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

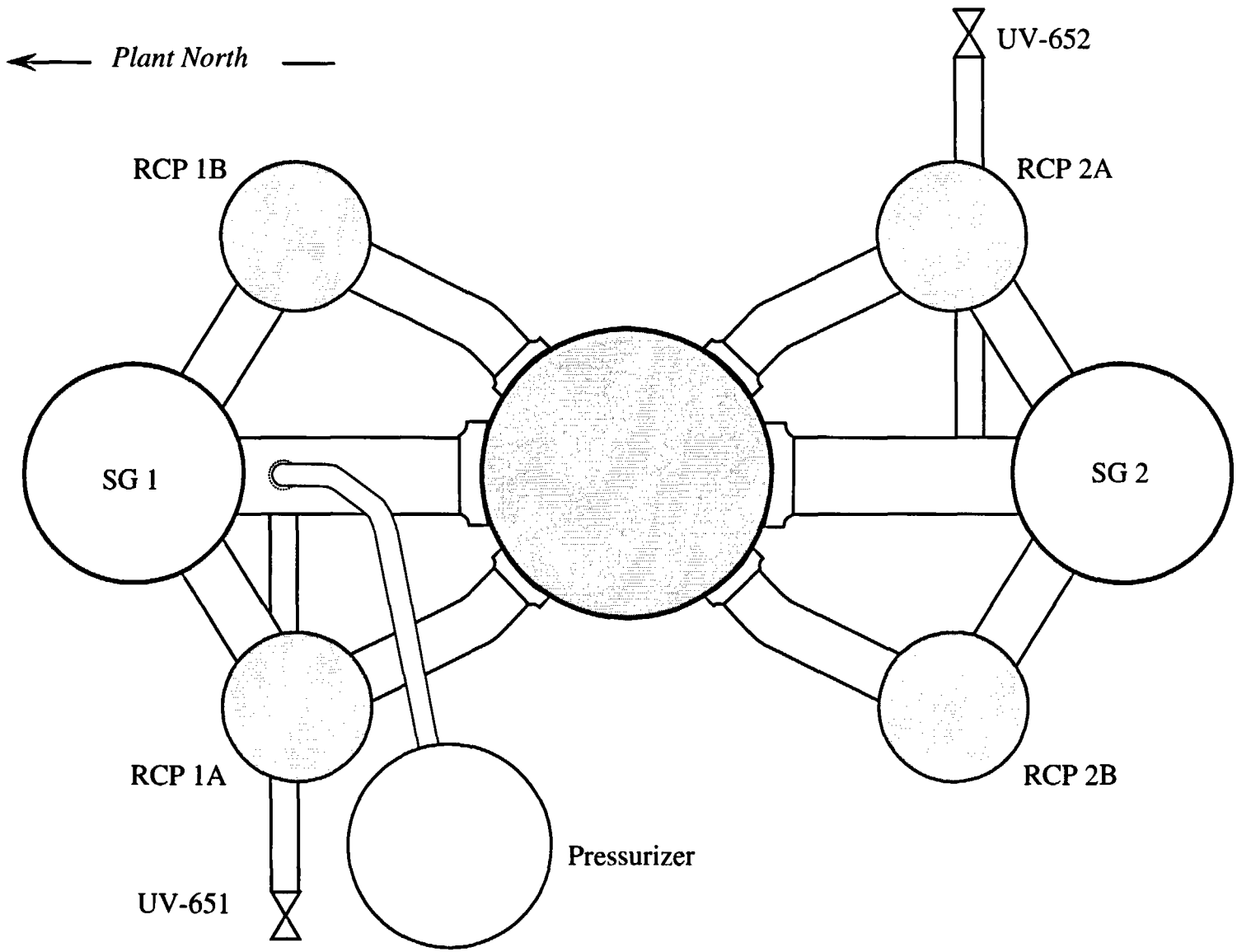
- Introductions and meeting objectives – *Carl Churchman*
- Technical discussions – *Jeff Brown*
  - Configuration
  - Unit 1 vibration history
  - Phenomenological
  - Modifications
  - Final modification selection and development
- Modification process – *Mo Karbassian*
- Open discussion

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

Configuration



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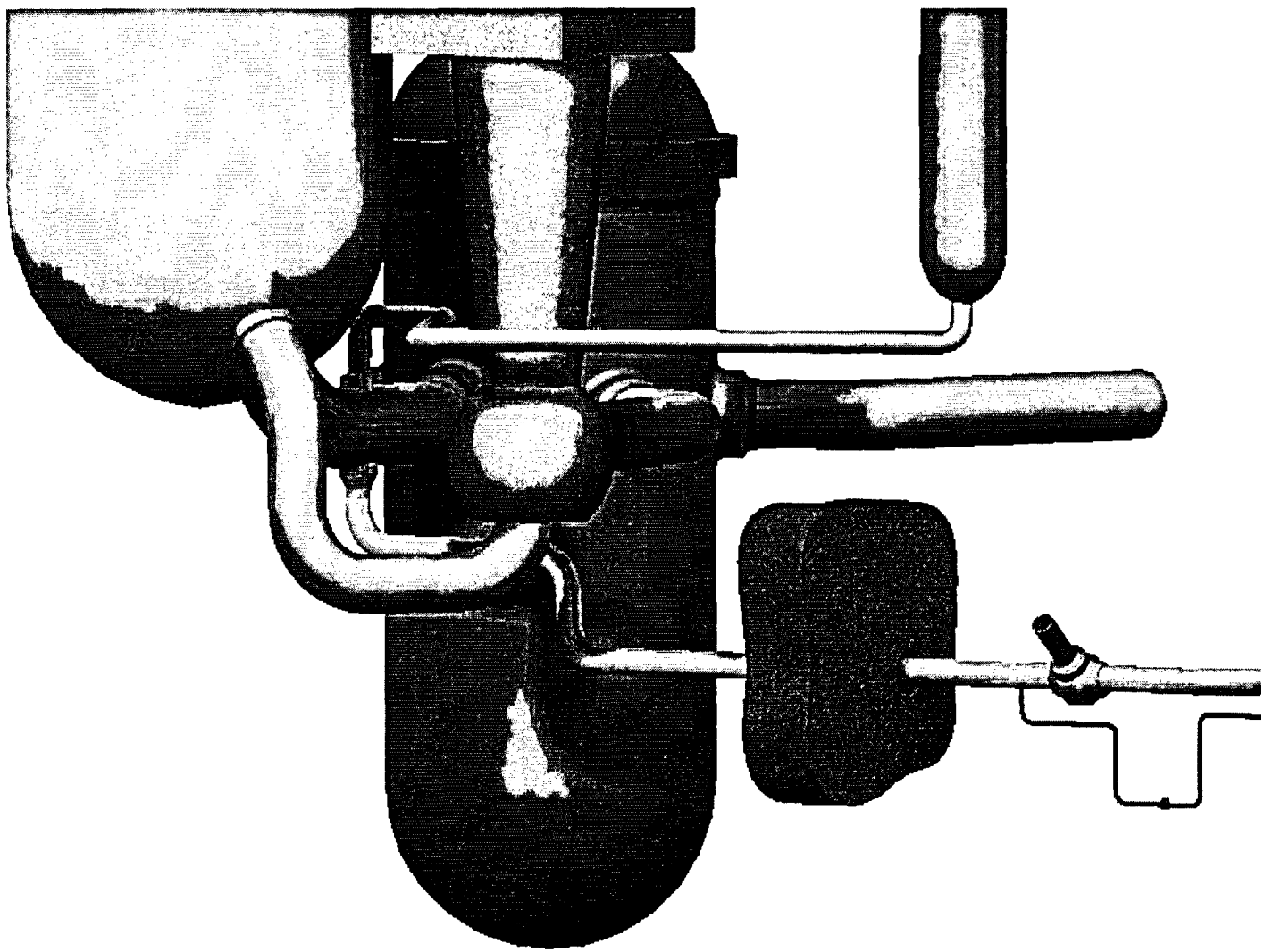

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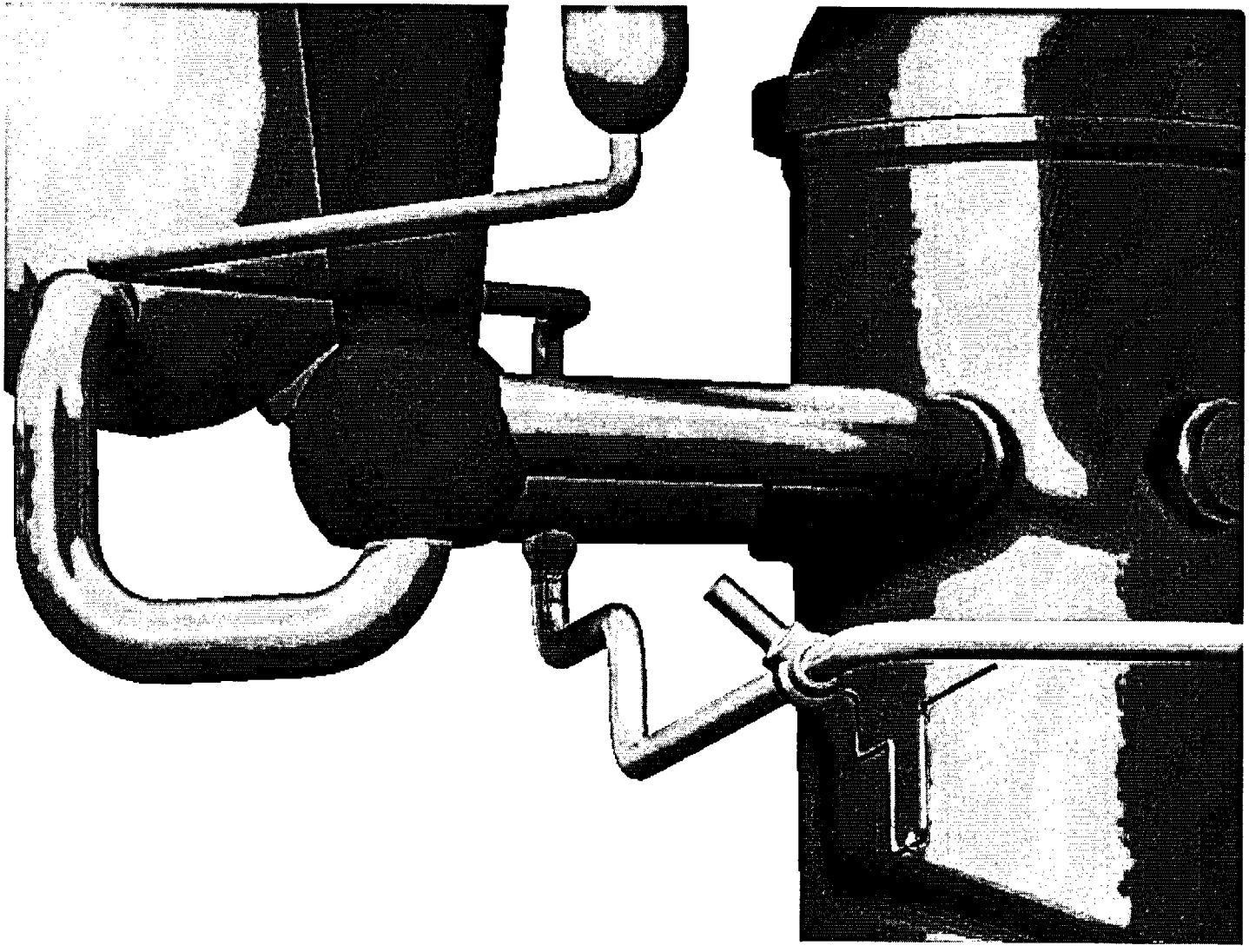

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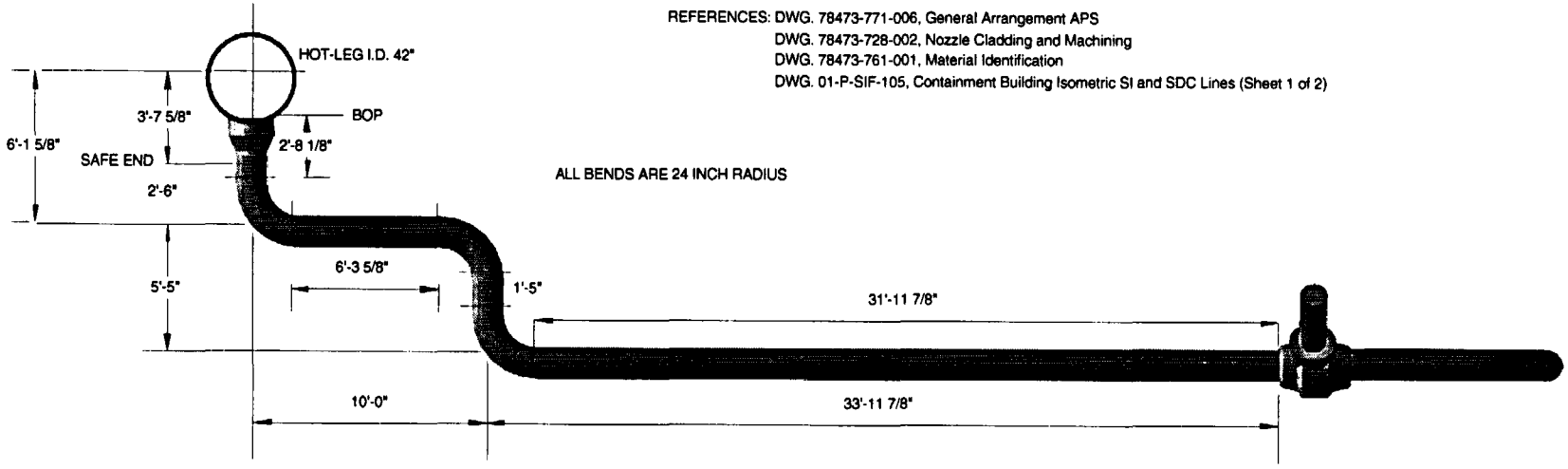

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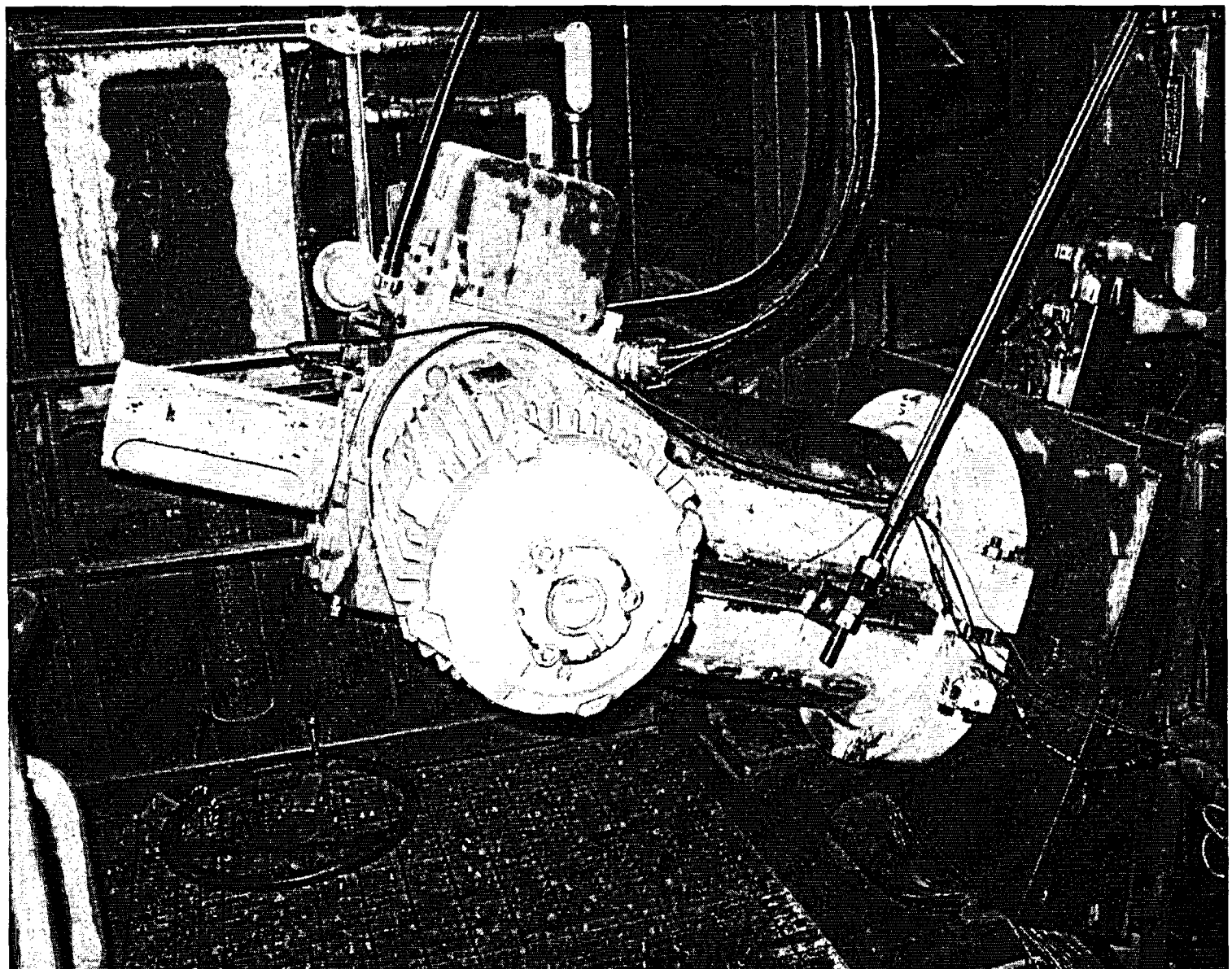


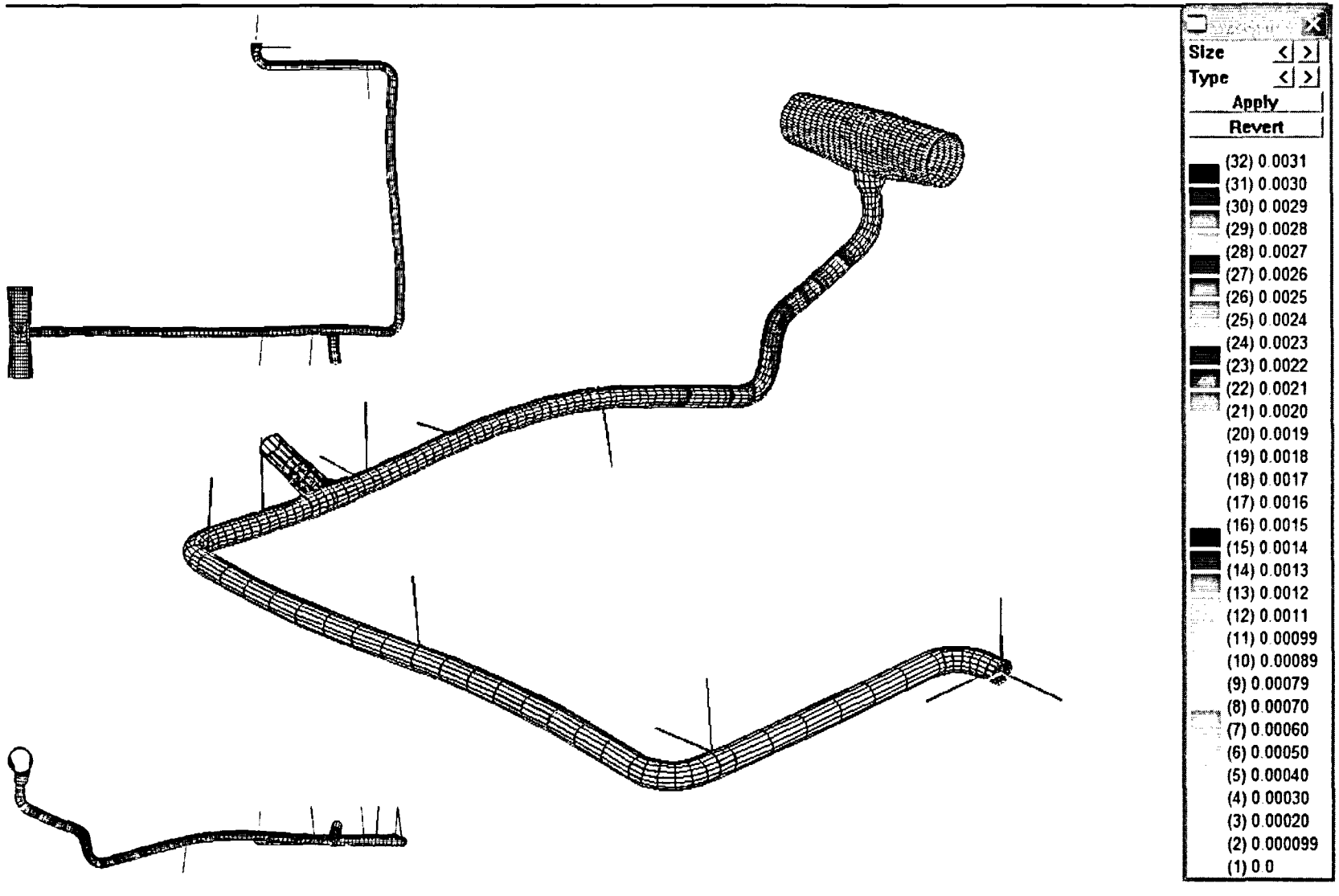
Configuration

- **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



Unit 1 Vibration History

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

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

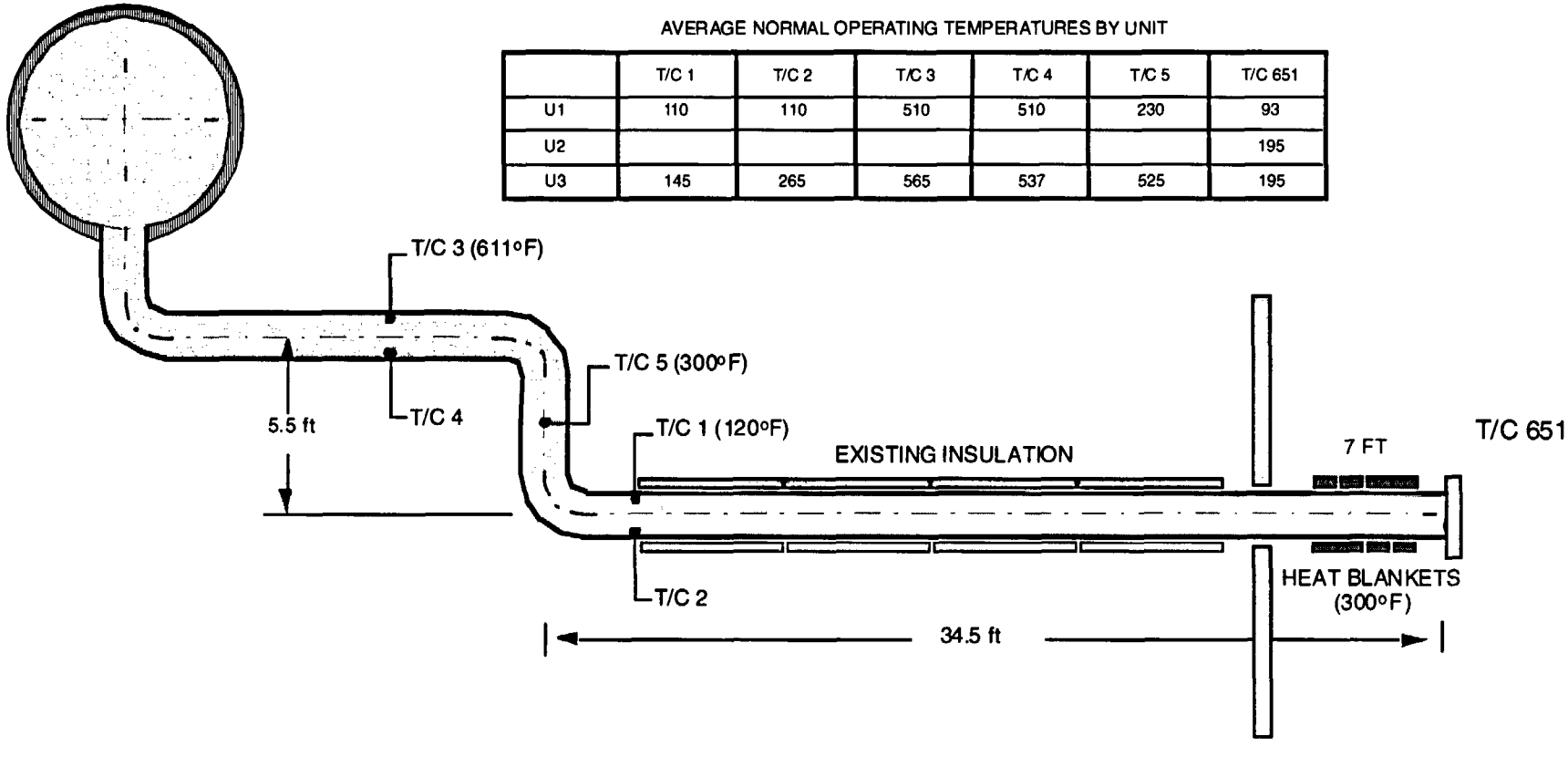
- **Supporting Facts**
  - **Unit 1 vibration amplitude proportional to RCS flow rate**
    - **Correlated to RCS temperature (density) – Proportional change in amplitude with changes in RCS temperature**
    - **Demonstrated during phenomenological testing**
  - **Vibration frequency proportional to 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

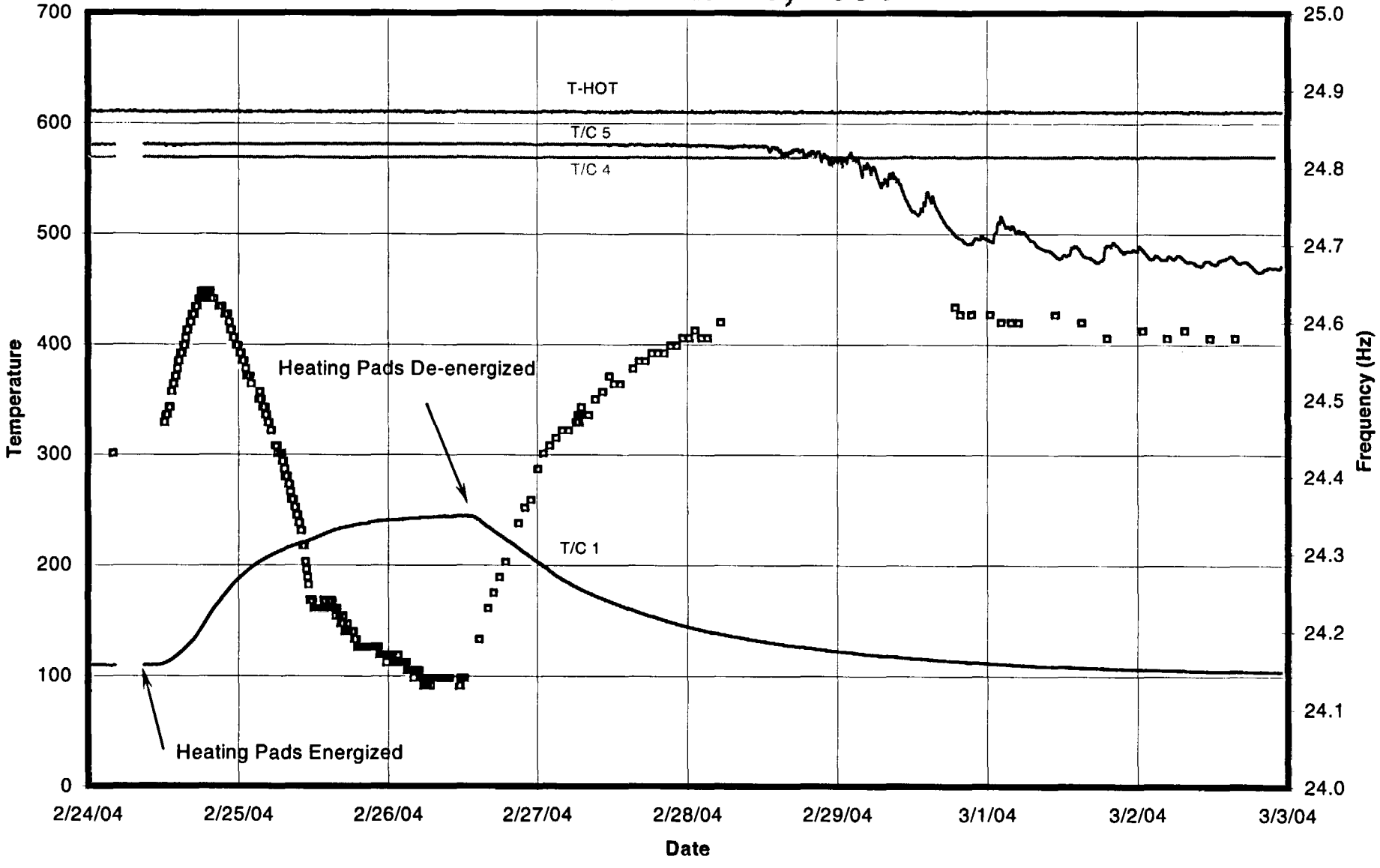
	T/C 1	T/C 2	T/C 3	T/C 4	T/C 5	T/C 651
U1	110	110	510	510	230	93
U2						195
U3	145	265	565	537	525	195



Phenomenological

Unit 1 SDC Suction Line Temperature and Vibration Frequency

Feb. 19 – Mar. 3, 2004



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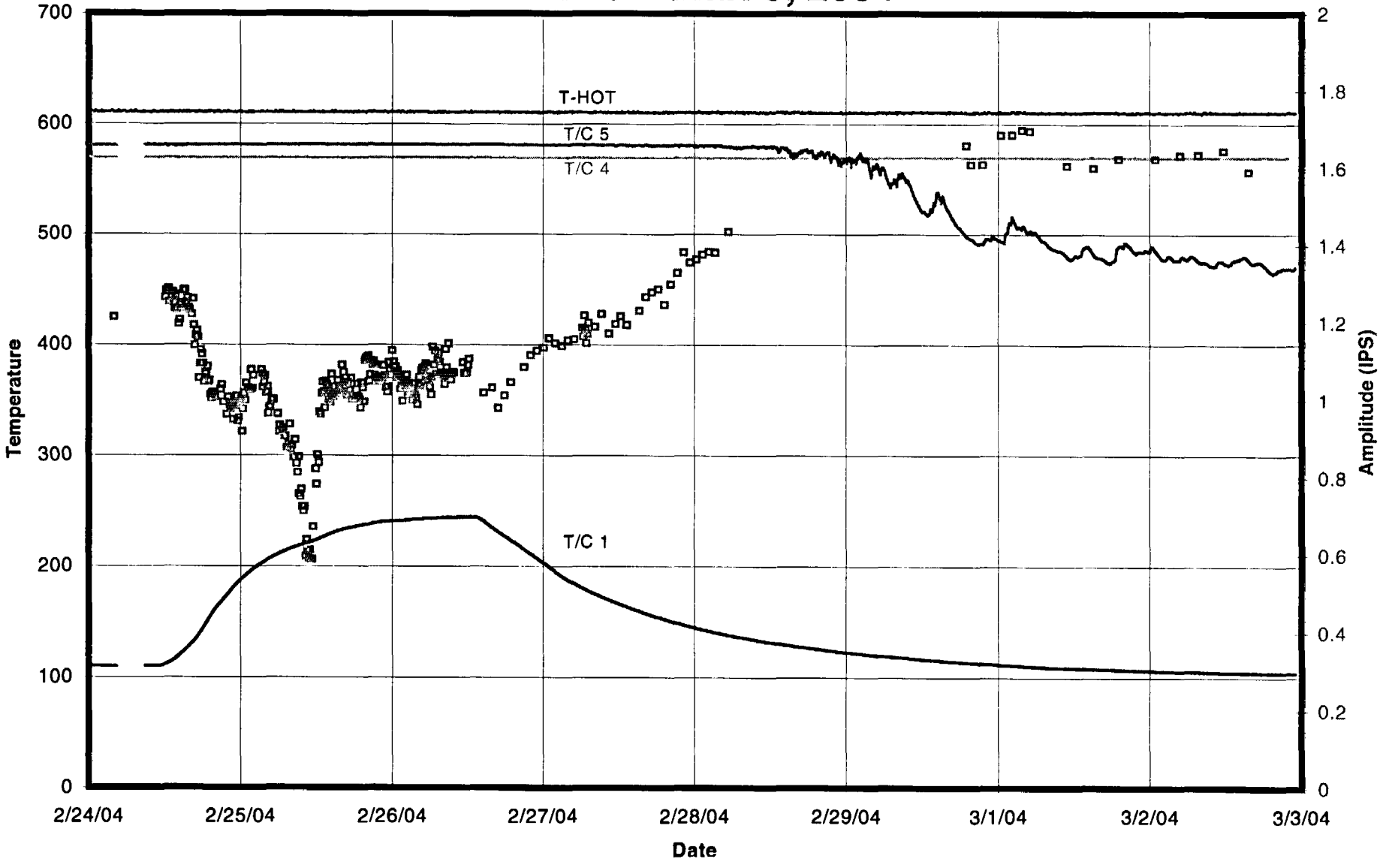
Unit 1 SDC Suction Line Temperature and Vibration Amplitude

