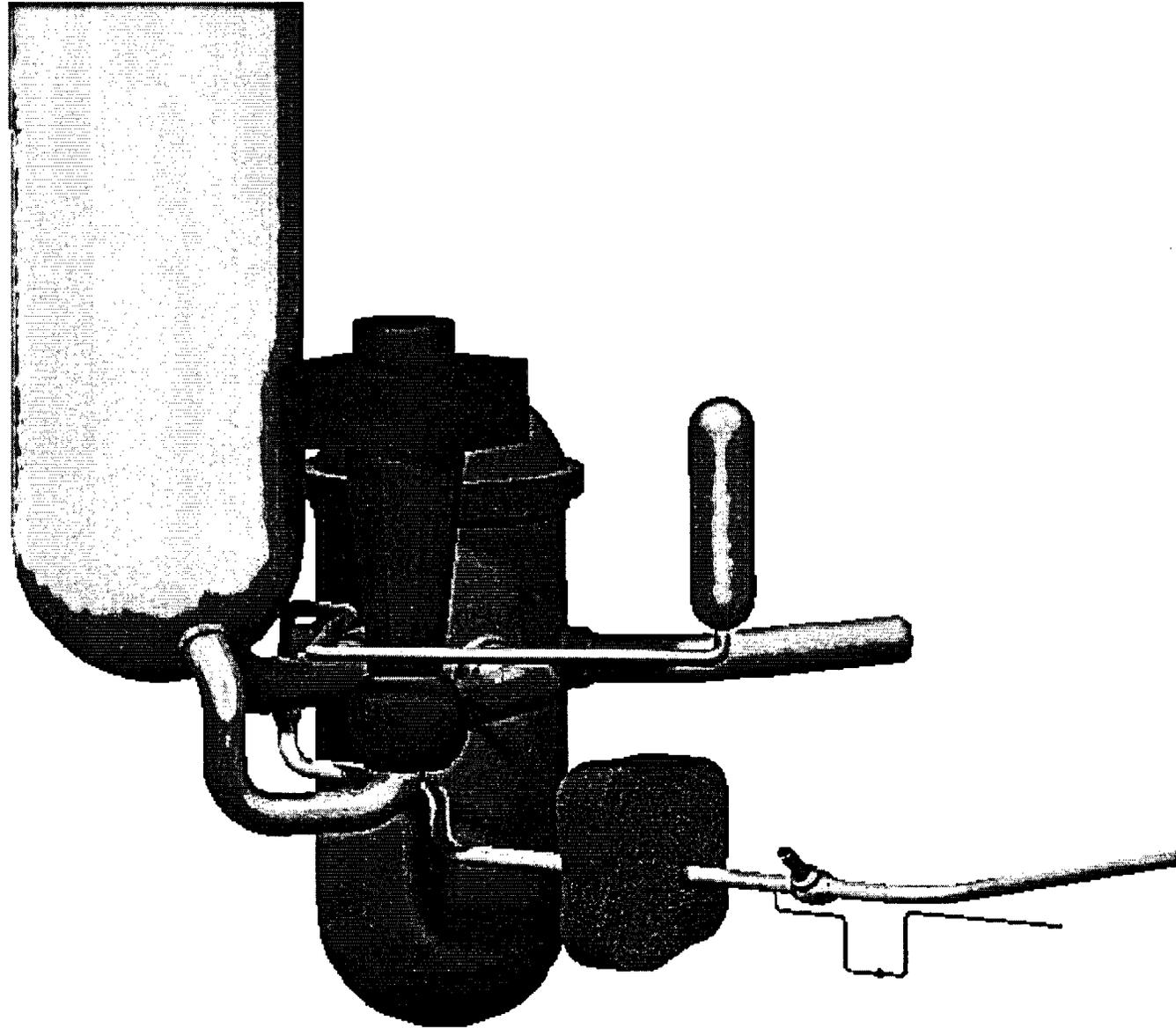
**Commodity Relocation**

**Support Installation**

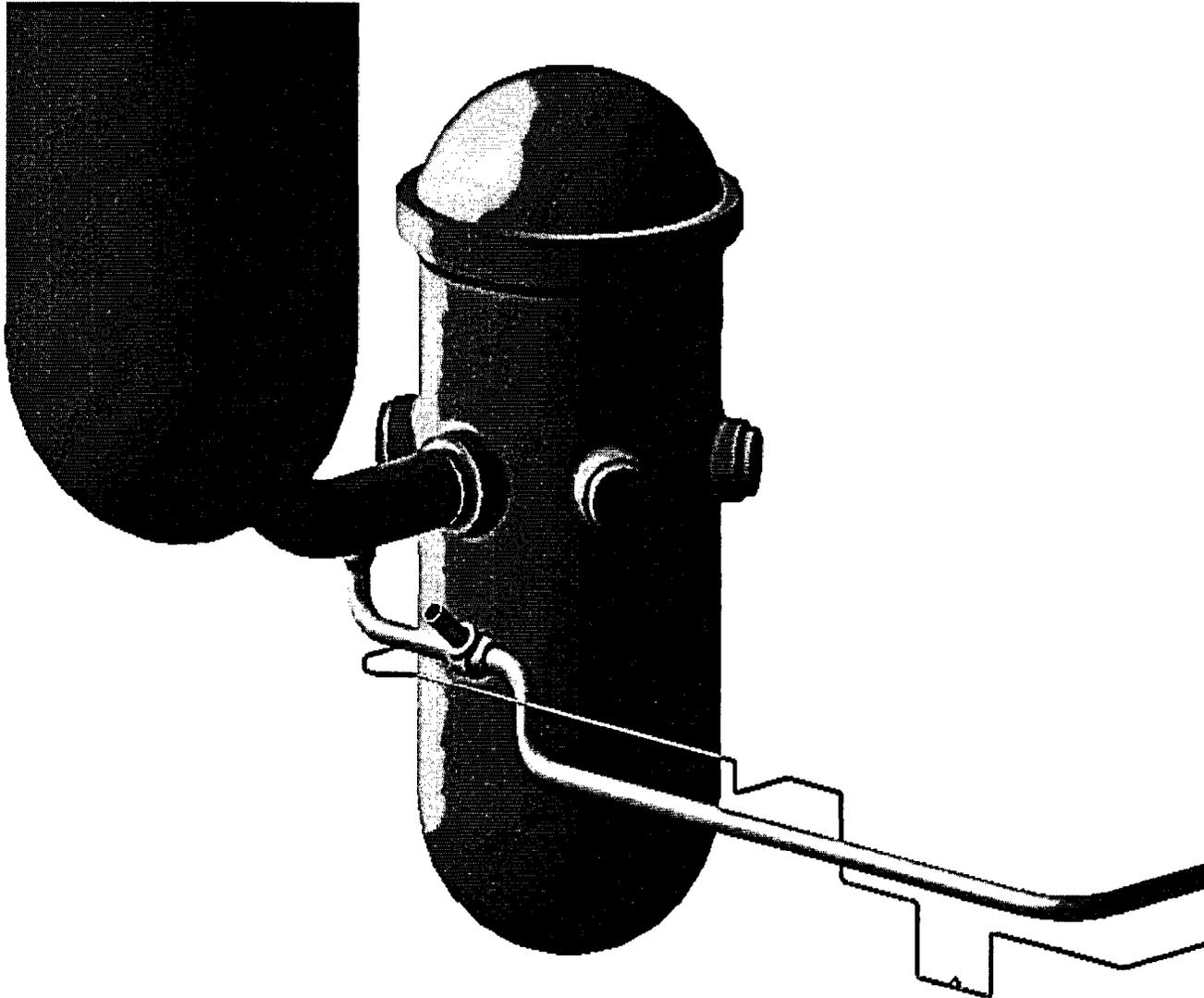
**SDC Piping Cut In Progress**



# Existing Valve Location



## Proposed Valve New Location



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# Design Details

## Physical Changes

- ◆ Relocate Shut-Down Cooling (SDC) Valve SI-V651 From Outside SG Compartment to Inside
- ◆ Re-Route the 3” RCS Hot Leg Injection (SI) Piping
- ◆ Add One Missile Shield
- ◆ Add One Pipe Whip Restraint
- ◆ Add Several Pipe Supports
- ◆ Conduit Relocation
- ◆ Platform Installation



# Design Detail

## **Critical Design Basis Analysis/Evaluations**

- **Equipment Qualification (EQ)**
- **Jet Impingement Evaluation**
- **Missile Evaluation**
- **ASME Class I Piping Analysis**
- **Hydraulic Evaluation of Both Piping**
- **MOV Pressure Locking/Thermal Binding**
- **Safety Analysis (Boron Dilution)**

# Design Detail- EQ

## Environmental Considerations

- **Normal Plant Condition**
  - **Thermal Effects ( Process and RCS Temperature)**
  - **Radiation Effects (Additional Exposure Due to RCS Components (N-16 and Neutrons))**
  
- **Post Accident Condition**
  - **Pressure and Temperature (P/T) Effects**
  - **Radiation Effects**
  
- **Seismic Qualifications**

# Design Detail- EQ

## PVNGS Licensing Criteria:

- **10 CFR 50.49**
- **Regulatory Guide 1.89 Revision 1, June 1984**
- **NUREG 588**



# EQ: Normal Environment

## Temperature Evaluation

- **CFX ANSYS is Used for the Valve/Operator Modeling**
- **Steady State Temperature of All Critical Components is Calculated**
- **Electrical Cable Routing is Selected to Stay Within IEEE Code Requirement**

## ◆ Result

- **Increase in Temperature is Within the Design of the Component**
- **Replacement Interval for The MOV Operator Non-Metallic Sub-components is Increased**
- **MOV Operator Will Be Instrumented for Temperature Monitoring**

# EQ : Normal Environment

## Radiation Evaluation

- **Source Term for Radiation Exposure to the MOV Operator Includes 1% Failed Fuel, N-16**
- **Neutron Contribution at New Location is Negligible**
  - **The MOV/Operator is Located Outside of Possible Streaming Area**

## ◆ **Result**

- **Increase in Normal Radiation Is Within the Design of the Component**
- **No reduction in life is expected**

# EQ : Post Accident Environment

- ◆ Pressure/Temperature Evaluation
  - **Licensing Criteria**
    - **NUREG 588 and Reg. Guide 1.89, Rev. 1**
  - **Selection of Limiting Postulated Breaks**
    - **Based on the Function of SI-V 651**
    - **Postulated Breaks Include Secondary Lines (3-6" IDs) and Feed Water Lines**
    - **Only SBLOCA Is Considered**
    - **MSLB Not Considered, Piping Outside of Compartment**

# EQ : Post Accident Environment

- ◆ P/T Evaluation Results

- **Existing Containment EQ Profile for MSLB and LOCA Remains Bounding**

# EQ : Post Accident Environment

## Radiation Evaluation Criteria:

- **Licensing Basis:**
  - **NUREG 588 and Reg. Guide 1.89, Rev. 1**
- **Source Term –**
  - **100% NG , 50% iodine and 1% solid.  
Instantaneous / Homogenous Release**
- **Iodine Removal/Plate out**
  - **Credit Is Taken for Spray and Iodine Removal  
Within the Sprayed Compartment**
  - **Plate-Out Contribution Is Conservatively  
Calculated Based on Maximum Iodine Loading  
per NUREG / CR 0009**

# EQ : Post Accident Environment

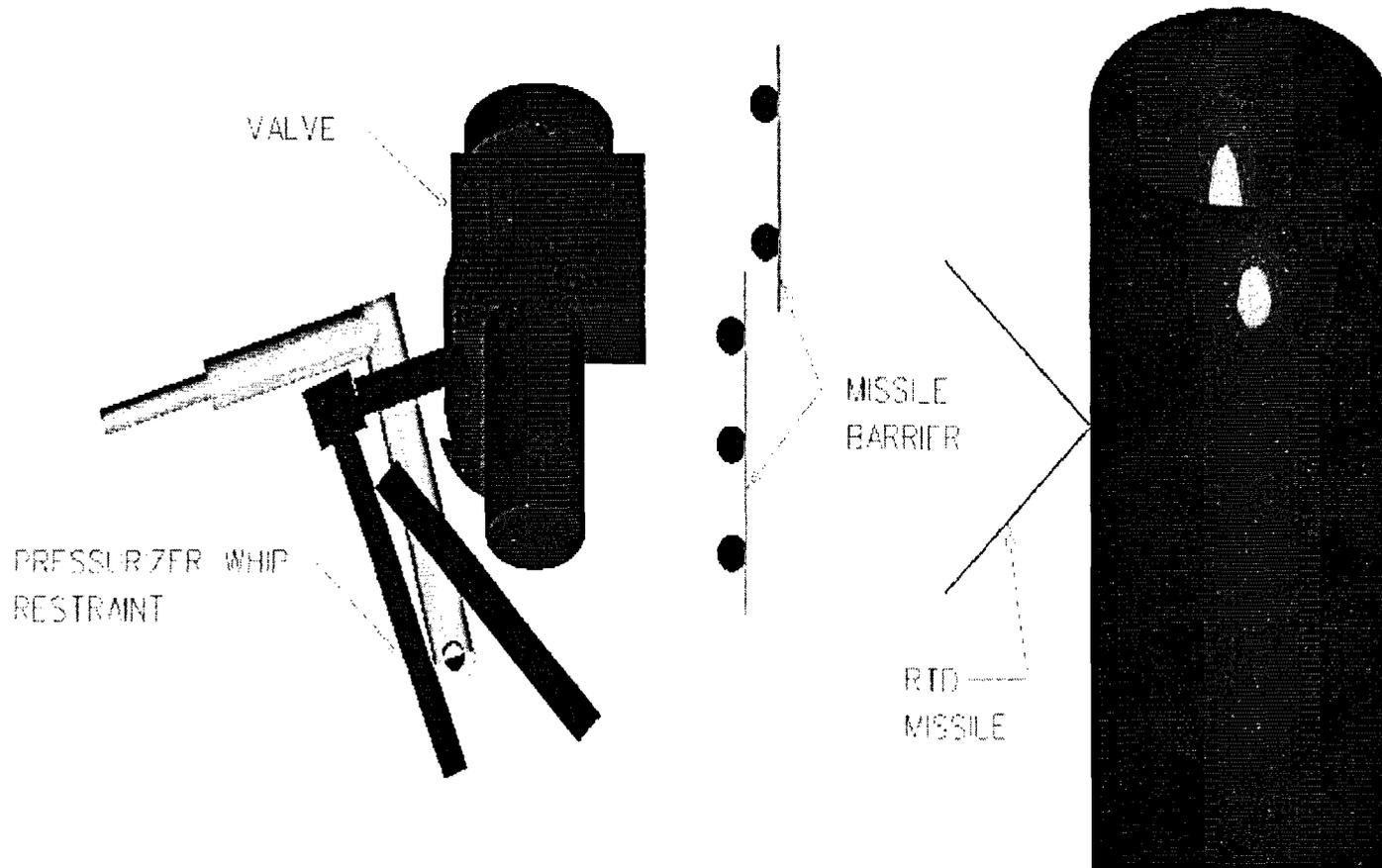
Radiation Evaluation Conclusion:

- **Total Integrated Exposure + LOCA (180 Day)  
Remains Within the Existing Tested Exposure**



# Jet Impingement/Missile Evaluation

- **A New Pipe Whip Restraint Will Be Installed at the Pressurizer Spray Line Terminal End to Protect the MOV**
- **A New Missile Shield Will be Installed to Protect the MOV from Hot Leg RTD Nozzle Ejection**
- **No Other Effects From Other Postulated Jets or Missiles**



