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Results of Damage Control Tactics and Equipment Tests—Phase III: Cold Water Tests

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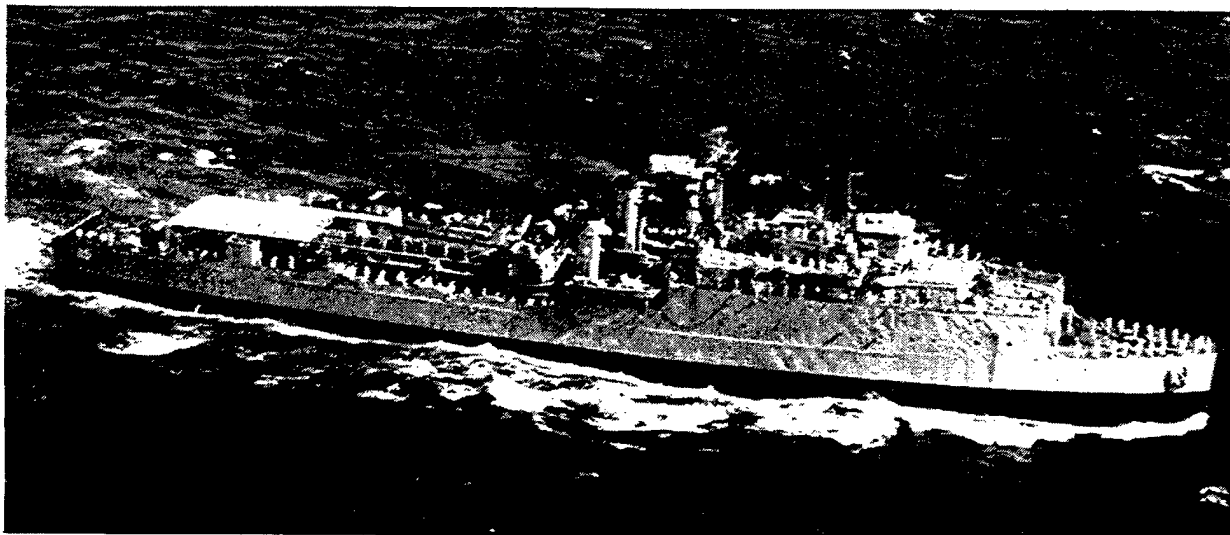
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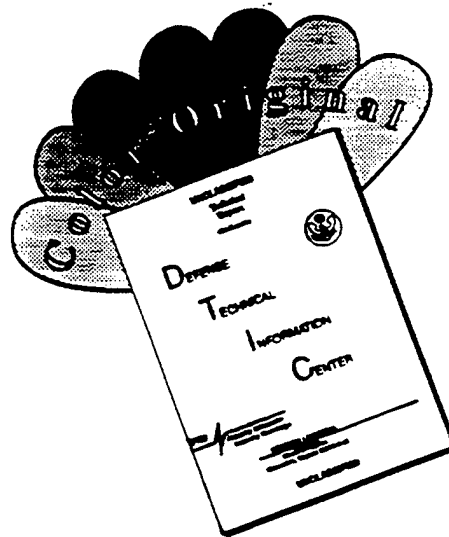
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12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE
13. ABSTRACT (<i>Maximum 200 words</i>) This report summarizes data from the cold water series of damage control tests involving pipe patching and hull repair. Two different anti-explosure suits were also evaluated.			
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RESULTS OF DAMAGE CONTROL TACTICS AND EQUIPMENT TESTS - PHASE III: COLD WATER TESTS

1.0 INTRODUCTION

Research and development to address damage control tactics, techniques, and procedures were initiated by the Naval Sea Systems Command (NAVSEA) and the Naval Research Laboratory (NRL). This research was aimed at improving integrated damage control tactics and techniques, equipment, and secondary damage modeling.

Surface Ship Survivability, NWP 62-1 Series (reference (1)), and the Naval Ships' Technical Manual (NSTM), Chapter 079, Volume 2 (reference (2)) are silent on tactics and procedures for attacking a combination flooding/fire incident. Repair and recovery from flooding incidents are often considered in isolation from a fire incident in fleet training tactics and doctrine. Yet, flooding may occur simultaneously with a fire incident, e.g., due to a collision or detonation of a weapon. The damage control test program will ultimately provide an opportunity to integrate a simultaneous flooding and fire casualty.

The test series discussed in this report was the first test series to evaluate the effects of cold water on the effectiveness of damage control activities. The repair activities evaluated in these tests included pipe patching and hull repair. Two different anti-exposure suits were also evaluated during this series. All of the damage control equipment used in these tests is currently available to the repair team.

The port wing wall of the ex-USS SHADWELL, the NRL full-scale fire research platform (reference (3)) was used for this test series. The port wing wall was modified to simulate a single flooded compartment. In future test series, a second flooded compartment will be added to evaluate progressive flooding threats. These modifications are discussed in reference (d).

2.0 OBJECTIVE

The primary objective of the FY 95 testing was to develop the empirical data necessary in quantifying individual functional damage control tactics and techniques, including equipment setup times in uncontrolled flooding scenarios. These data can then be used to analyze repair party manning issues and damage control tactics and procedures. New personnel protective equipment can also be evaluated. The results of the FY 95 testing are discussed in references (5) and (6).

The primary objective of the FY 96 testing is to expand from the individual damage control tasks (dewatering, shoring, pipe repair, and hull repair) to include the damage control repair station organization from the on-scene leader and below. New personnel protective equipment will also be evaluated.

The specific objectives of this test series were (1) to quantify the effects of cold water on damage control repair activities, (2) compare the effectiveness of different clothing and anti-exposure suits, and (3) evaluate the time to transport various pieces of damage control equipment to the scene of an incident. This report details the results of the damage control tests. The evaluation of the effects of cold water and the evaluation of the anti-exposure suits will be reported separately.

3.0 DAMAGE CONTROL ALLOWANCES

3.1 Damage Control Equipment Allowances - Pipe patching equipment used in this test series included onboard allowances as well as a piece of Nondevelopmental Item (NDI) gear. The Jubilee patch is currently available to shipboard damage control teams. The chain wrench, currently available to submarine damage control teams, is being included in the Damage Control Allowance for surface ships this year.

Hull repairs were accomplished using equipment currently available in the repair locker. The box/bucket patch and wood plugging kits were utilized. The box/bucket patches were used in conjunction with both metal shoring and with the "J" or "T" bolts.

3.2 Personnel Protective Equipment - Three protective clothing ensembles were evaluated during this test series. The ensembles evaluated included the following:

- (1) Coveralls, cotton T-shirt, shorts, socks, long-sleeved shirt, pants, firefighting helmet, gloves, and boots. This ensemble served as the control garment (designated as CON).
- (2) North Atlantic Treaty Organization (designated as NATO) anti-exposure suit, coveralls (worn under suit), firefighting helmet, gloves, and boots.
- (3) Naval Clothing and Textile Research Facility (designated as NAVCLO) anti-exposure suit, coveralls (worn under suit), firefighting helmet, gloves, and boots.

A fourth ensemble using microencapsulation (ENCAP) as a chemical means of insulation was used in one test. The evaluation of the personnel protective clothing was conducted by the Naval Health Research Center (NHRC). The results of this evaluation will be reported separately.

4.0 TEST COMPARTMENTS

The port wing wall of the ex-USS SHADWELL, shown in Fig. 1, was used for the Damage Control testing. The areas between FR 74 and 95 of the first and second decks were the