Feb. 19 – Mar. 3, 2004



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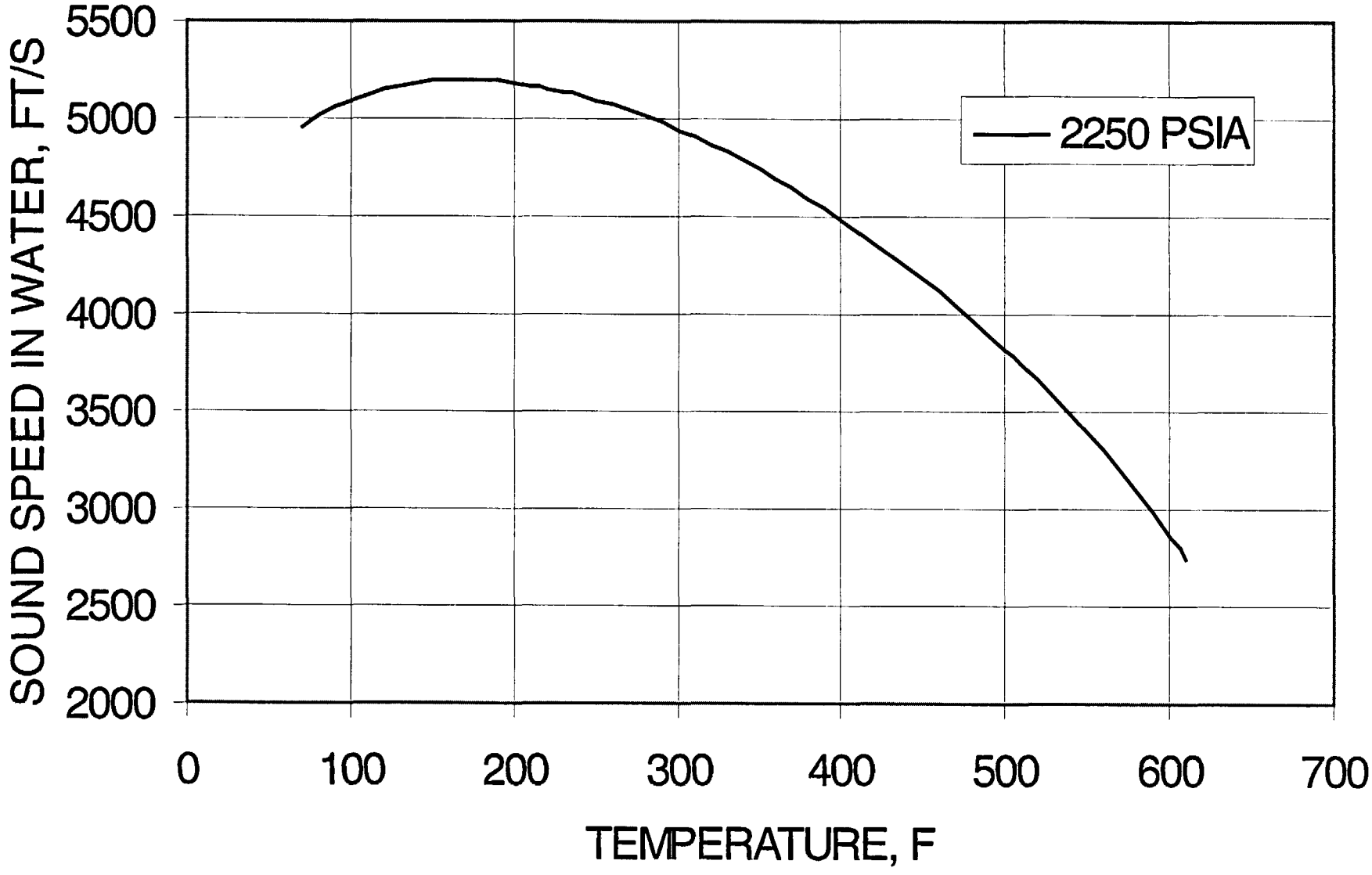
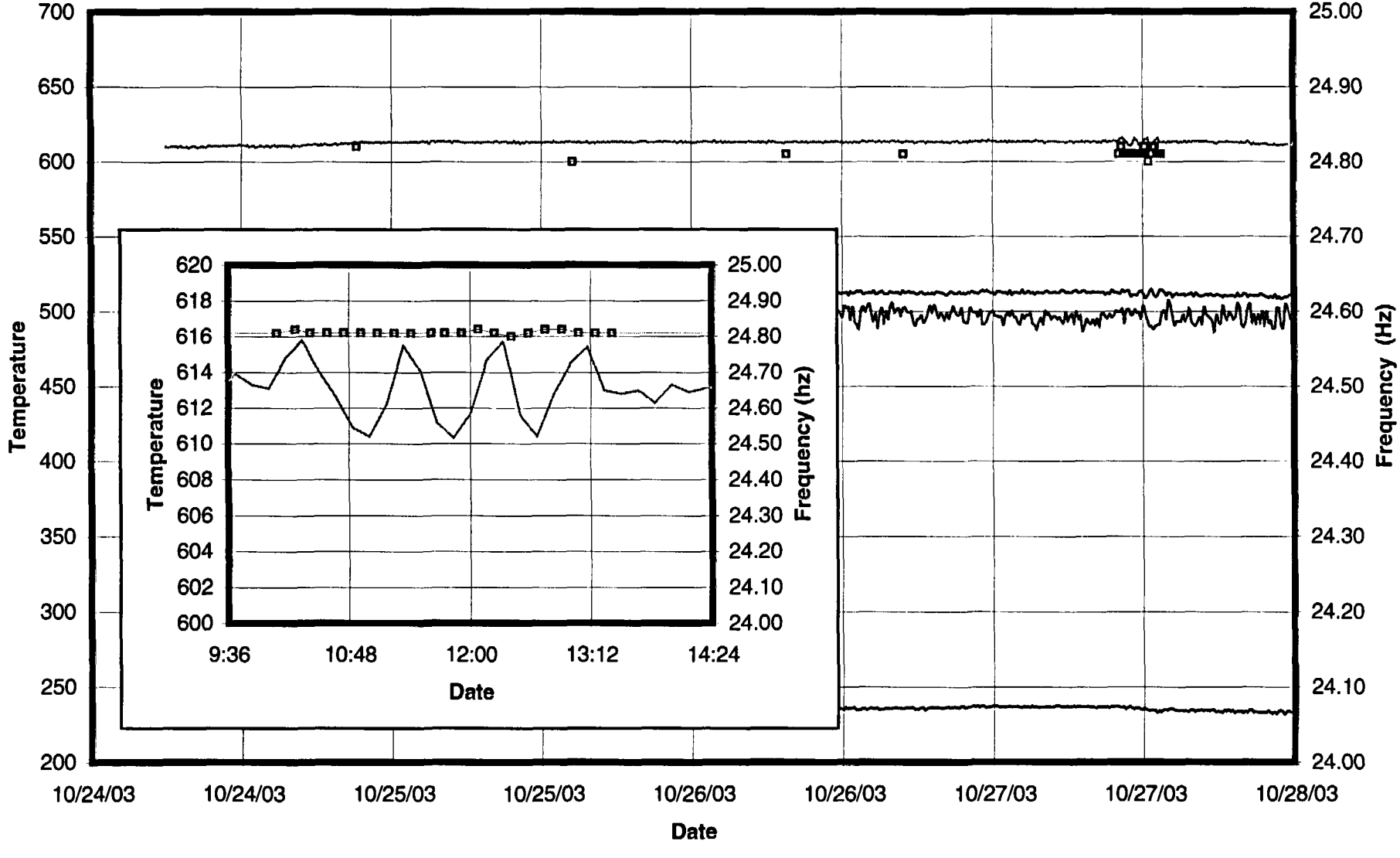


Phenomenological

Unit 1 SDC Suction Line Temperature and Vibration Frequency

MTC Testing, Oct. 23 – 27, 2003



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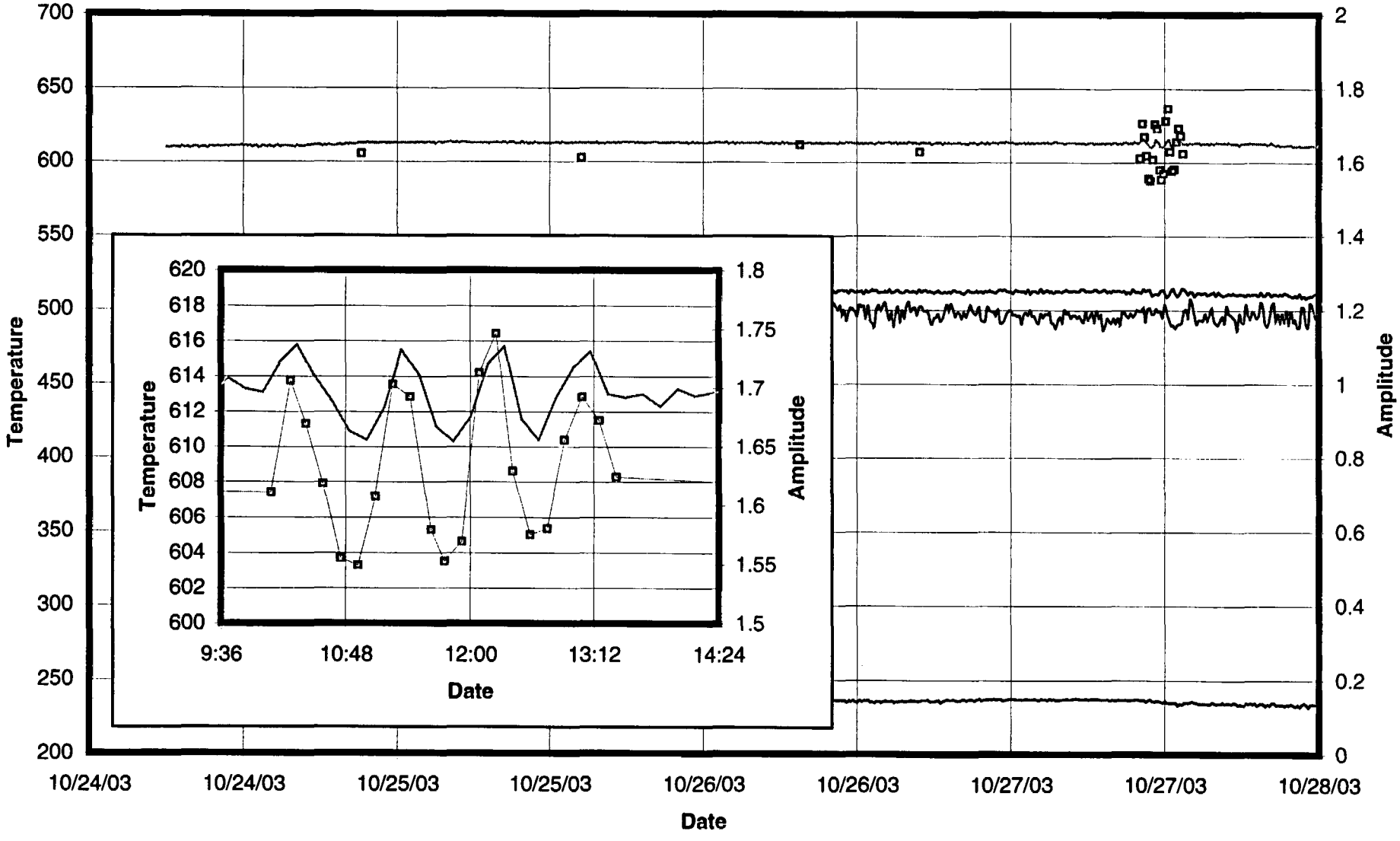
Unit 1 SDC Suction Line Temperature and Vibration Amplitude

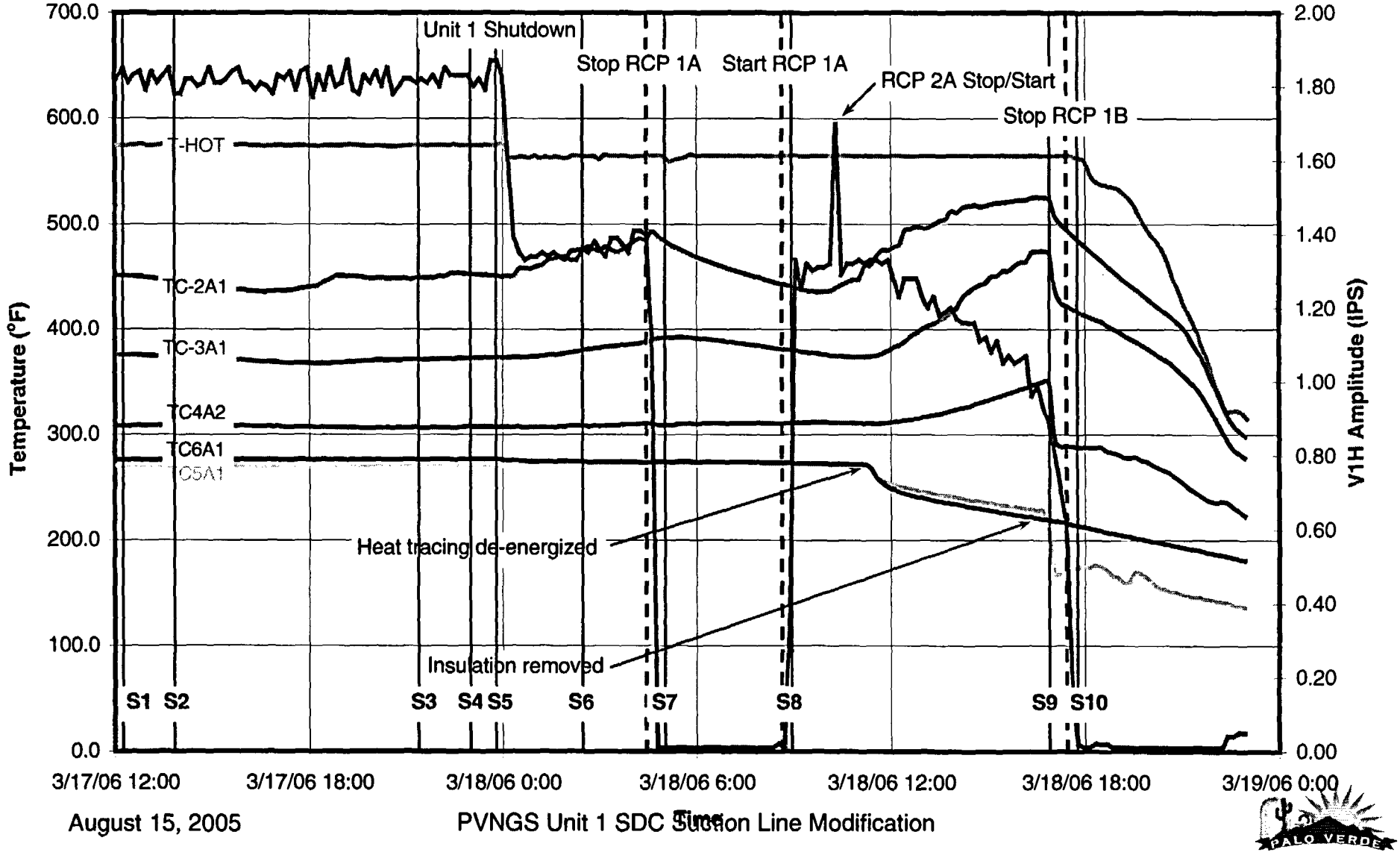
MTC Testing, Oct. 23 – 27, 2003



Phenomenological

Unit 1 SDC Suction Line Vibration

March 17 - 18, 2006 (SNOW)



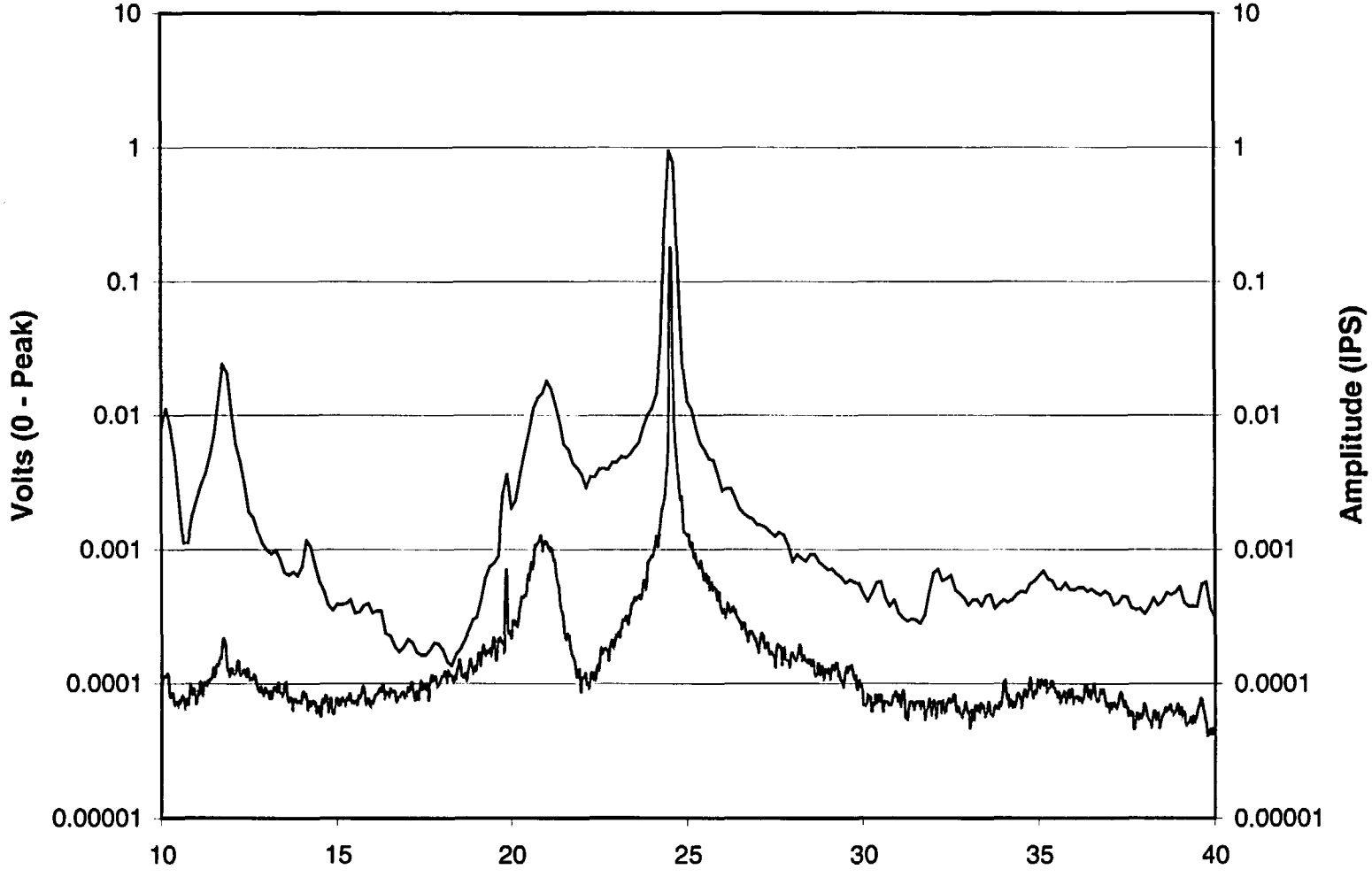
August 15, 2005

PVNGS Unit 1 SDC Suction Line Modification

Phenomenological

Unit 1 SDC Suction Line Pressure and Vibration Measurements

April 6, 2006



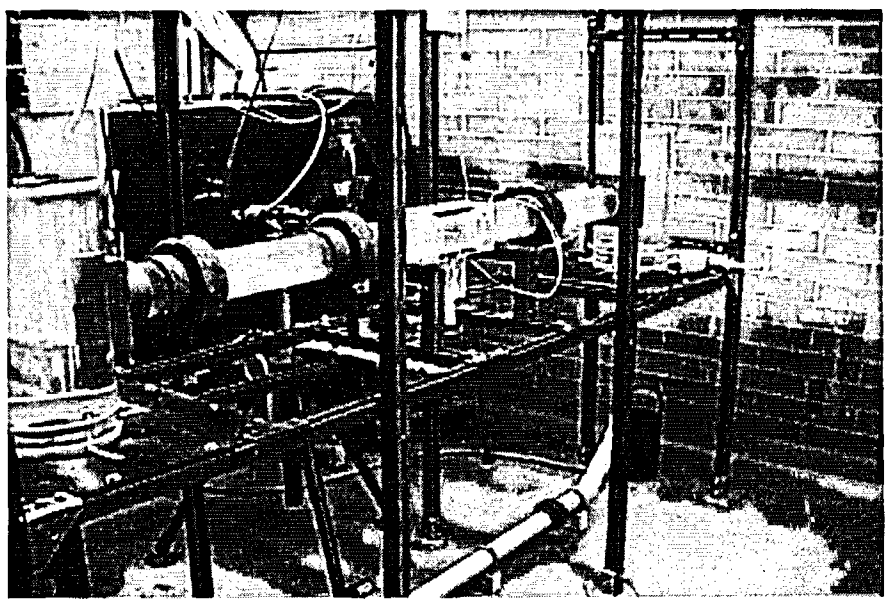
August 15, 2005

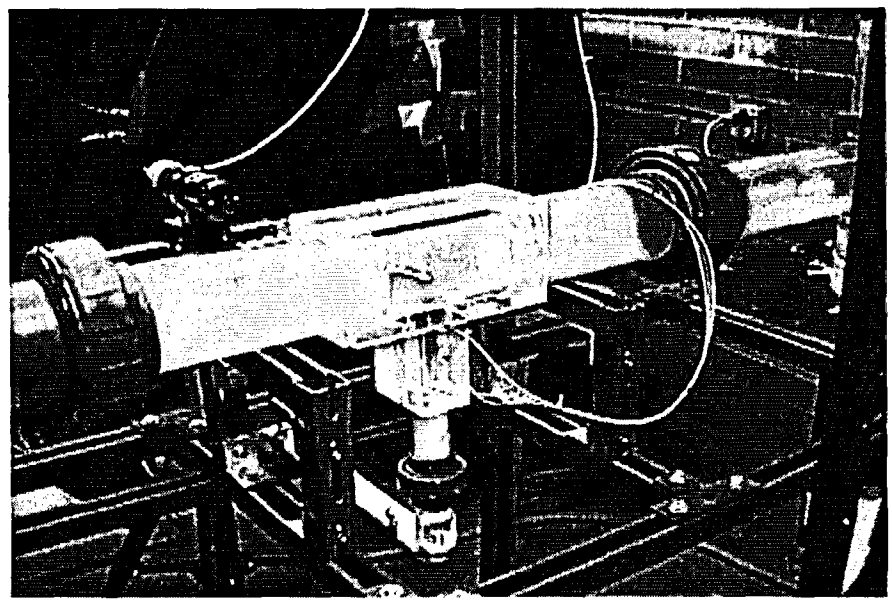
PVNGS Unit 1 SDC Suction Line Modification

Phenomenological

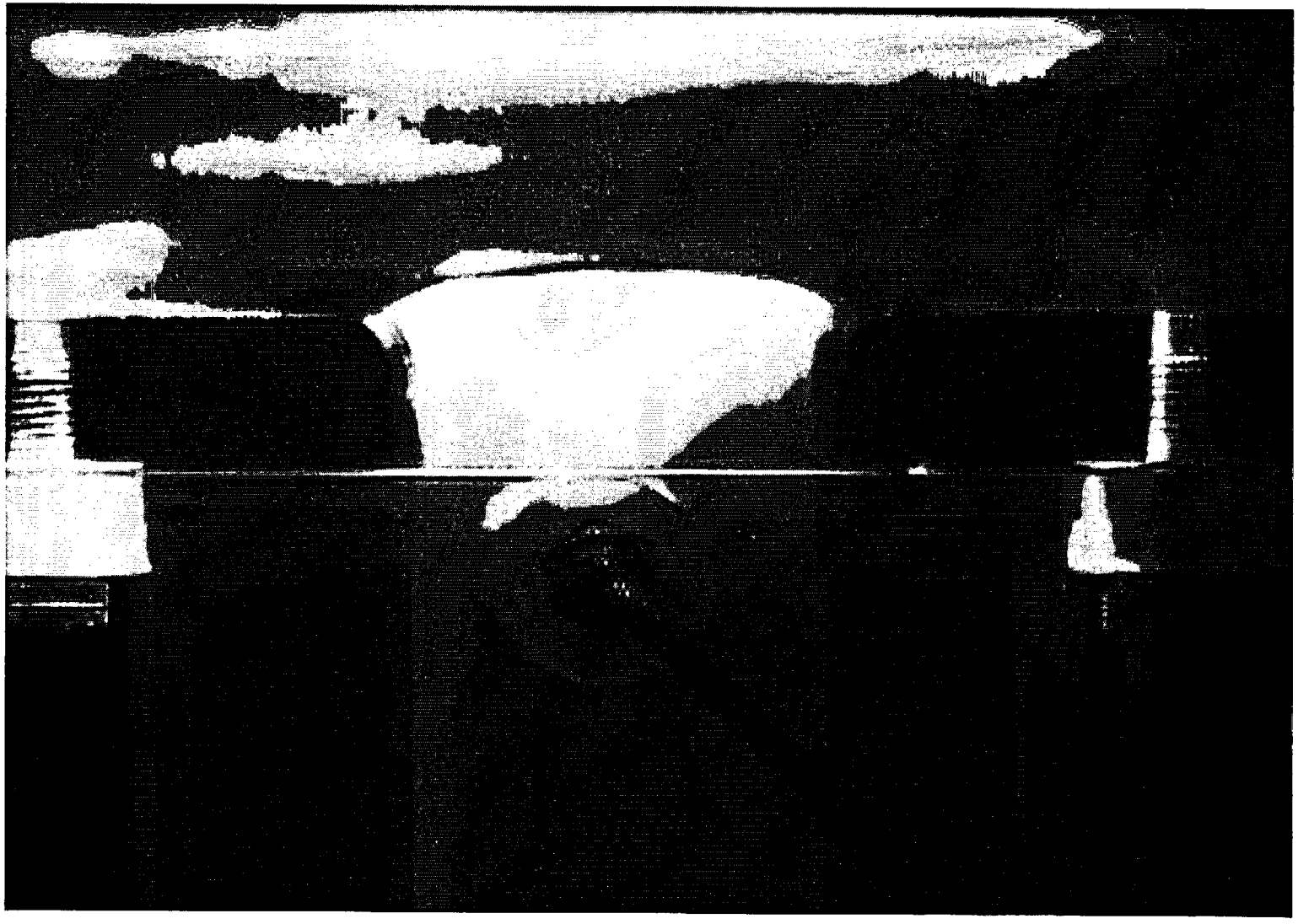
- Research programs
  - ASU Phase I – vortex shedding characterization and turbulence penetration depth parametric assessment
  - ASU Phase II – scaled acoustic coupling experimentation and quantification of modification effects

Phenomenological
ASU – Phase I





Phenomenological
ASU – Phase I



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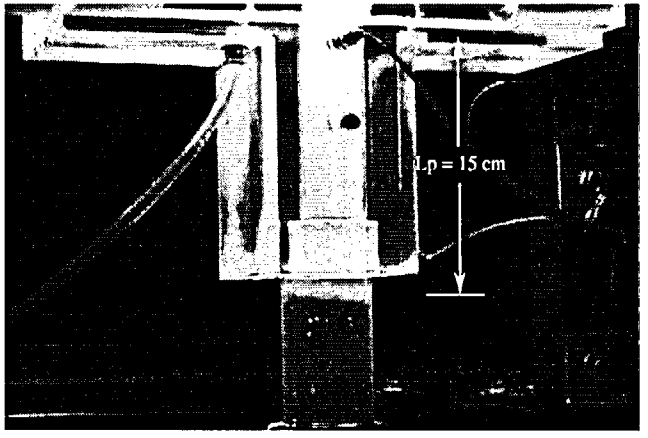
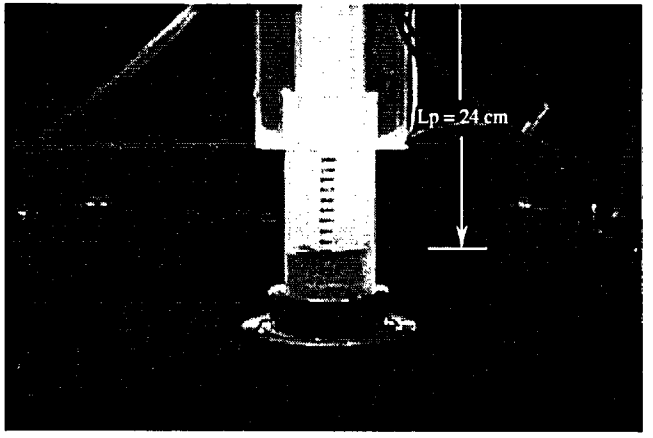
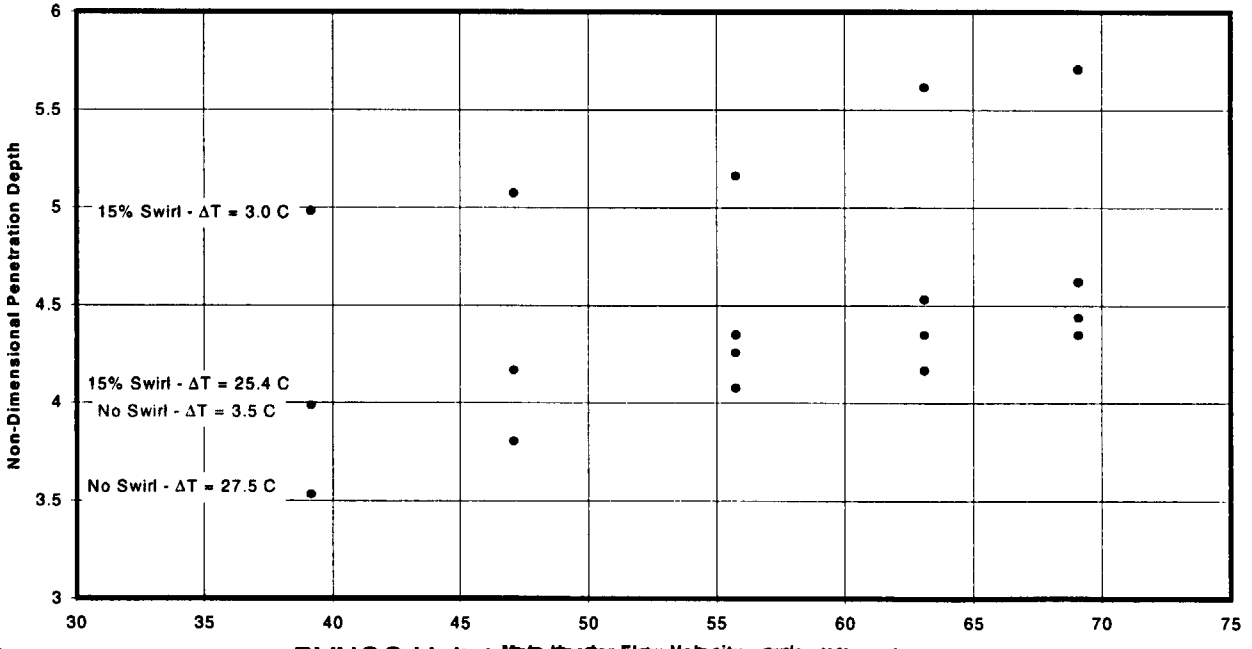
ASU – Phase I