August 15, 2005

PVNGS Unit 1 SDC Suction Line Modification



# ASME Class 1 Piping Analysis

- ◆ **Bechtel Computer Code ME-101, C1 Used for the analysis**
- ◆ **Evaluated both the SDC and Hot Leg Injection Piping**
- ◆ **Calculated Stresses and Usage Factors Continue to Meet Code Allowable**

# Hydraulic Evaluations

- ◆ **The Following Changes were Considered**
  - **Increased Hot Leg Injection (SI) Piping Length**
  - **Valve Location Change**
  
- ◆ **Result**
  - **Minimal Effect on Hydraulic losses**
  - **Documentation of Impact on Analysis in Progress.**

# Pressure Locking

## ◆ Criteria

- **NUREG 1275, GL 95-07**
- **Bonnet Pressurized Cold, Then Heated Up**

## ◆ Analysis Results

- **Pressure Relief Valve Is Installed on SI-651 Bonnet**
- **Limits Bonnet Pressure**
- **Capacity of the Installed Relief Valve is Verified**

# Thermal Binding

## ◆ Criteria

- SOER 83-9
- Occurs When Valve is Closed Hot and Then Cools Down
- Temperature Difference Has to be 200 Degrees Or Greater

## ◆ Result

- Thermal Binding is Prevented Because Temperature Limits Remain Protected by Current Operating Procedures

# Safety Analysis Consideration

## ◆ Criteria

- **Analyze for Consequences of an Inadvertent Boron Dilution Event**

## ◆ Result

- **651 Valve Open (SDC)**
  - **No Effect on the Boron Dilution Analysis**
  - **Piping Length is Not Changed**
- **651 Valve Closed**
  - **No Effect on the Boron Dilution Analysis**
  - **SDC Piping Is Not Credited as Part of the RCS Volume**

# NRC Approval/Relief Request

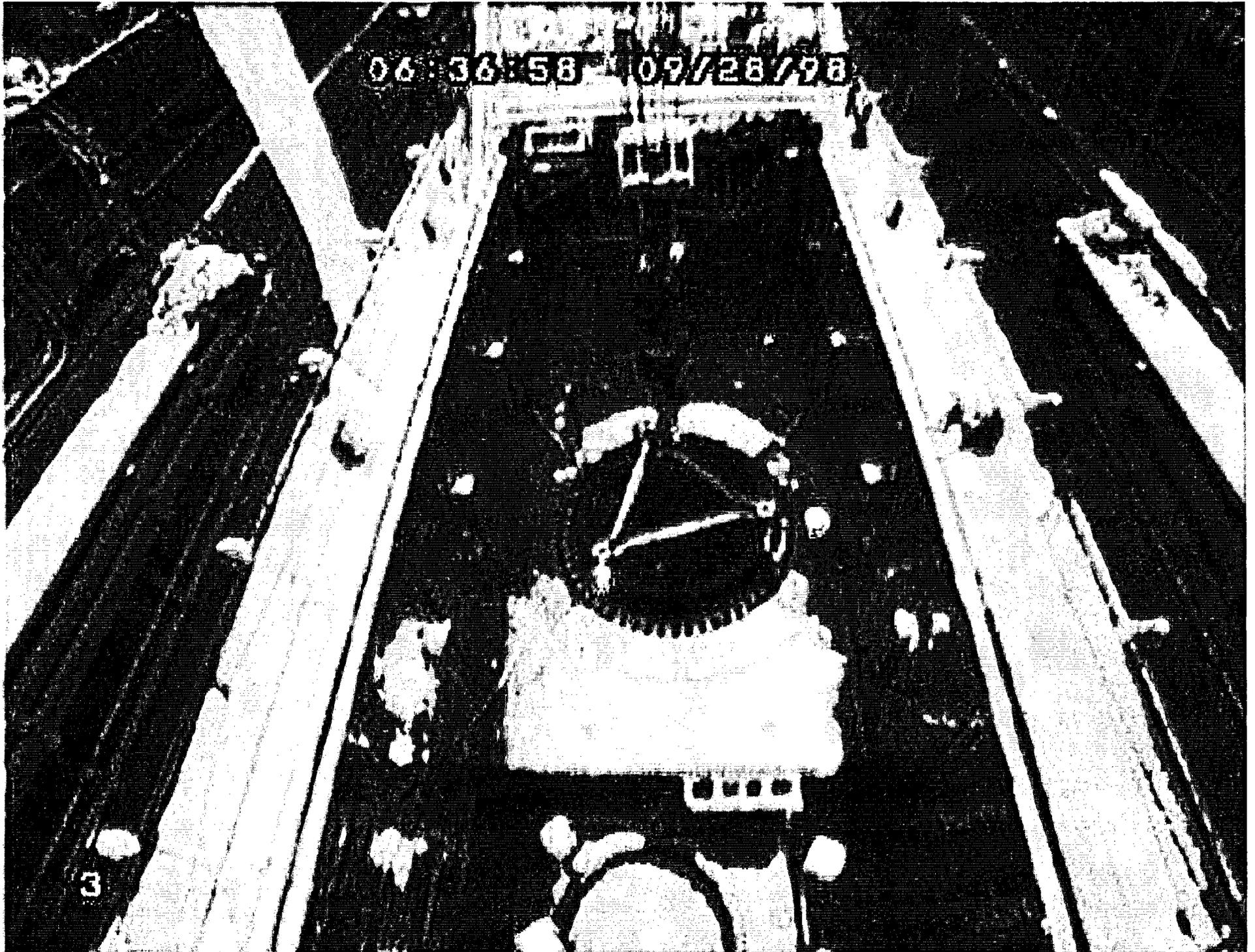
- ◆ 50.59 Screening and Evaluation is in Process
- ◆ NRC Approval is not Anticipated Because
  - No Technical Specification Change is Identified
  - The Change Satisfies Applicable Design Basis Requirements as Outlined Previously (EQ, Seismic, Missile, Jet Impingement, etc.)
  - Equipment Continues to Perform Its Intended Design Function
  - No Changes to Elements of Methodology Identified or Used During Evaluations
- ◆ NRC Code Relief Request is not Anticipated Because
  - Existing Approved Welding Processes Are Used
  - No Change in Post Weld Heat Treatment Requirement Is Identified



# Core Support Barrel Inspection

- ◆ **Two Part Inspection**
- ◆ **Initial Inspection While the CSB is Inside the Reactor**
- ◆ **Detailed CSB Inspection in CSB Stand**
- ◆ **Detailed Inspection Criteria Is Developed**
- ◆ **Detailed Inspection Will take Place After Valve Re-location**

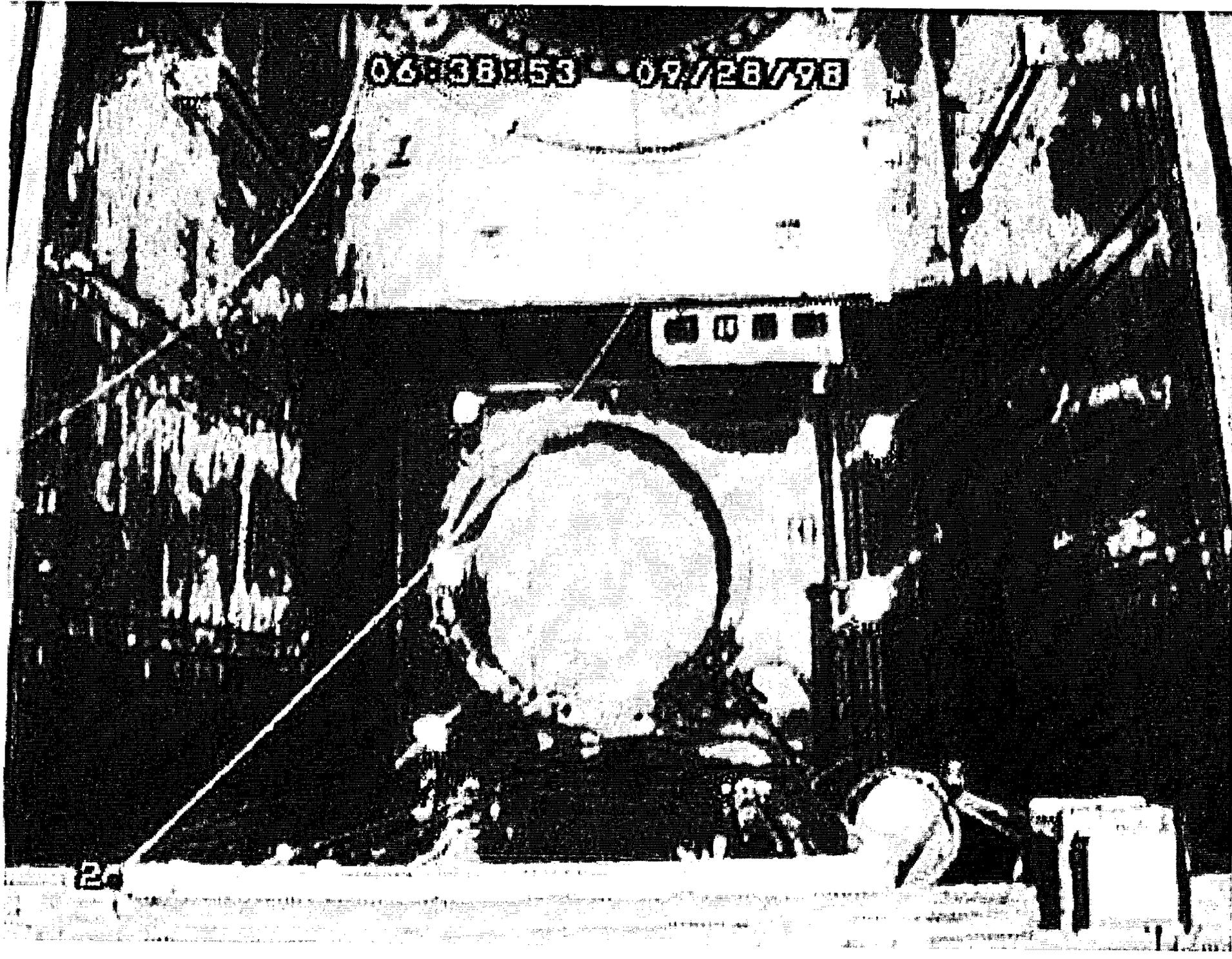




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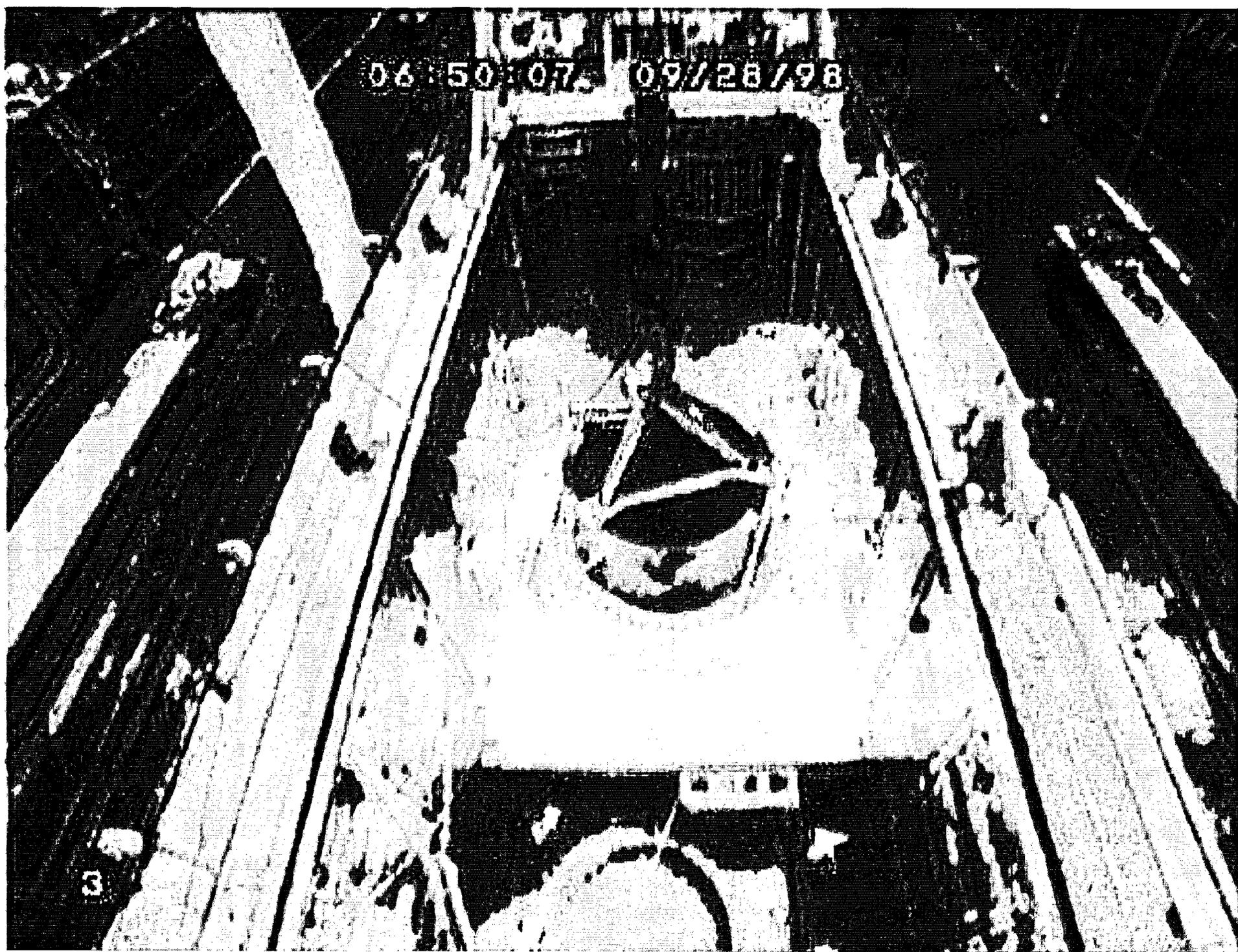
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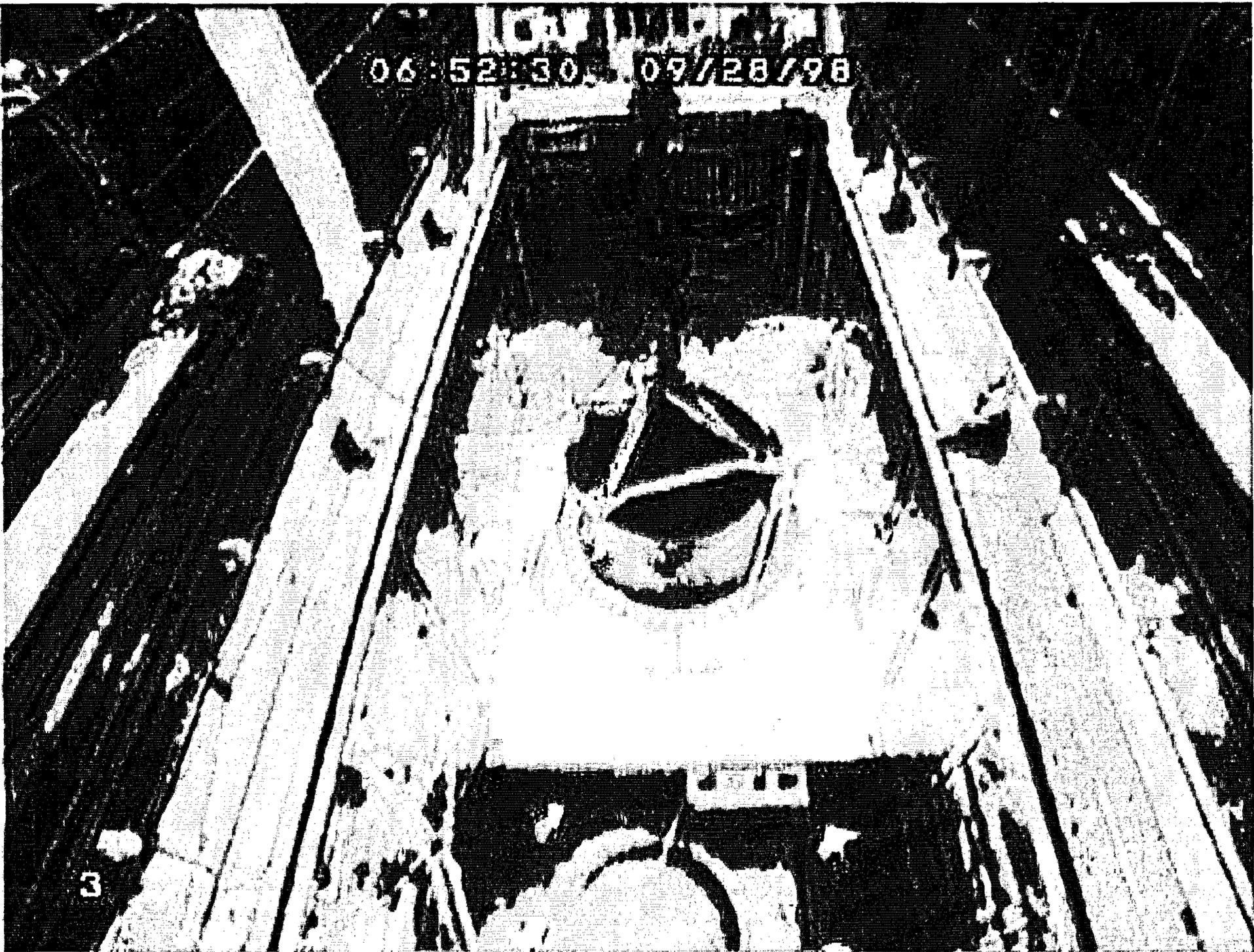