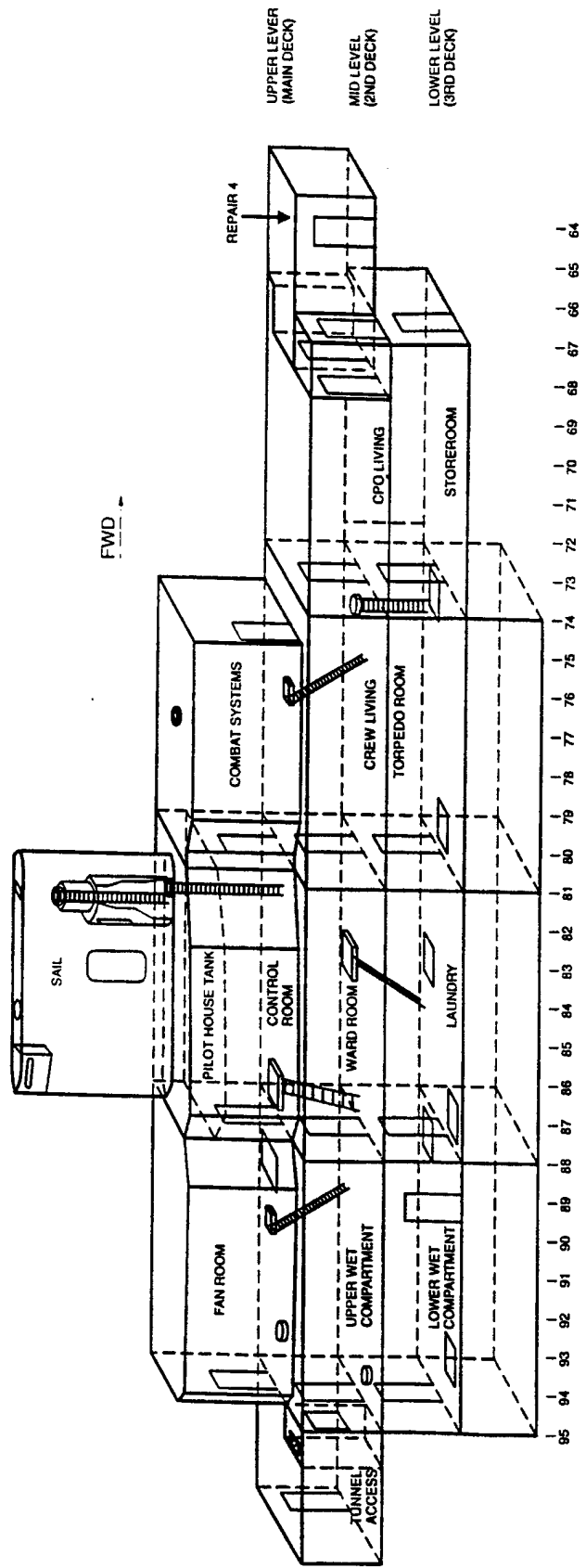


Fig 1 - Port wing wall test area

primary test areas. All of the damage locations were in the Upper Wet Compartment, shown in Fig. 2. The Figures contained in Appendix A show the instrumentation layout and damage locations for each of the compartments in the test area. Details of the experimental setup are contained in references (4) through (6).

In each of the tests, the repair teams were mustered in the Repair 4 area. The teams were staged just forward of the watertight door at FR 74. When the damage was called away, the teams passed through the door and then up the ladder at 2-76-2 to the main deck. On the main deck, the teams proceeded aft through WTD 1-81-2, JD 1-87-2, and WTD 1-88-2 into the Fan Room. The Fan Room provided access to the Upper Wet Compartment via a watertight hatch (WTH 1-89-2). Each of the repair parties entered and exited the Upper Wet Compartment through this hatch.

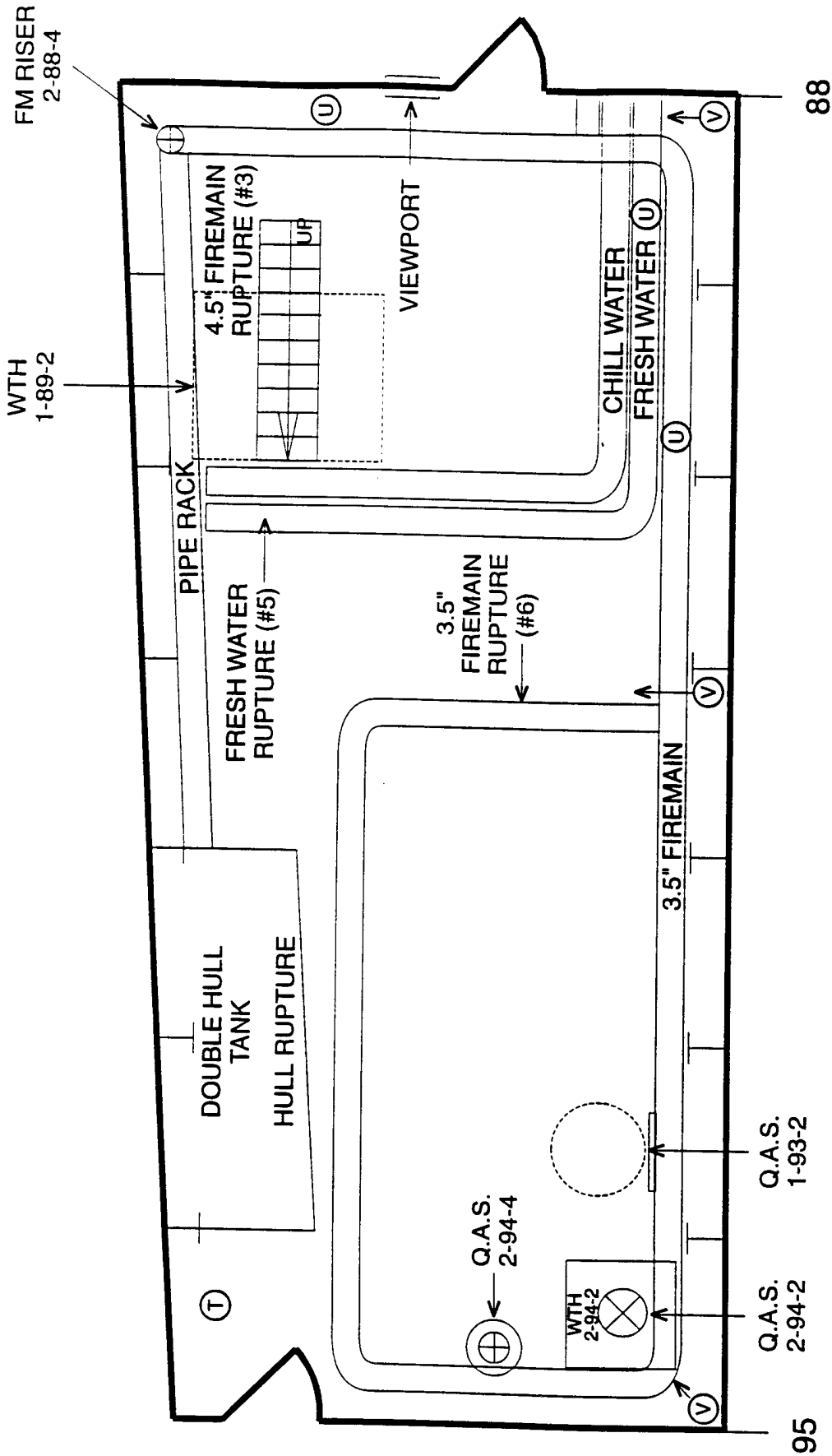
The Upper Wet Compartment, shown in Fig. 2, contained three separate water lines: firemain, chill water, and fresh water. The fresh water line consisted of copper/nickel (90/10) pipe with an outside diameter of 60.3 mm (2.375 in.) and a wall thickness of 2.1 mm (0.083 in.). This line entered the compartment along the inboard bulkhead at FR 88 and ran aft to FR 90. At FR 90, the fresh water line turned and ran to the outboard bulkhead, where the line terminated. The fresh water line was supplied by a single pump, a 1322 lpm (350 gpm), Godiva pump, connected to the line at 2-88-2. A pressure reducing valve maintained a static pressure of 3.8 bar (55 psi) in the fresh water line. The chill water line, which consisted of copper/nickel (90/10) pipe with an outside diameter of 60.3 mm (2.375 in.) and a wall thickness of 2.1 mm (0.083 in.), was not used during this test series.

The firemain consisted of a loop between FR 91 and FR 95. A line branched off of this loop on the inboard side of the compartment at FR 91. This line extended to FR 88, where it turned and extended to the outboard bulkhead. This line supplied the pipe mockup located along the outboard bulkhead at FR 88. All of the pipe in the firemain loop was copper-nickel (90/10) with an outside diameter of 88.9 mm (3.5 in.) and a wall thickness of 2.4 mm (0.095 in.). The pipe mockup, shown in Fig. 3, contained several different pipe sizes. The pipe used during these tests had an outside diameter of 114 mm (4.5 in.) and had a wall thickness of approximately 3 mm (0.125 in.).

The firemain was supplied by two pumps. The ship 3778 lpm (1000 gpm) electric fire pump supplied the rupture in the firemain loop. A 1322 lpm (350 gpm) Godiva pump supplied the pipe mockup rupture via the connection at 2-88-2. Each of these pumps maintained a static pressure of approximately 7.6 bar (110 psi).

5.0 DAMAGE

All of the pipe and hull damages for this test series were contained in the Upper Wet Compartment. A total of three separate pipe ruptures were used during this test series. All of the



2ND PLATFORM	REV: 8/23/95
FILE: SUB2-95	DATE: 4/19/94

95

Q.A.S. 2-94-2

Q.A.S. 1-93-2

88

Fig. 2 - Upper Wet Compartment layout



Fig. 3 - Pipe mockup in Upper Wet Compartment

ruptures were on pressurized systems. A pressurized system or non-isolated system is a system where the flow of water to the rupture cannot be secured. An isolated system is a system where the flow of water to the rupture can be secured by closing control valves. Two of the ruptures were in the firemain and the third was in the fresh water line.

The fresh water rupture, shown in Fig. 4, was a split seam rupture, measuring 76.2 mm x 12.7 mm (3.0 in. x 0.5 in.), located at 2-90-2. The fresh water rupture was used in place of the chill water rupture used in the FY 95 test series. The chill water rupture, shown in Fig. 5, was located along the centerline of the compartment. Due to the amount of traffic anticipated in the compartment, it was determined that it would be safer to use the fresh water rupture, which was located near the outboard bulkhead. The dimensions of the chill water rupture (152.4 mm x 12.7 mm (6.0 in. x 0.5 in.)) were similar to those of the fresh water rupture. A pressure reducing valve maintained a static pressure of 3.8 bar (55 psi) in the fresh water line. The fresh water insert rupture flowed approximately 102 ℓ pm (27 gpm) and had a nominal residual pressure of 0.2 bar (3 psi).