Penetration Depth Correlation



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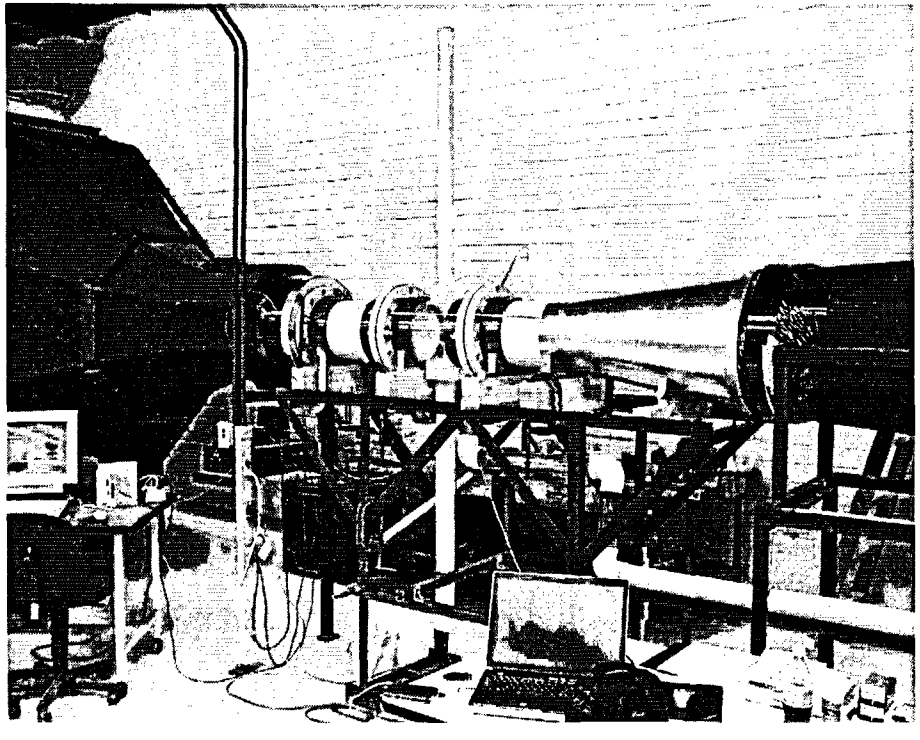
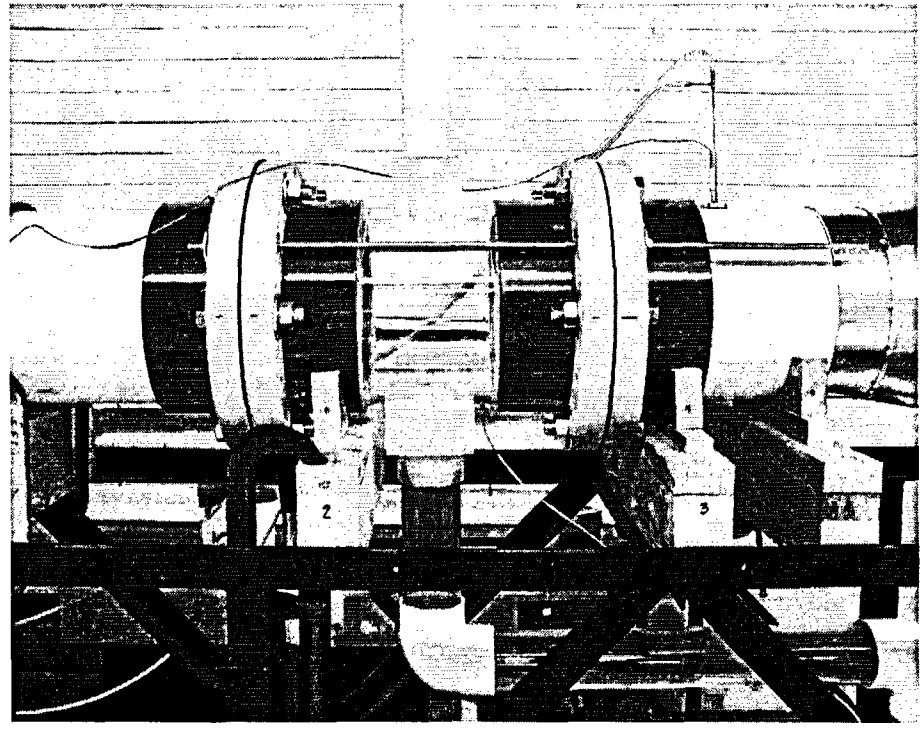
ASU – Phase II

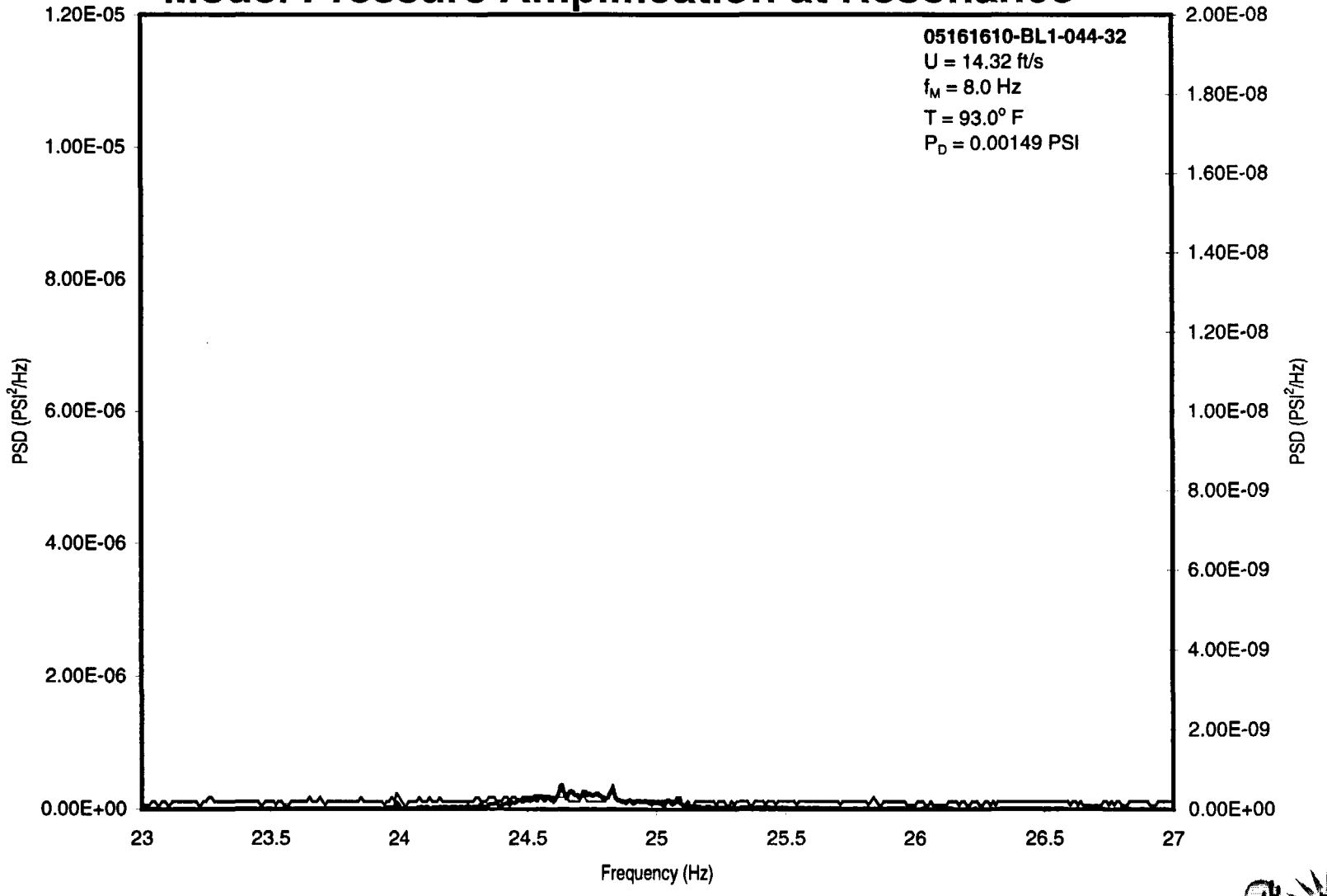




Phenomenological

ASU Phase II

Model Pressure Amplification at Resonance



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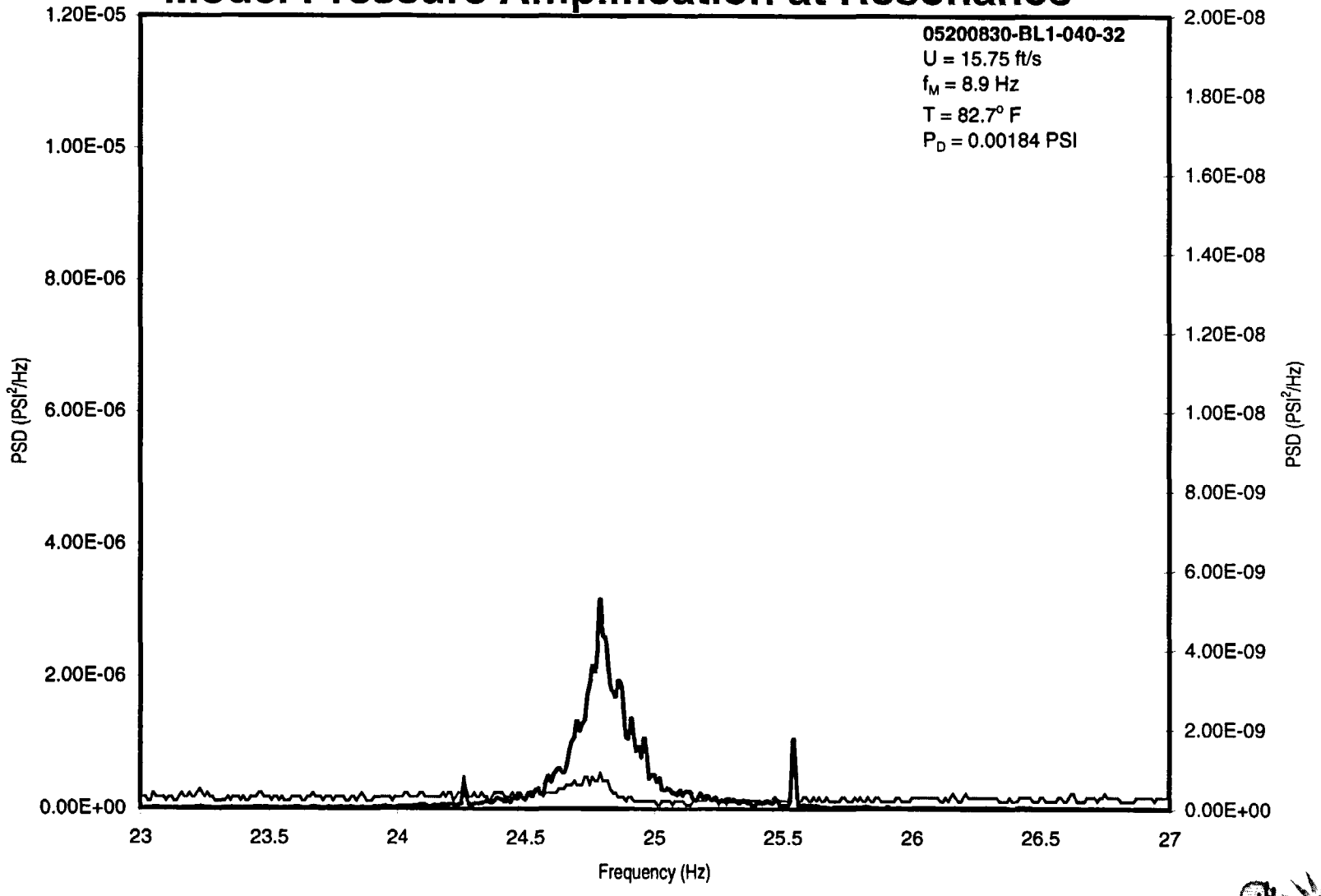

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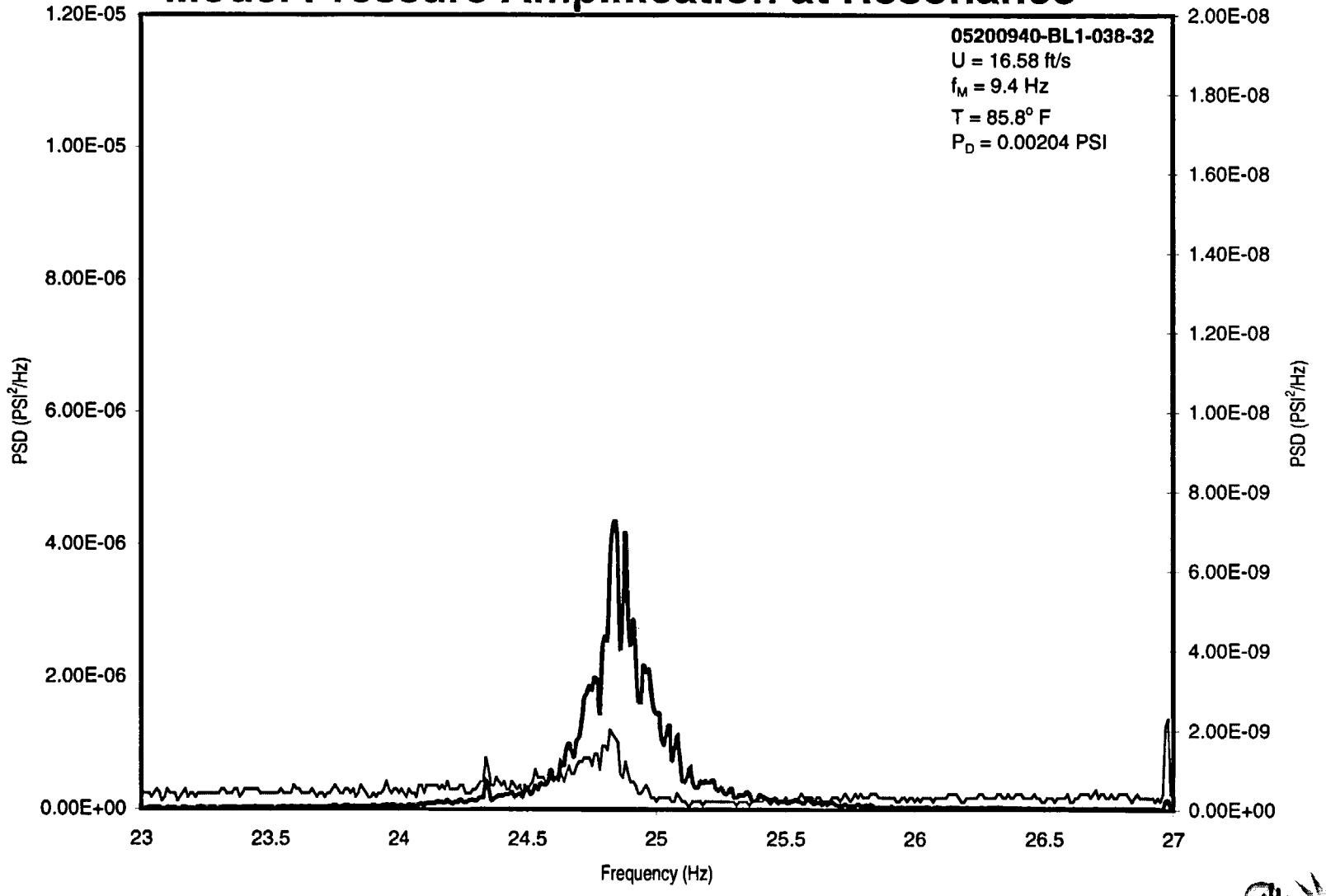

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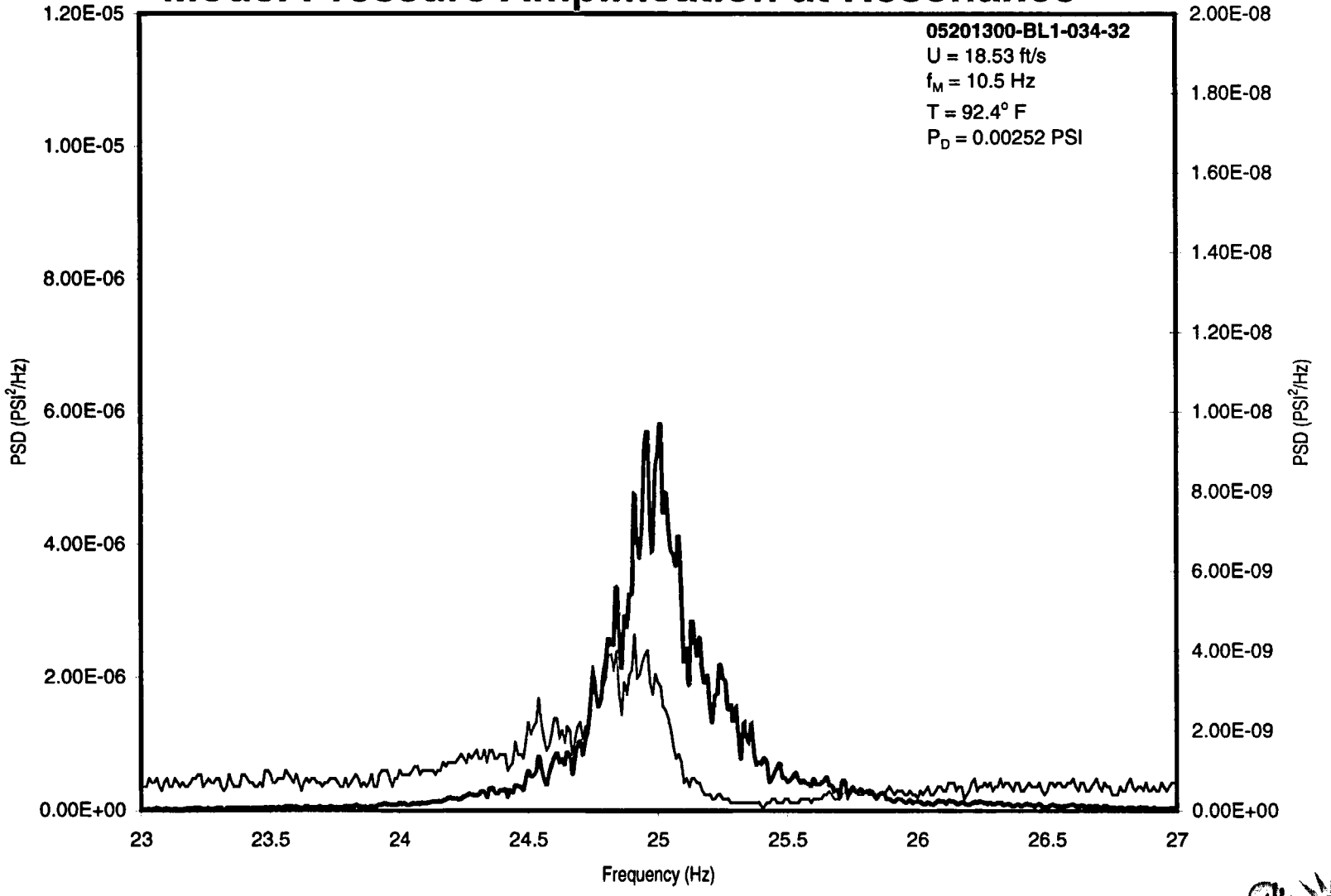

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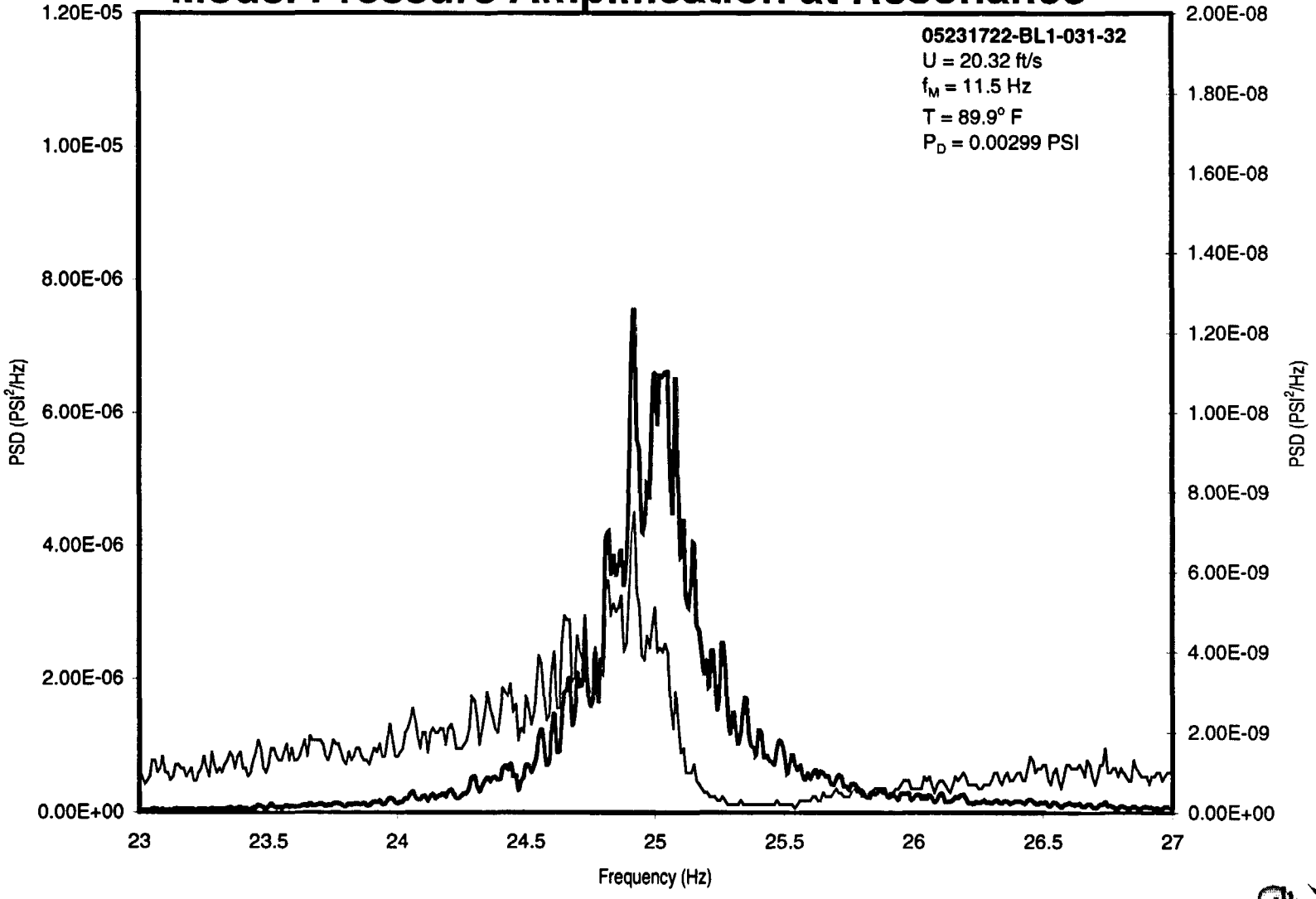

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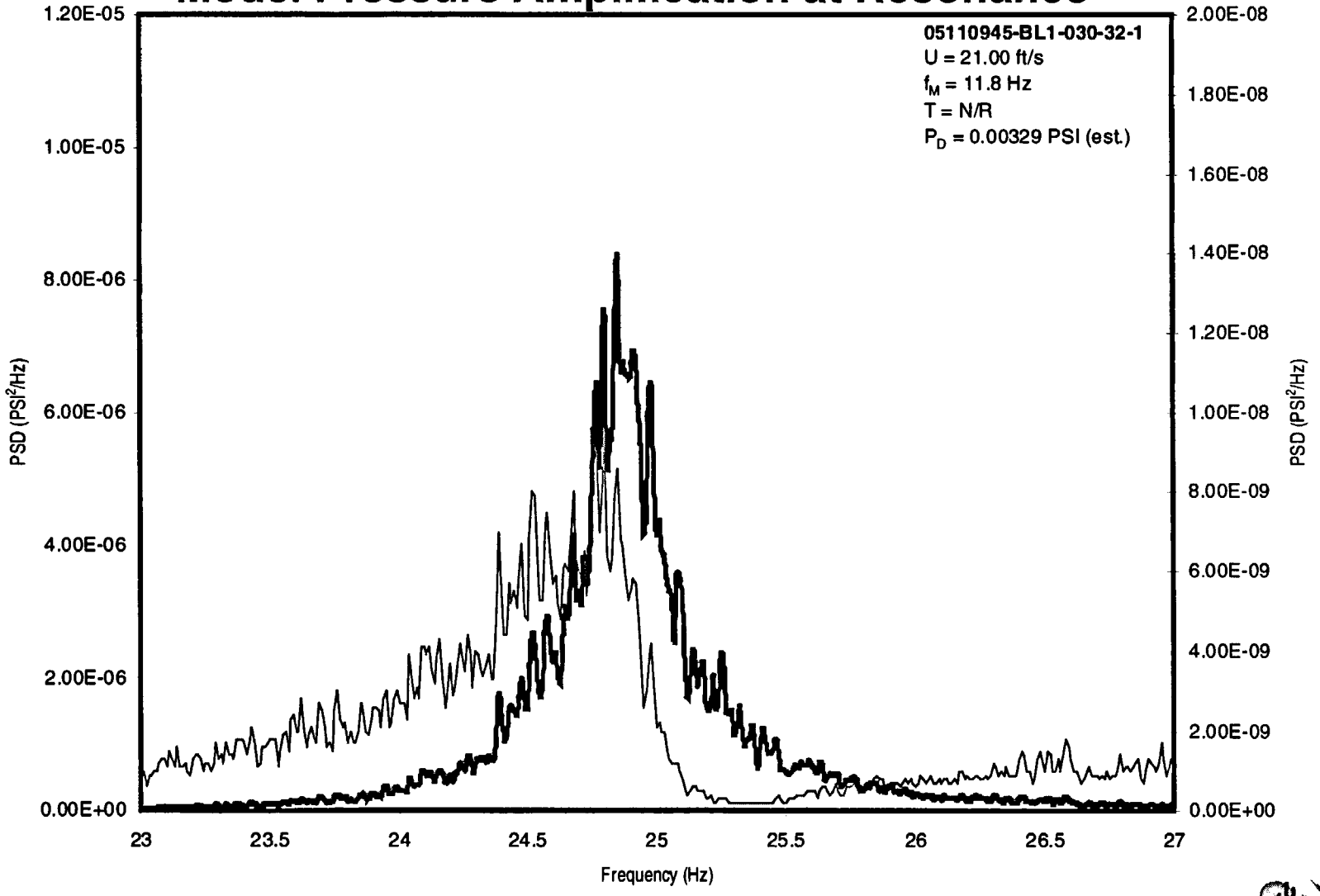

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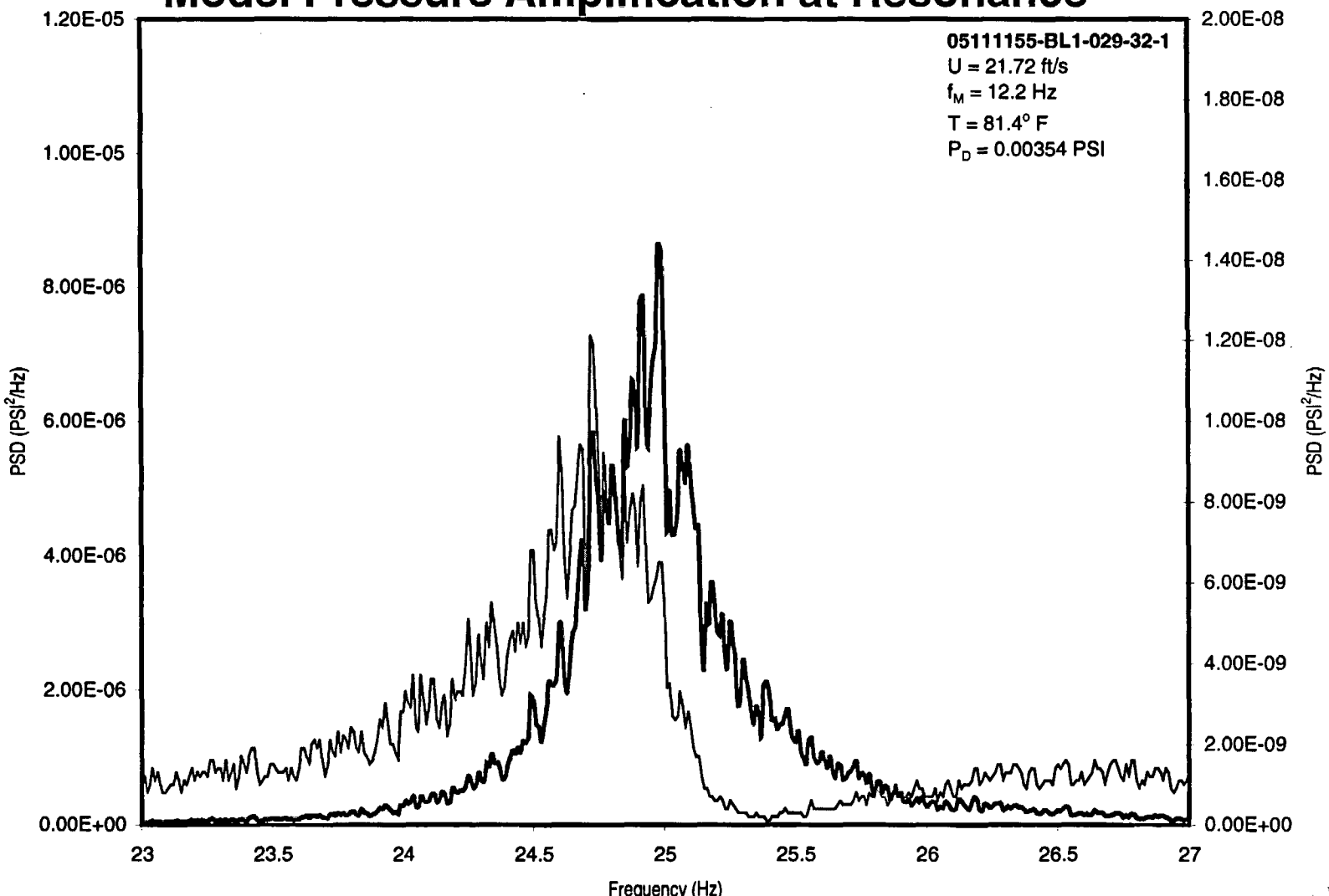