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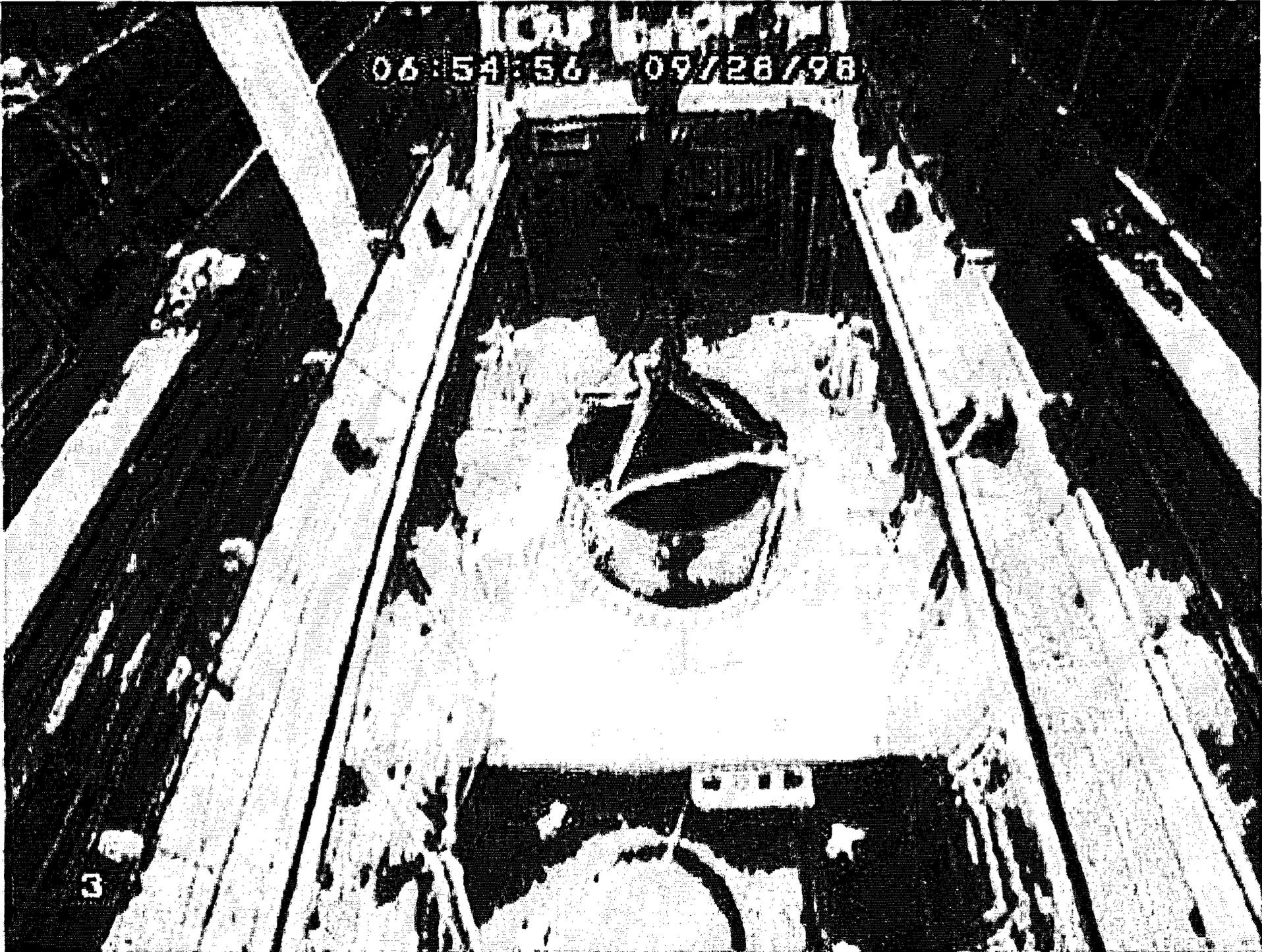
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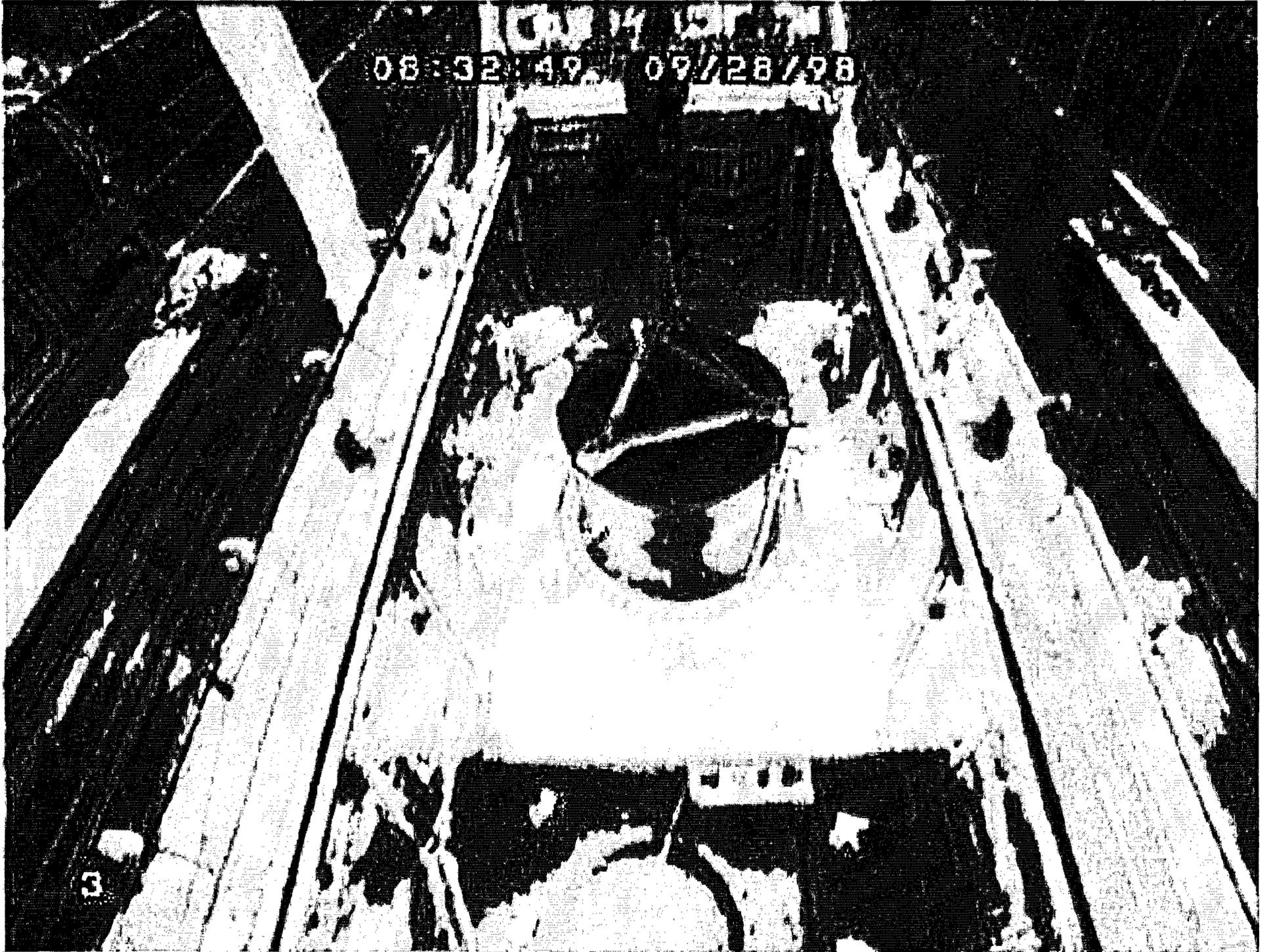
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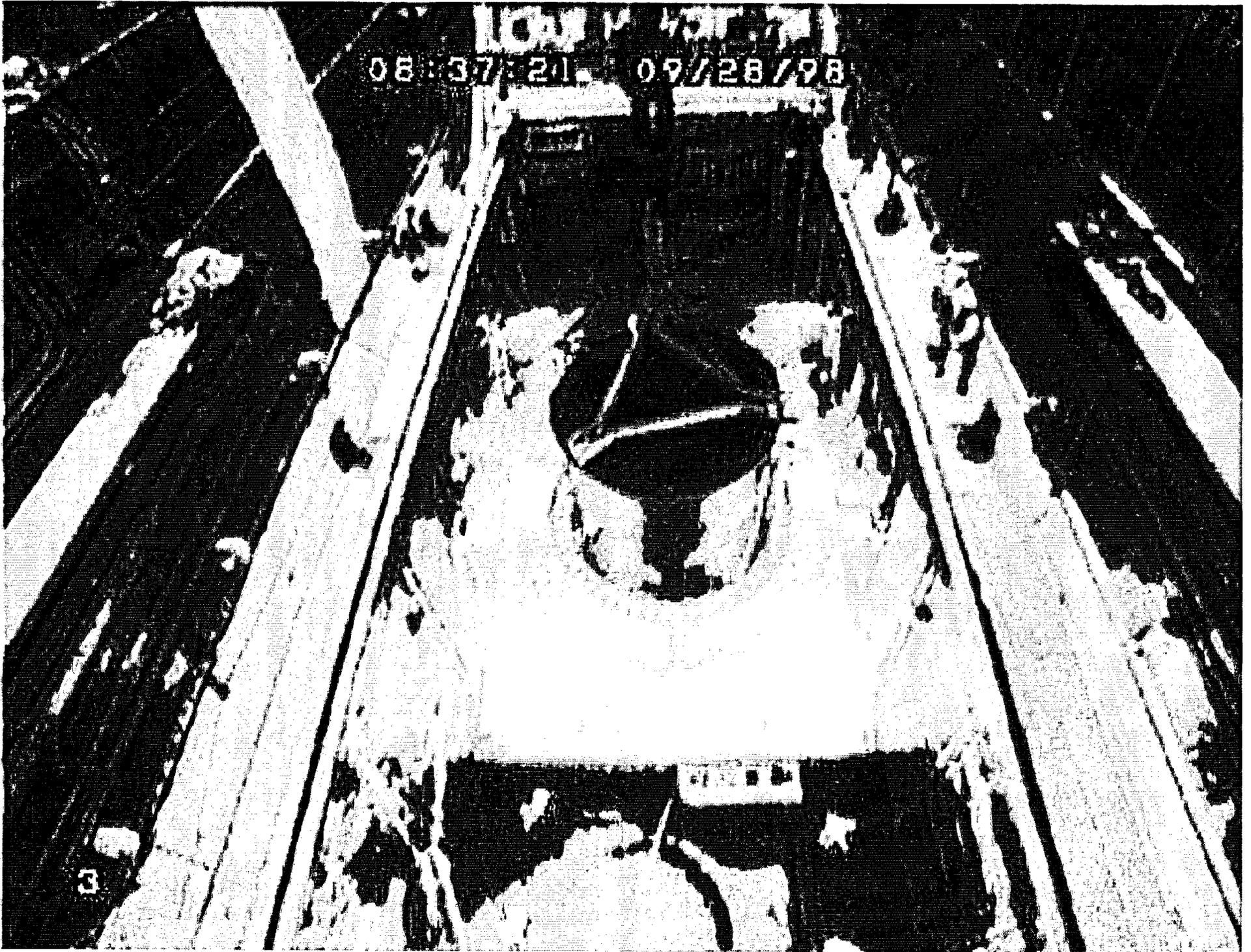