The pipe mockup rupture, shown in Fig. 6, simulated compound damage with jagged edges. This rupture, measuring 50.8 mm (2.0 in.) by 50.8 mm (2.0 in.), flowed approximately 946 ℓ pm (250 gpm) and had a residual pressure of 2.2 bar (32 psi). The second firemain rupture, shown in insert Fig. 5 -Chill water pipe rupture

Fig. 7 was located at 2-91-2 in the firemain loop. This rupture measured 101.6 mm (4.0 in.) by 38.1 mm (1.5 in.) and simulated simple compound damage with jagged edges. With a residual pressure of 3.4 bar (50 psi), this rupture flowed 681 ℓ pm (180 gpm).

Two types of hull ruptures were used during this test series. Both of the hull ruptures were supplied by water contained in the double hull (storage) and pilot house tanks. The hull ruptures were located in the storage tank (Fig. 2). Water contained in the pilot house, located above the storage tank, supplied the storage tank with additional water. The first rupture, shown in Fig. 8, was intended to simulate an explosion rupture. This rupture consisted of a single circular hole with a diameter of approximately 178 mm (7 in.). Initially, the rupture flowed 13497 ℓ pm (2969 gpm) with a static head of 5.3 m (17.5 ft). After three minutes of unobstructed flow (i.e., no repair in progress) the rupture flowed 6233 ℓ pm (1371 gpm) with a static head of 1.1 m (3.7 ft). After 4 minutes of unobstructed flow the water in the tank was at equilibrium with the water in the Upper Wet Compartment. The second rupture, shown in Fig. 9, simulated a rip or gash in the hull. This rupture had a total hole area of approximately 161 cm^2 (25 in^2). Initially, the rupture flowed 10,064 ℓ pm (2659 gpm) with a static head of 5.5 m (18 ft). After three minutes of unobstructed flow, the rupture flowed 8709 ℓ pm (2301 gpm) with a static head of 4.1 m (13.5 ft). After 4 minutes of unobstructed flow the water in the tank was at equilibrium with the water in the Upper Wet Compartment.

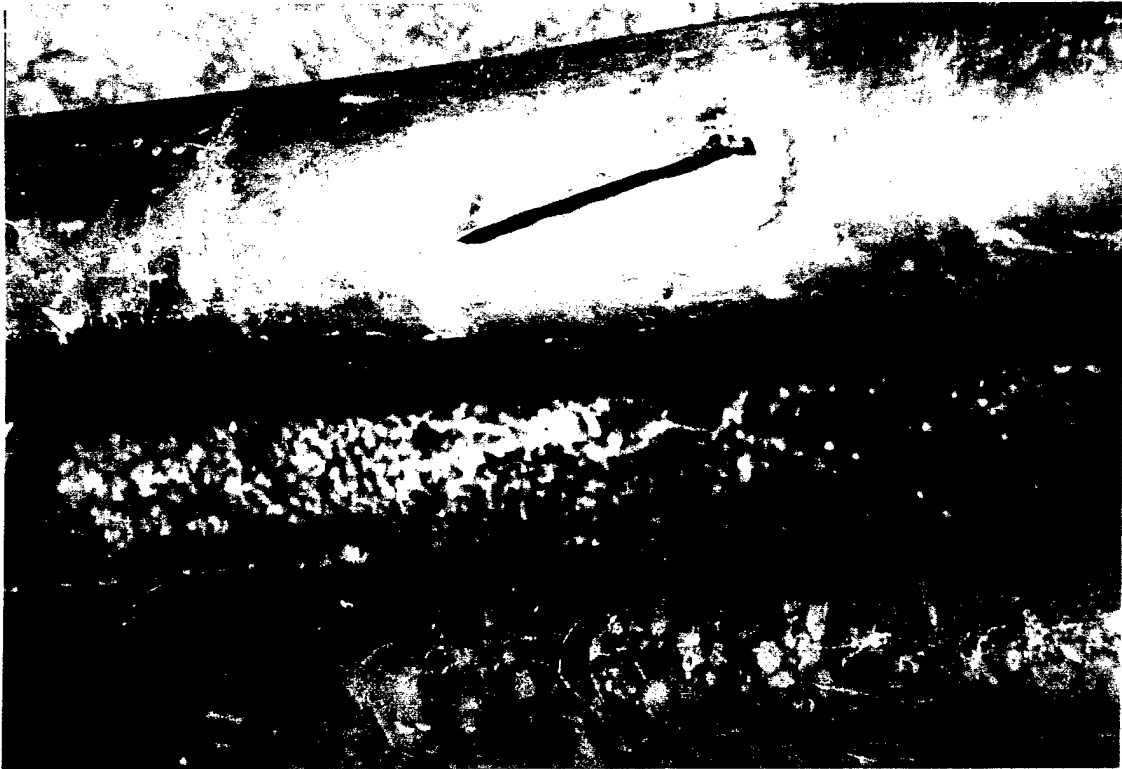


Fig. 4 - Fresh water pipe rupture



Fig. 5 - Chill water pipe rupture

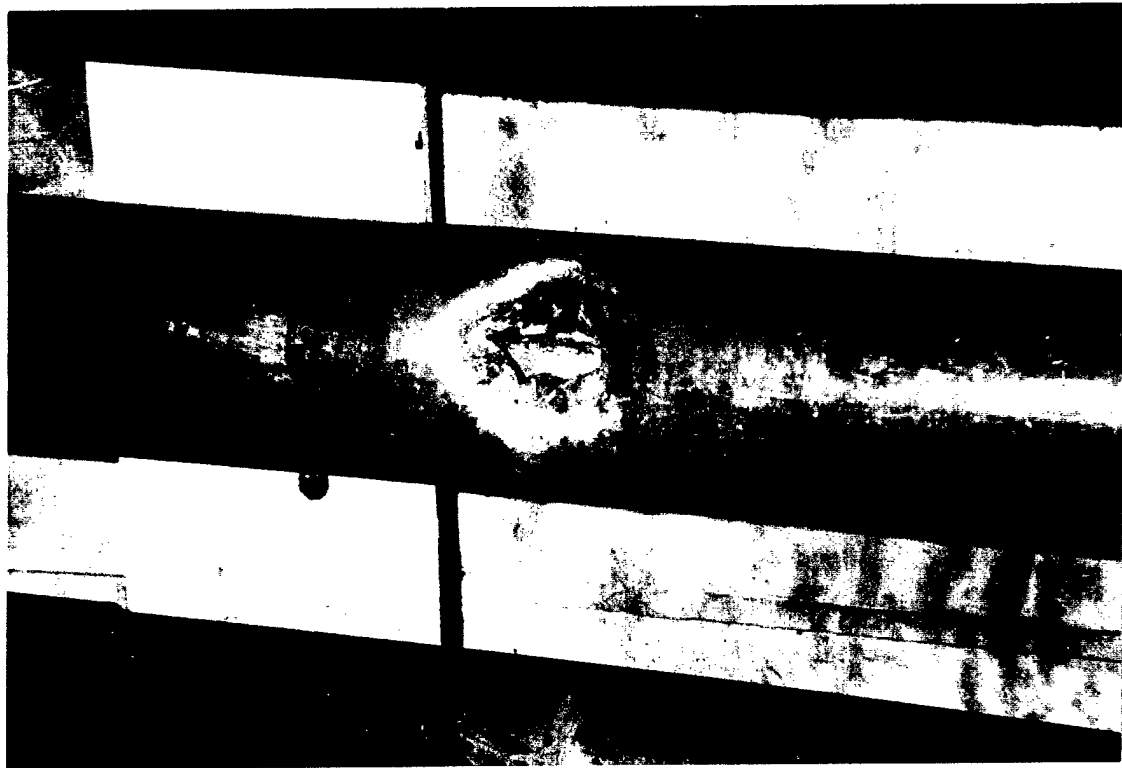


Fig. 6 - Pipe mockup rupture in 114mm (4.5 in.) diameter pipe



Fig. 7 - Rupture in 89mm (3.5 in.) diameter firemain pipe



Fig. 9 - Rip/gash hull rupture



Fig. 8 - Explosion hull rupture

6.0 INSTRUMENTATION

The test area was instrumented to provide pressure, flow rate, liquid level, and temperature measurements. The instrumentation layout is shown in the Figures contained in Appendix A. In addition, a complete description of all of the instrumentation, including video and audio, is provided in the channel listing contained in Appendix B. To provide the physiological data required for the evaluations of the anti-exposure suits, each of the test participants was instrumented by NHRC for body temperature, body movement activity, heart rate, and blood pressure. The instrumentation of the test participants was performed under the supervision of a medical doctor.

Water temperature was measured with a single thermocouple string in the Upper Wet Compartment. The string, located at 2-94-2, consisted of seven type-K, inconel-sheathed thermocouples. The thermocouples were positioned at 0.3, 0.6, 0.9, 1.2, 1.5, 1.8, and 2.1 m (1.0, 2.0, 2.9, 3.9, 4.9, 5.8, and 6.8 ft) above the deck.