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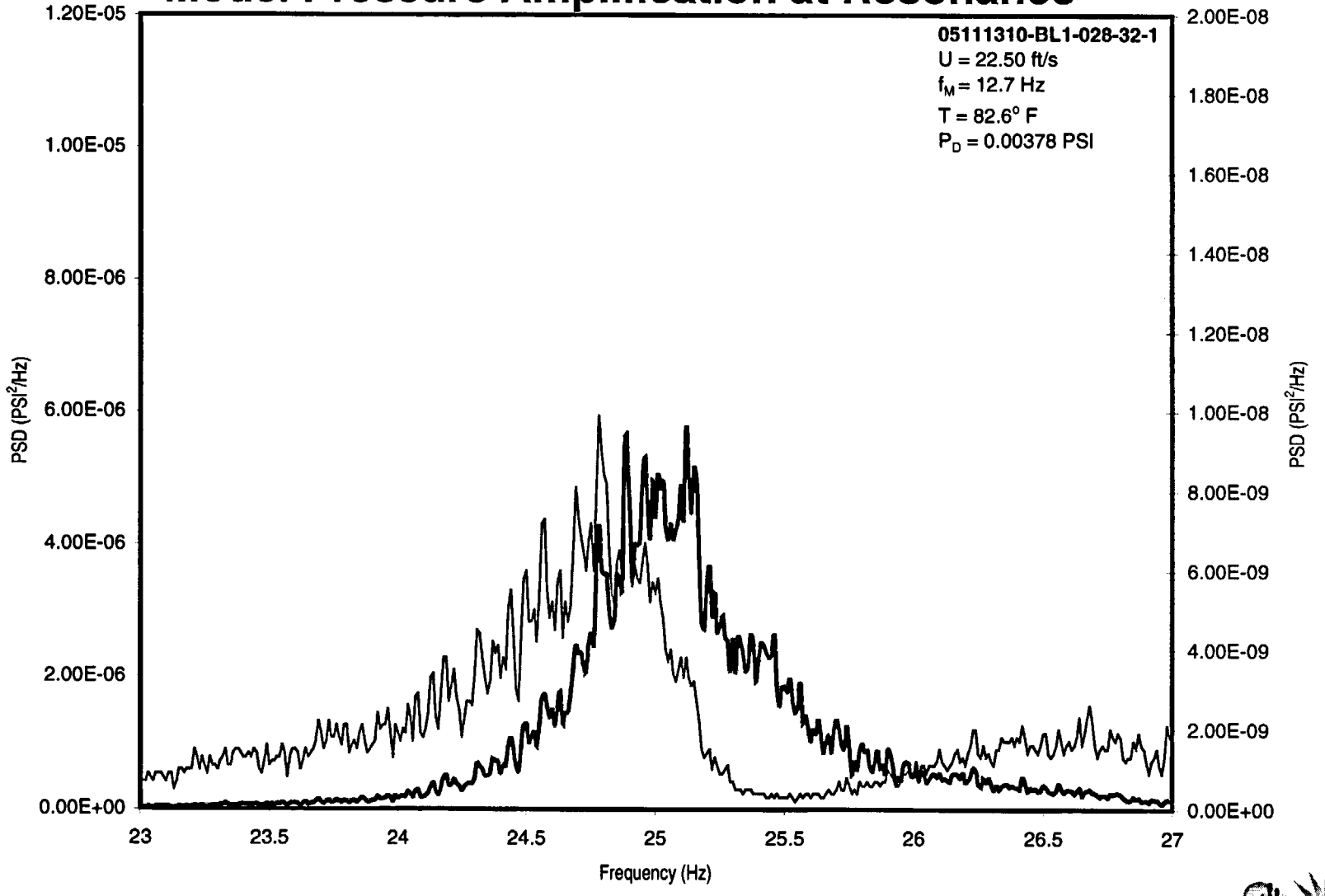

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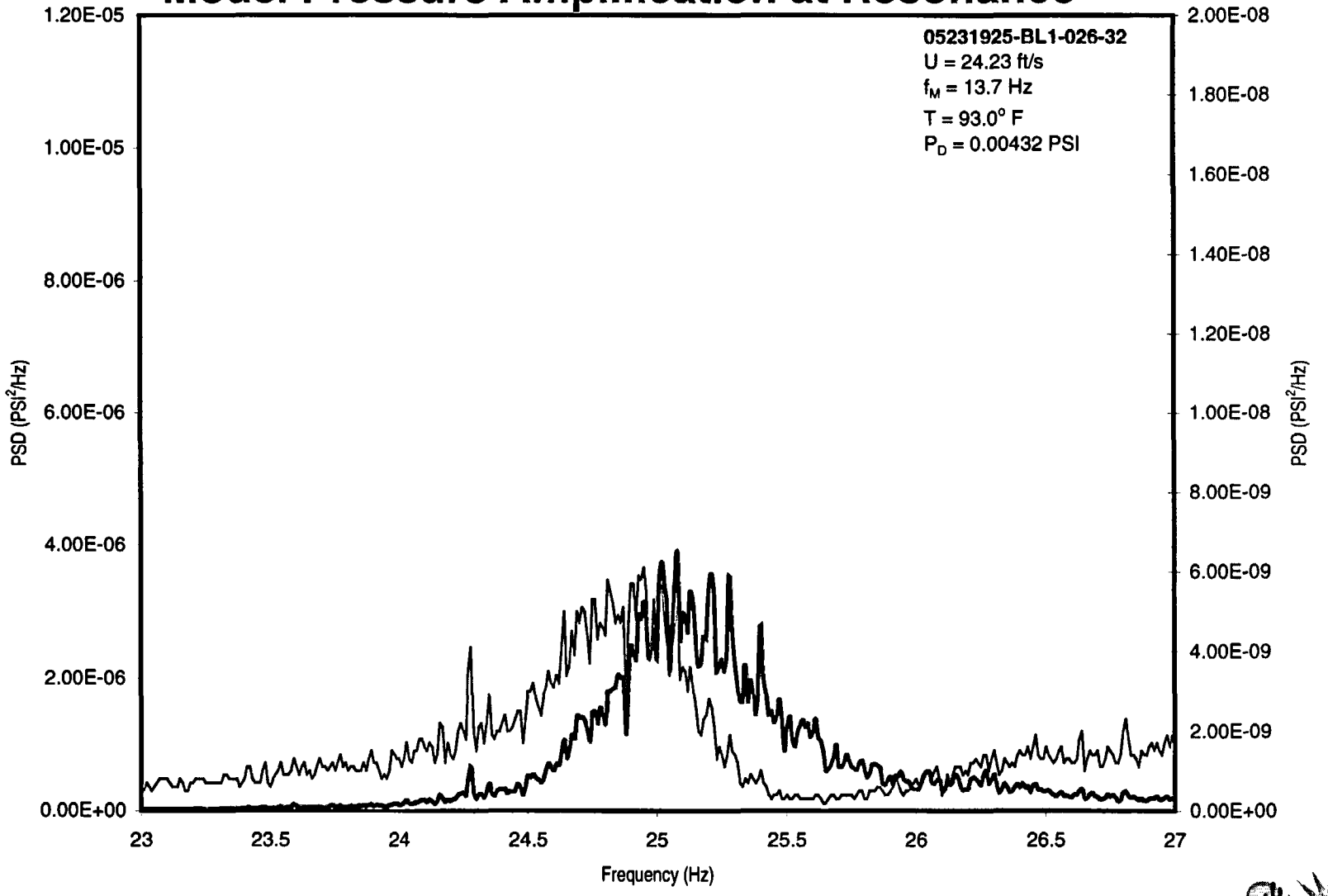

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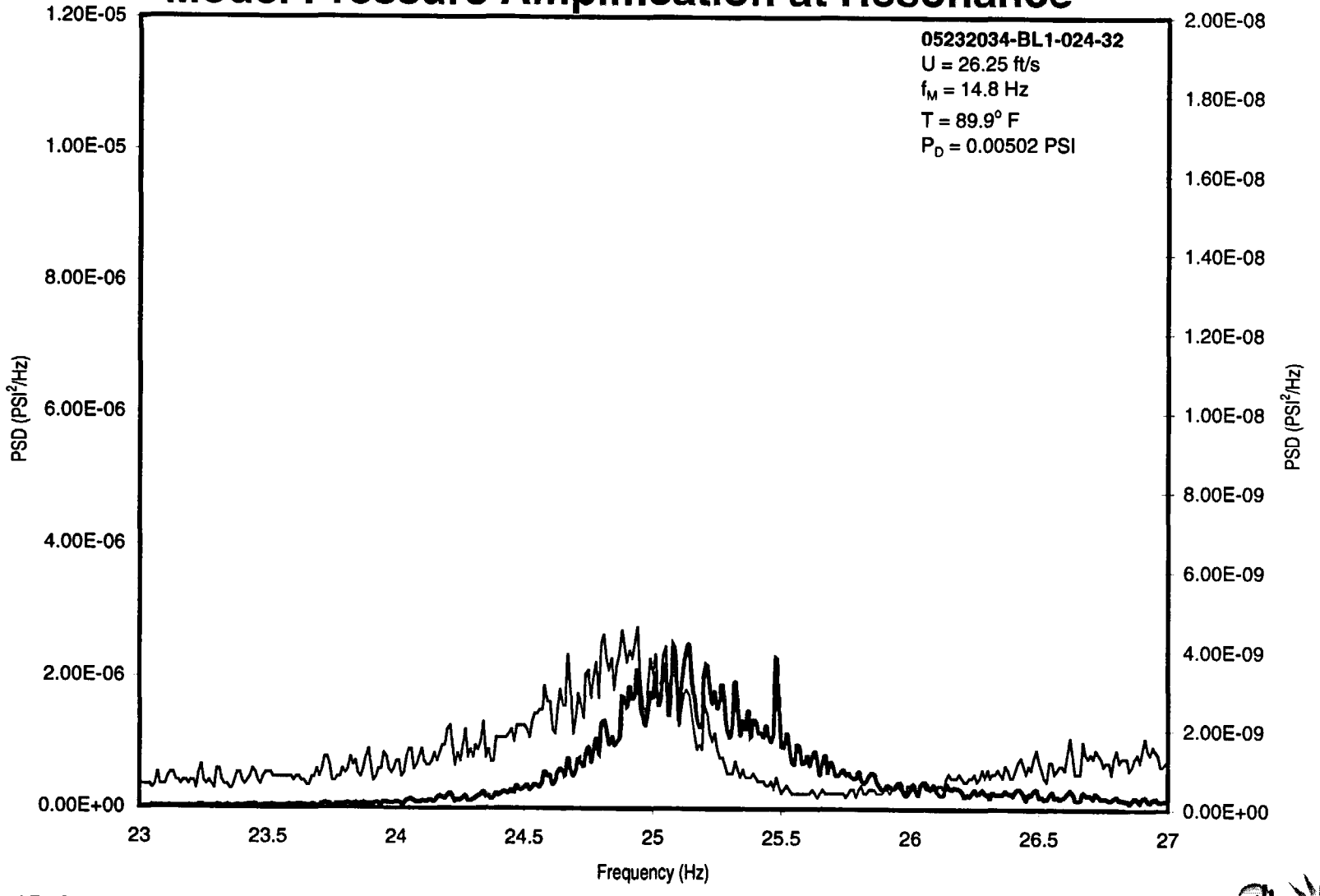
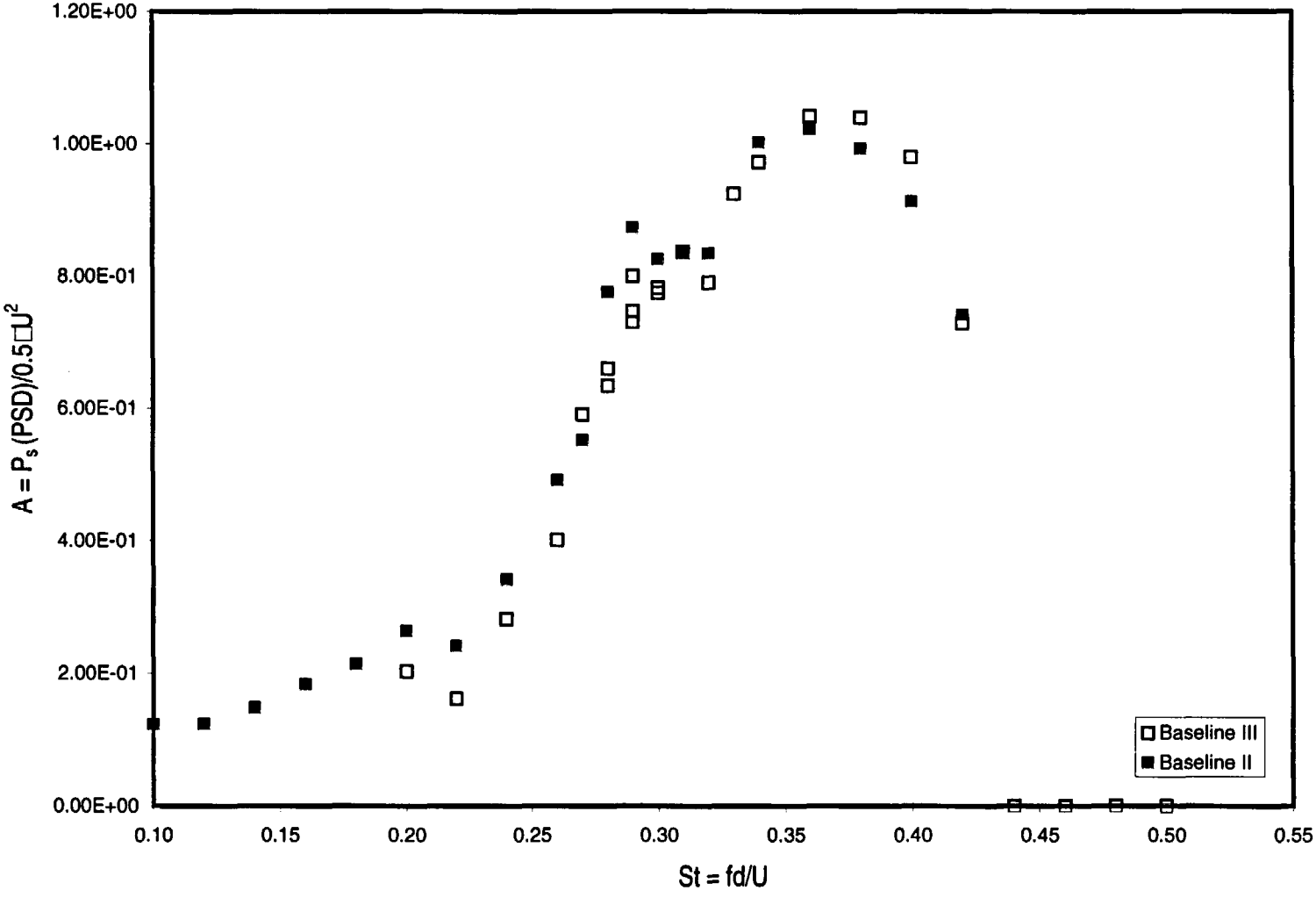


Phenomenological

ASU – Phase II

Normalized Model Acoustic Amplification



Modifications

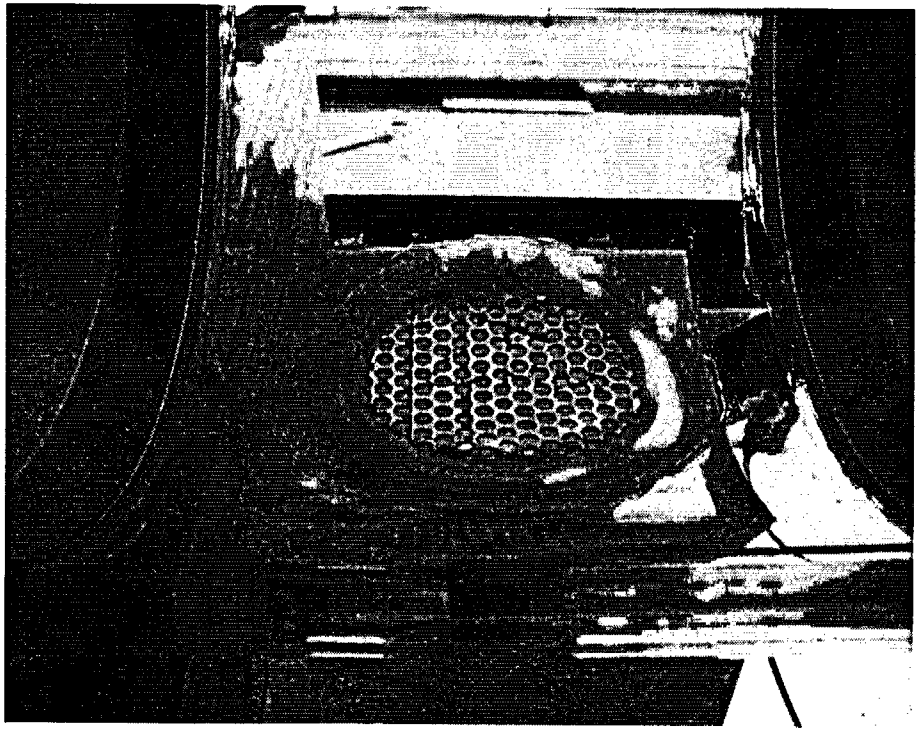
Modification Development and Selection

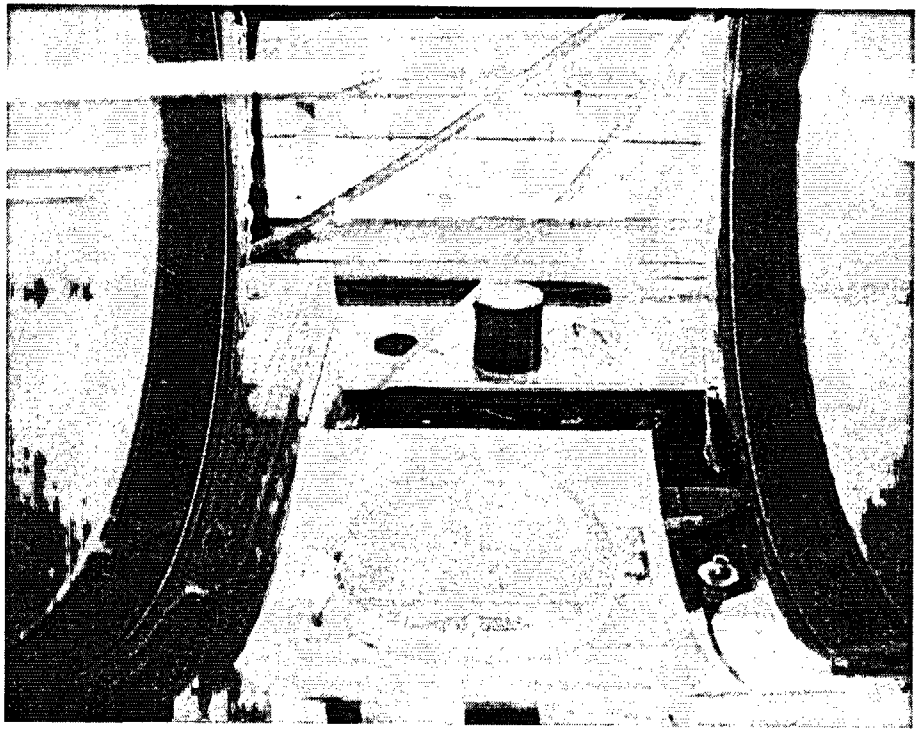
- Consultant and EPRI expert panel recommendations
- Approach predicated on flow-induced vibration hypothesis
- Modifications designed to de-couple acoustic process
  - Shift shedding frequency
  - Shift acoustic frequency
  - Modification of nozzle geometry is typical approach
    - Unable to quantify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

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

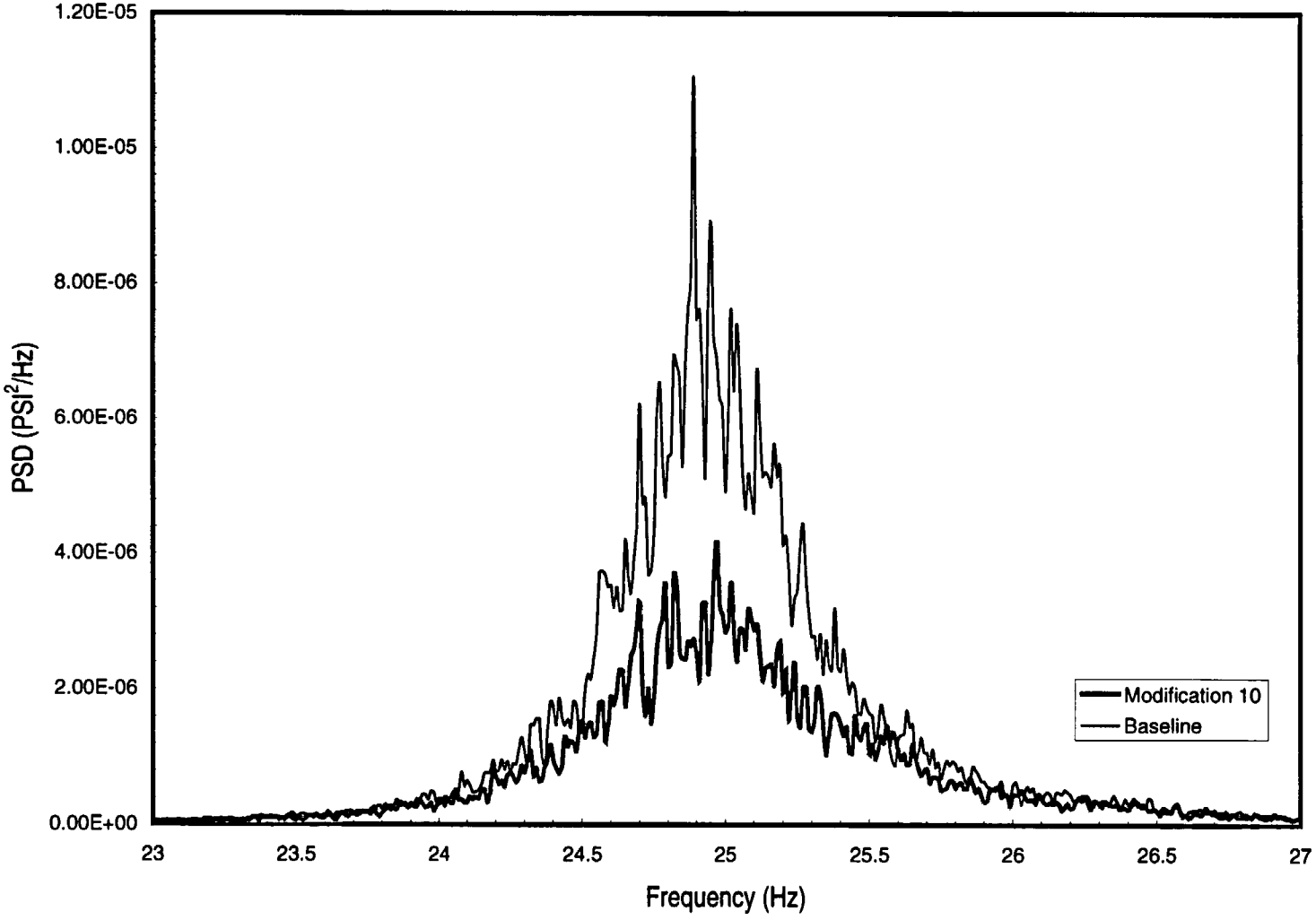
Modification Mock-Up Testing





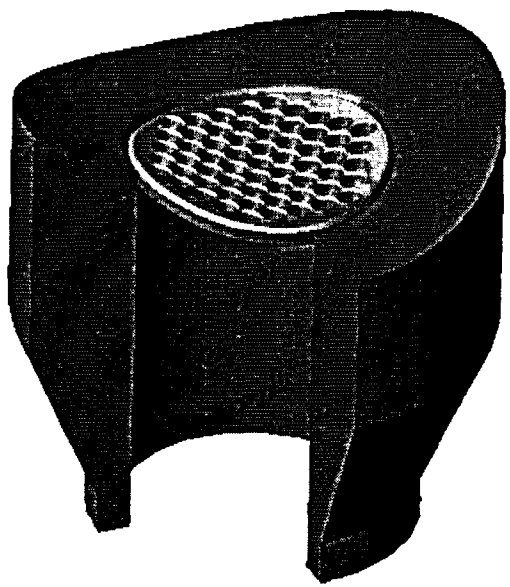
Vortex Plate Modification

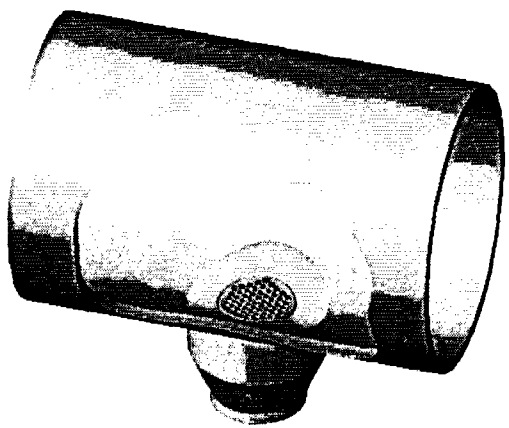
Reduction in Acoustic Pressure with Vortex Plate Model



Vortex Plate Modification

- **U1R12 final modification – grid plate**

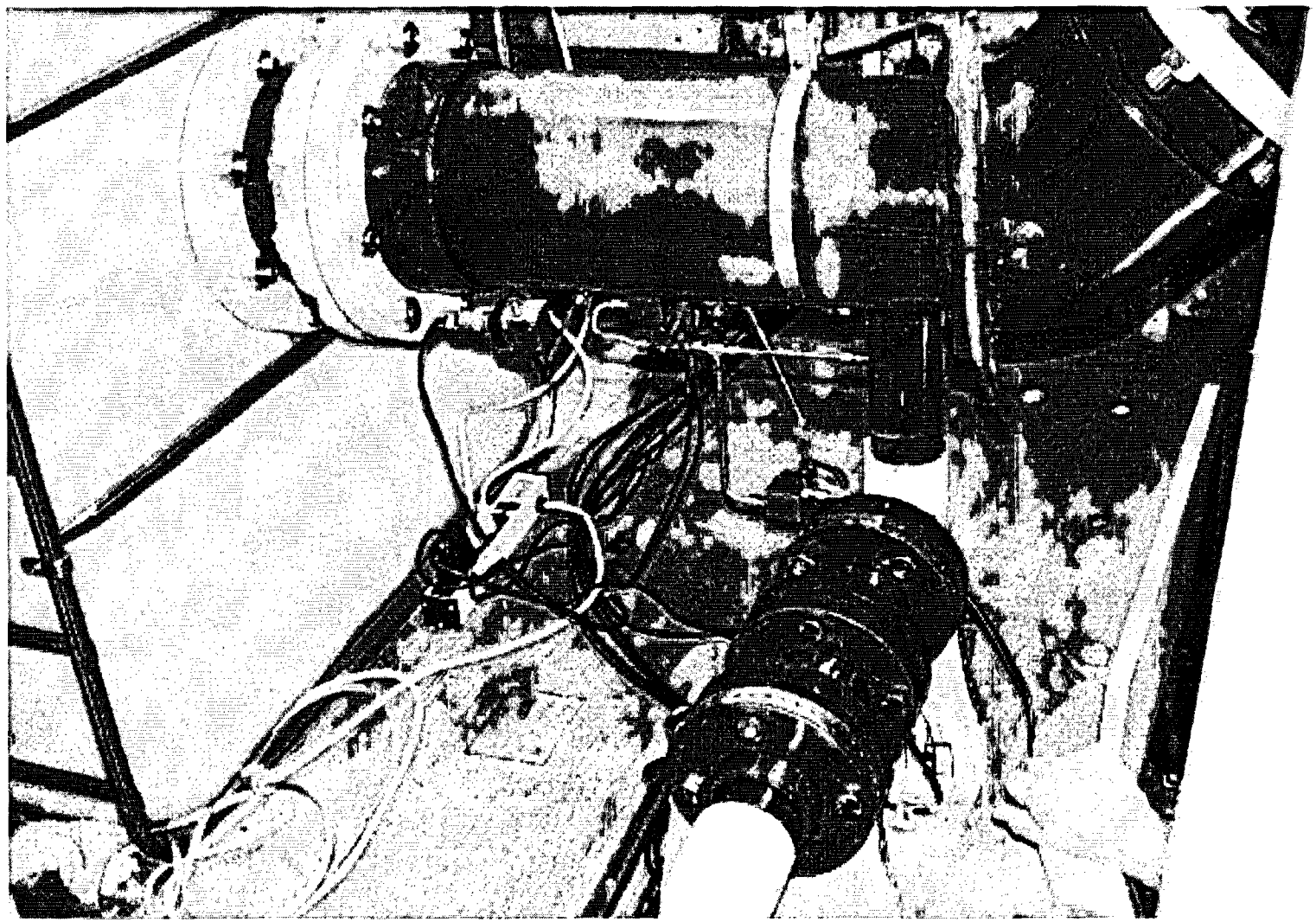




Vortex Plate Modification

- **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



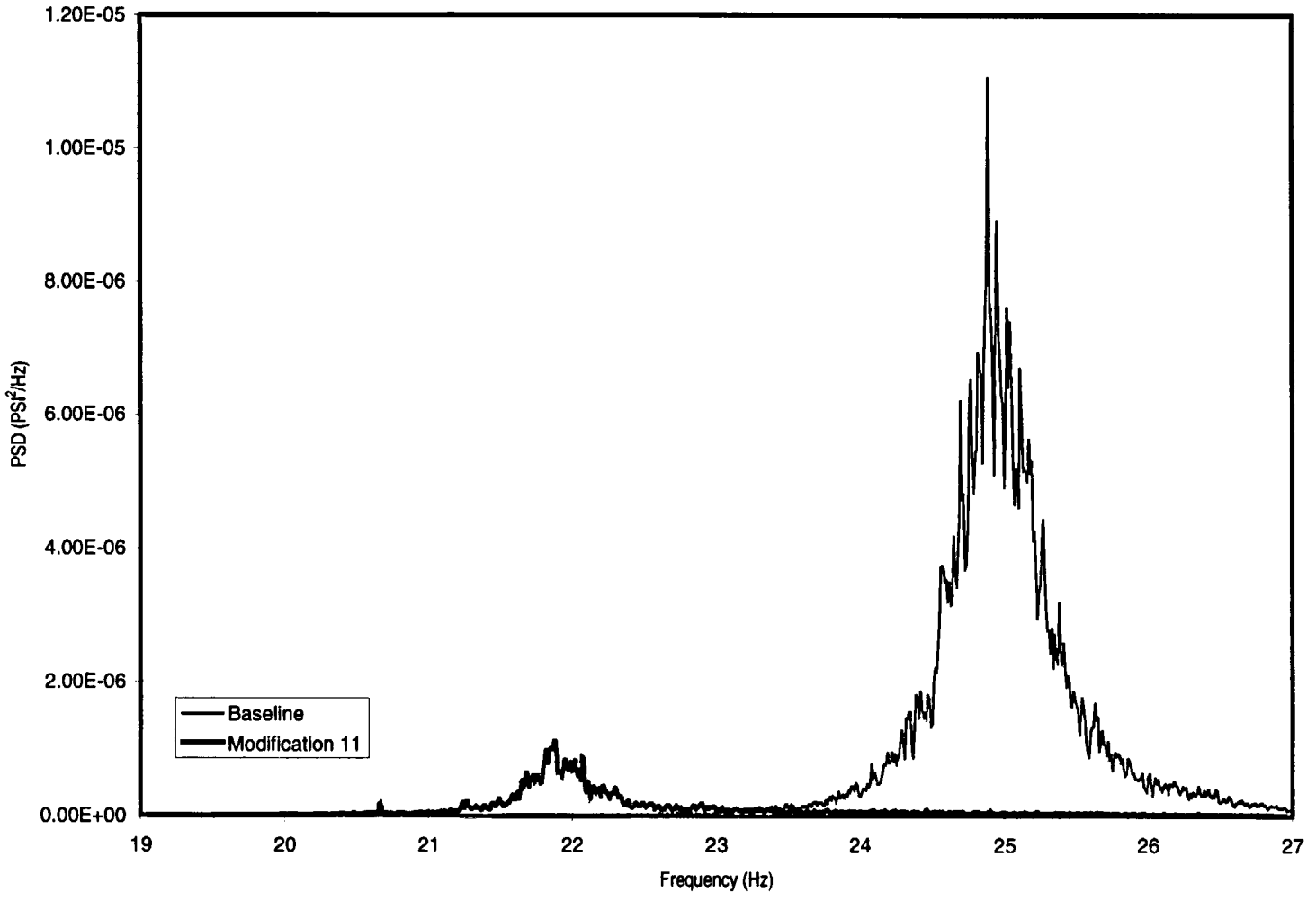
Final Modification – Isolation Valve Relocation