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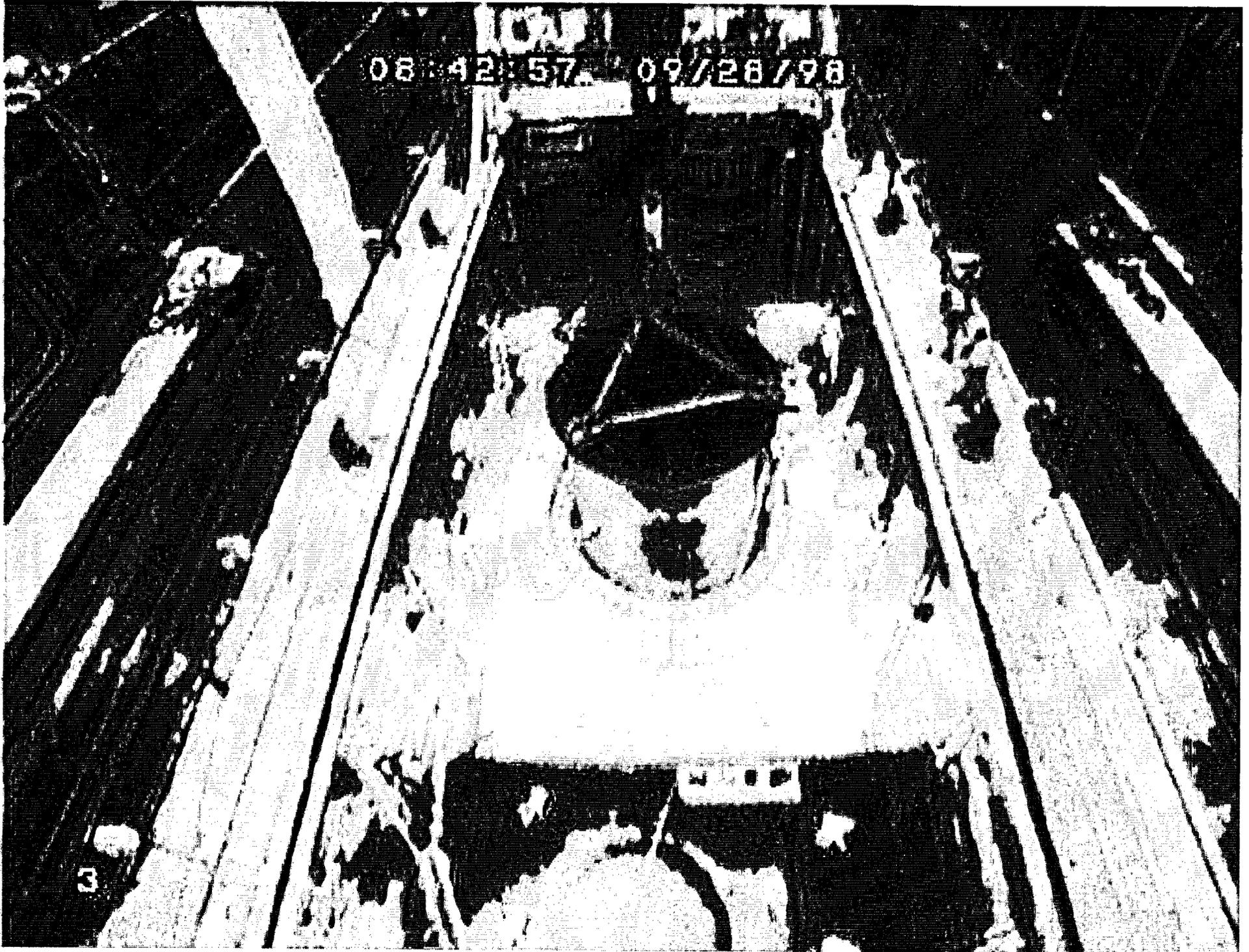


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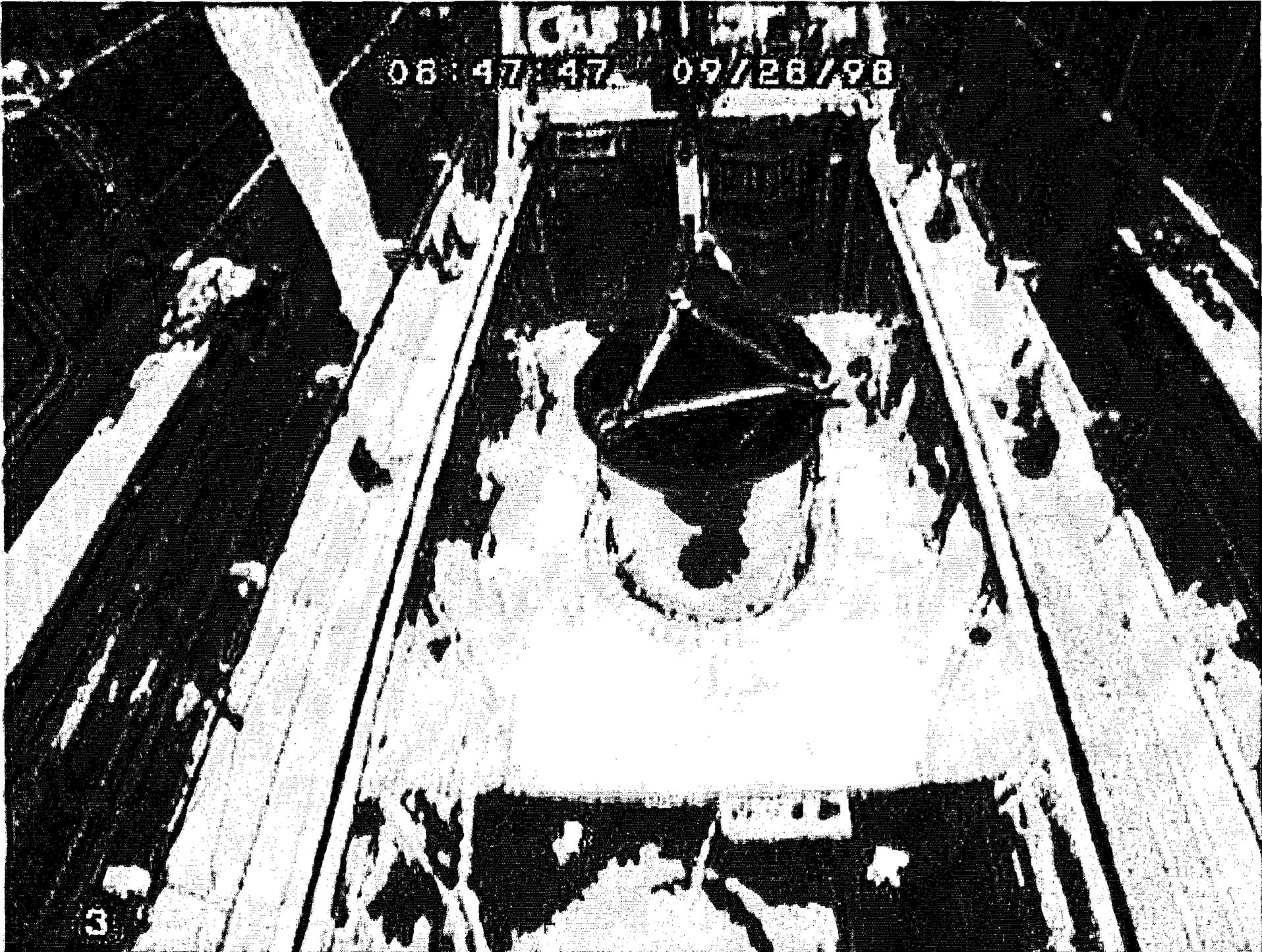


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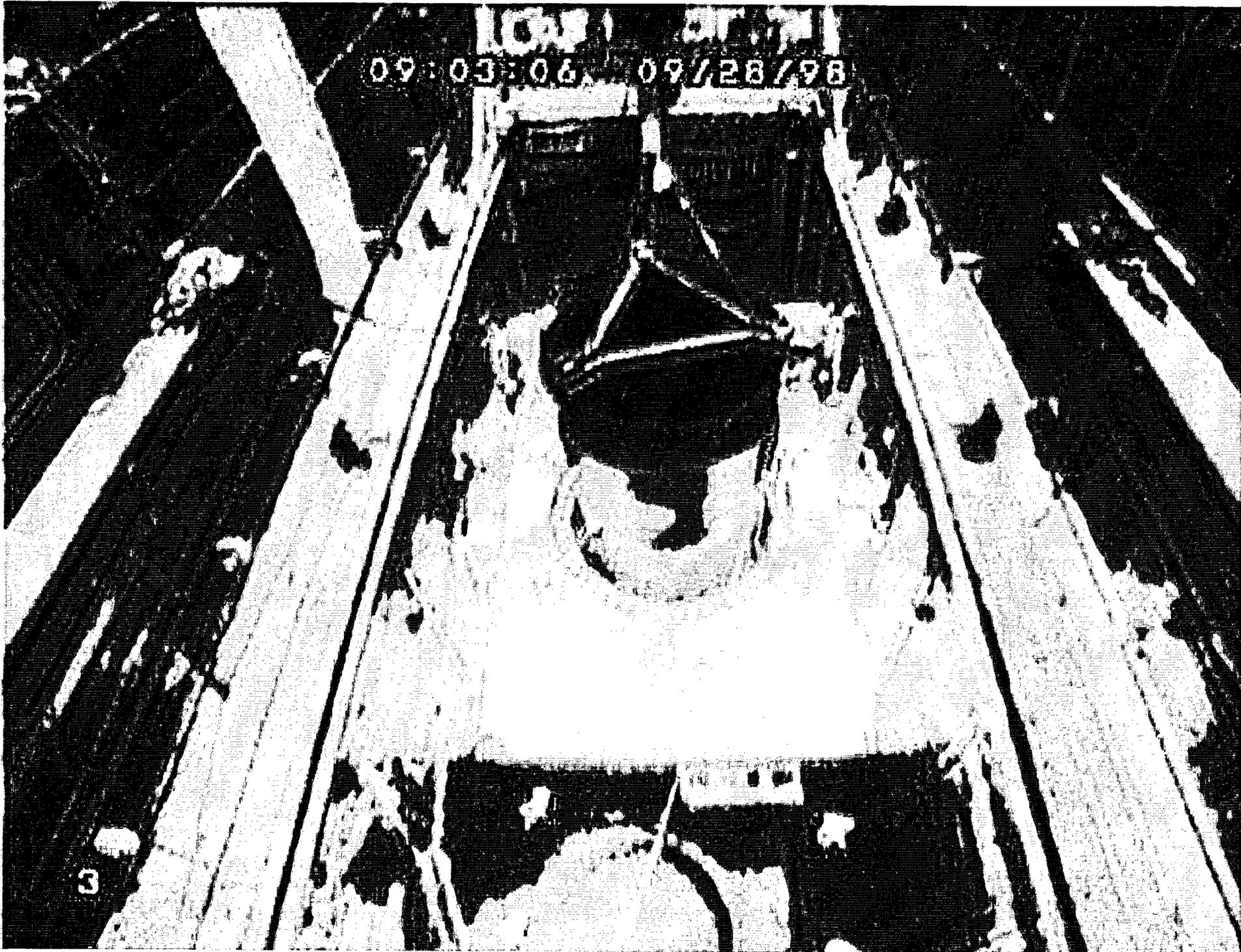


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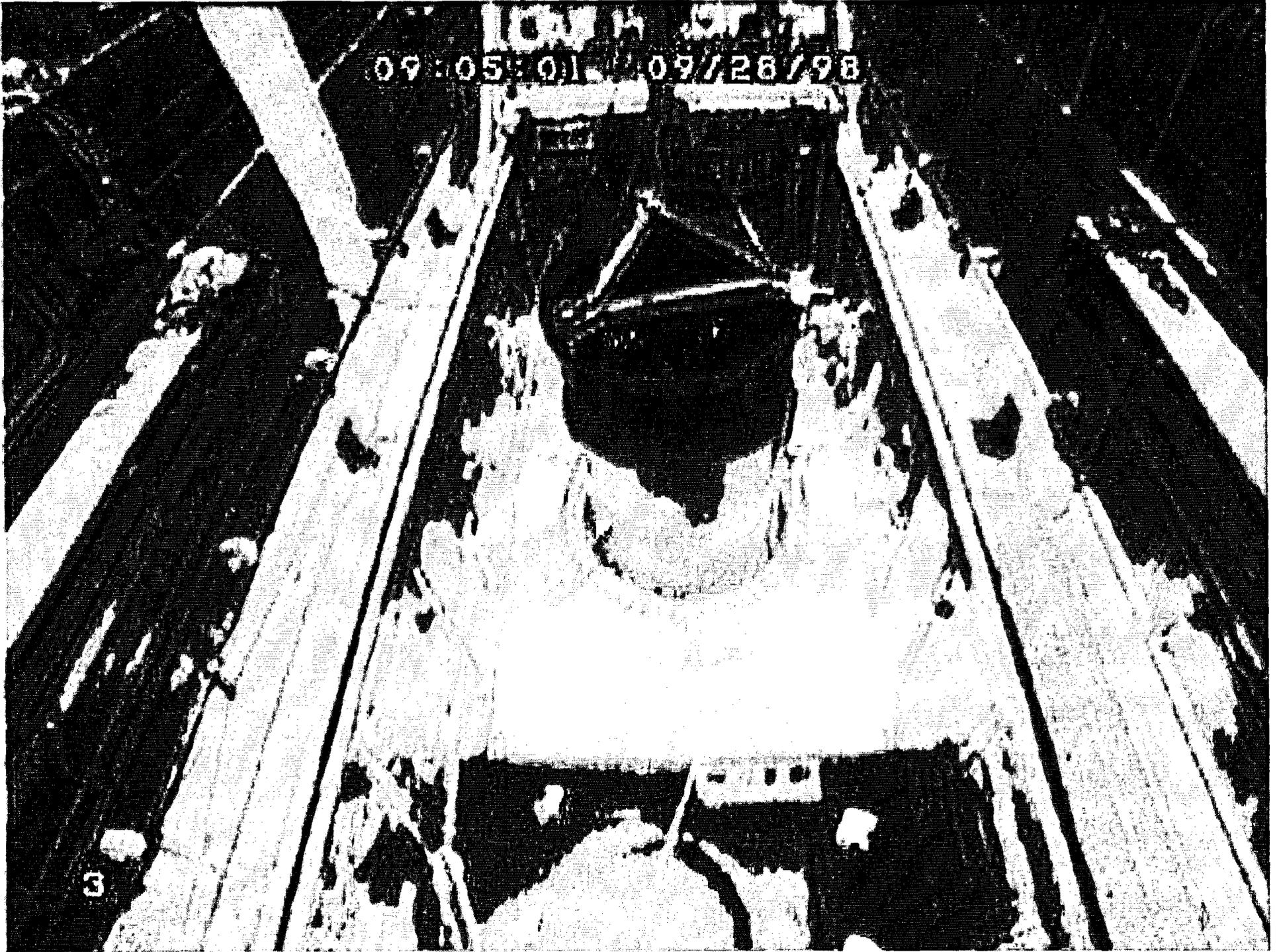
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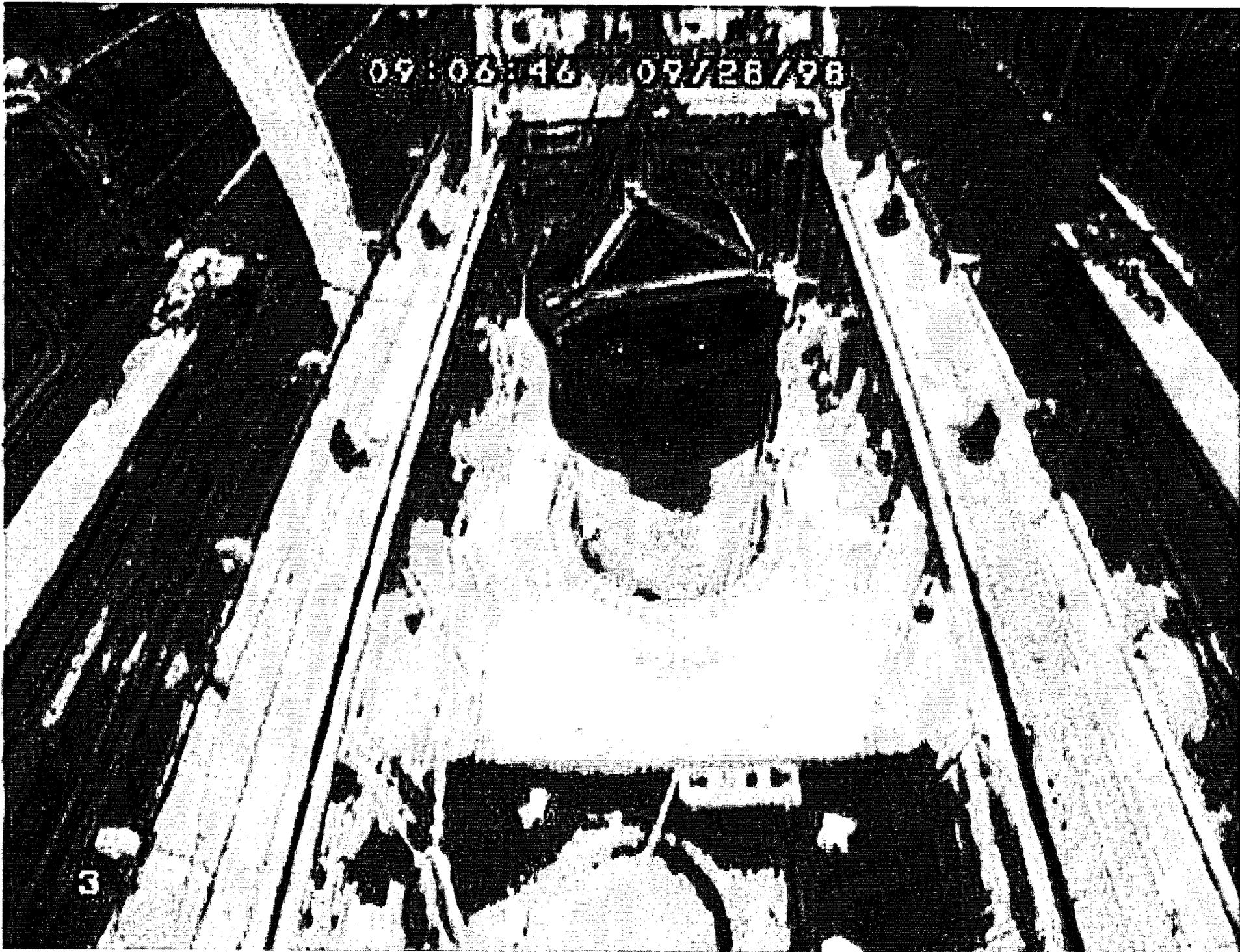