Flow rate was measured to determine the effectiveness of the pipe repair activities. The flow rates were measured using Controlotron ultrasonic flowmeters. To measure the flowrate through the 89 mm (3.5 in.) firemain rupture, a flowmeter was located on the firemain at 1-79-2. The flow rate through the 114 mm (4.5 in.) firemain rupture was measured with an ultrasonic flowmeter located at 2-88-0. The fresh water flow rate was measured using an ultrasonic flowmeter located at 2-90-1.

Pressure measurements were made to determine the effectiveness of the pipe repair activities. The firemain pressure was measured at two locations. The firemain pressure measurements at 1-79-2 along the port wing wall were made using a Setra Model 207 pressure transducer with a range of 0 to 34.5 bar (0 to 500 psi). The firemain pressure, measured at 2-88-2, was made using a Setra Model 207 pressure transducer with a range of 0 to 17.2 bar (0 to 250 psi). The fresh water pressure was also measured at 2-88-2 with a Setra Model 207 pressure transducer with a range of 0 to 17.2 bar (0 to 250 psi).

The ambient environmental conditions (temperature and relative humidity) were measured at weather and in the Upper Wet Compartment before each test. These measurements were made using a sling psychrometer. Wind speed was recorded using an anemometer located on the flight deck at FR 67.

Water level measurements were made using fiberoptic pressure sensors. These measurements were recorded by the Damage Control Flooding Sensor Computer, developed by NSWC Annapolis. The water levels in the pilot house, storage tank, Upper Wet Compartment and Lower Wet Compartment were all recorded. The water level in the storage tank was not recorded during this test series.

Each repair team was paired with an on-scene observer. The on-scene observer recorded qualitative data relative to the effectiveness of the repair. The observers made visual determinations of the effectiveness of the repair activity. This effectiveness was based on the effect of the repair on the damage, the repair technique and the time to complete the repair activity.

7.0 EXPERIMENTAL DESIGN

The proposed test matrix (Appendix C) was developed to allow a reliable statistical analysis of the test data. The statistical test design was used to determine the effects of each test variable on the effectiveness of the repair and the effects of improved performance as a function of test repetition (i.e., "learning curve effects"). The matrix was designed to eliminate fatigue as a factor by providing adequate rest time for each of the repair teams between tests. Due to on-site considerations, the actual test schedule (Appendix D) deviated slightly from the proposed schedule.

The tests were conducted February 12-16, 1996 aboard the ex-USS SHADWELL. Each of the repair teams consisted of PQS qualified crewmembers from the USS EISENHOWER. The hull repair team (Team A) consisted of four people. Each of the pipe patching teams (Teams B1 and B2) consisted of two people. Table 1 shows the composition of each of the repair teams.

Table 1. Damage control repair team composition

Team No.	Rating and Name
A1	HT3 Stachowiak
	SHSN Lacey
	EMFN Rice
	BMSN Farmer
B1	DCFR McFarland
	ABFAA Quesada
B2	FA Ibarra
	DC2 Hisel

7.1 Pipe Patching Procedures – Pipe ruptures and damages in various water systems were repaired using either Jubilee patches or Banding kits with a chain wrench. All of the pipe repairs were performed in the Upper Wet Compartment (2-89-2-L). The Jubilee patches and banding kits were used on the firemain and fresh water systems.

The Jubilee patch, shown in Fig. 10, consisted of a gasket material and a light, flexible cylinder split on one side. The split incorporates flanges and bolt holes, which allow the cylinder to be closed. To effect the patch, the gasket material was wrapped around the pipe rupture. The cylinder was then placed around the gasket material with the bolt holes approximately 180 degrees from the rupture. With the patch in place, bolts were inserted through the flanges and tightened until the leak was stopped or significantly reduced.

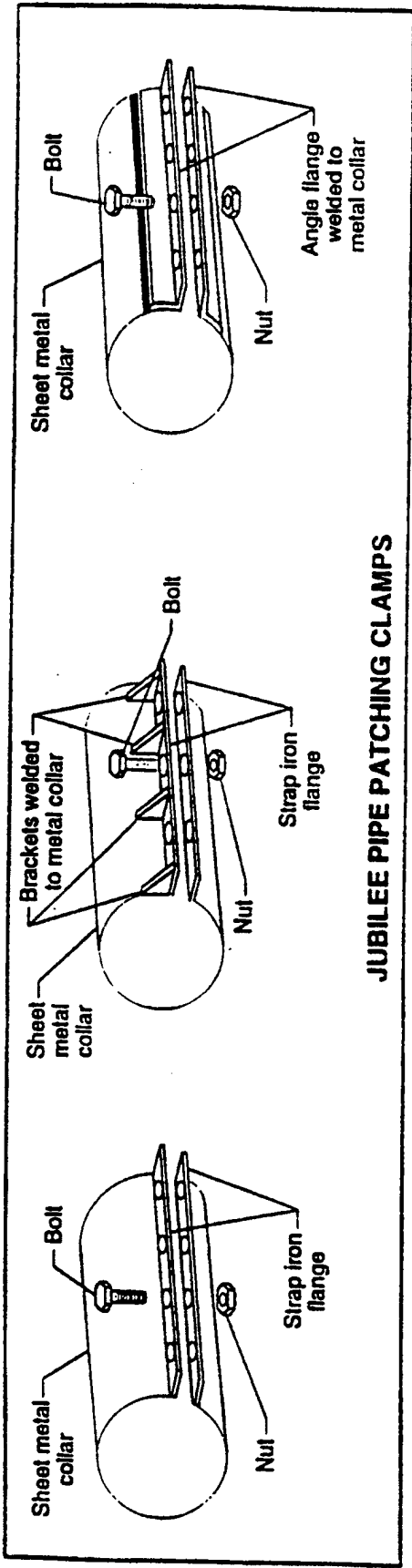
The Banding kits, shown in Fig. 11, consisted of a gasket material, screen wire, pre-fabricated metal plates (strongbacks) for various sized pipes (PVC strongbacks were used in some of the tests), a chain wrench, metal bands, and a banding tool. To affect this repair, the hole was covered with the gasket material, then the screen mesh, followed by the strongback. The chain wrench was then clamped in the center of the patch to hold it in place while the banding tool was used to secure bands on each end. Once the ends were banded, the chain wrench was removed and the patch was banded in the center. Additional bands were used to reduce the flow of water.

7.2 Hull Repair Procedures - All of the hull repair tests were performed in the Upper Wet Compartment using the double hull tank. The hull damages included holes resulting from implosions and explosions. Temporary repairs were effected with the bucket/box patches using "J" and "T" bolts and metal shoring and with a combination of wooden wedges and plugs.

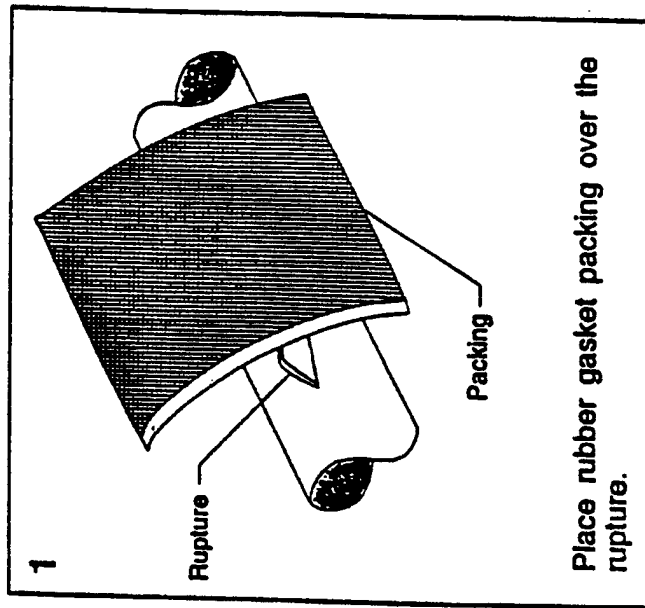
The hull damages were patched using either the box or the bucket patches. The procedures for each of these repairs were similar. Both the bucket and the box had predrilled holes in them. Depending on the nature of the hull rupture, either "J" bolts or "T" bolts were inserted through the holes in bucket/box with the "J" or "T" outside of the concave side of the patch. The bolts were secured with nuts and washers on the convex side. Gasket material available from the repair locker was positioned between the bucket/box and the hull. The bolts were positioned such that the "J" or "T" was over the solid plating. The patches were then drawn tight to the hull/gasket with the nuts on the inner end until the leakage was stopped or minimized. The bucket/box patch is shown in Fig. 12.

In cases where metal shoring was used in conjunction with the box/bucket patches, the patch was held in place over the shore by two or three of the team members. The remaining team member(s) positioned the shoring to hold the patch in place over the rupture. The bucket patch with metal shoring is shown in Fig. 13.