Final Modification – Isolation Valve Relocation

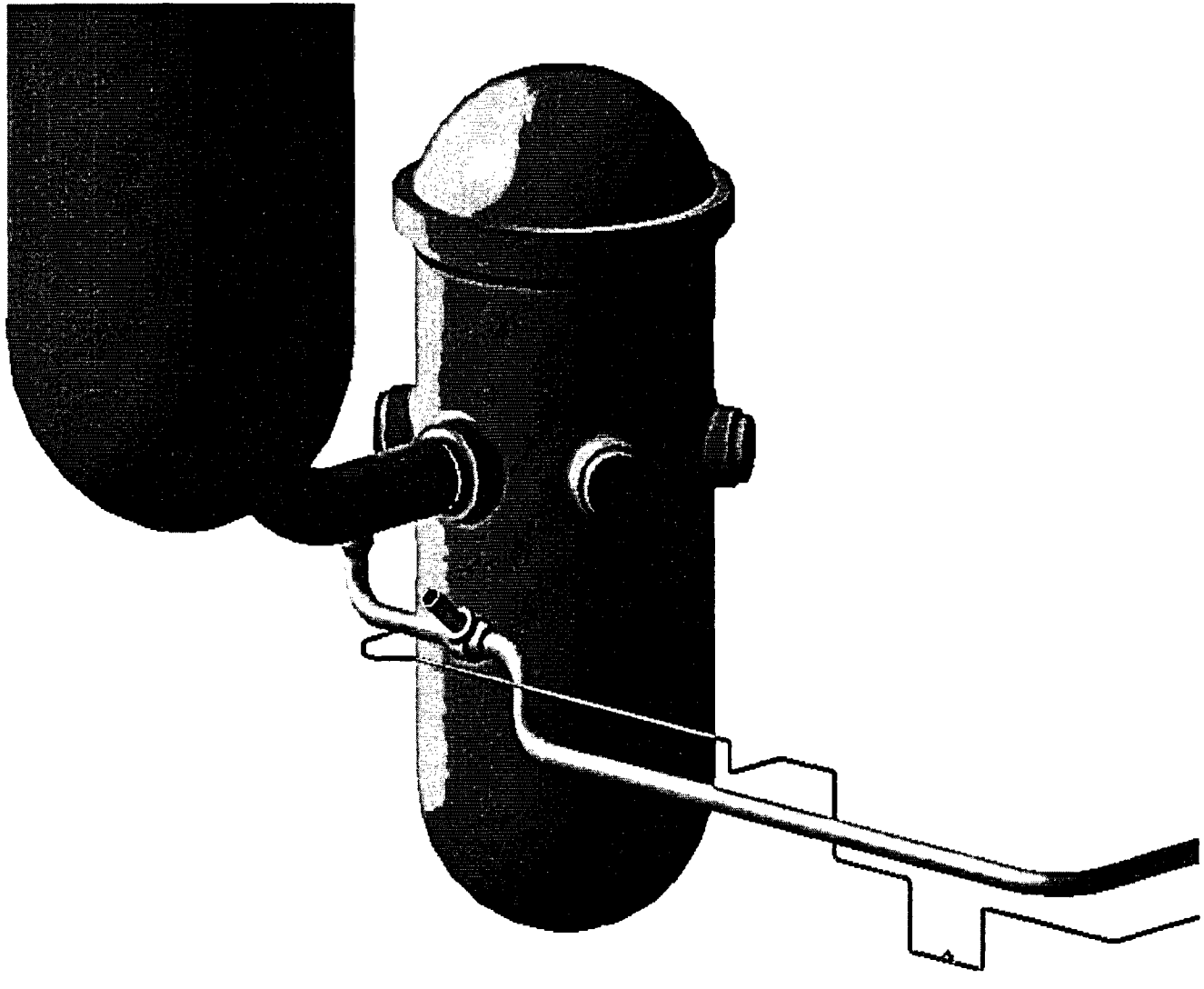
- Modification proposed by consultants and EPRI expert panel
- Arizona State University testing demonstrated significant reduction in pressure amplitude
- Valve relocation towards RCS to increase acoustic frequency away from shedding modes and pipe modes