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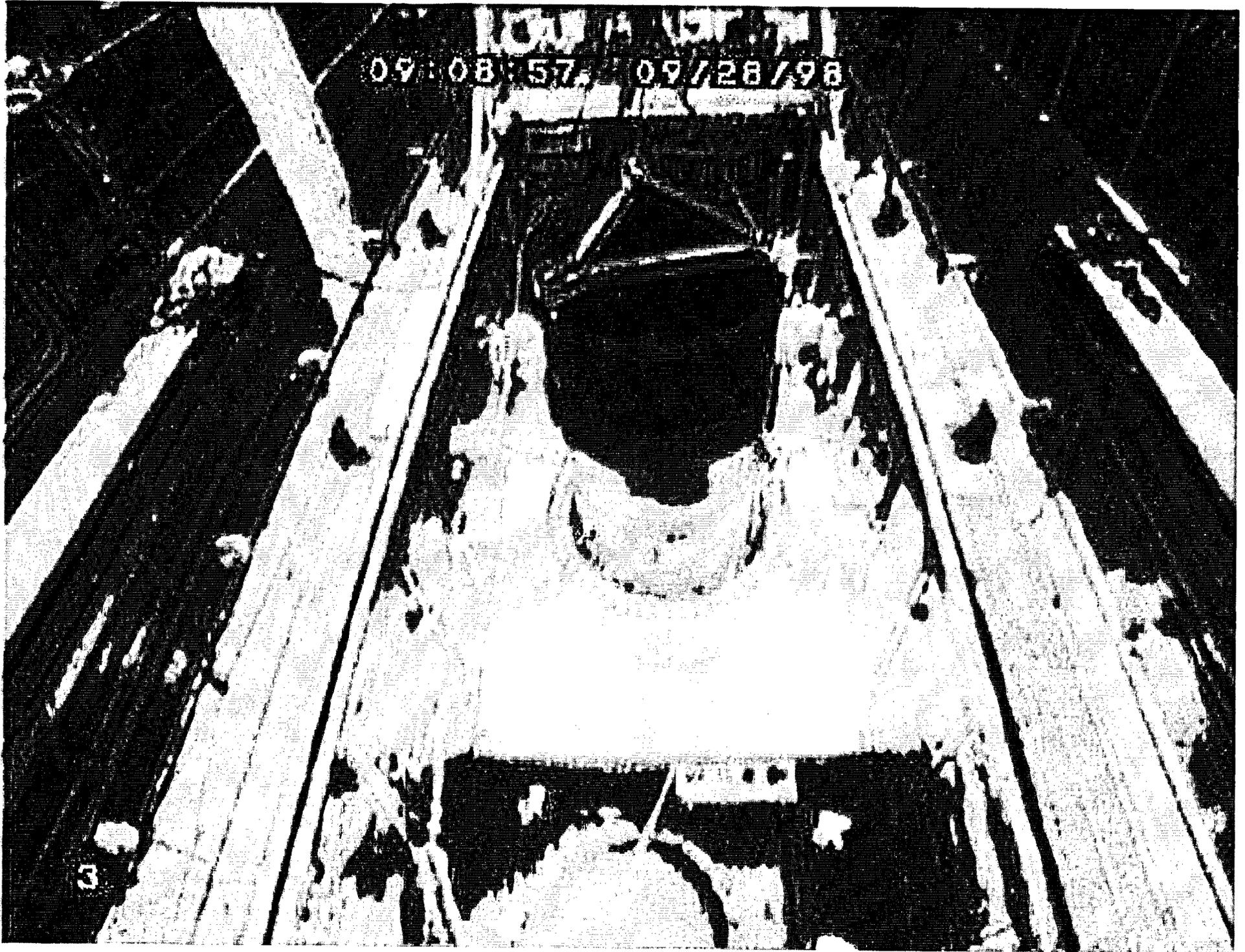


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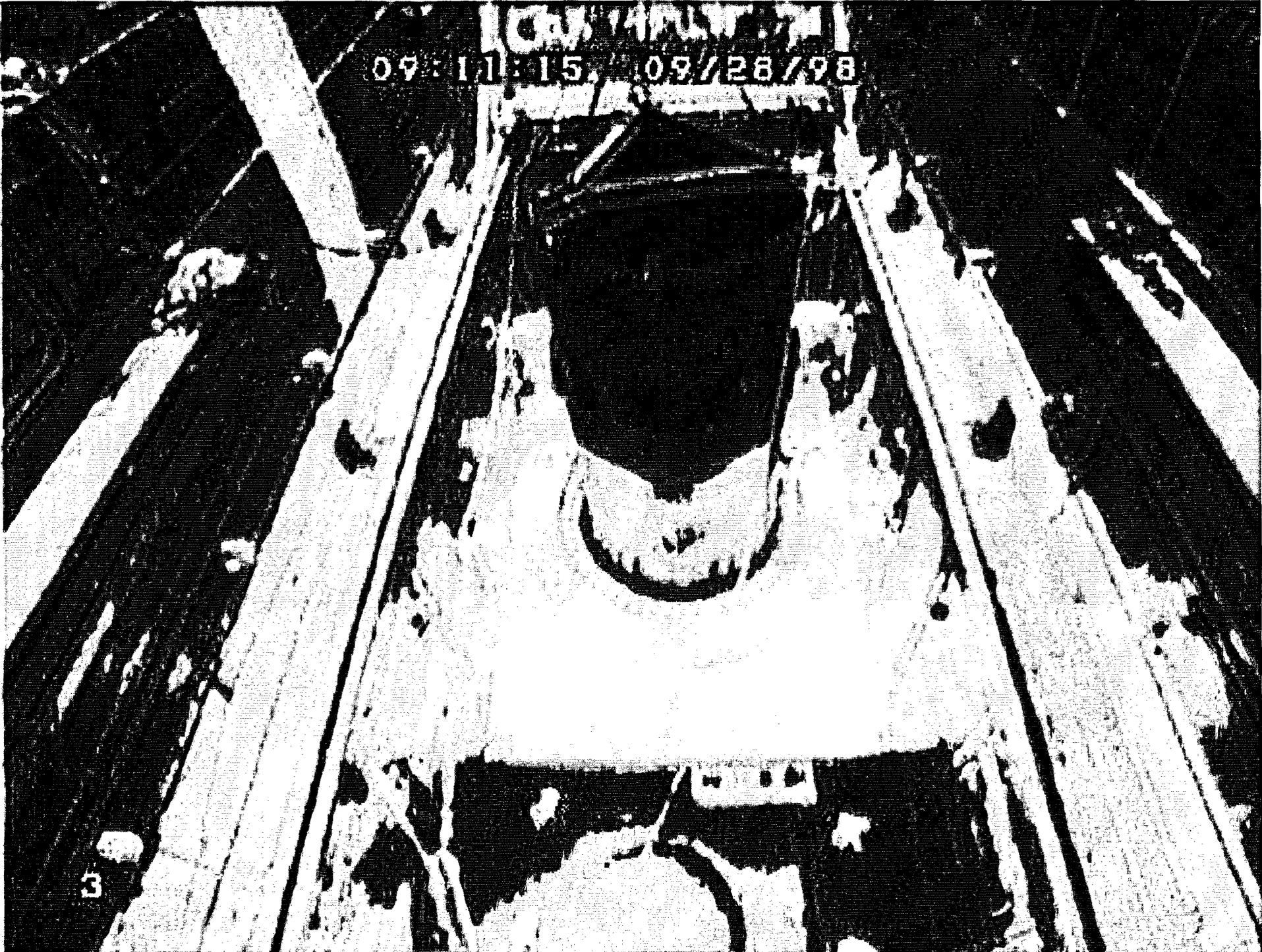


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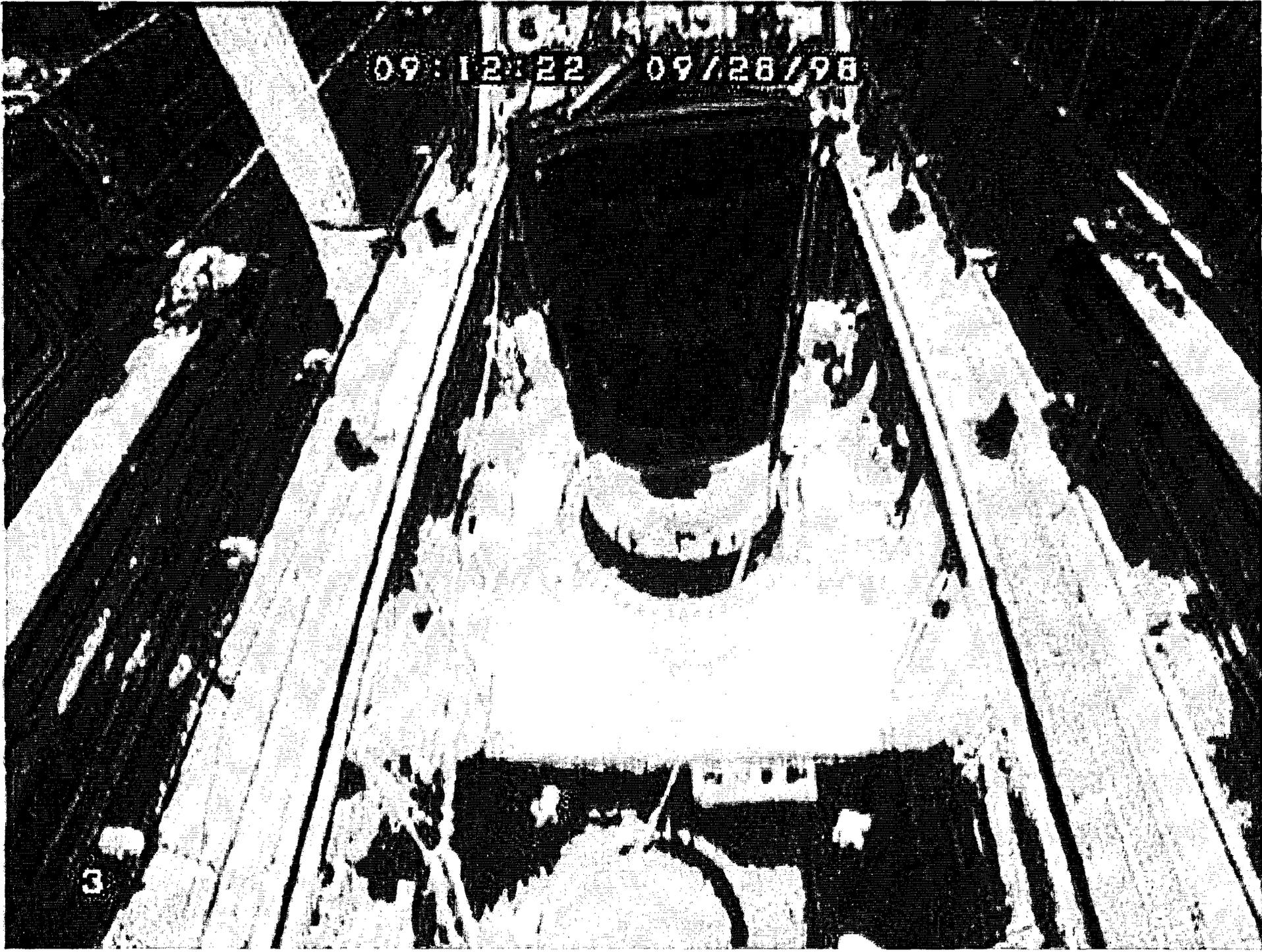