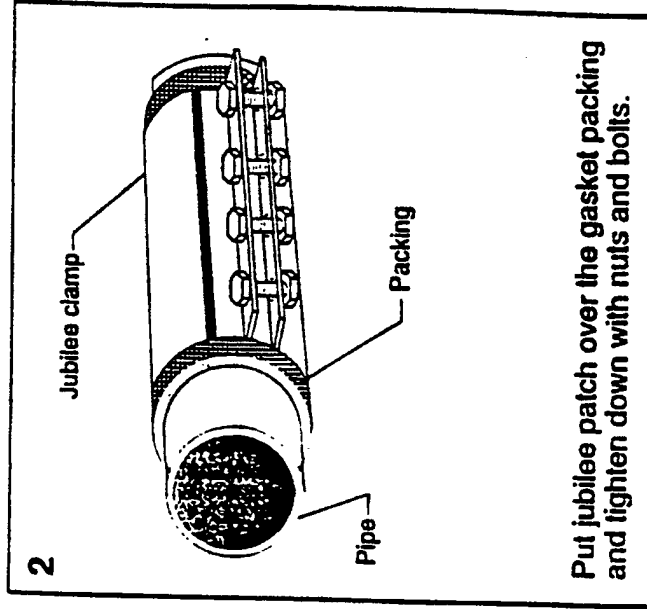
The hull damages were also repaired using plugs and wedges and a gasket material. The largest plug or wedge which could be wedged in the hole was inserted first. This was followed with progressively smaller plugs and wedges, wrapped with a sealant material such as gaskets, canvas, and oakum, being inserted into the remaining parts of the hole until the leakage was minimized or stopped. This repair is shown in Fig. 14.



JUBILEE PIPE PATCHING CLAMPS

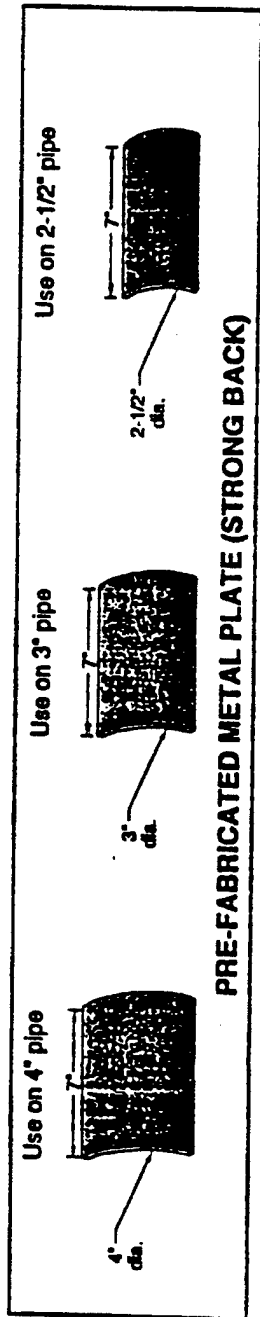


Place rubber gasket packing over the rupture.

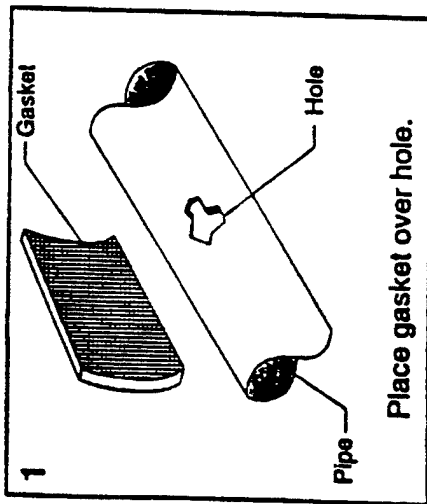


Put jubilee patch over the gasket packing and tighten down with nuts and bolts.

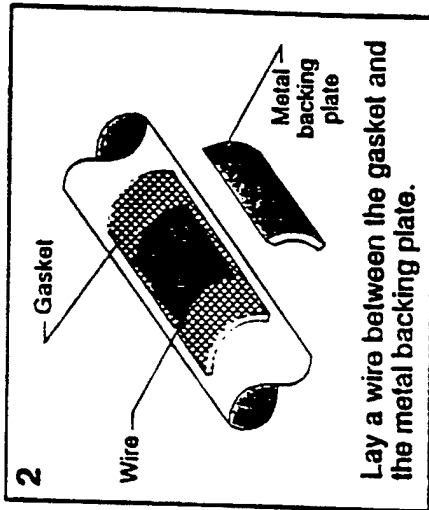
Fig. 10 - Jubilee pipe patch



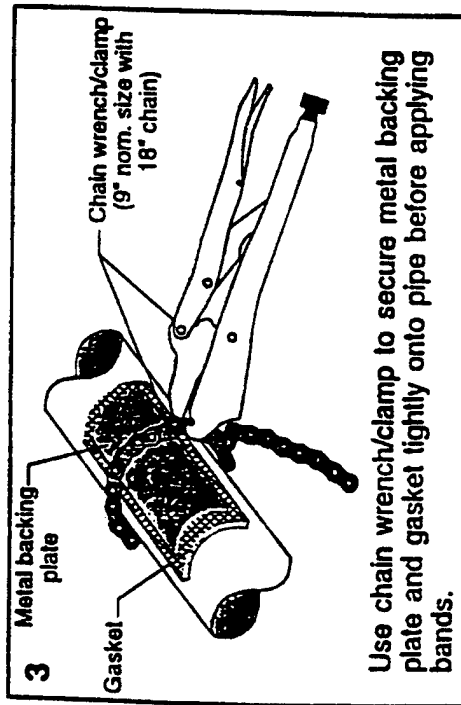
PRE-FABRICATED METAL PLATE (STRONG BACK)



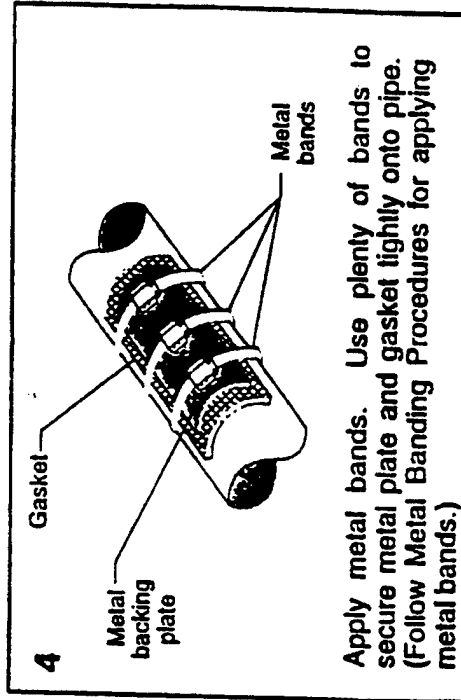
Place gasket over hole.



Lay a wire between the gasket and the metal backing plate.



Use chain wrench/clamp to secure metal backing plate and gasket tightly onto pipe before applying bands.



Apply metal bands. Use plenty of bands to secure metal plate and gasket tightly onto pipe. (Follow Metal Banding Procedures for applying metal bands.)