Final Modification – Isolation Valve Relocation

Model Suction Pressure Amplification with Relocated Valve



Final Modification – Isolation Valve Relocation



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

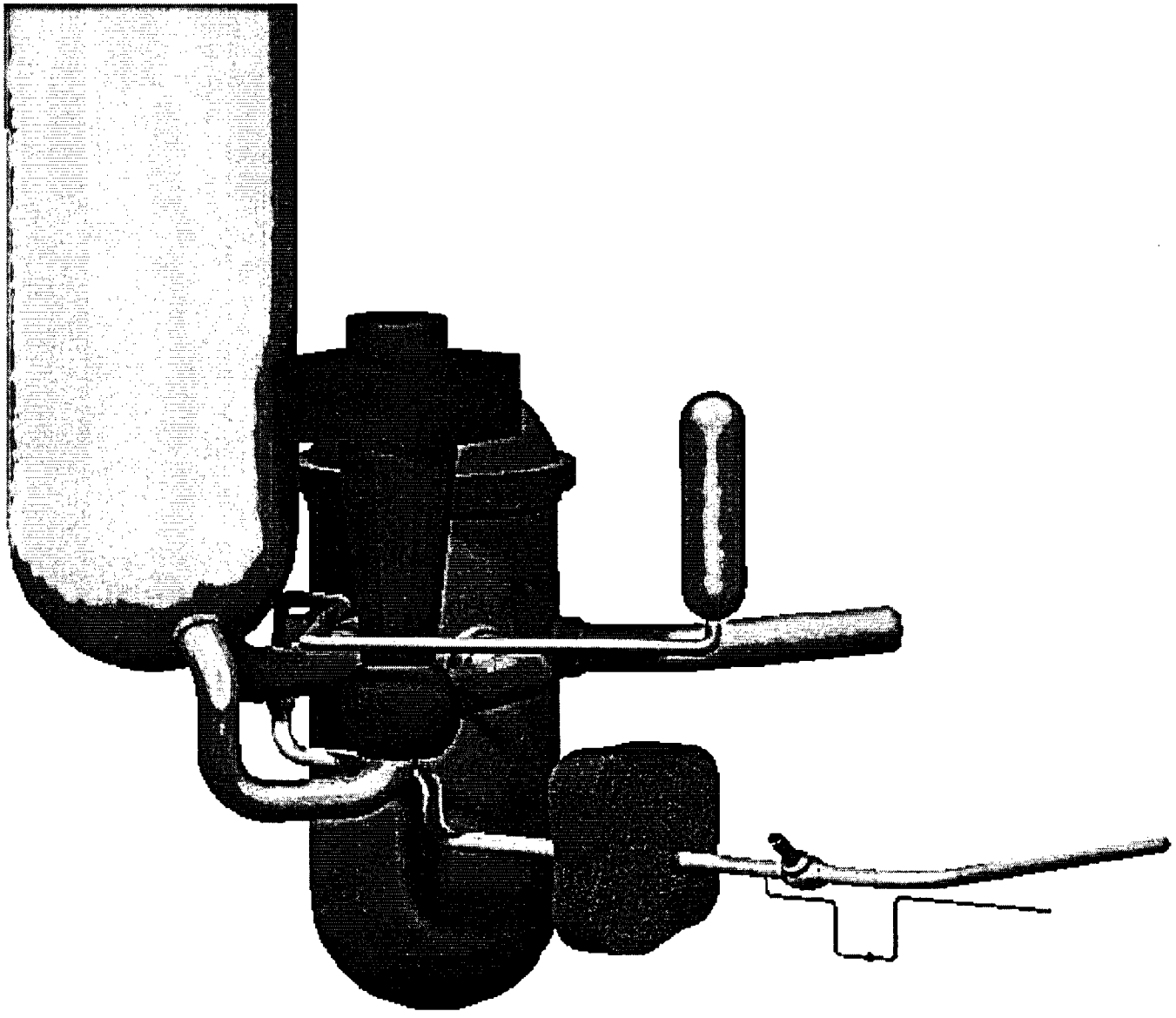
Modification Activities

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

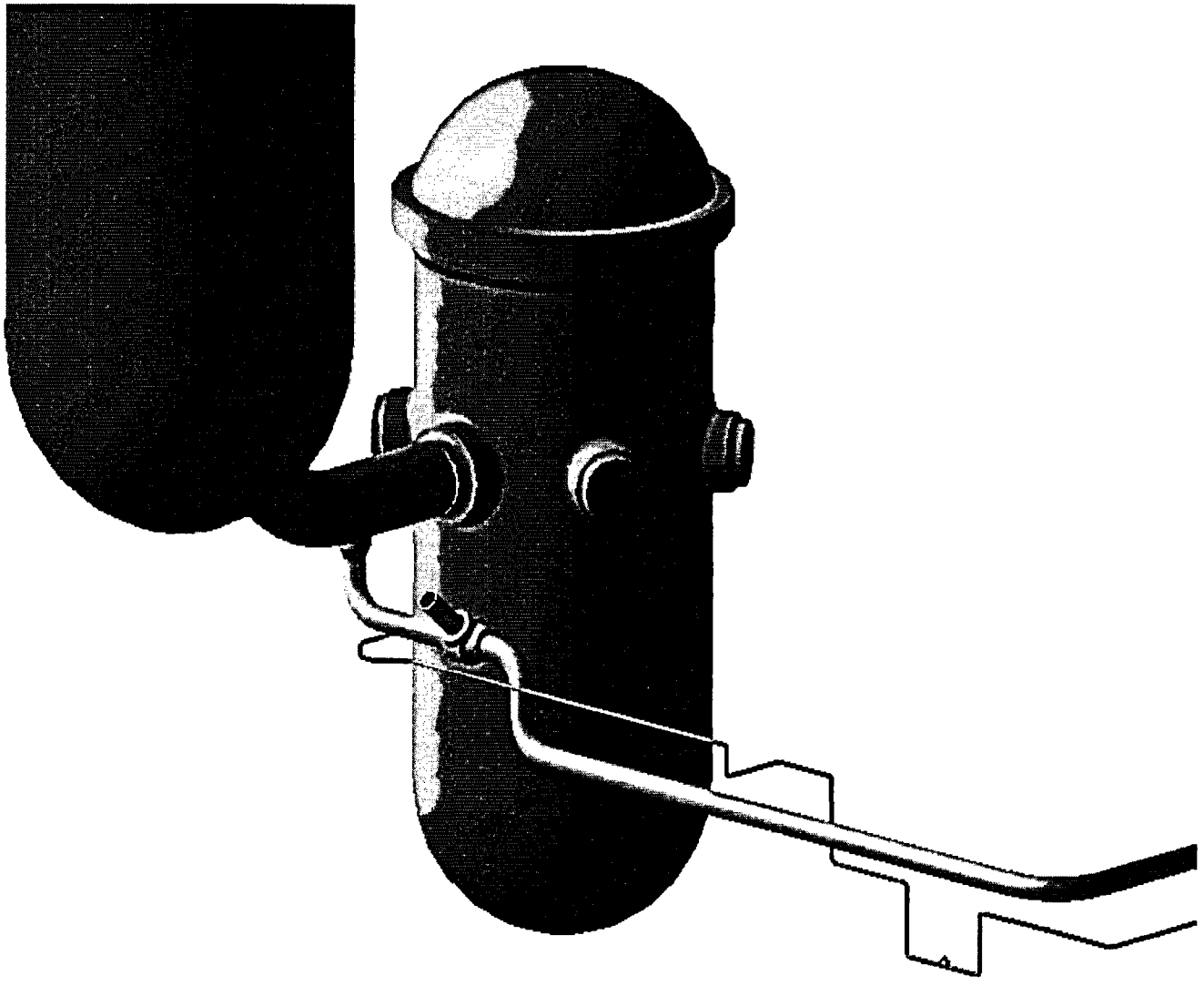
Status

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



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**

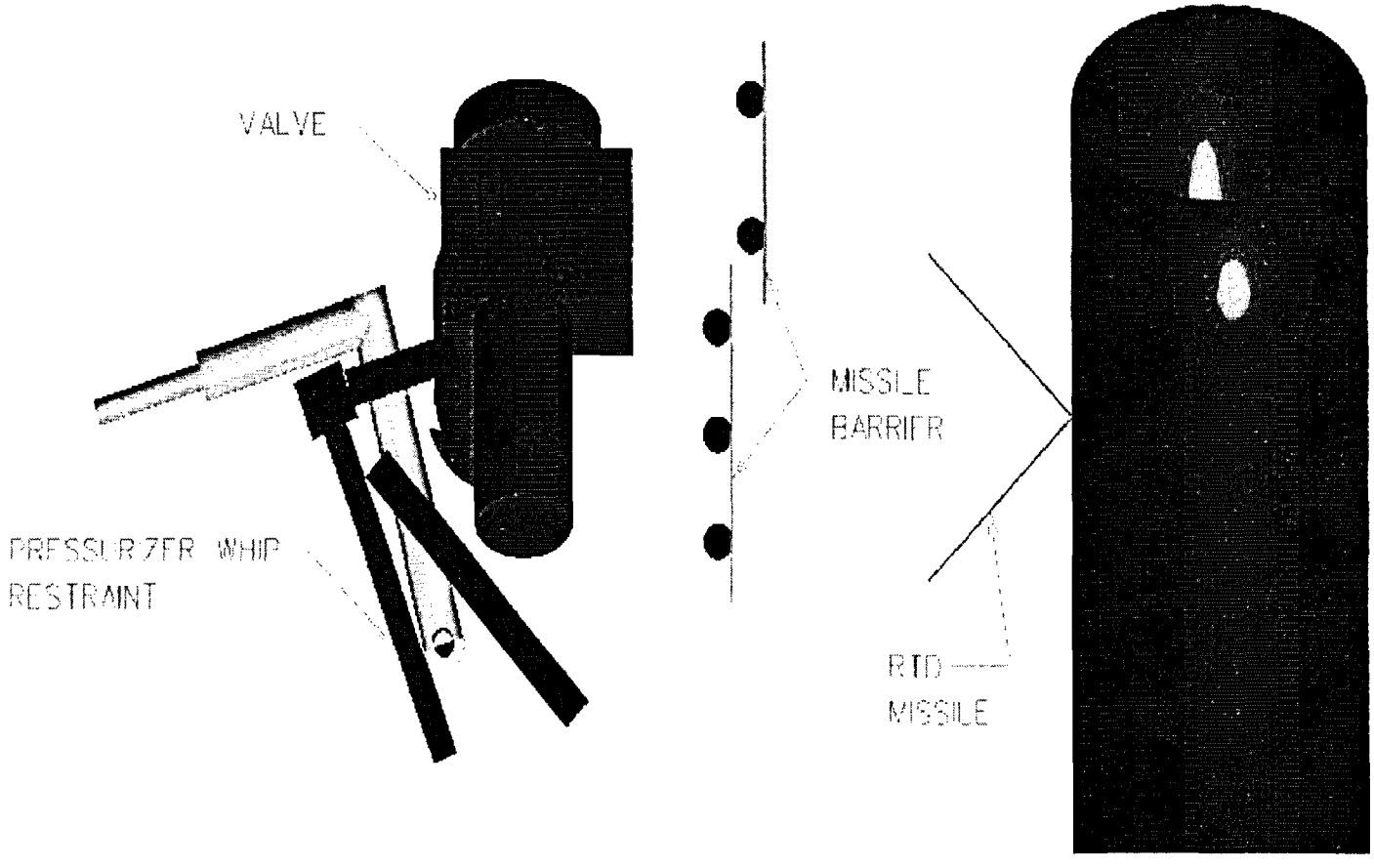
EQ : Post Accident Environment

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**


VALVE
MISSILE
BARRIER
PRESSURIZER WHIP
RESTRAINT
RTD
MISSILE

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**

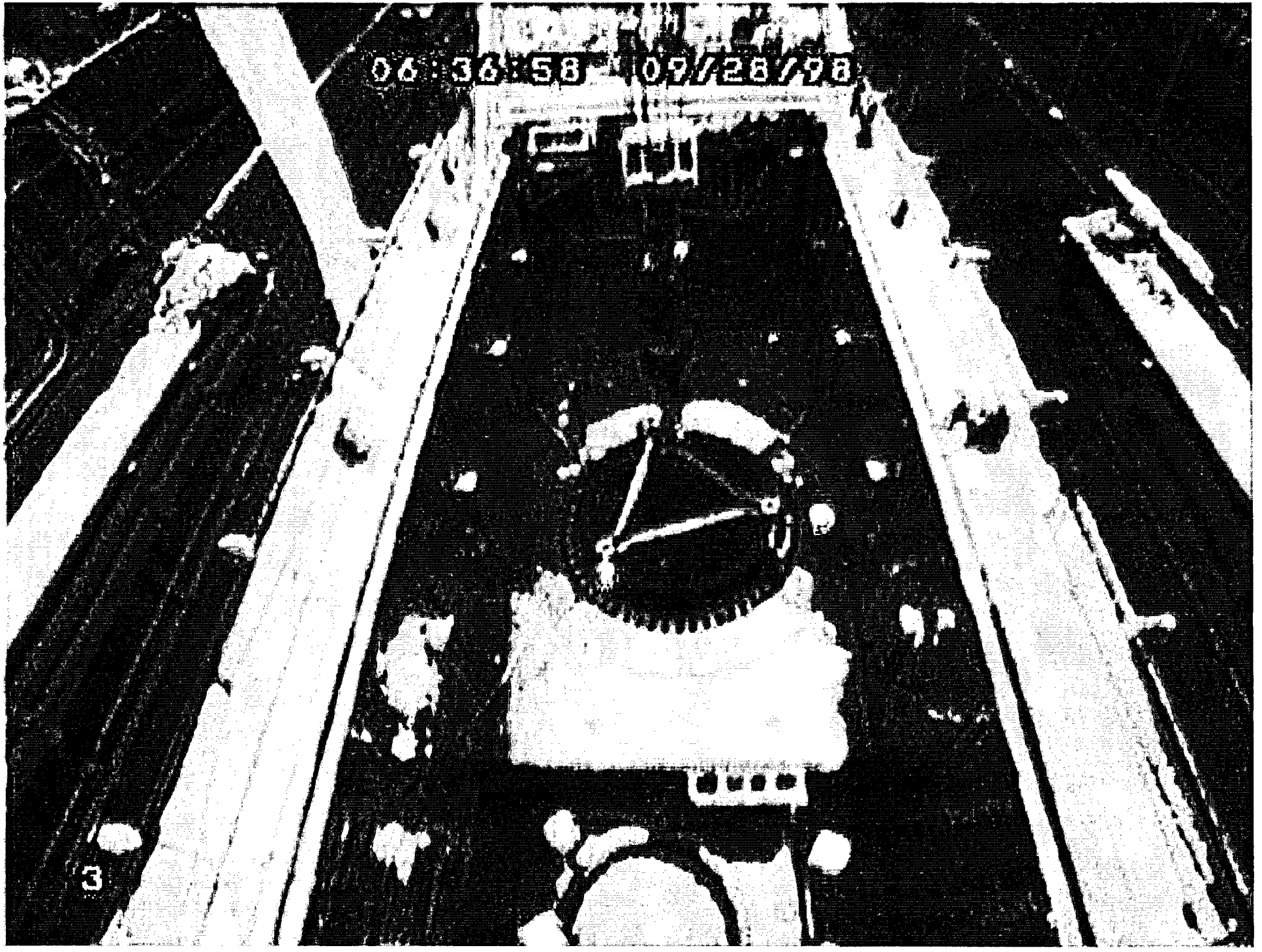
NRC Approval/Relief Request

- 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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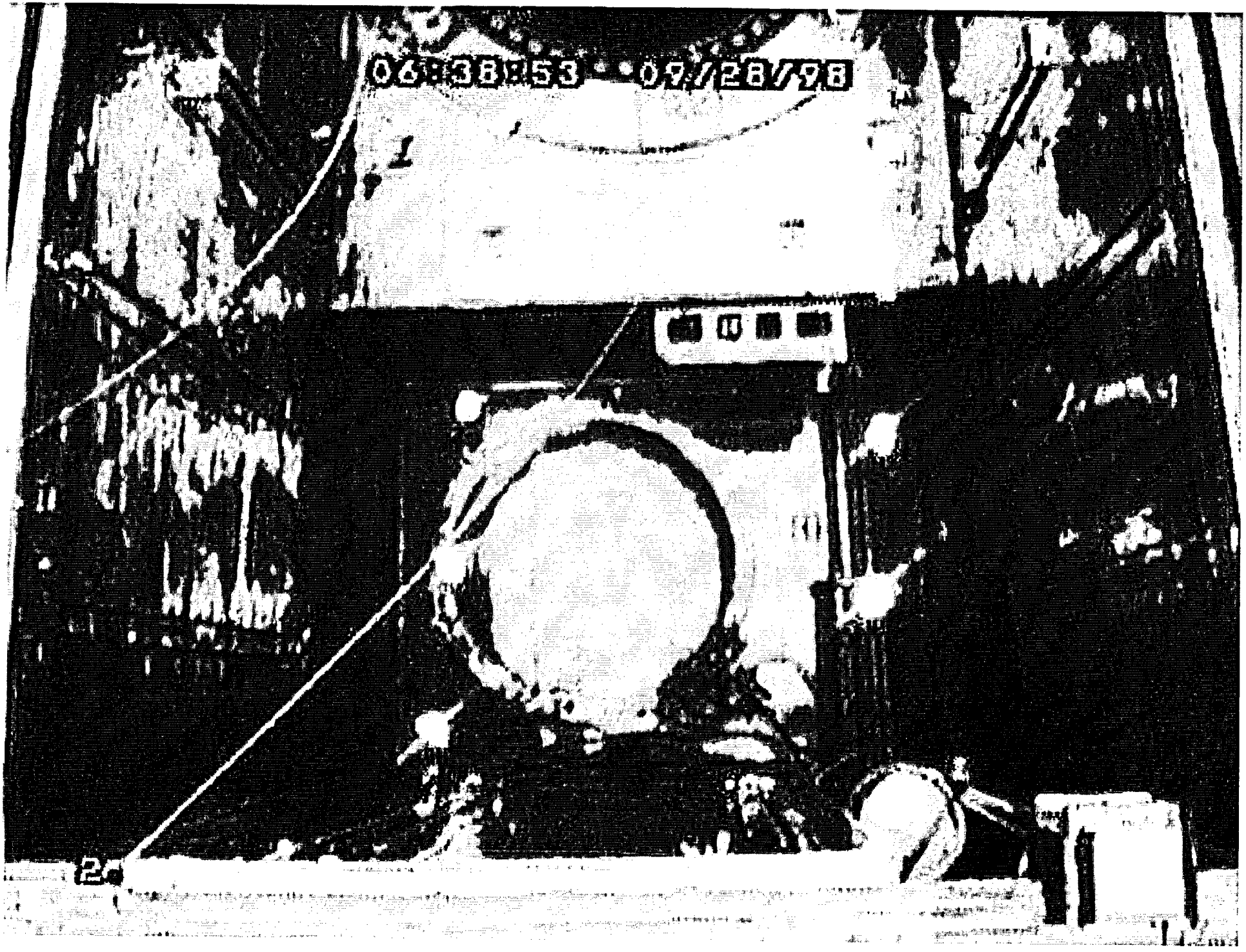
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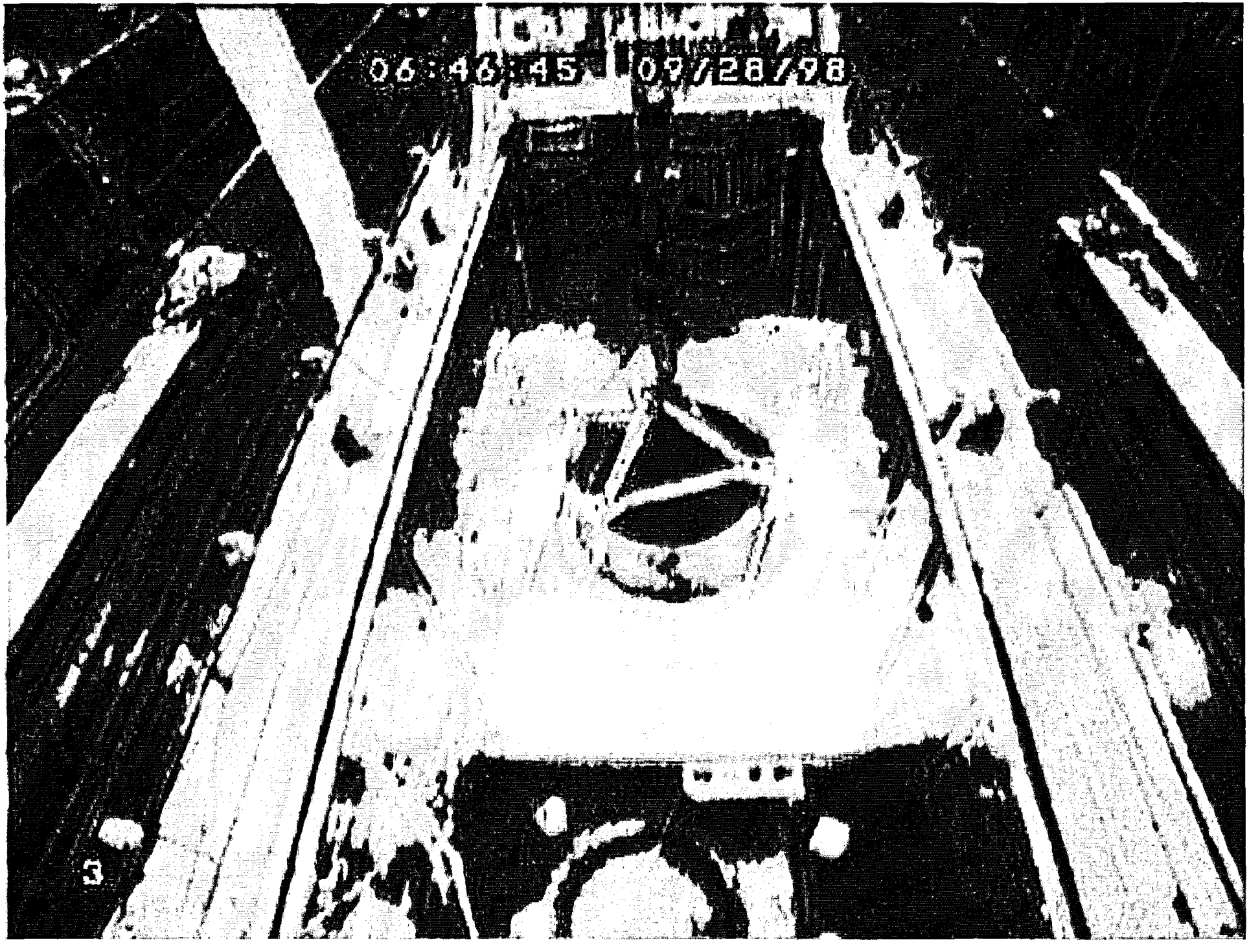
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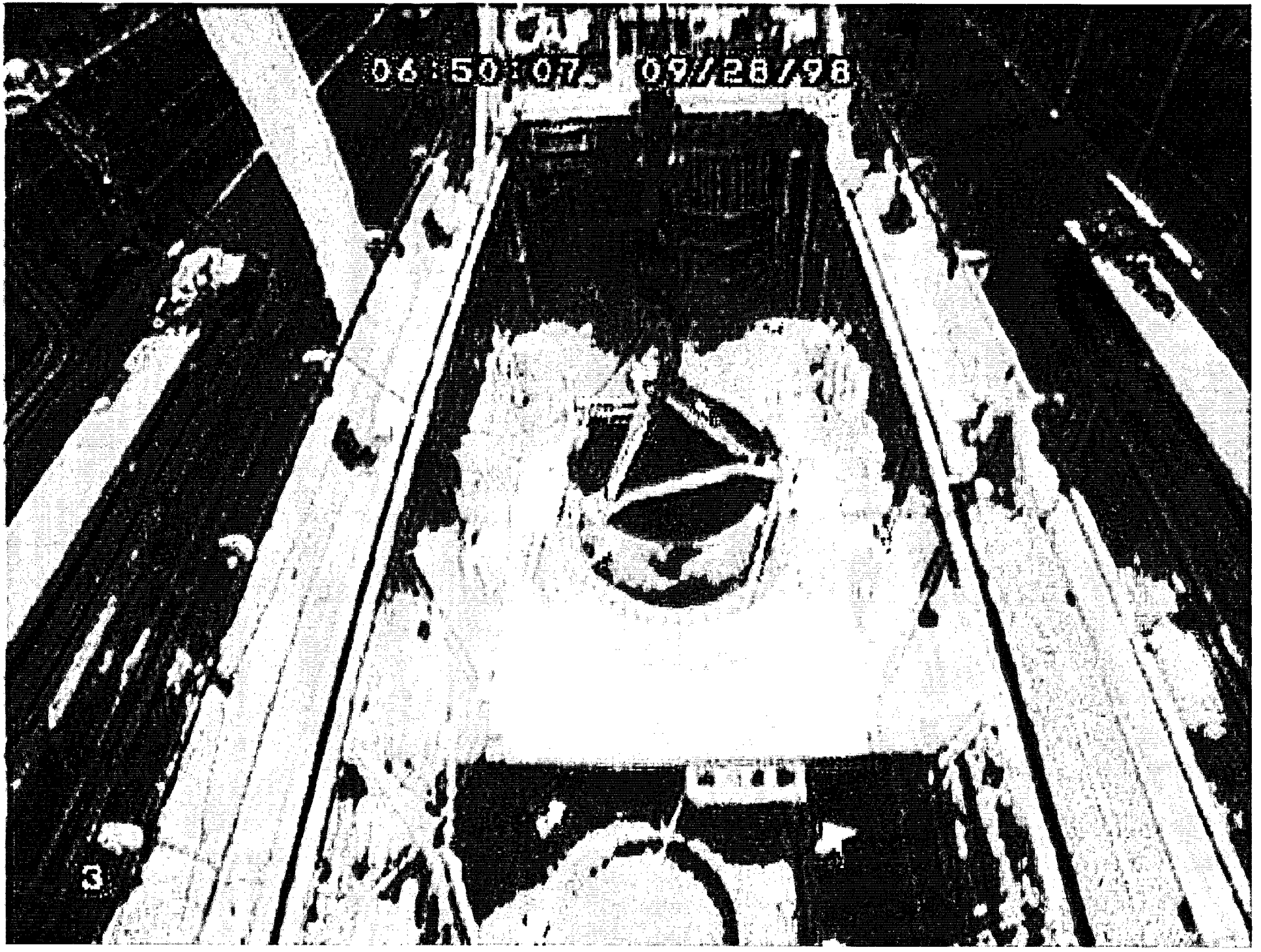