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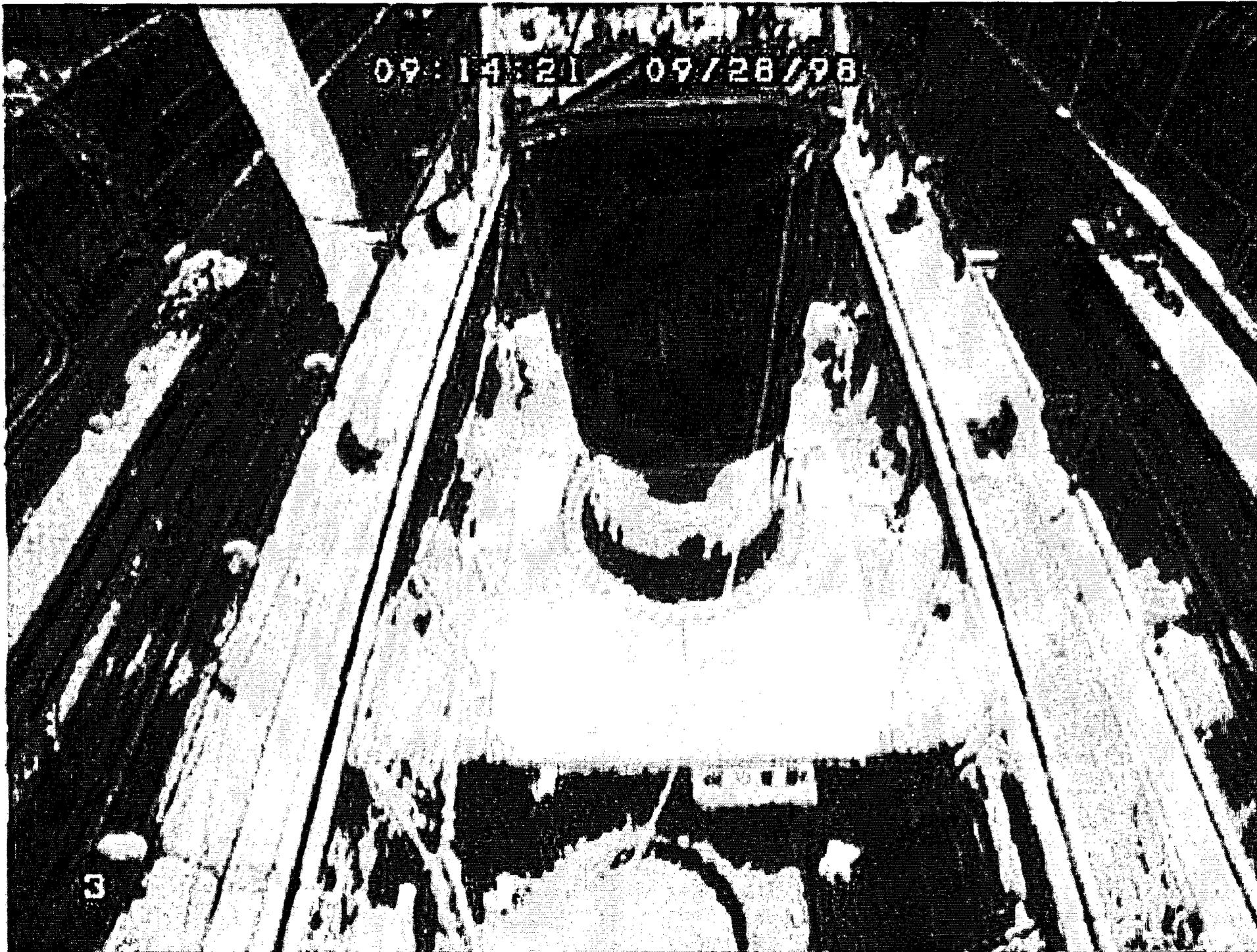
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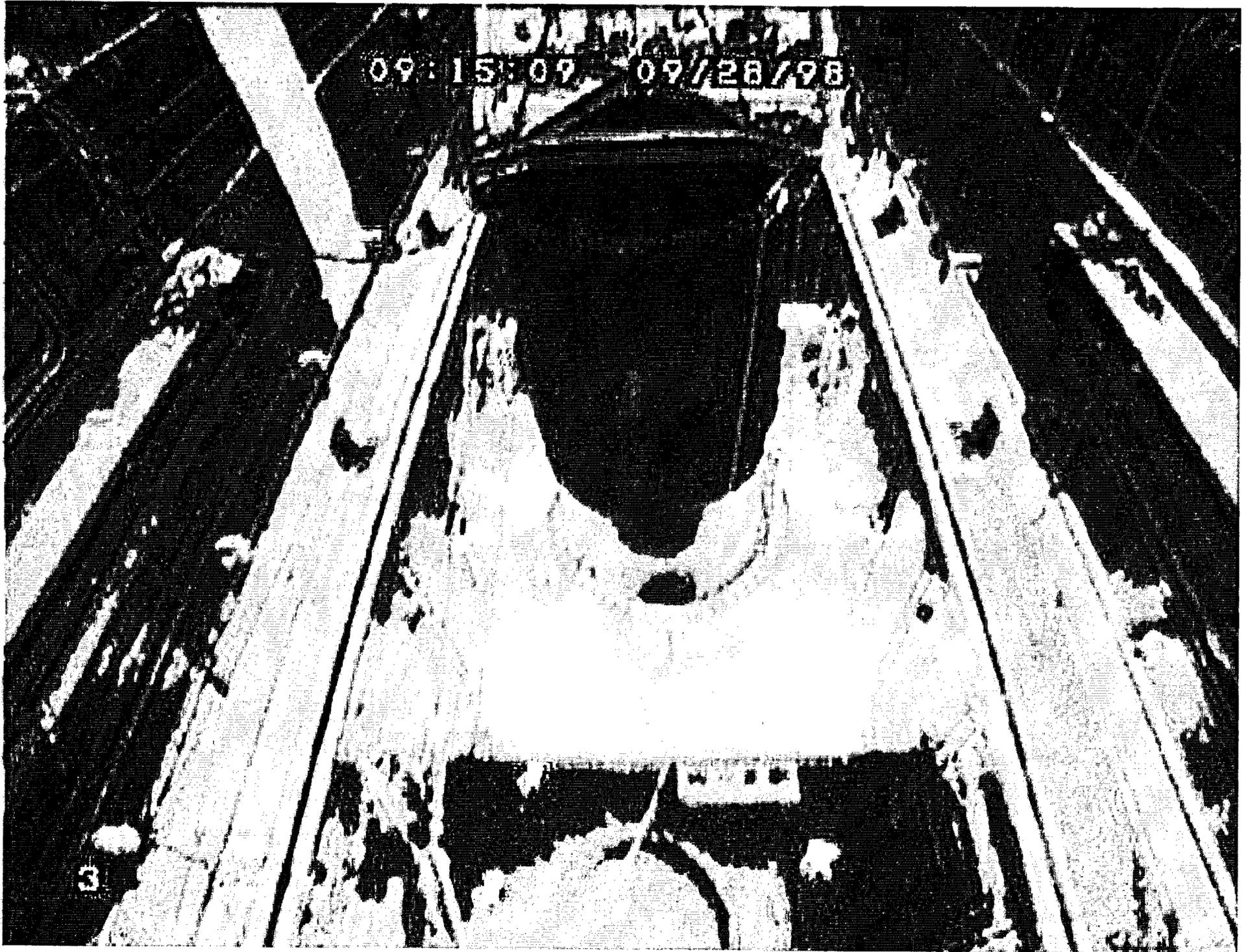
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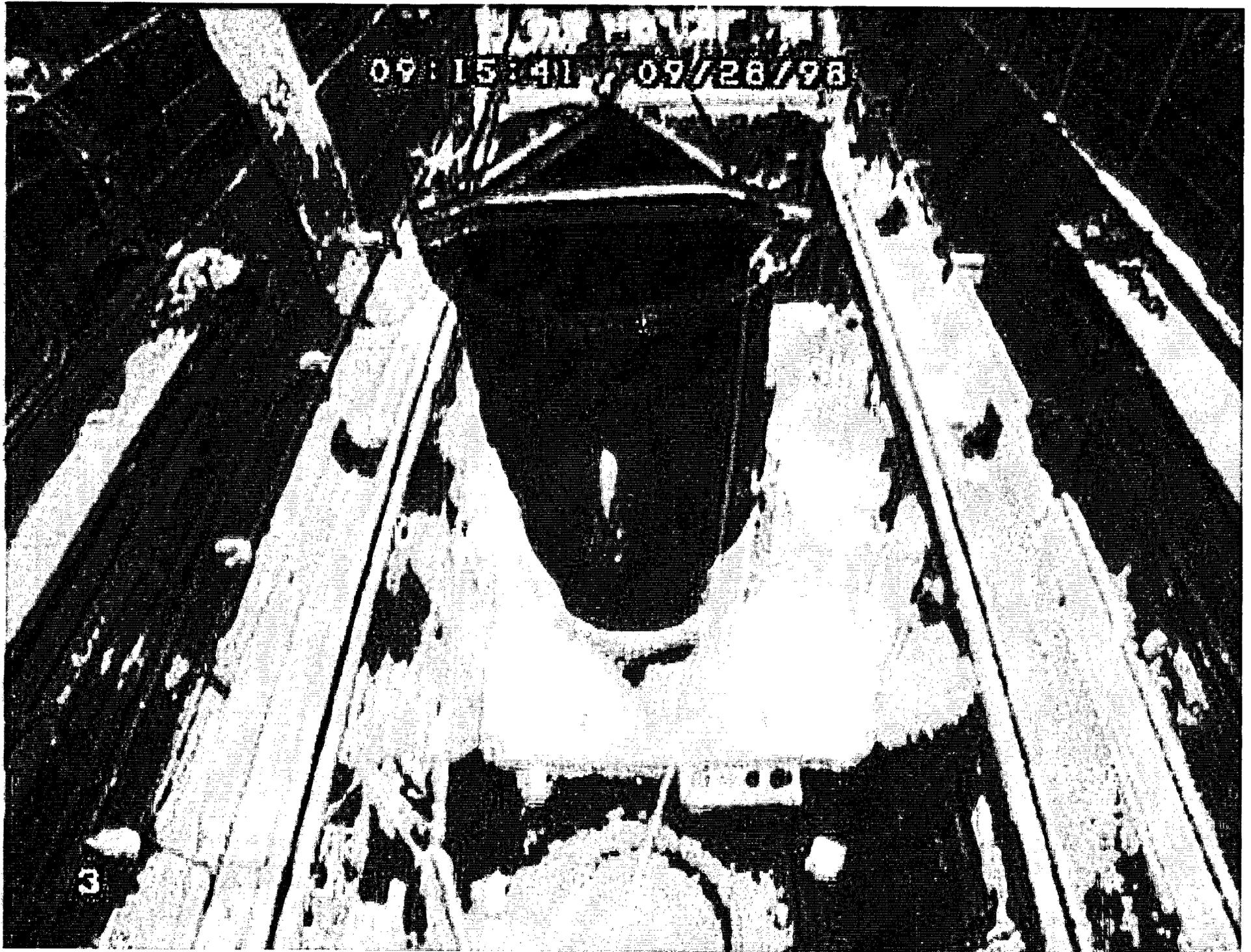


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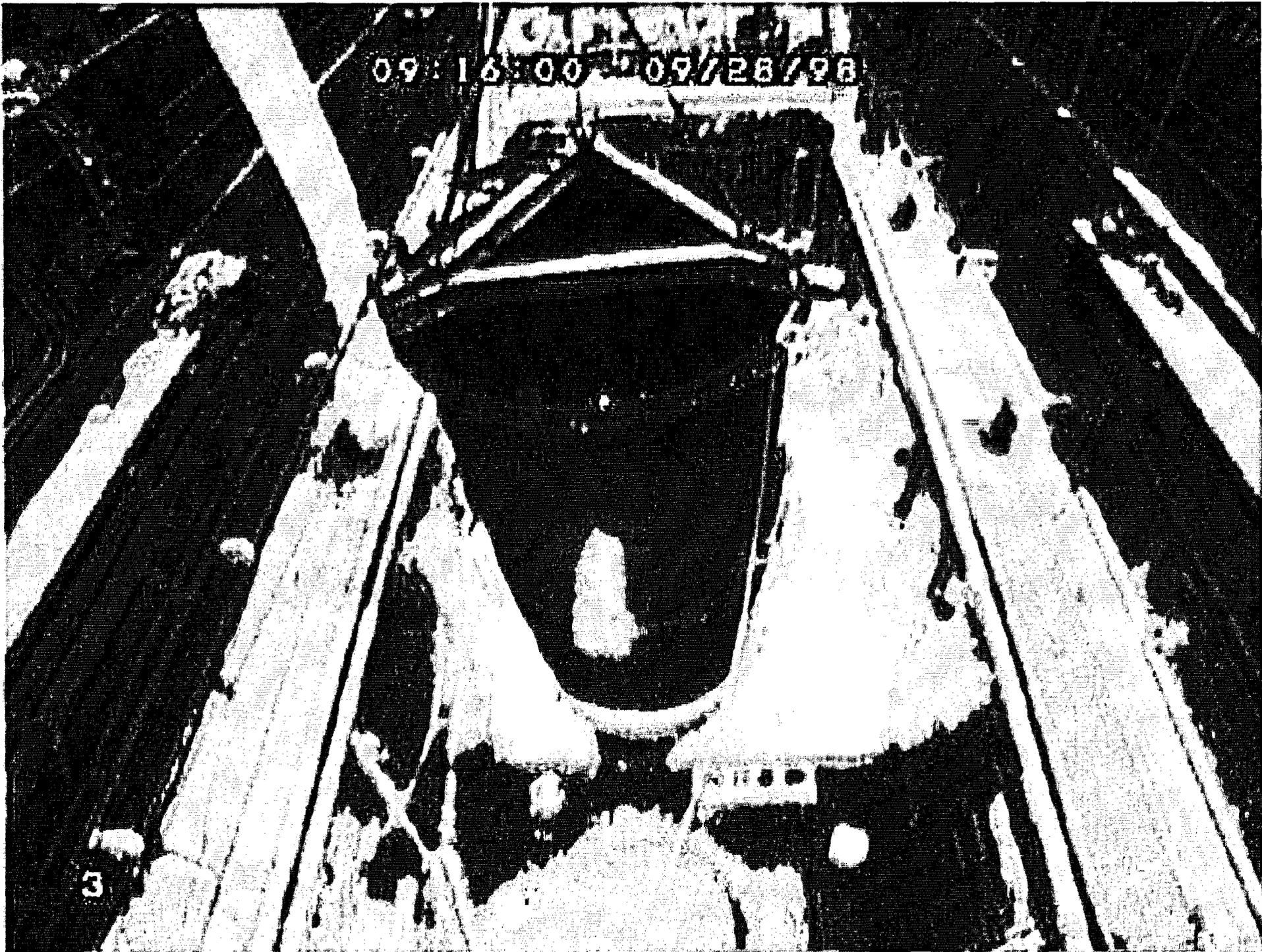