Fig. 11 – Banding kit with chain wrench pipe patch

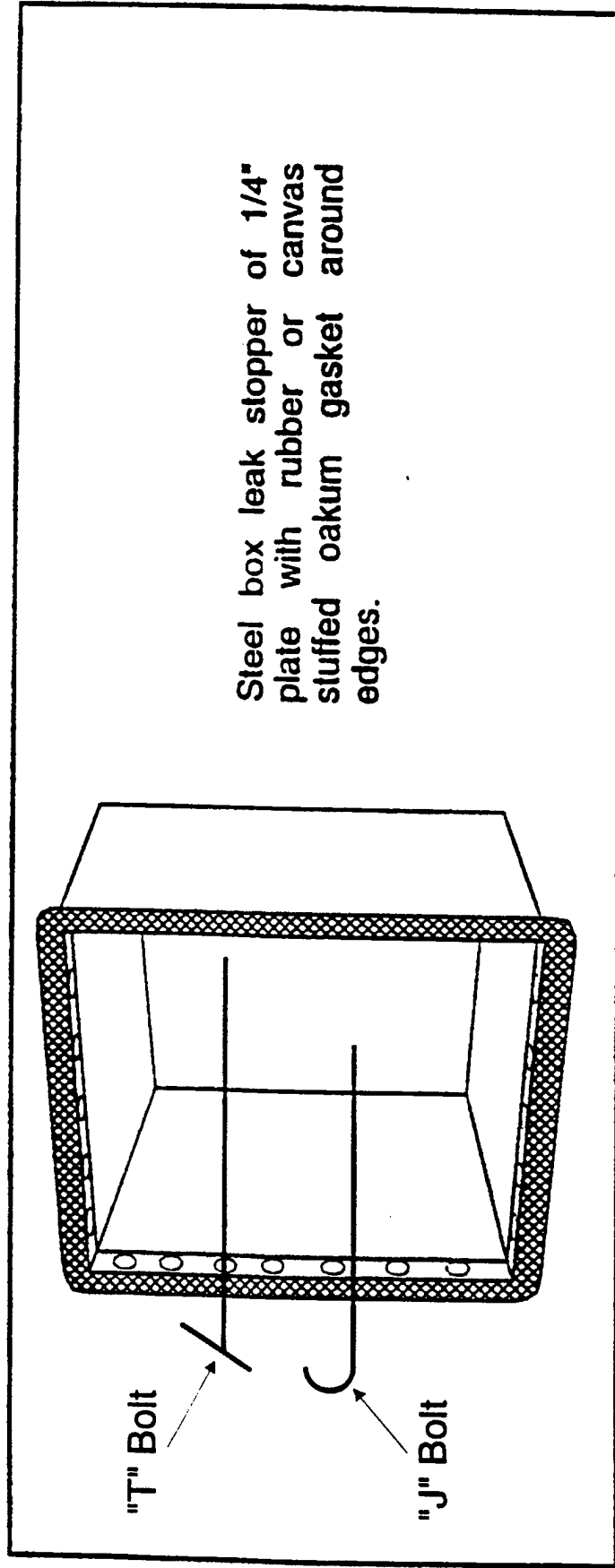


Fig. 12 - Box patch hull repair

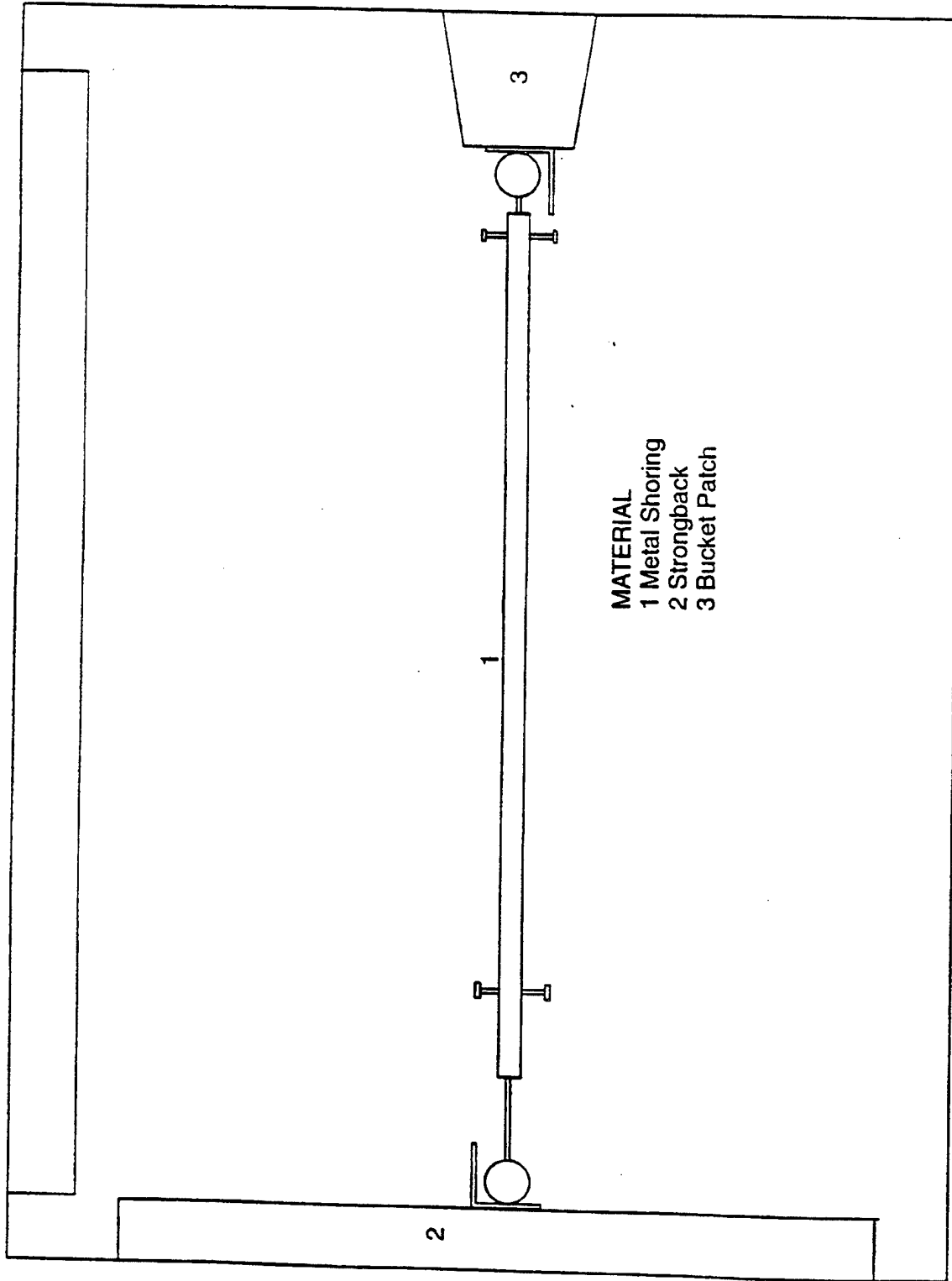
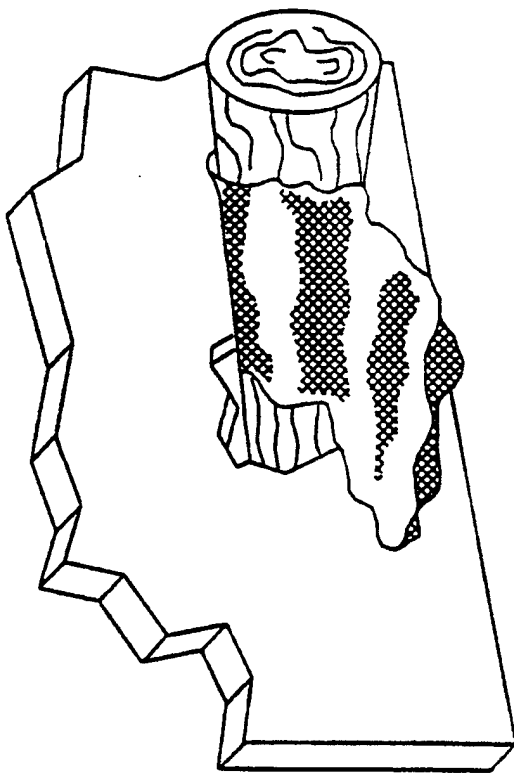
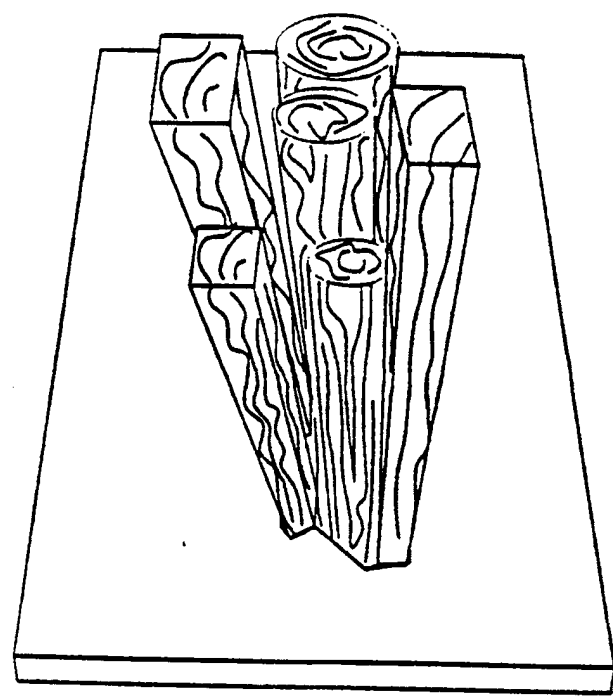


Fig. 13 – Bucket patch with metal I-shoring



Stop jagged leaks using combinations of conical/square ended plugs and wedges.

OR



Stop jagged leaks by inserting plug wrapped with cloth.

Fig. 14 – Plugs and wedges hull repair

8.0 MEASURES OF PERFORMANCE

The results of these tests focused primarily on the effectiveness of the repair activity and the time to complete the repair. The time to complete the repair was recorded by both the on-scene observers and the control room. The effectiveness of the repair was determined by the on-scene observers and analysis of the data. The on-scene observers made their judgements based on a set of effectiveness criteria. They determined if the repair was effectively completed in accordance with Naval Ships' Technical Manual (NSTM), Chapter 079, Volume 2 (reference (b)). This determination resulted in either an effective, marginal, or ineffective rating from the on-scene observers. Data analysis was required for the pipe patching tests to determine if the repair satisfied the quantitative criteria (i.e., flow reduction). The effectiveness criteria for each repair activity are shown in Table 2. The overall effectiveness is a combination of the qualitative effectiveness, determined by the on-scene observer, and the quantitative effectiveness. If either of these was marginal or ineffective then the overall effectiveness was judged to be marginal or ineffective.

Table 2. Summary of Effectiveness Criteria

Repair	Effectiveness Criteria
Pipe patch - Jubilee patch	time to complete repair < 45 minutes
	90-100% reduction in flow
Pipe patch - Banding kit	time to complete repair < 45 minutes
	90-100% reduction in flow
Hull patch	time to complete repair < 45 minutes
	reduction in flow rate such that it is less than the assumed dewatering rate of 945 lpm (250 gpm)

9.0 RESULTS

9.1 Pipe Patching Tests - The pipe rupture (three scenarios) and pipe patching material (two materials) were varied. Each test scenario was repeated three times, resulting in 36 tests. Two pipe patching teams were used during this test series. Both teams performed each of the scenarios three times with one exception. In test CW-15, team B2 repaired a rupture in the fresh water pipe instead of in the 114 mm (4.5 in.) firemain.