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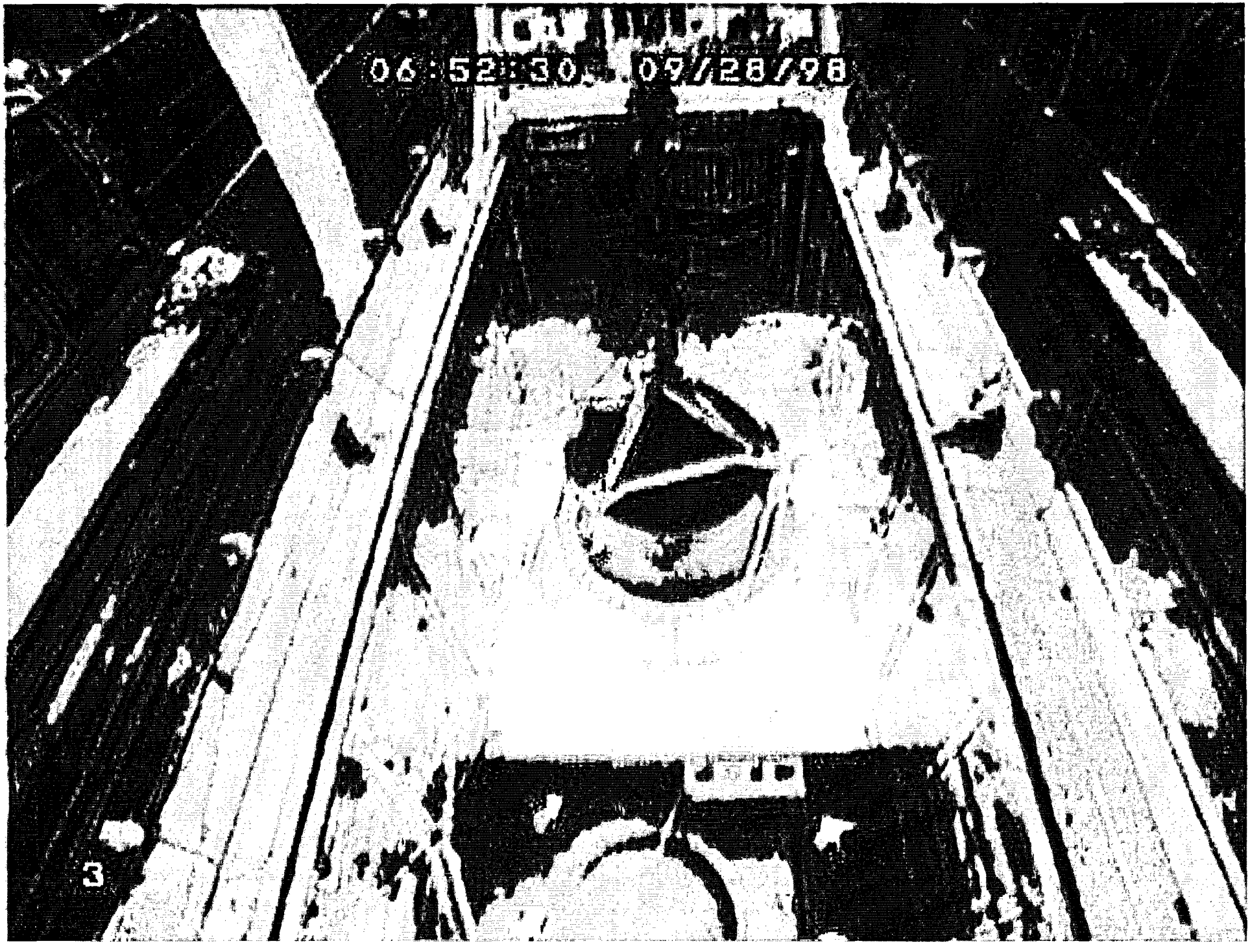
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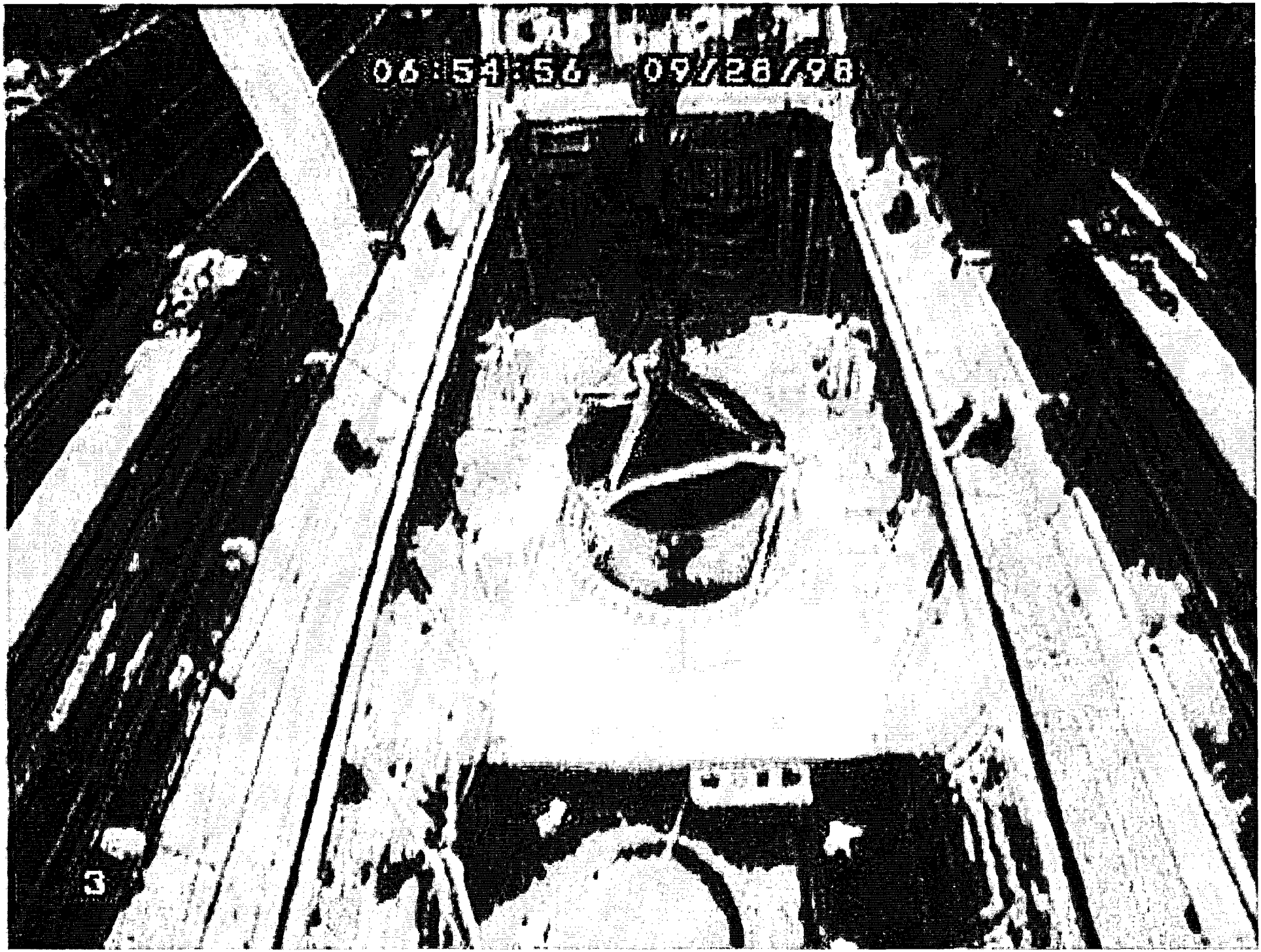
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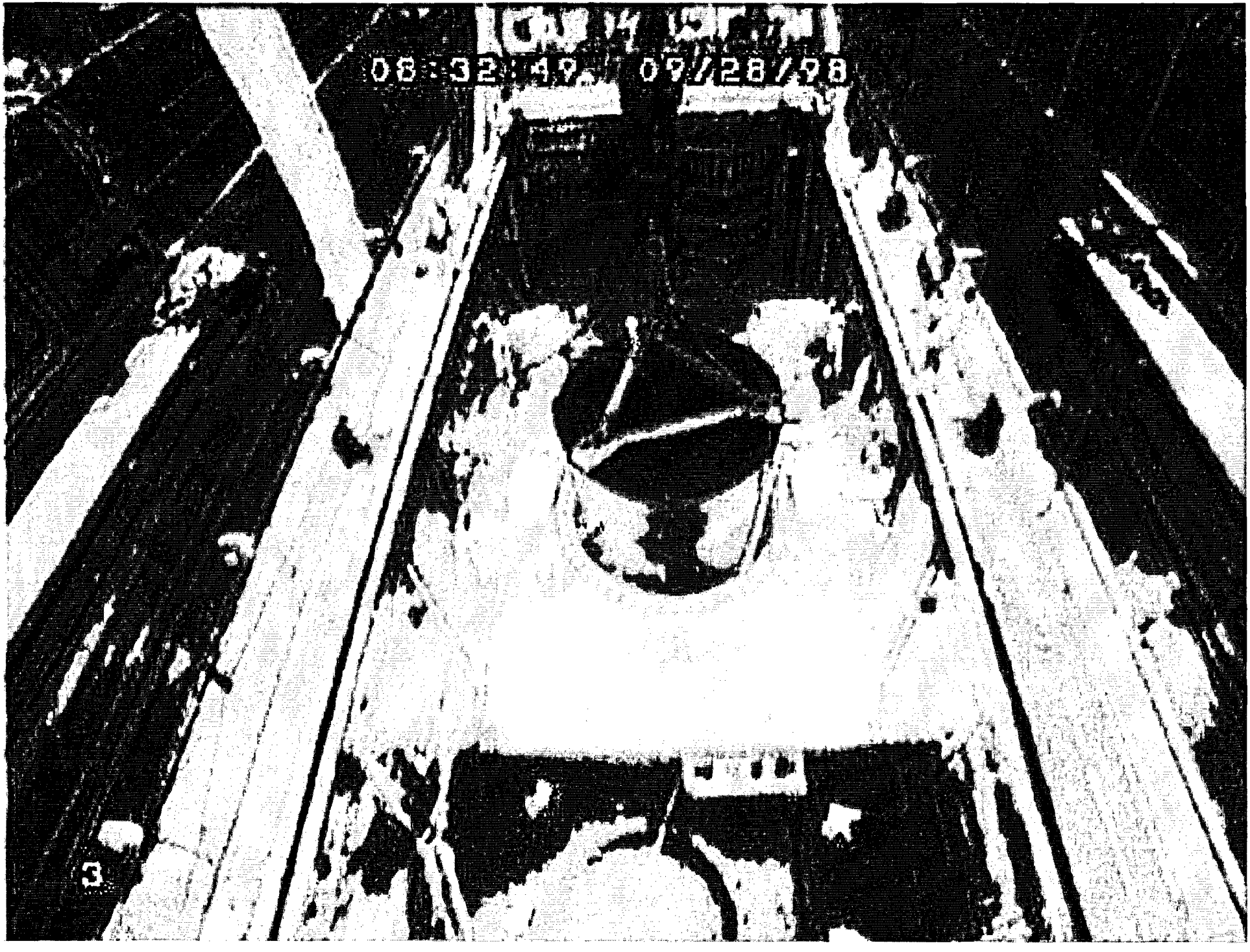
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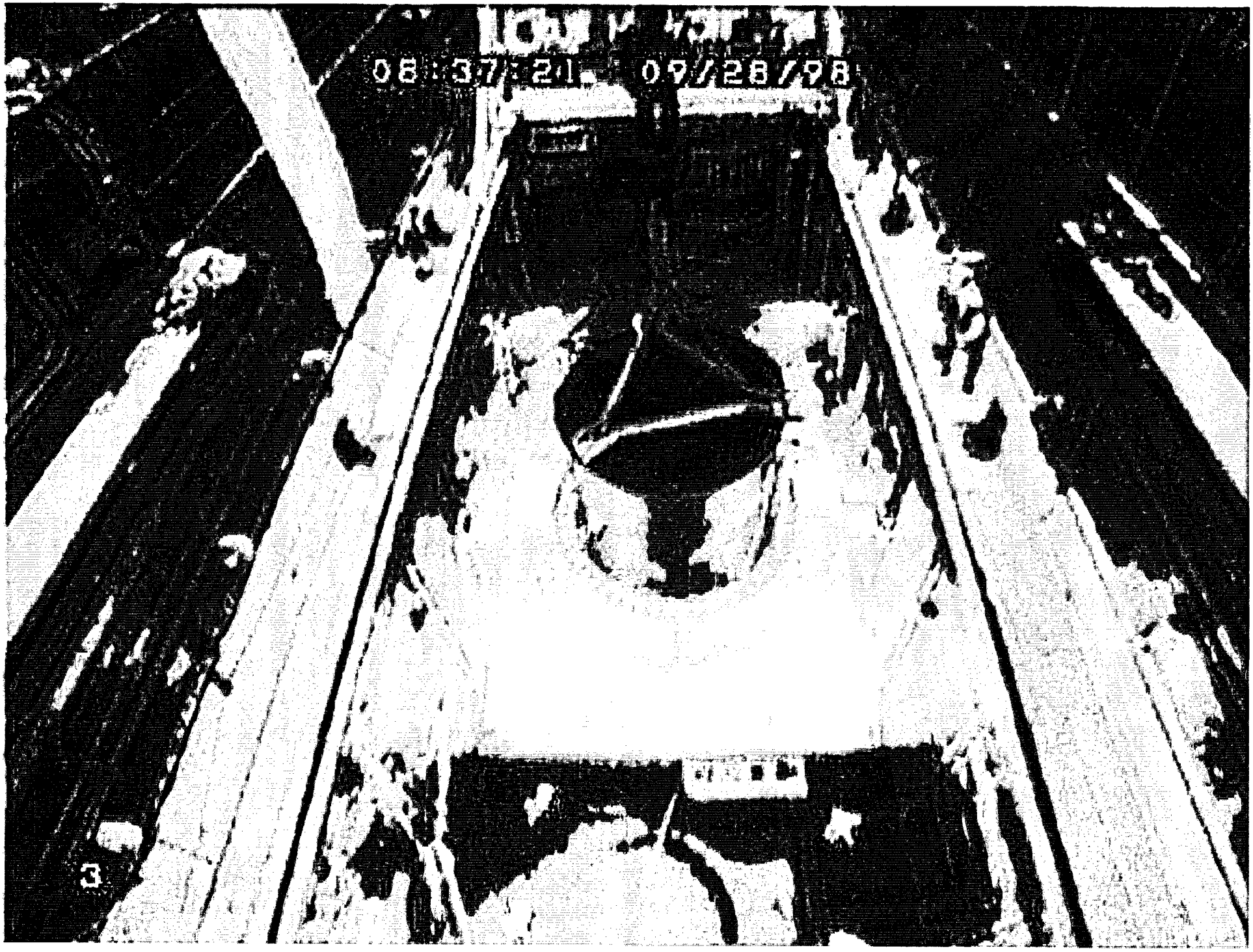
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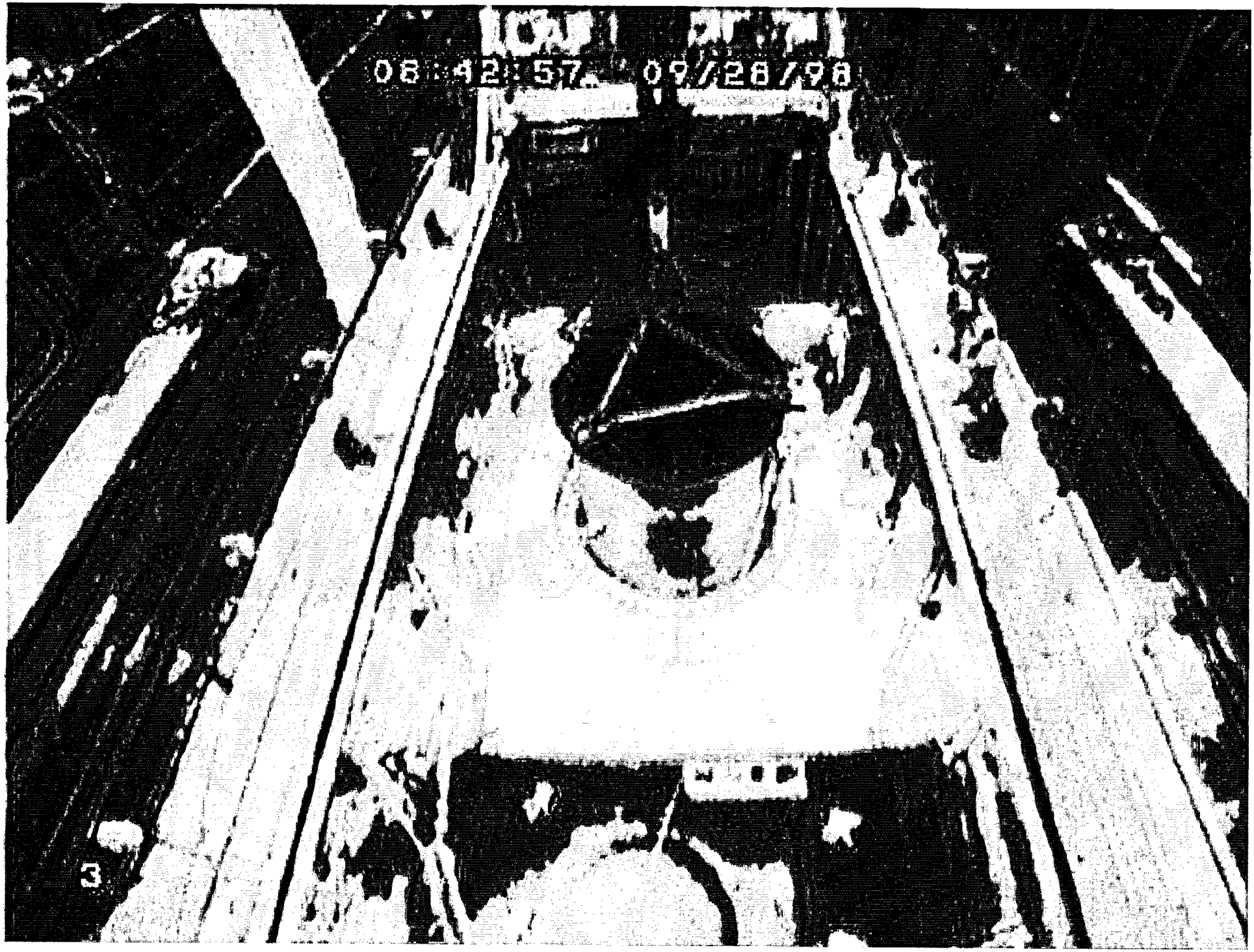
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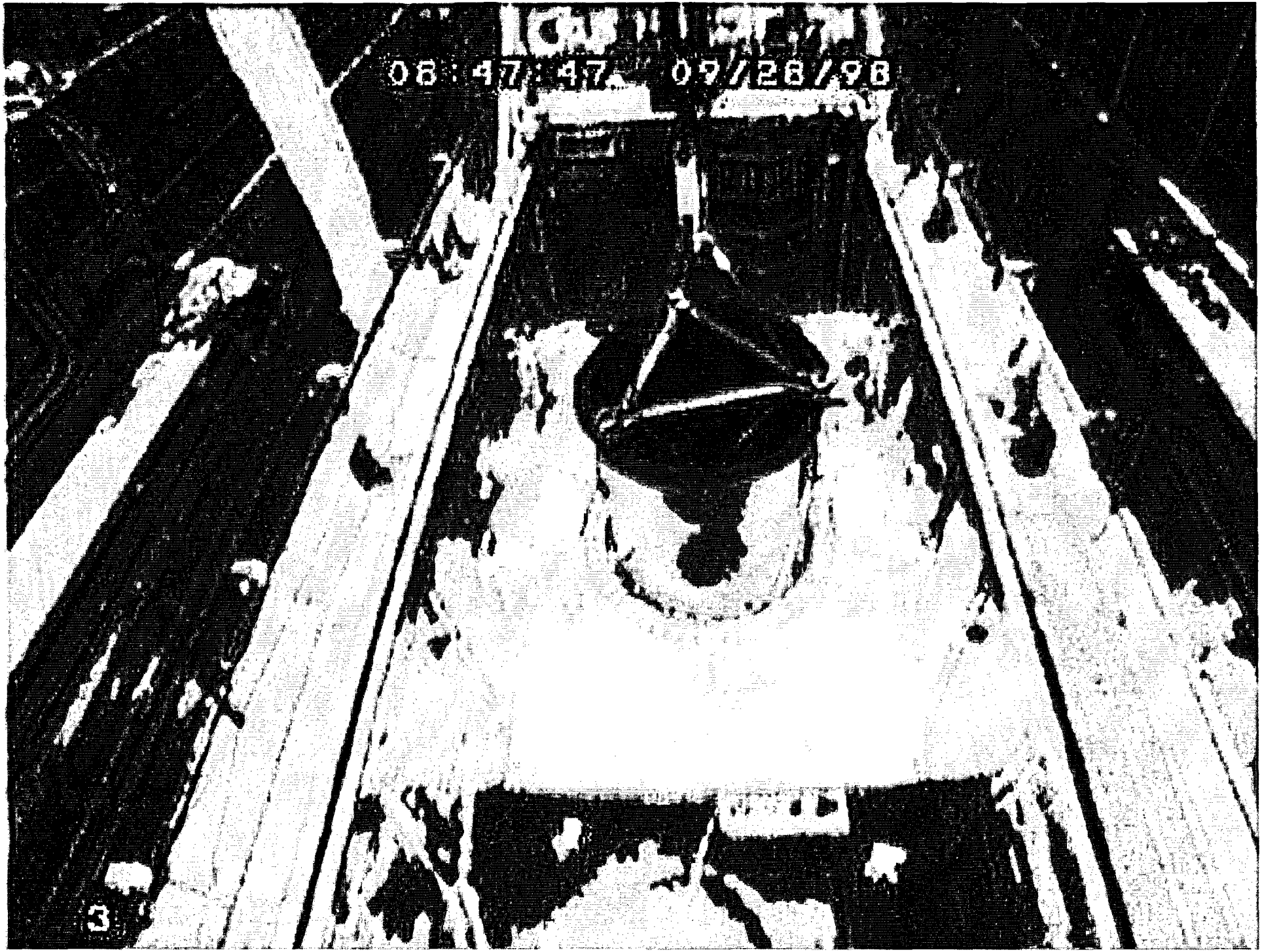
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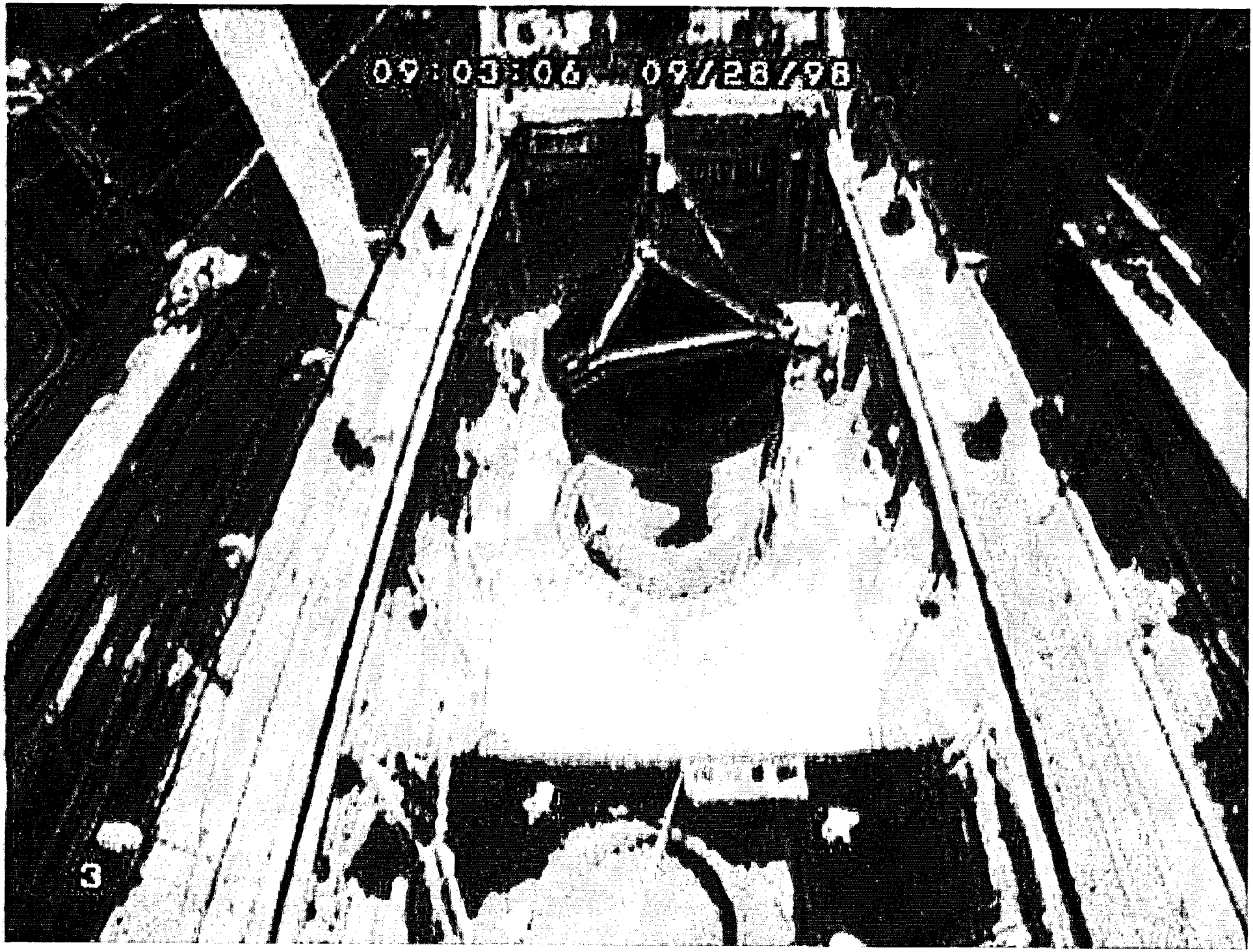
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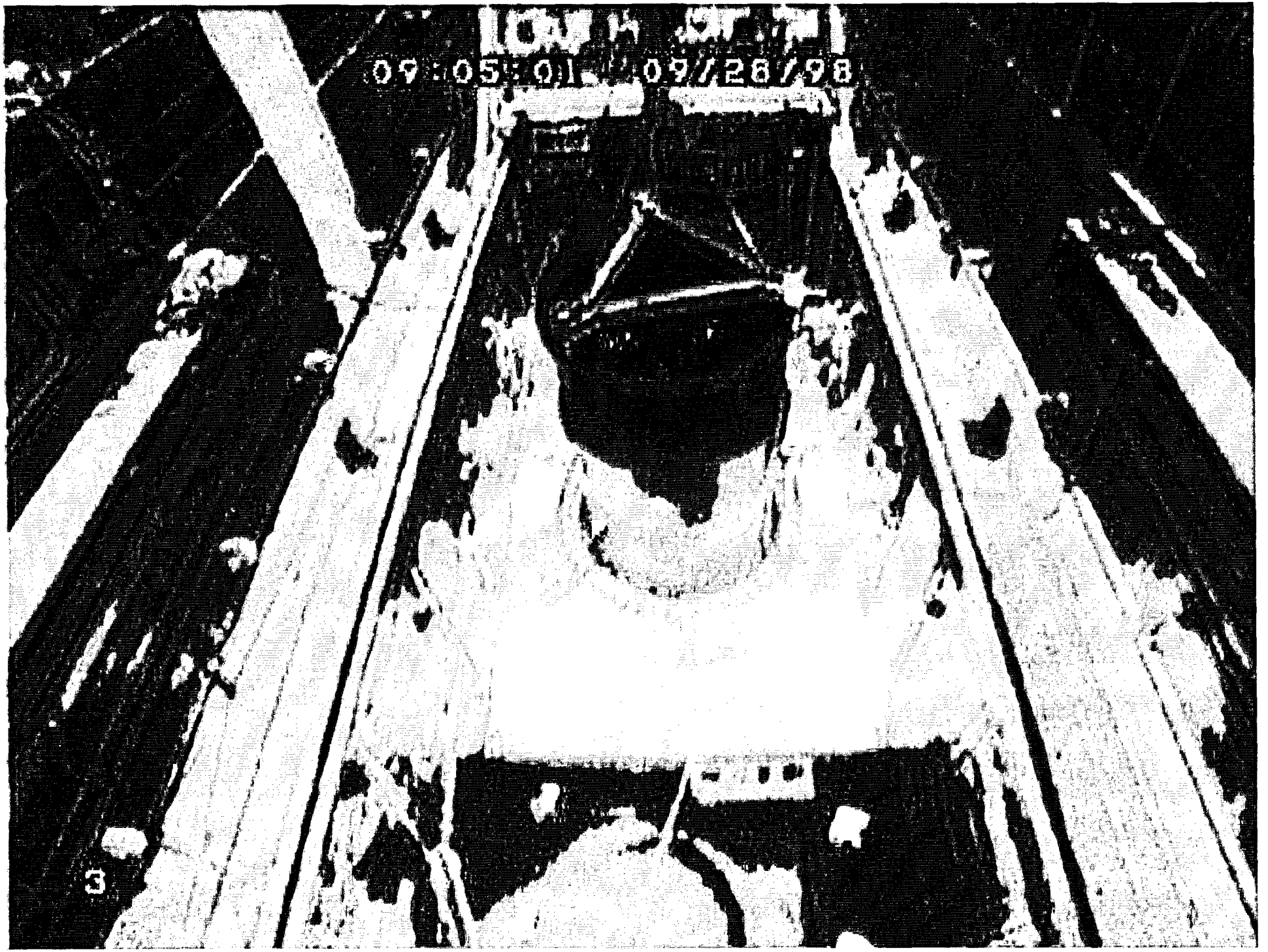
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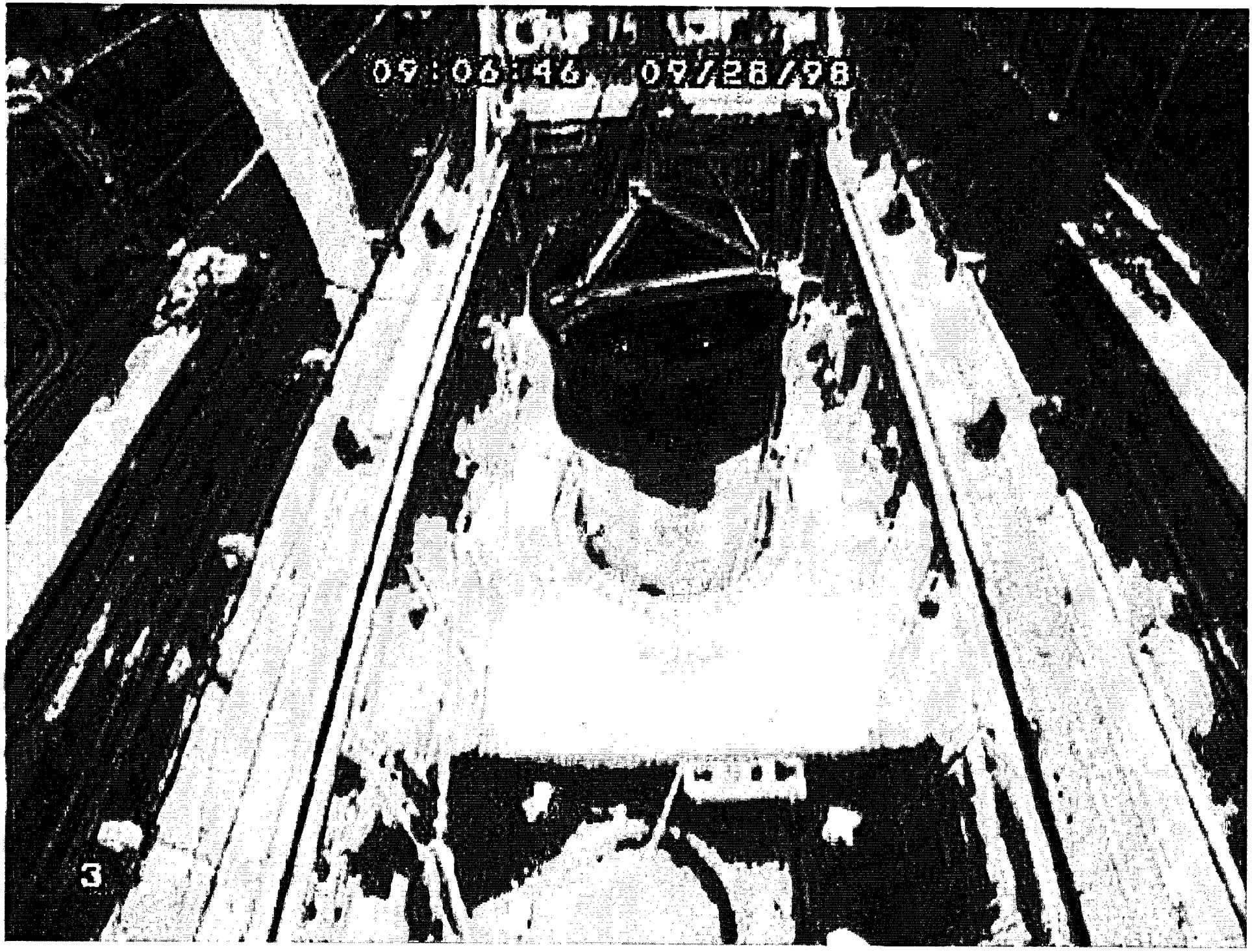
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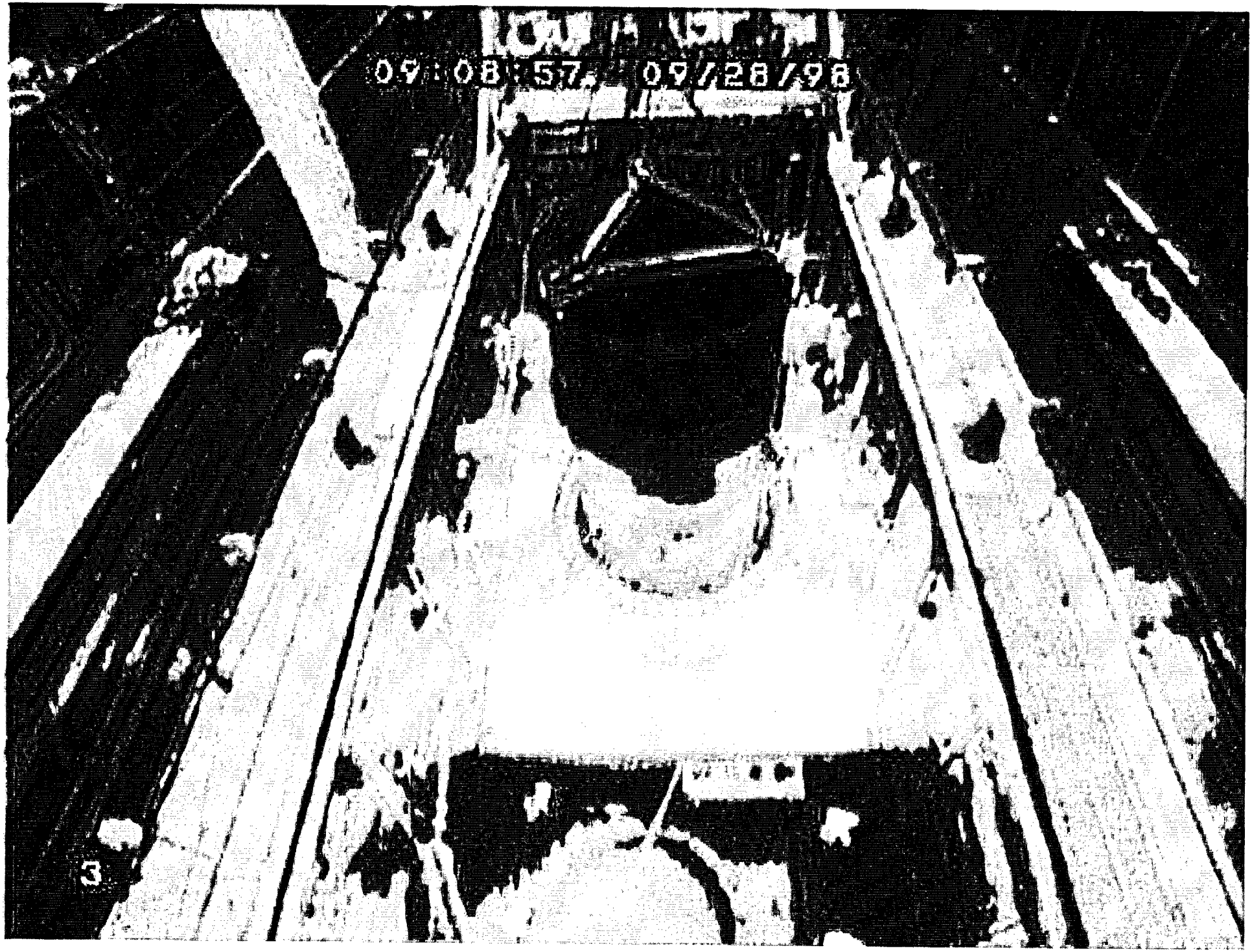
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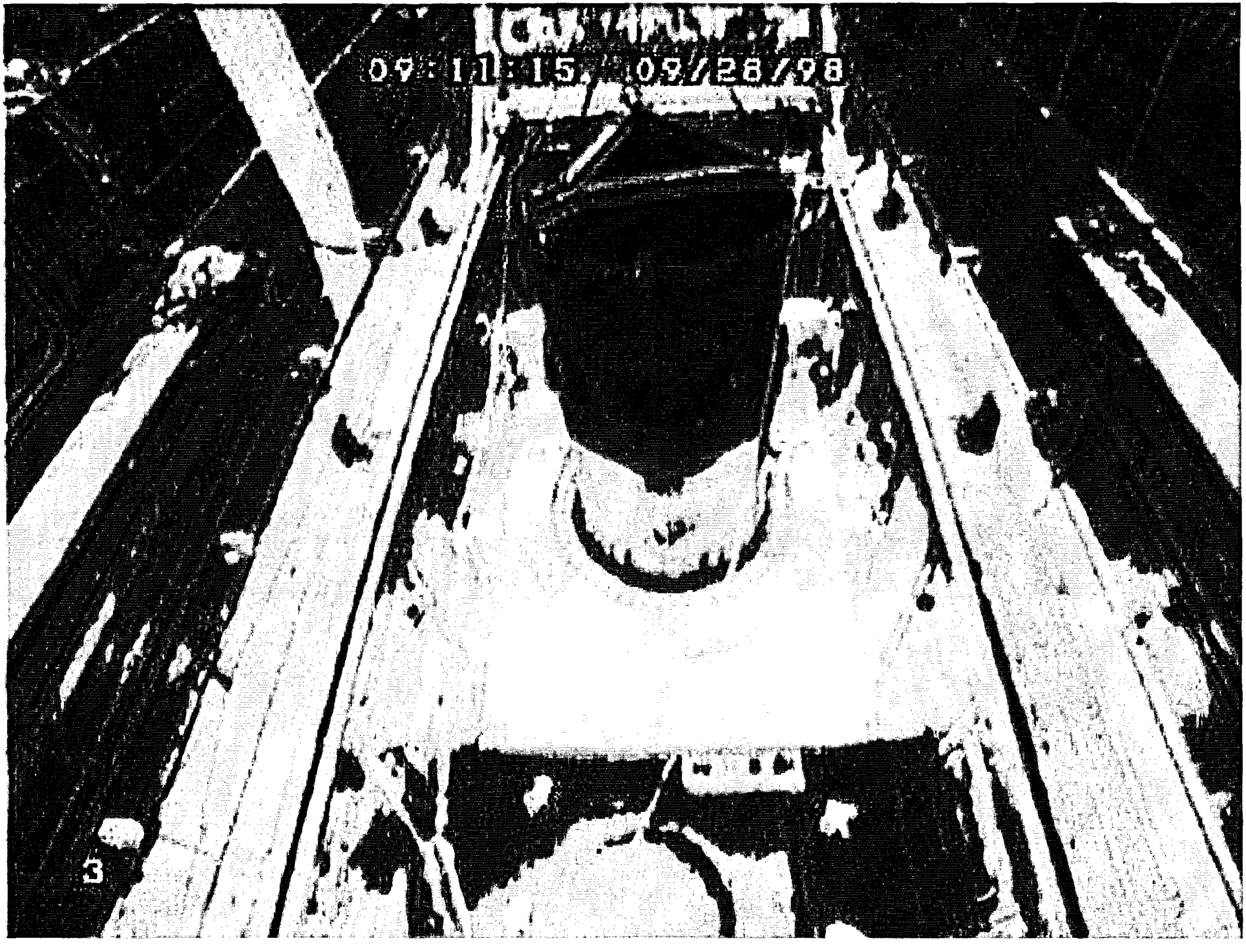
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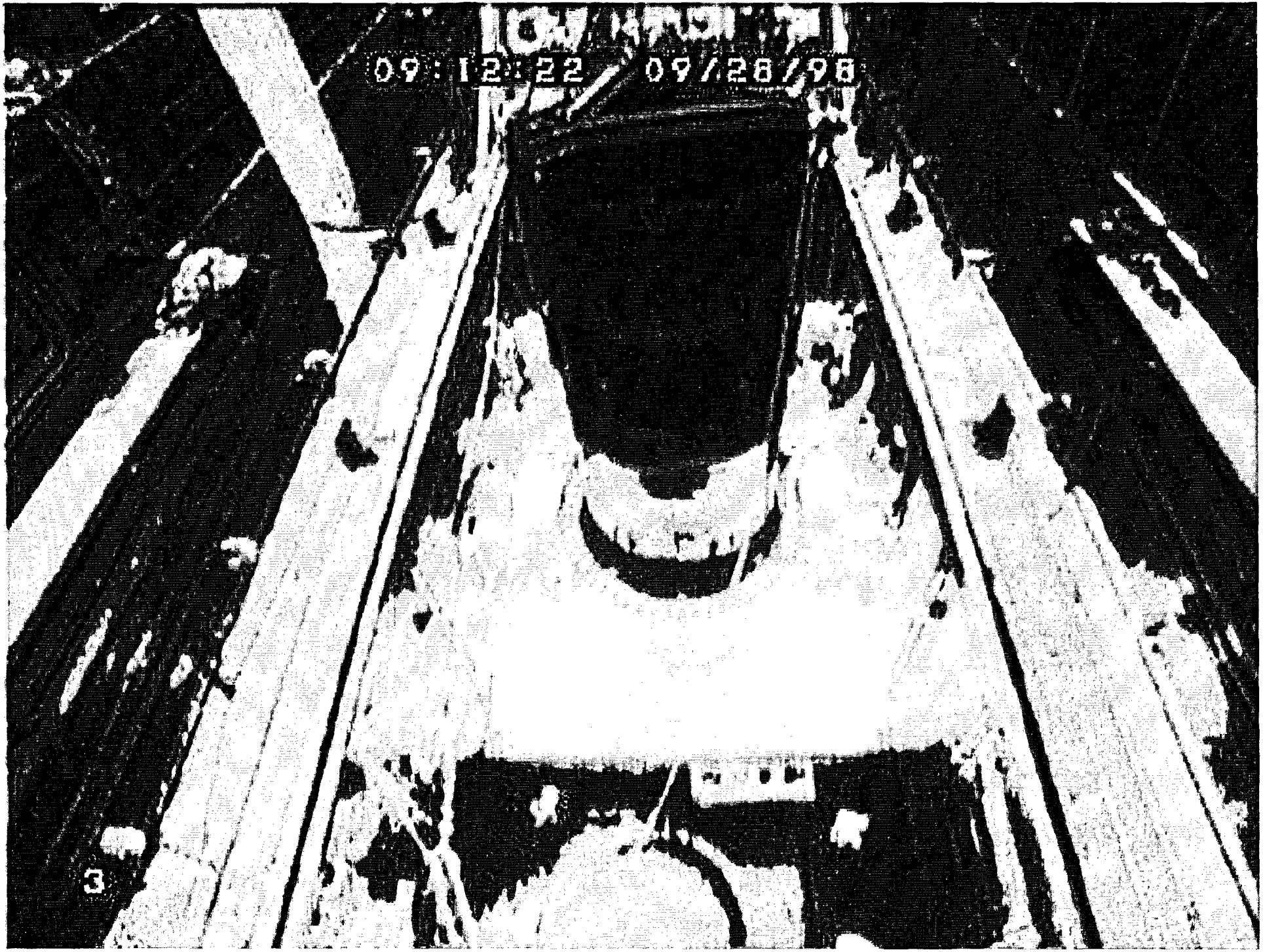
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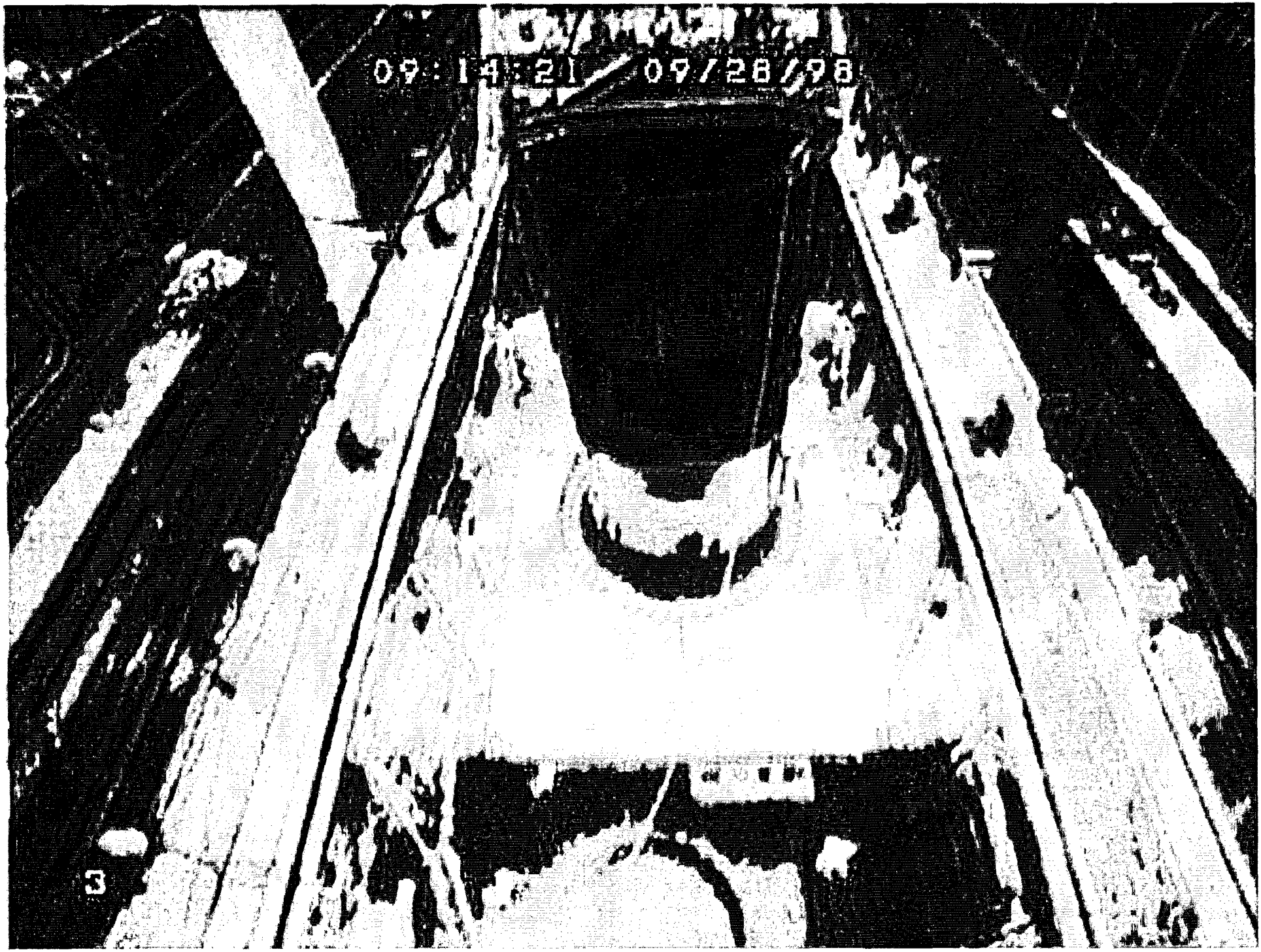