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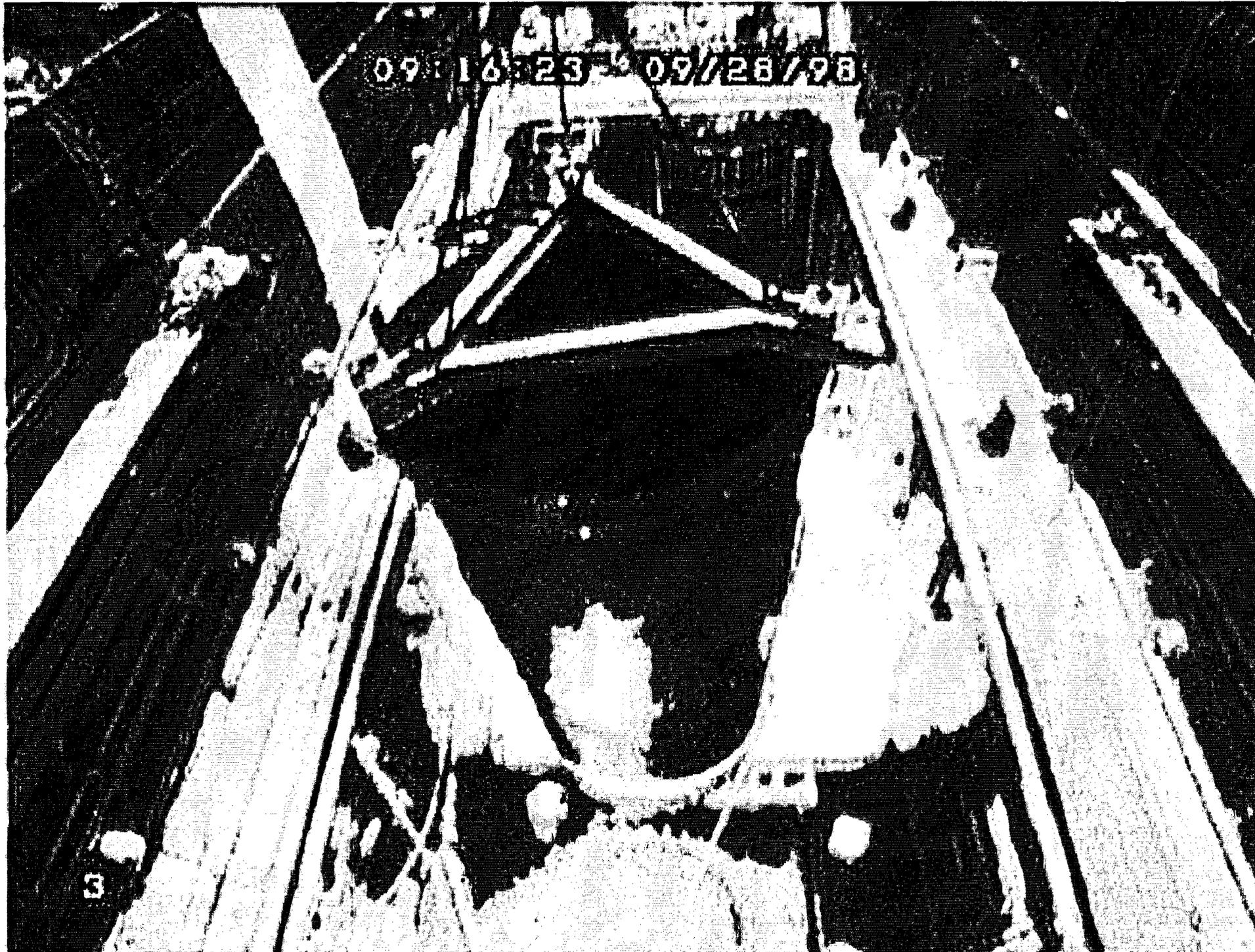
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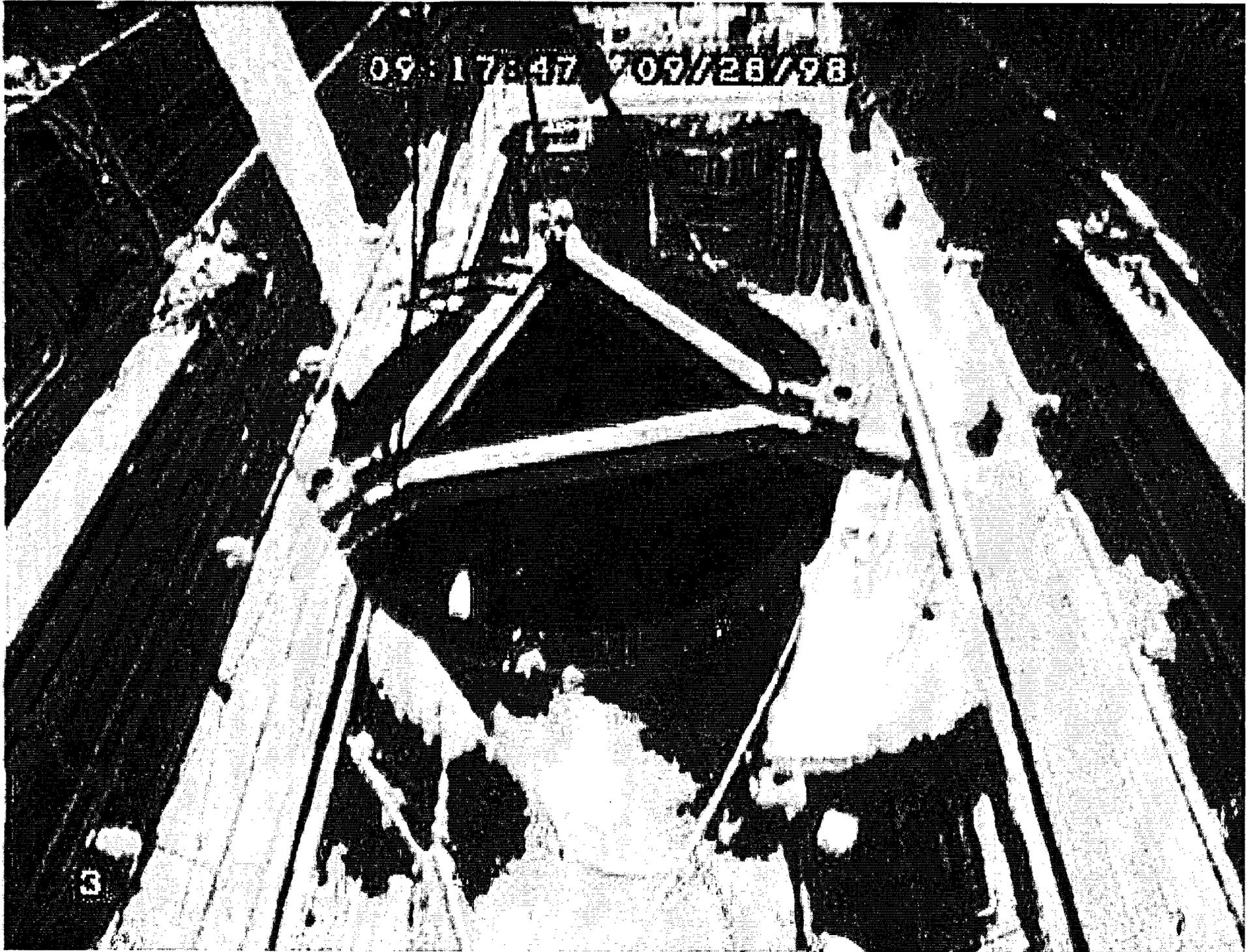
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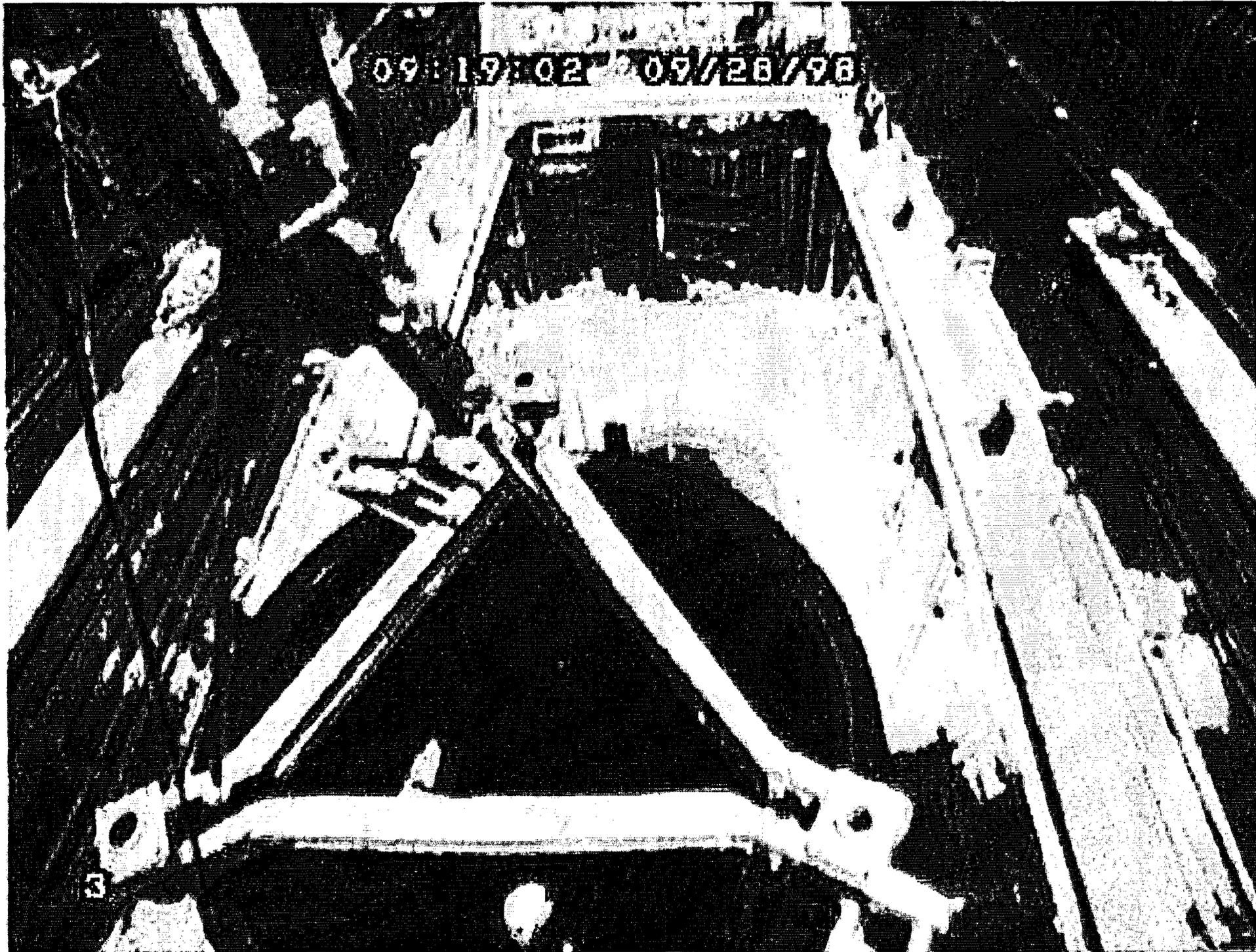
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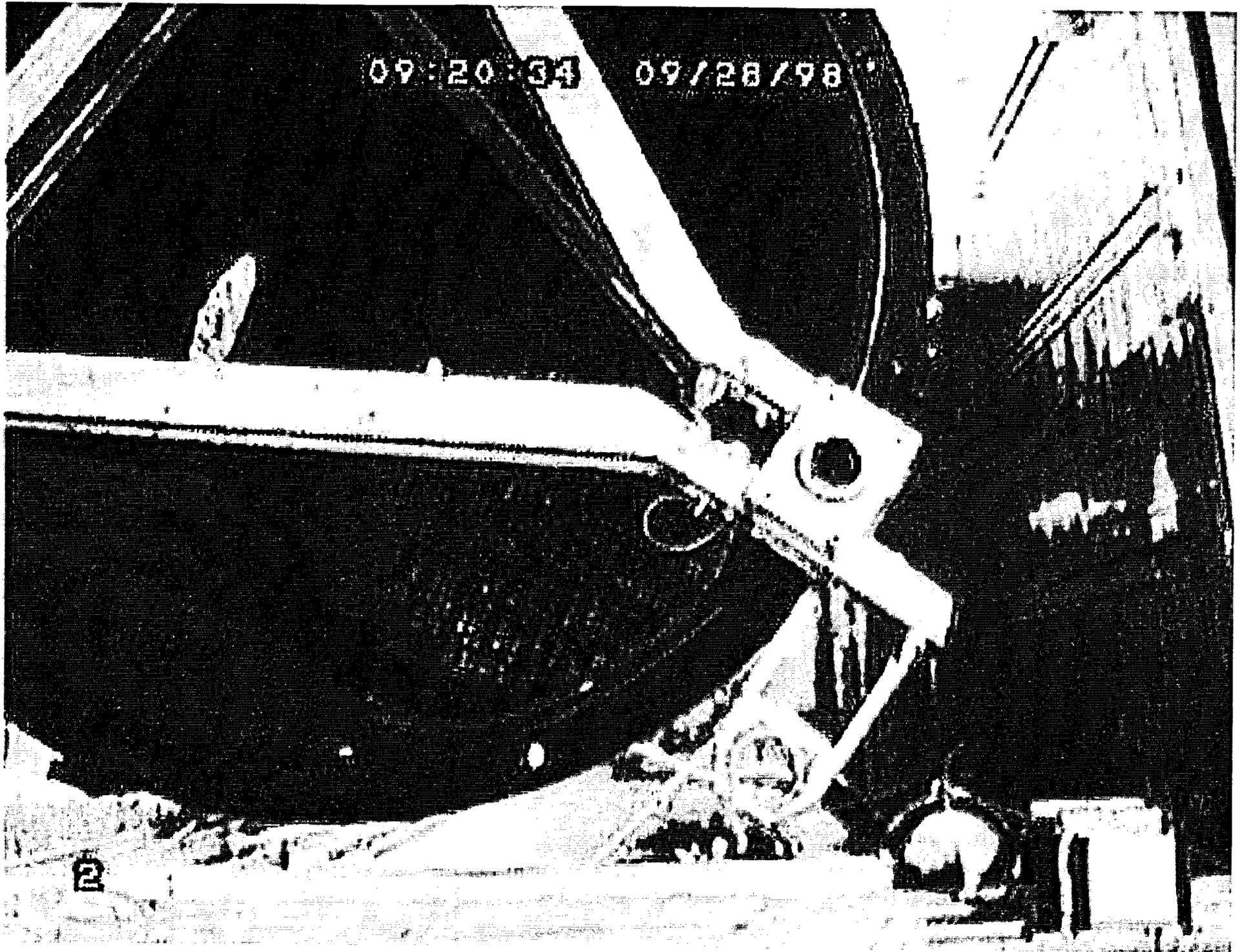
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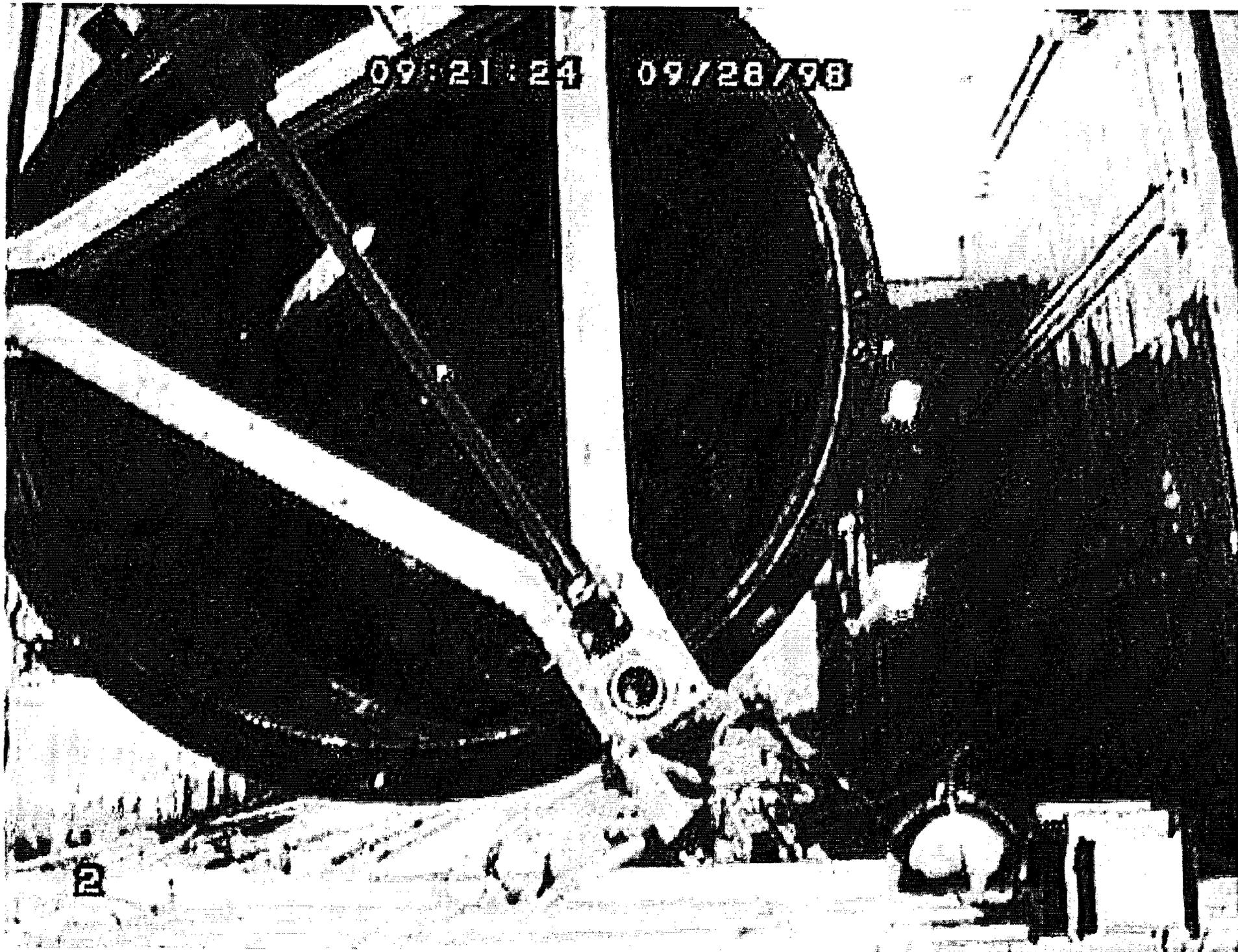
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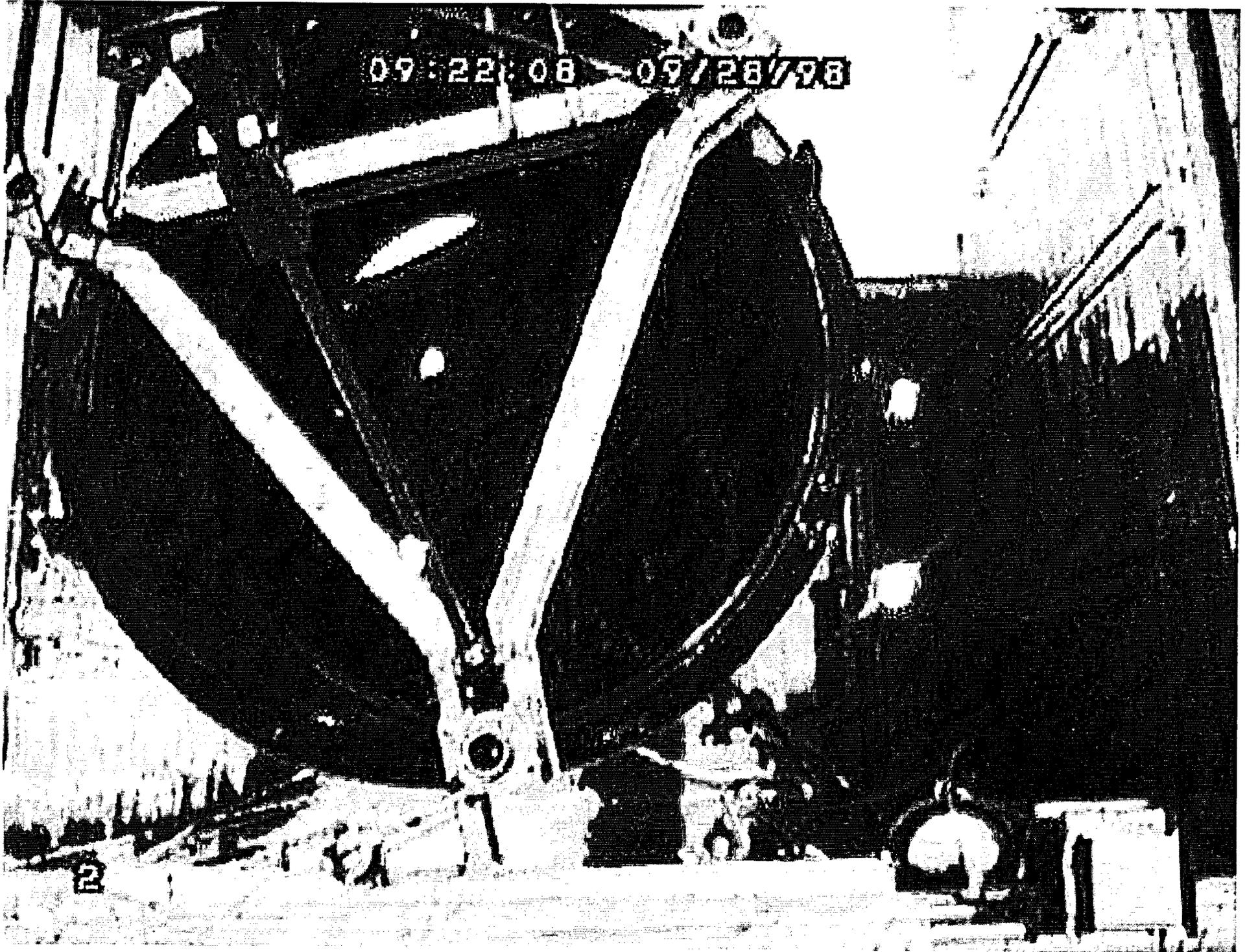
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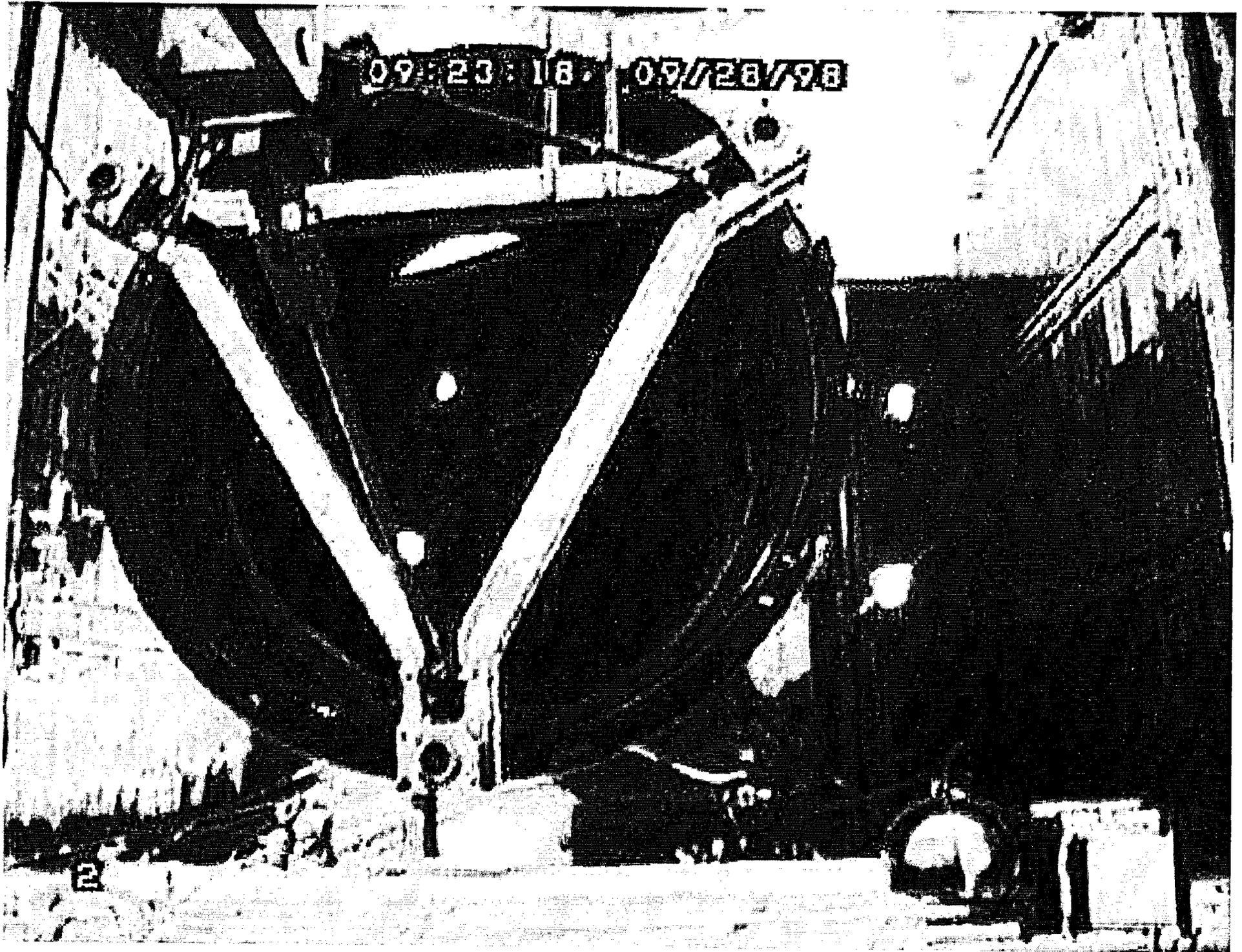
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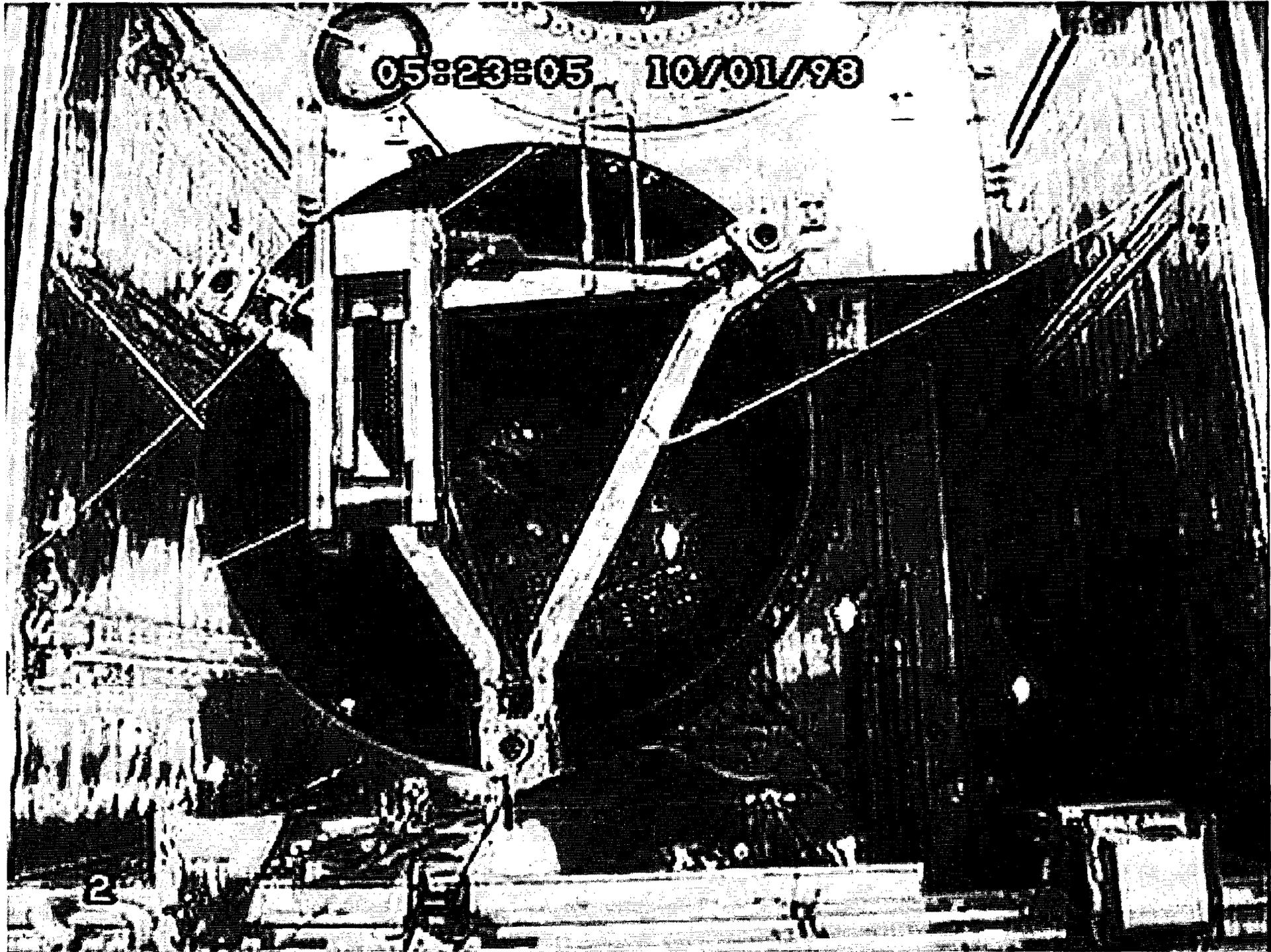