Table 3 summarizes the data for each pipe patching test. Included in this Table are the following: (1) test number, (2) test scenario, (3) repair team number, (4) flow rate through the water line, (5) residual pressure in the water line when the leak was initiated (measured at 2-88-2), (6) residual water pressure at the completion of the test, (7) flow rate at the completion of the test, (8) total amount of water flowed during the test, (9) overall effectiveness as determined by

Table 3. Summary of Pipe Patching Tests

Test	Damage/Repair Equipment	Team	Flow (ppm (gpm))	Residual Pressure (bar (psi))	Residual Pressure at Test Completion (bar (psi))	Flow at Test Completion (ppm (gpm))	Total Flow 00(l (gal))	Overall Effectiveness of Repair	Transit Time (min:sec)	Repair Time (min:sec)
CW-5	3.5-in. firemain / pipe wrench with banding kit	B1	681 (180)	3.4 (50)	6.9 (100)	333 (88)	not available	ineffective	0:38	26:14
CW-8			833 (220)	5.5 (80)	6.9 (100)	151 (40)	6737 (1780)	ineffective	0:30	15:10
CW-12			700 (185)	3.6 (53)	5.9 (85)	45 (12)	3323 (878)	effective	0:28	13:08
CW-3		B2	681 (180)	4.1 (60)	5.8 (84)	469 (124)	8138 (2150)	ineffective	0:50	14:10
CW-13			704 (186)	3.4 (50)	4.5 (65)	378 (100)	not available	ineffective	0:33	14:33
CW-17			681 (180)	3.4 (50)	5.8 (84)	363 (96)	5867 (1550)	ineffective	0:22	13:24
CW-1			568 (150)	2.8 (40)	5.0 (72)	0 (0)	1067 (282)	effective	0:50	2:10
CW-15	3.5-in. firemain / Jubilee patch	B1	662 (175)	3.8 (55)	6.2 (90)	3.8 (1)	10197 (2964)	effective	1:00	18:06
CW-16			681 (180)	3.4 (50)	6.9 (100)	0 (0)	3709 (980)	effective	0:25	6:59
CW-6			636 (168)	3.4 (50)	5.0 (73)	not available	3664 (968)	ineffective	0:40	10:34
CW-7		B2	681 (180)	3.6 (53)	6.6 (95)	3.8 (1)	2752 (727)	effective	0:29	4:35
CW-11			674 (178)	3.4 (50)	6.9 (100)	0 (0)	2260 (597)	effective	0:25	2:53
CW-4			946 (250)	1.9 (27)	2.0 (29)	946 (250)	not available	ineffective	0:41	11:41
CW-9	4.5 in. firemain / pipe wrench with banding kit	B1	927 (245)	2.2 (32)	4.2 (61)	518 (137)	8649 (2285)	ineffective	0:30	15:49
CW-10			920 (243)	2.2 (32)	3.4 (50)	not available	11325 (2992)	ineffective	0:44	14:17
CW-1			not available	0.3 (4.0)	1.7 (25)	295 (78)	4156 (1098)	ineffective	0:50	14:00
CW-16		908 (240)	1.9 (28)	4.1 (60)	163 (43)	5204 (1375)	ineffective	0:21	16:05	
CW-2		not available	2.8 (40)	5.4 (78)	not available	not available	ineffective	1:48	3:06	
CW-14	4.5 in. firemain / Jubilee patch	B1	908 (240)	2.1 (30)	102 (27)	5.2 (75)	8327 (2200)	ineffective	2:03	10:32
CW-18			1060 (280)	2.6 (38)	6.1 (89)	38 (10)	3039 (803)	effective	0:27	6:26
CW-5			1211 (320)	2.1 (30)	2.9 (42)	1060 (280)	not available	ineffective	0:47	5:14
CW-8		889 (235)	2.3 (34)	5.5 (80)	288 (76)	7437 (1965)	ineffective	0:33	13:27	
CW-12		973 (257)	2.6 (37)	6.8 (99)	272 (72)	4731 (1250)	ineffective	0:28	7:57	

Table 3. Summary of Pipe Patching Tests (Continued)

Test	Damage/Repair Equipment	Team	Flow (gpm)	Residual Pressure (bar (psi))	Residual Pressure at Test Completion (bar (psi))	Flow at Test Completion (gpm)	Total Flow 00(l (gal))	Overall Effectiveness of Repair	Transit Time (min:sec)	Repair Time (min:sec)
CW-6	2.375 in. fresh water / pipe wrench with banding kit	B1	114 (30)	0.3 (5)	4.3 (62)	0 (0)	not available	effective	0:28	6:48
CW-7			102 (27)	0.3 (5)	4.3 (63)	3.8 (1)	390 (103)	effective	0:25	12:44
CW-11			102 (27)	0.3 (5)	3.4 (50)	3.8 (1)	363 (96)	effective	0:30	11:09
CW-2		B2	106 (28)	0 (0)	0 (0)	106 (28)	not available	ineffective	0:36	7:58
CW-14			87 (23)	0.3 (5)	4.5 (65)	0 (0)	844 (223)	effective	2:00	16:10
CW-15			106 (28)	0.3 (5)	4.5 (65)	0 (0)	564 (149)	effective	0:40	10:19
CW-18			110 (29)	0.2 (3)	3.8 (55)	11 (3)	450 (119)	effective	0:22	8:10
CW-3			B1	121 (32)	0.3 (5)	4.1 (60)	0 (0)	212 (56)	effective	0:25
CW-13	98 (26)	0.3 (5)		4.3 (62)	0 (0)	356 (94)	effective	0:26	4:20	
CW-17	95 (25)	0.2 (3)		4.3 (63)	0 (0)	269 (71)	effective	0:19	4:36	
CW-4	B2	121 (32)		0.3 (5)	4.5 (65)	0 (0)	326 (86)	effective	0:41	2:00
CW-9		121 (32)		0.2 (3)	4.3 (63)	0 (0)	412 (109)	effective	0:24	4:05
CW-10		102 (27)		0.2 (3)	4.5 (65)	0 (0)	341 (90)	effective	0:25	3:53

the team observer, (10) the transit time (the amount of time required to get from Repair 4 to the Upper Wet Compartment), and (11) the time to complete the repair activity. The on-scene observers determined the ability of the team to properly effect the repair. An analysis of the flow rate data was conducted to determine if the flow reduction criteria contained in Table 2 were satisfied.

9.2 Results of Hull Repair Tests – A total of 18 hull repair tests were performed, involving two different hull ruptures and three hull patches. All of the hull repairs were performed by the same repair team (Team A).

Table 4 contains a summary of the hull repair tests. This table includes the general test information, the overall effectiveness, and the transit and repair times.

Table 4. Summary of Hull Repair Tests

Test	Damage	Repair Method	Overall Effectiveness	Transit Time (min:sec)	Repair Time (min:sec)
CW-4	Explosion rupture	bucket patch	ineffective	0:52	13:47
CW-8			marginal	0:27	6:09
CW-15			effective	0:30	16:53
CW-16			ineffective	0:29	5:42
CW-17			effective	0:34	6:06
CW-1	Explosion rupture	bucket patch with metal shoring	ineffective	0:40	14:40
CW-5	Explosion rupture	box patch	ineffective	0:30	9:40
CW-12	Explosion rupture	box patch with metal shoring	ineffective	0:33	5:13
CW-18	Rip/gash rupture	box patch	ineffective	0:20	7:23
CW-2	Rip/Gash rupture	box patch with metal shoring	ineffective	0:47	8:30
CW-3			ineffective	0:38	6:19
CW-10			ineffective	0:30	6:00
CW-14			ineffective	2:03	5:00
CW-6	Rip/Gash rupture	plugs and wedges	ineffective	0:40	16:03
CW-7			ineffective	0:25	14:49
CW-9			ineffective	0:28	9:04
CW-11			ineffective	0:30	10:20
CW-13			ineffective	0:53	12:14

10.0 SUMMARY

10.1 Environmental Conditions - Temperature, relative humidity, and wind speed are summarized in Table 5. Graphs of the water level, with respect to time, in the Upper Wet Compartment are provided in Appendix E.

Table 5. Temperature, Humidity, and Wind Speed

Test	Outside		Upper Wet Compartment		Average Water Temperature (°C)	Average Wind Speed (mph)
	Dry Bulb Temperature (°C)	Relative Humidity (%)	Dry Bulb Temperature (°C)	Relative Humidity (%)		
CW-1	12	100	12	100	10	11
CW-2	15	48	15	86	10	12
CW-3	17	50	17	46	8	13
CW-4	10	62	8	72	10	3
CW-5	11	80	8	80	9	4
CW-6	10	82	9	80	8	7
CW-7	15	79	16	77	10	11
CW-8	16	72	16	72	10	12
CW-9	21	72	19	83	10	10
CW-10	18	90	18	88	9	7
CW-11	20	100	18	83	11	8
CW-12	19	78	18	83	12	10
CW-13	9	89	10	87	9	10
CW-14	15	90	12	97	10	8
CW-15	15	100	13	81	8	8
CW-16	8	41	6	60	9	19
CW-17	3	100	5	100	9	17
CW-18	4	82	6	100	10	20

10.2 Personnel Protective Clothing - Protective clothing worn by the personnel for each test is summarized in Table 6. This variable will be evaluated with the pipe patching and hull

repair performance to determine if there are statistically significant differences attributable to the personnel protection (reference (7)).