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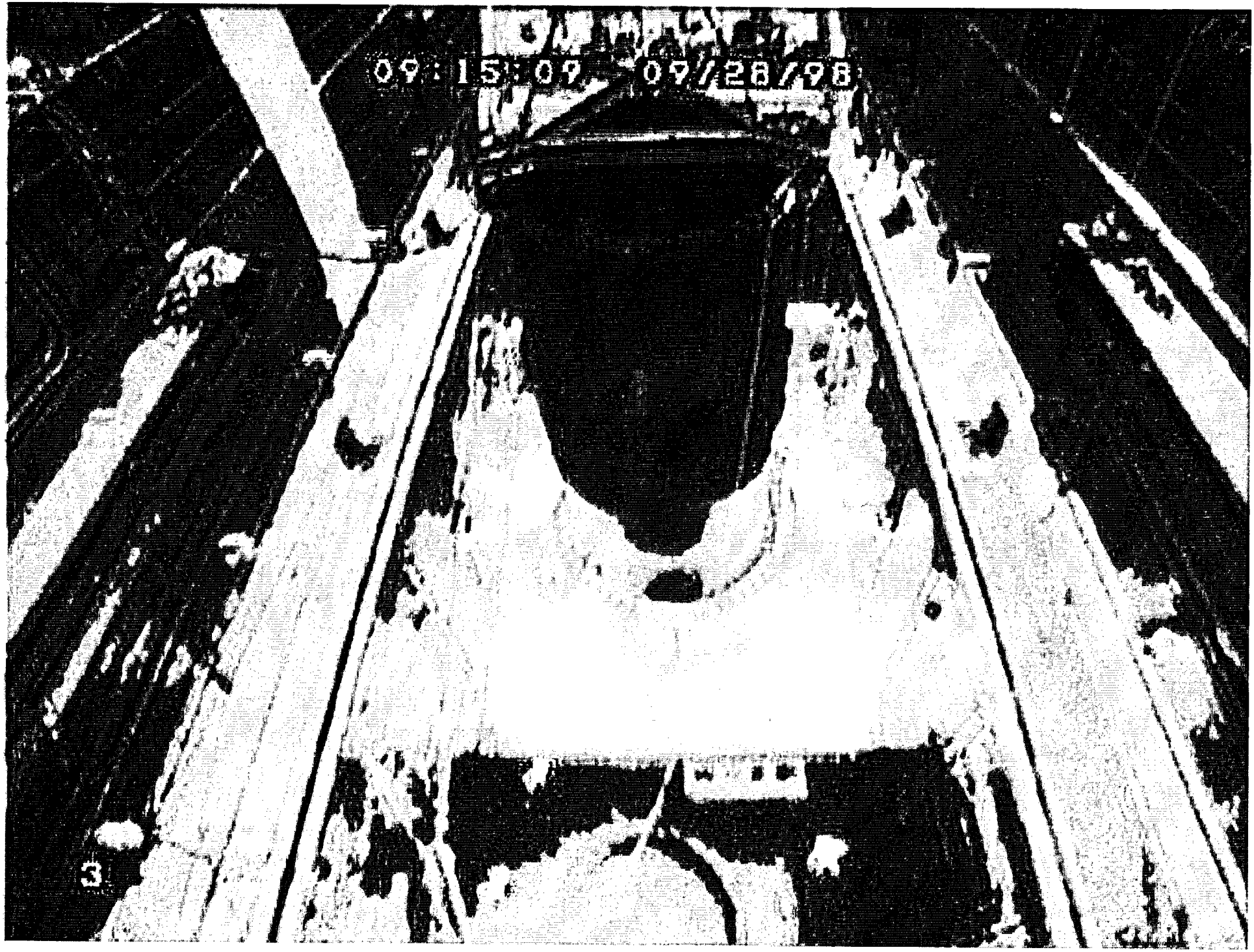
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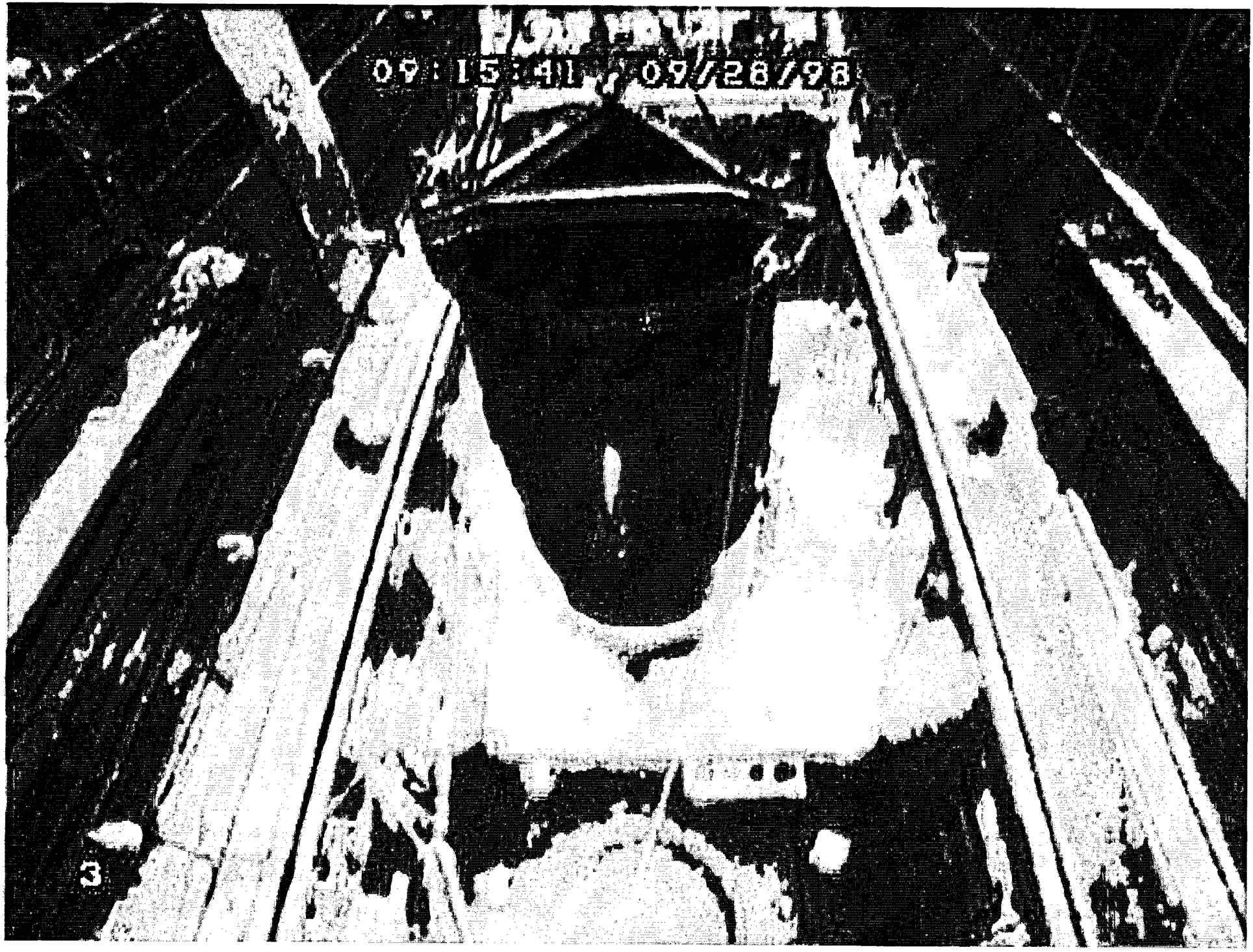
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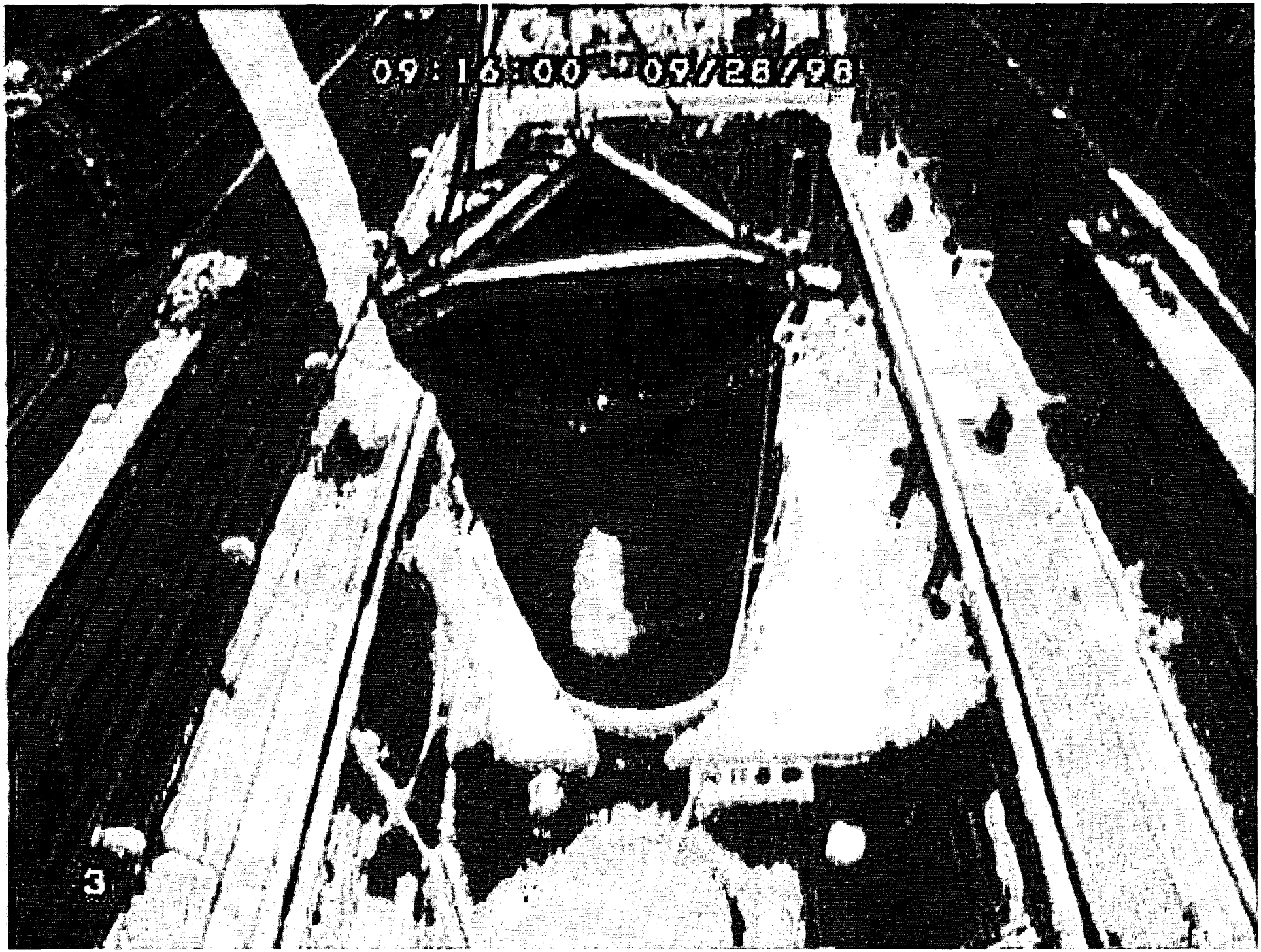
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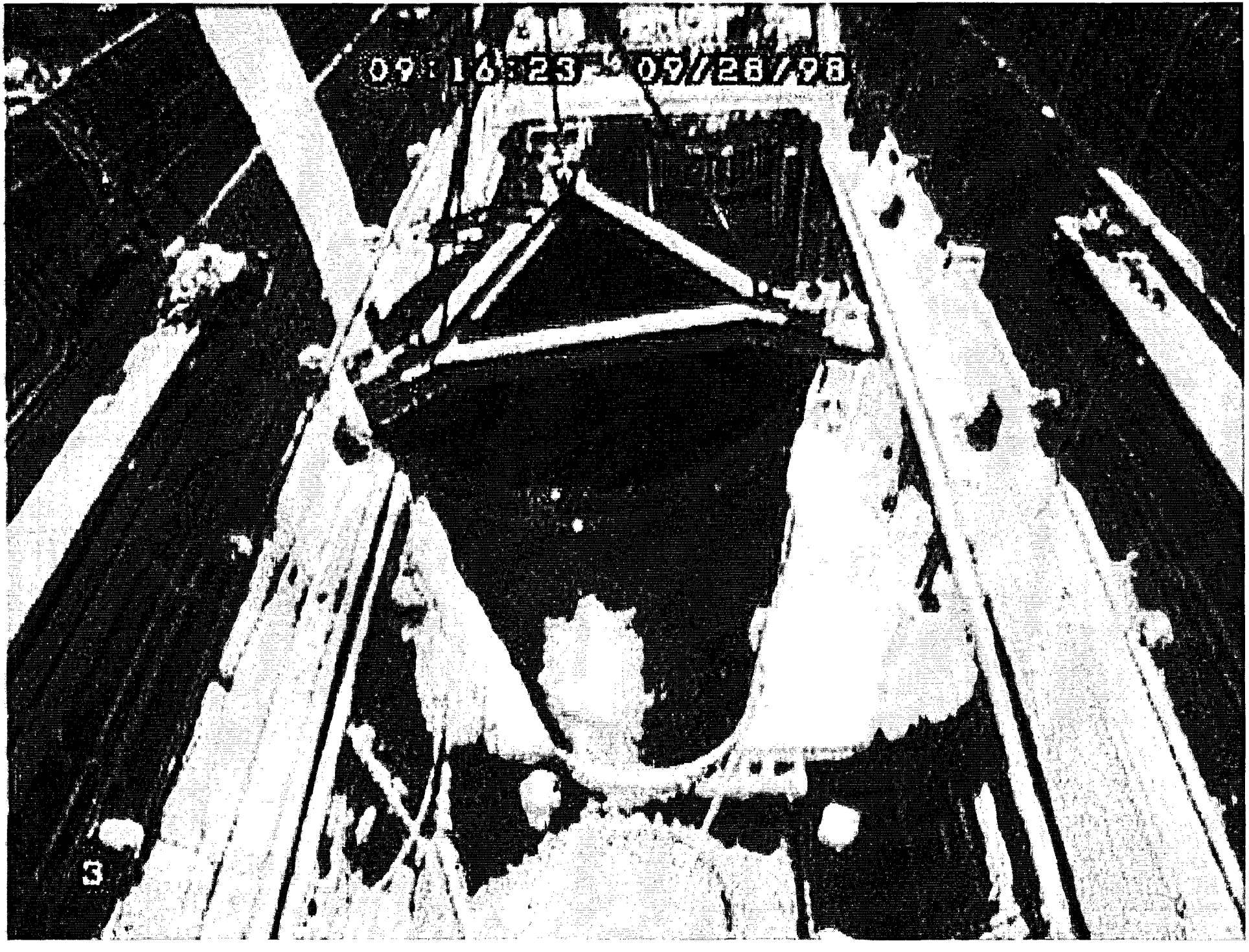
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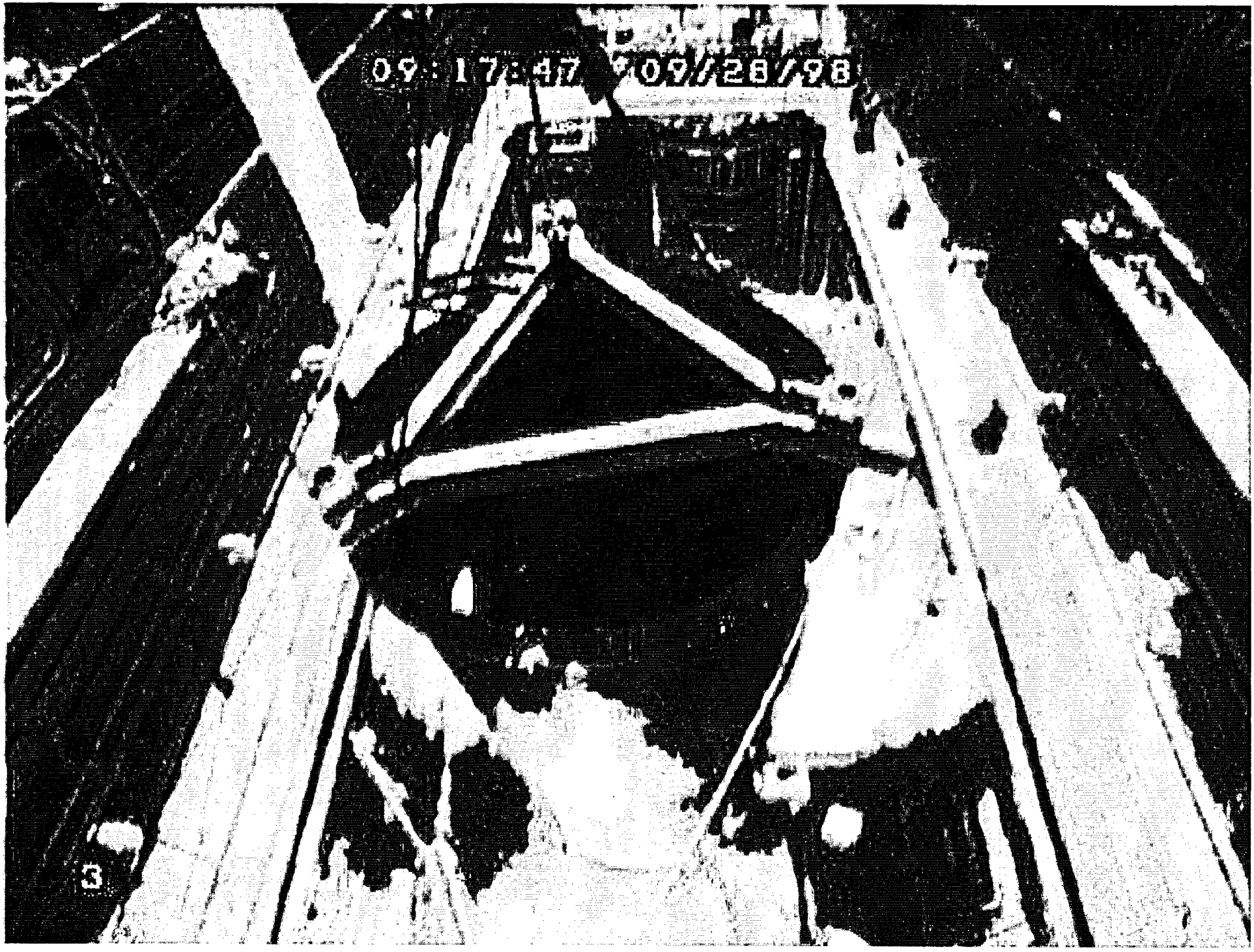
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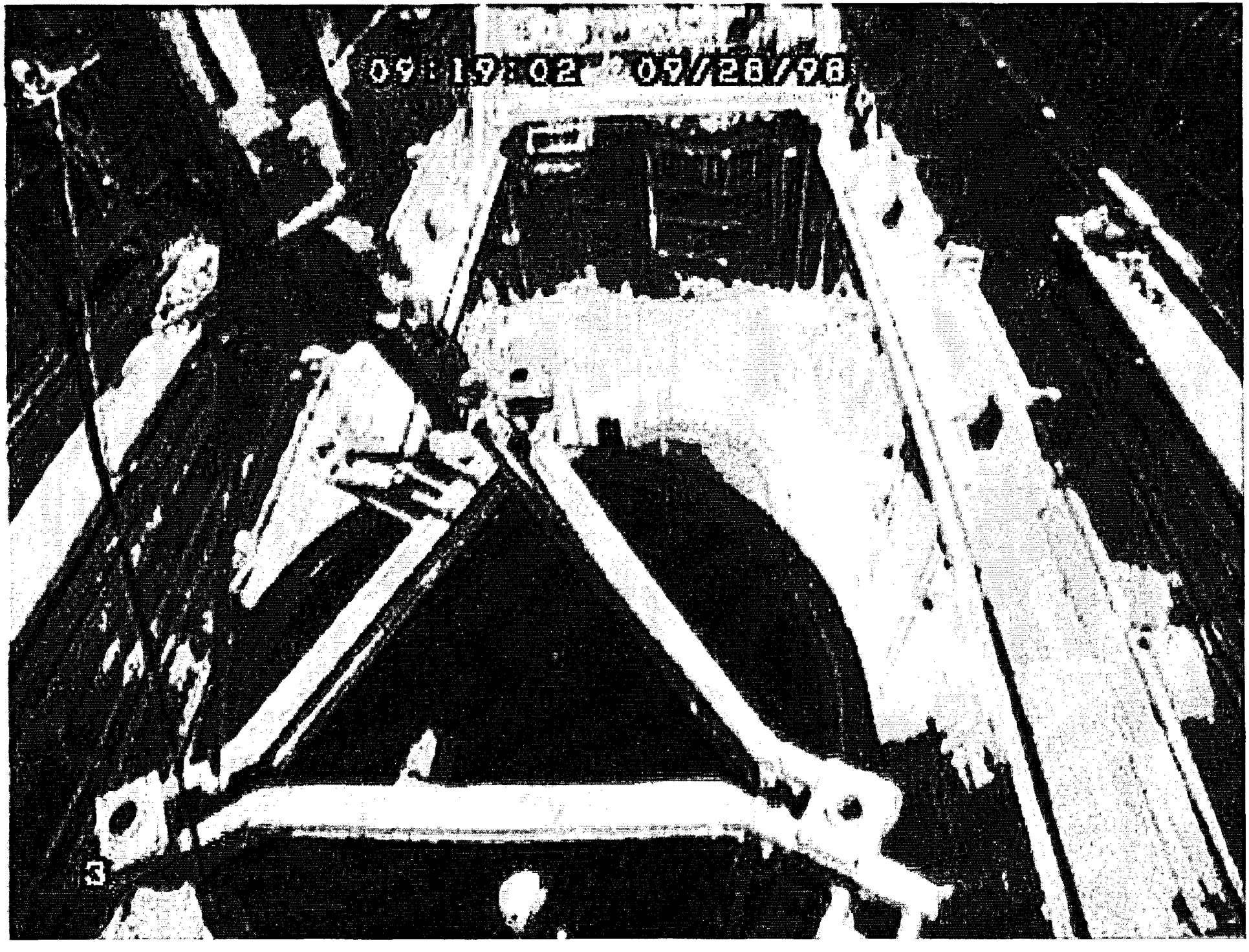
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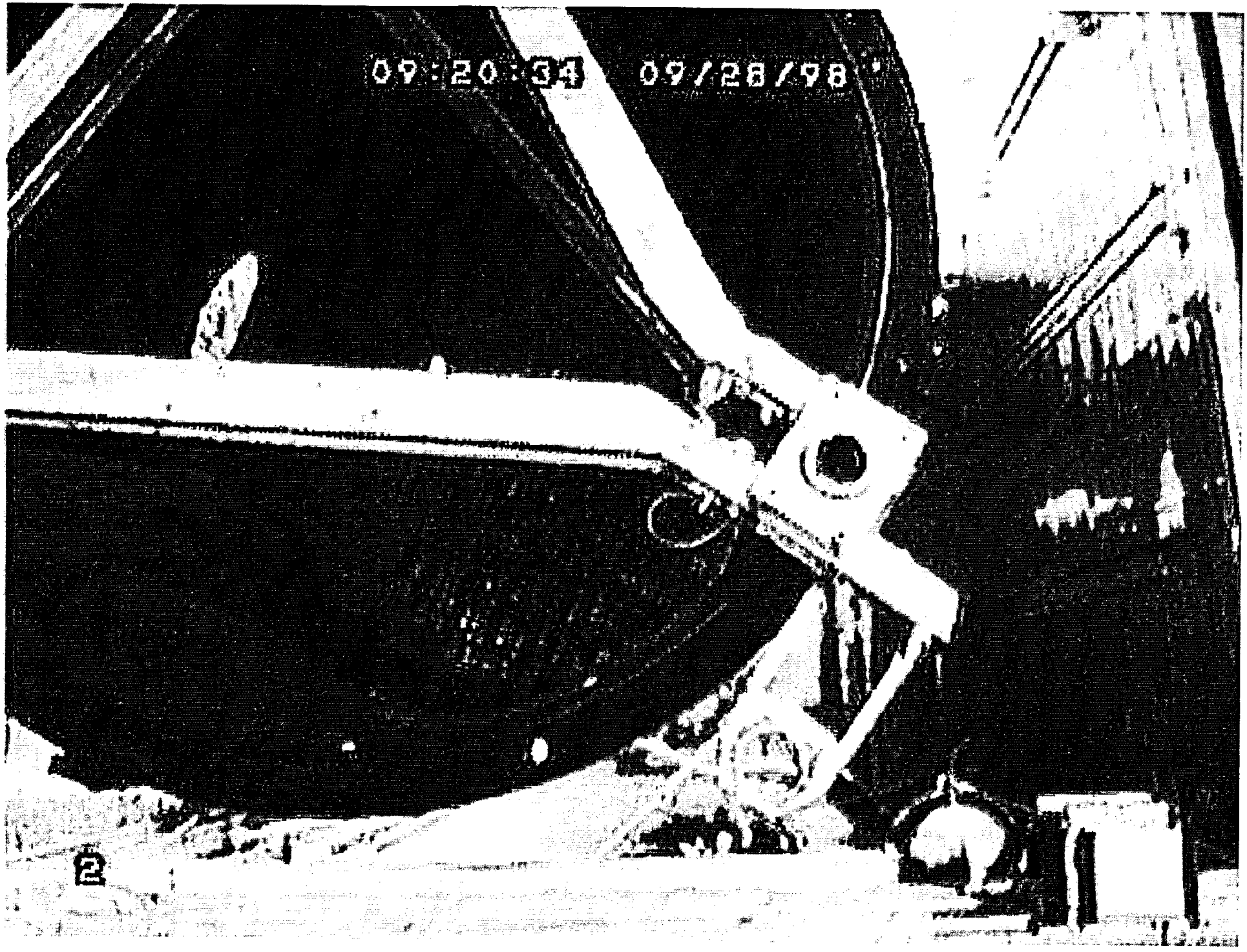
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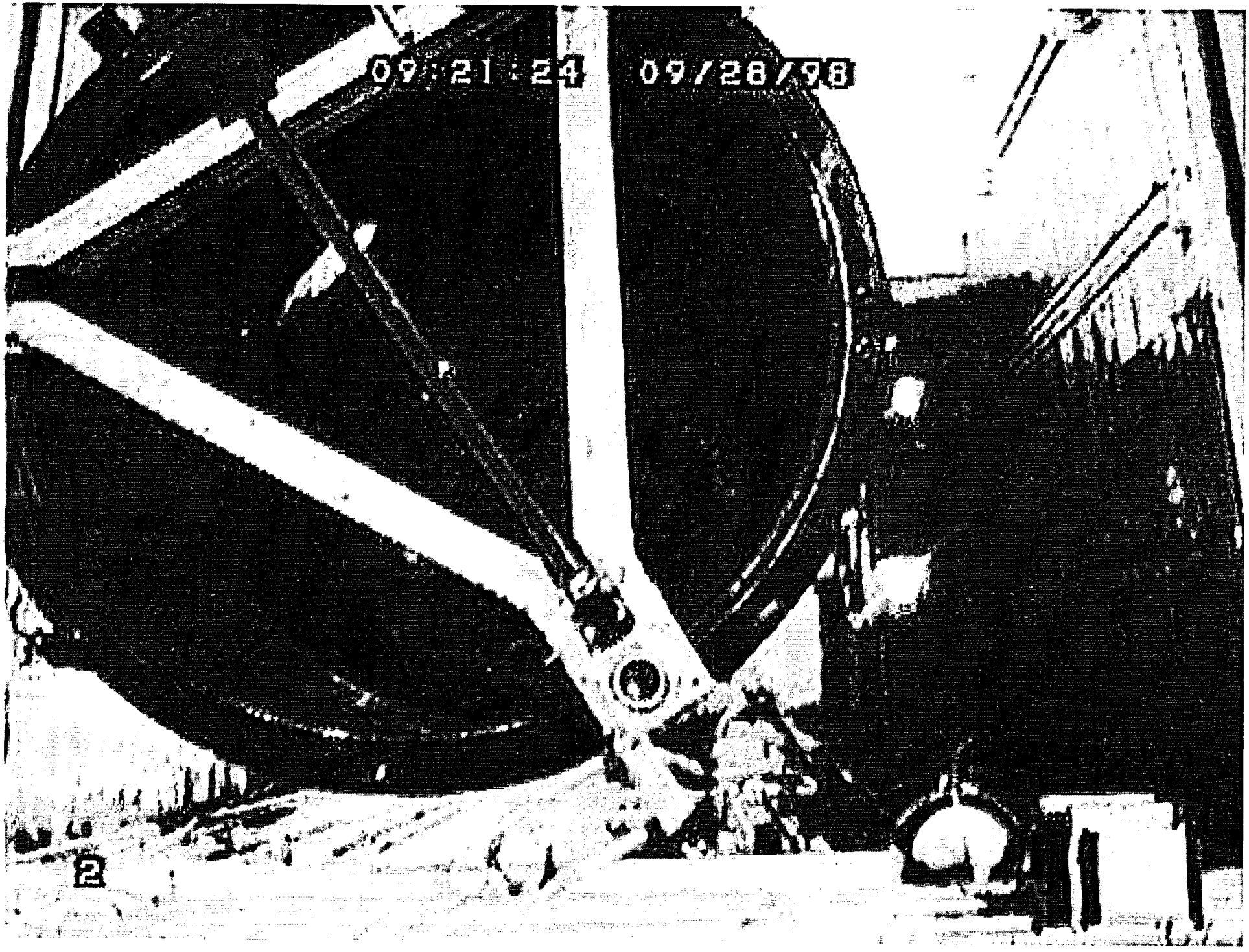
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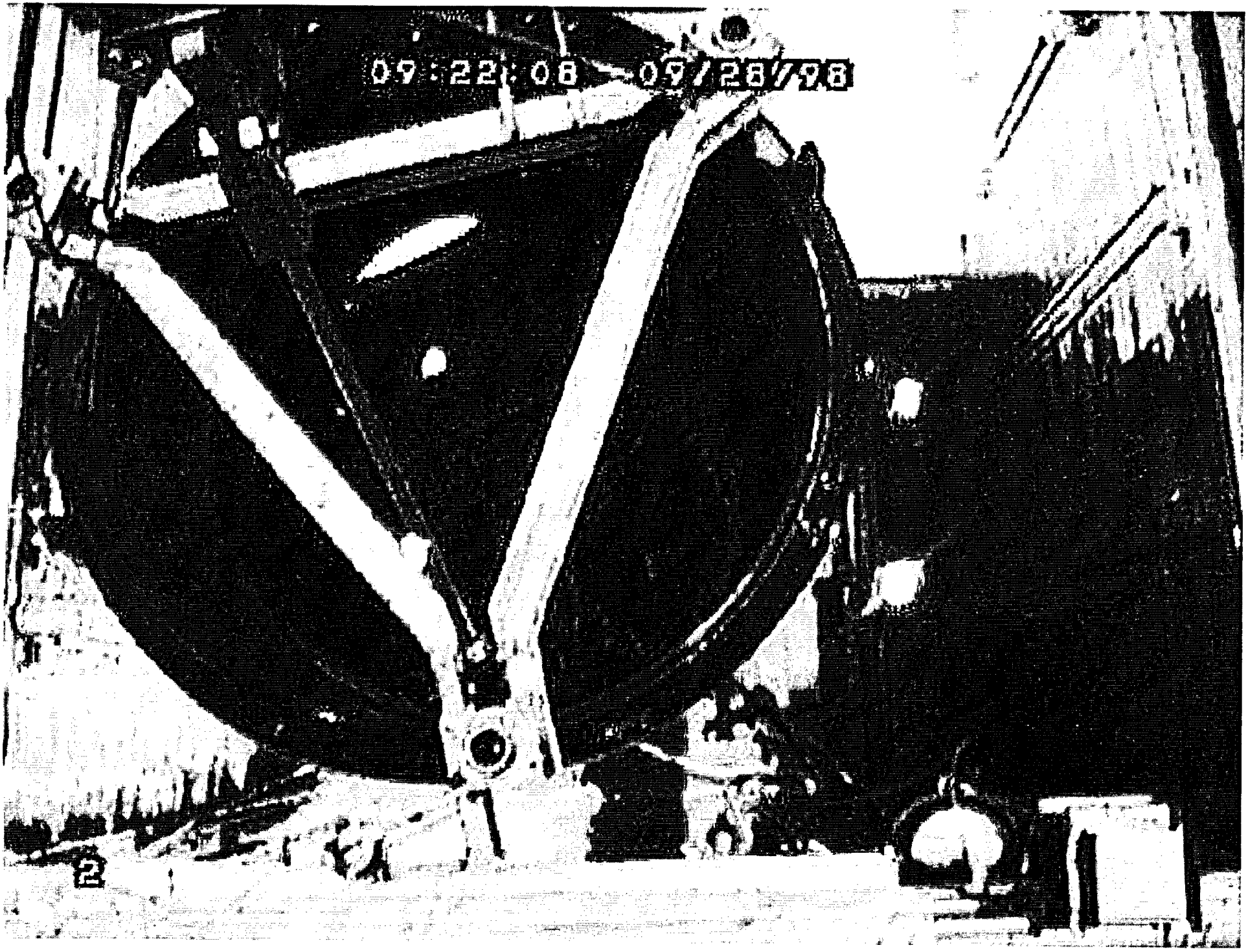
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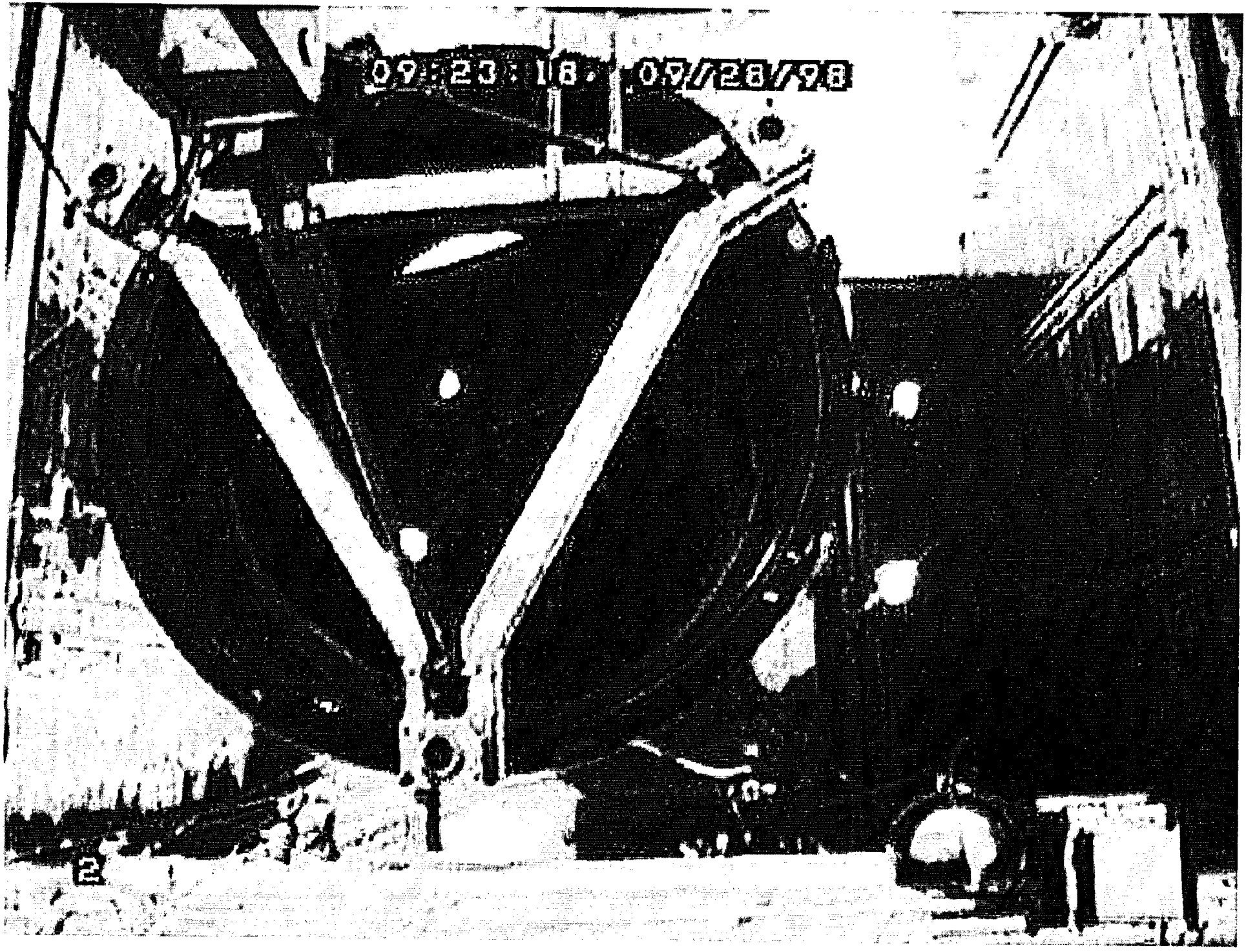
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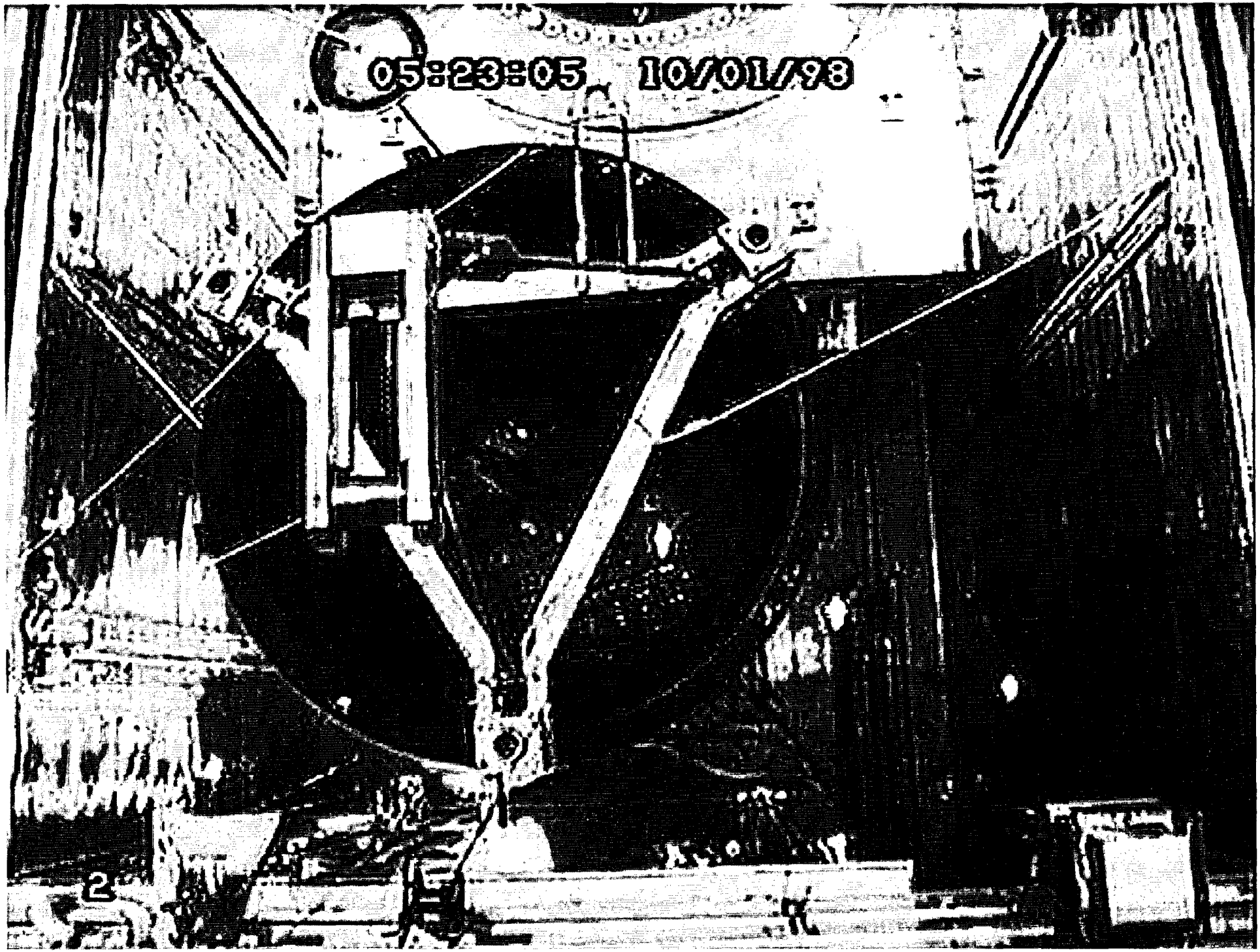
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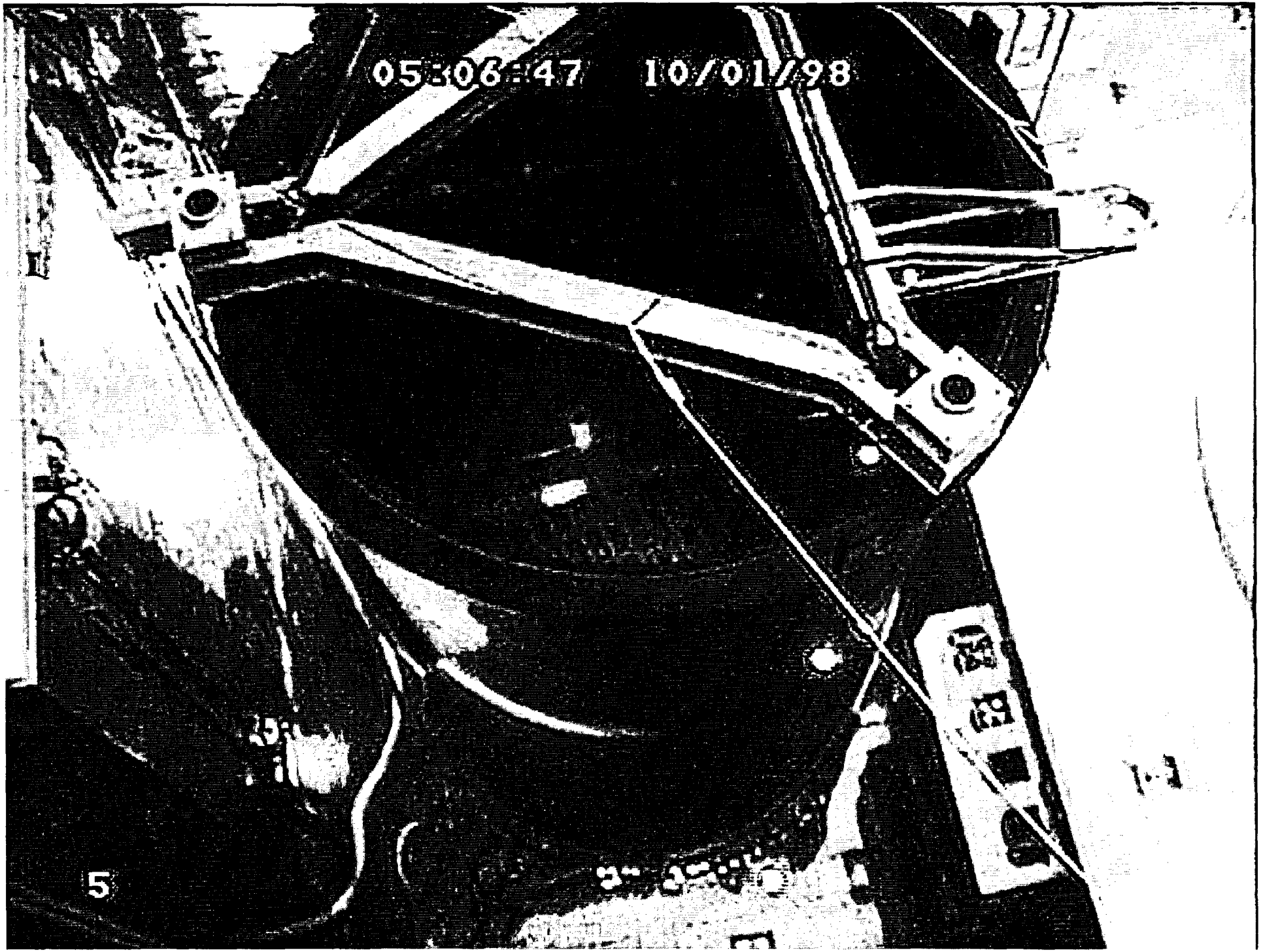
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Open Discussion