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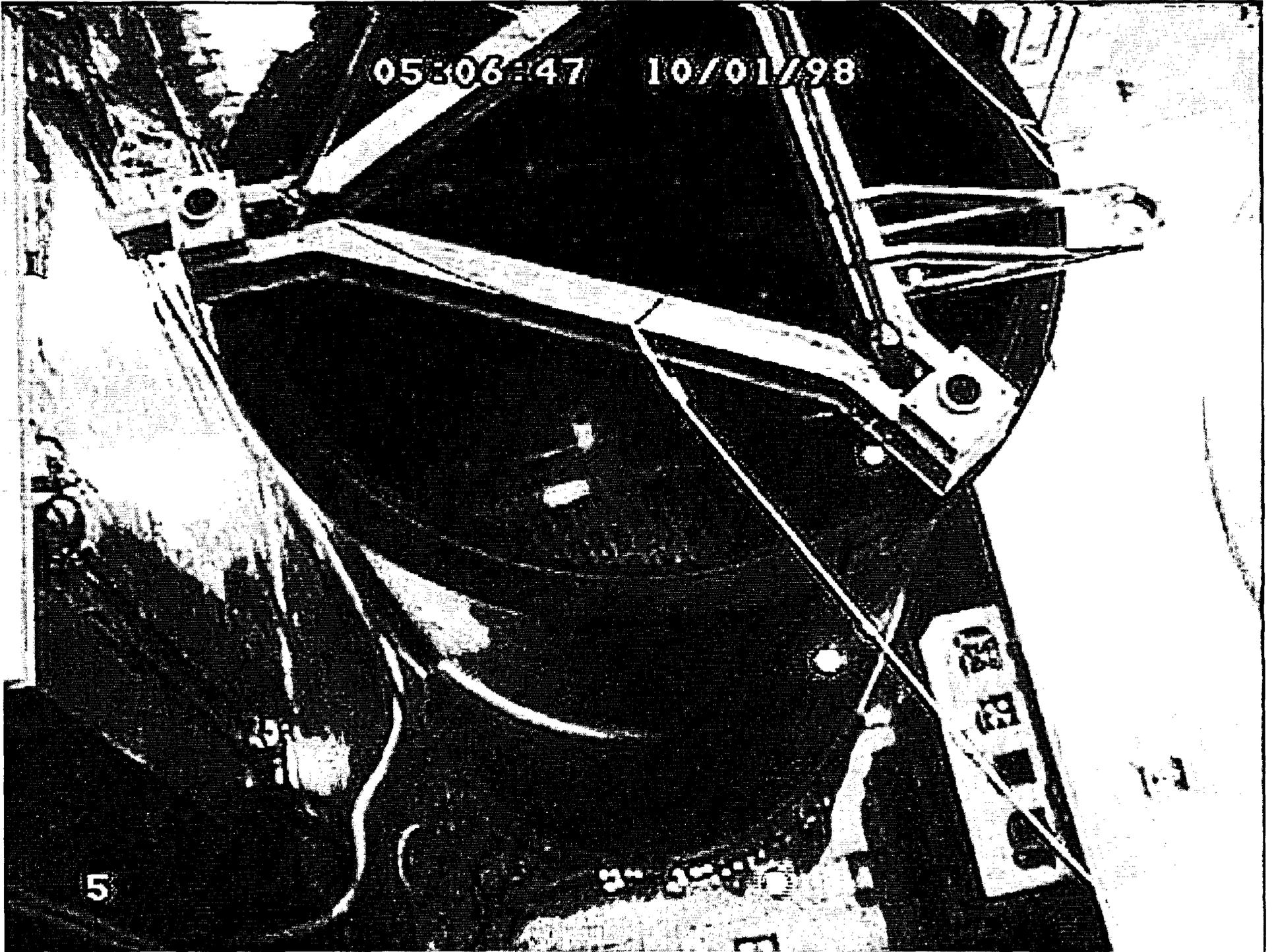
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# Open Discussion

August 15, 2005

PVNGS Unit 1 SDC Suction Line Modification