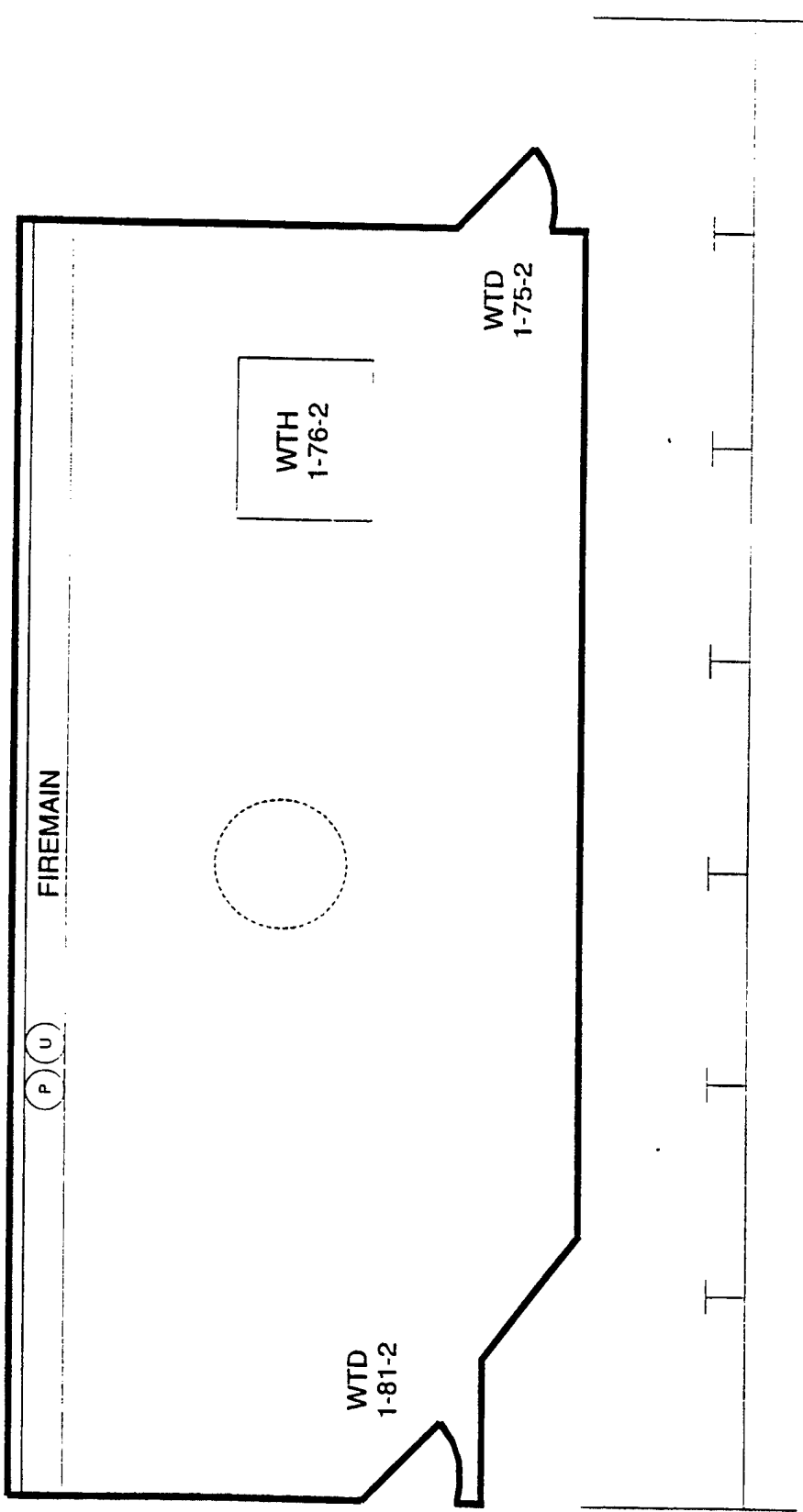
Table 6. Summary of Protective Clothing

Test	Protective Clothing
CW-1	CON
CW-2	CON
CW-3	CON
CW-4	NAVLO
CW-5	NAVLO
CW-6	NAVLO
CW-7	NATO
CW-8	NATO
CW-9	NATO
CW-10	CON
CW-11	CON
CW-12	ENCAP
CW-13	NAVLO
CW-14	NAVLO
CW-15	NAVLO
CW-16	NATO
CW-17	NATO
CW-18	NATO

Appendix A
Instrumentation Drawings

INSTRUMENT KEY

- Ⓐ AUDIO
- Ⓟ PRESSURE
- Ⓥ VIDEO CAMERA
- Ⓣ THERMOCOUPLE TREE
- Ⓤ ULTRASONIC FLOW METER

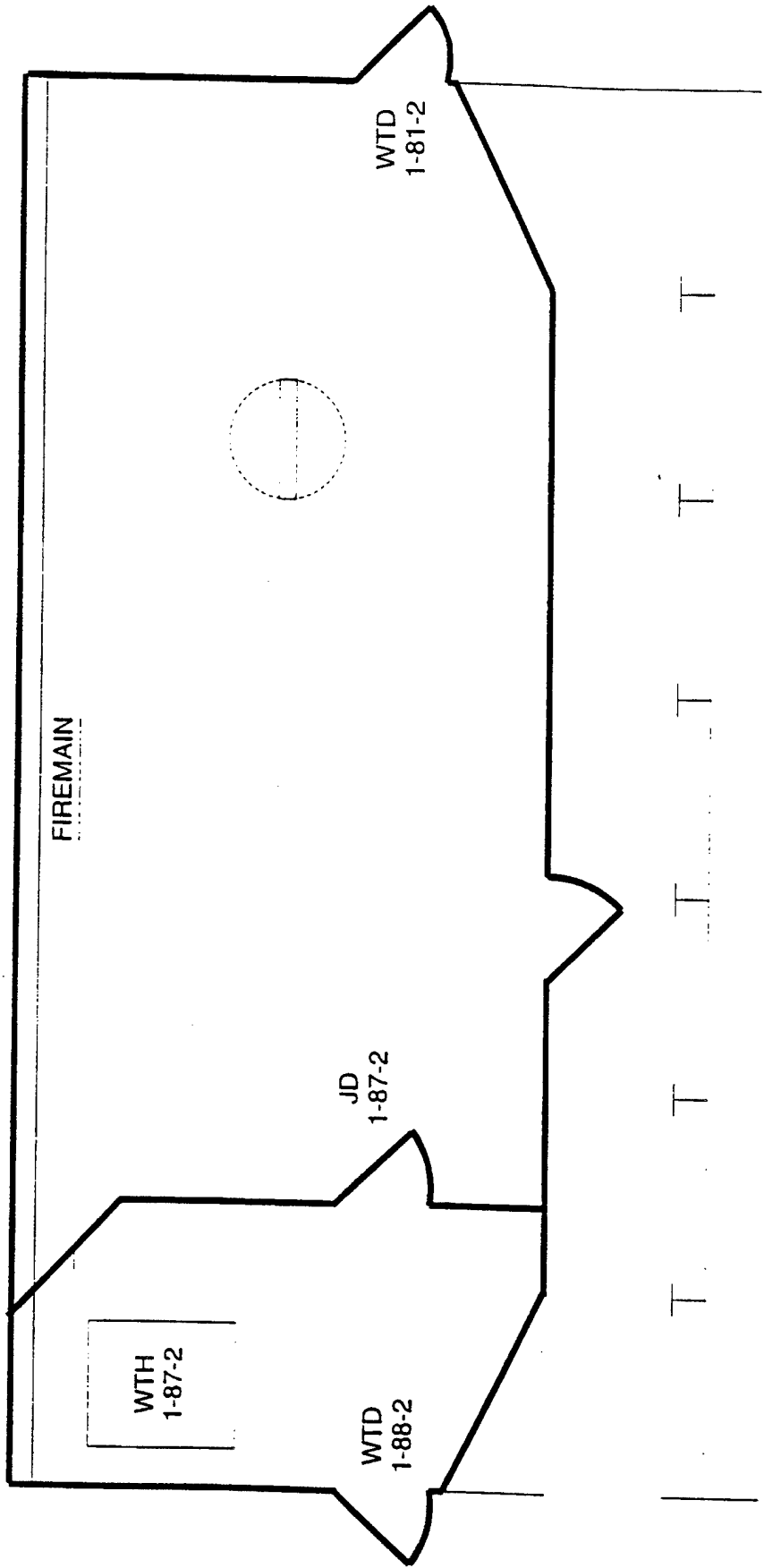


74

1ST PLATFORM	REV: 7/5/95
FILE: SUB1-81N	DATE: 4/19/94

81

Fig. A1 – Combat systems instrumentation layout



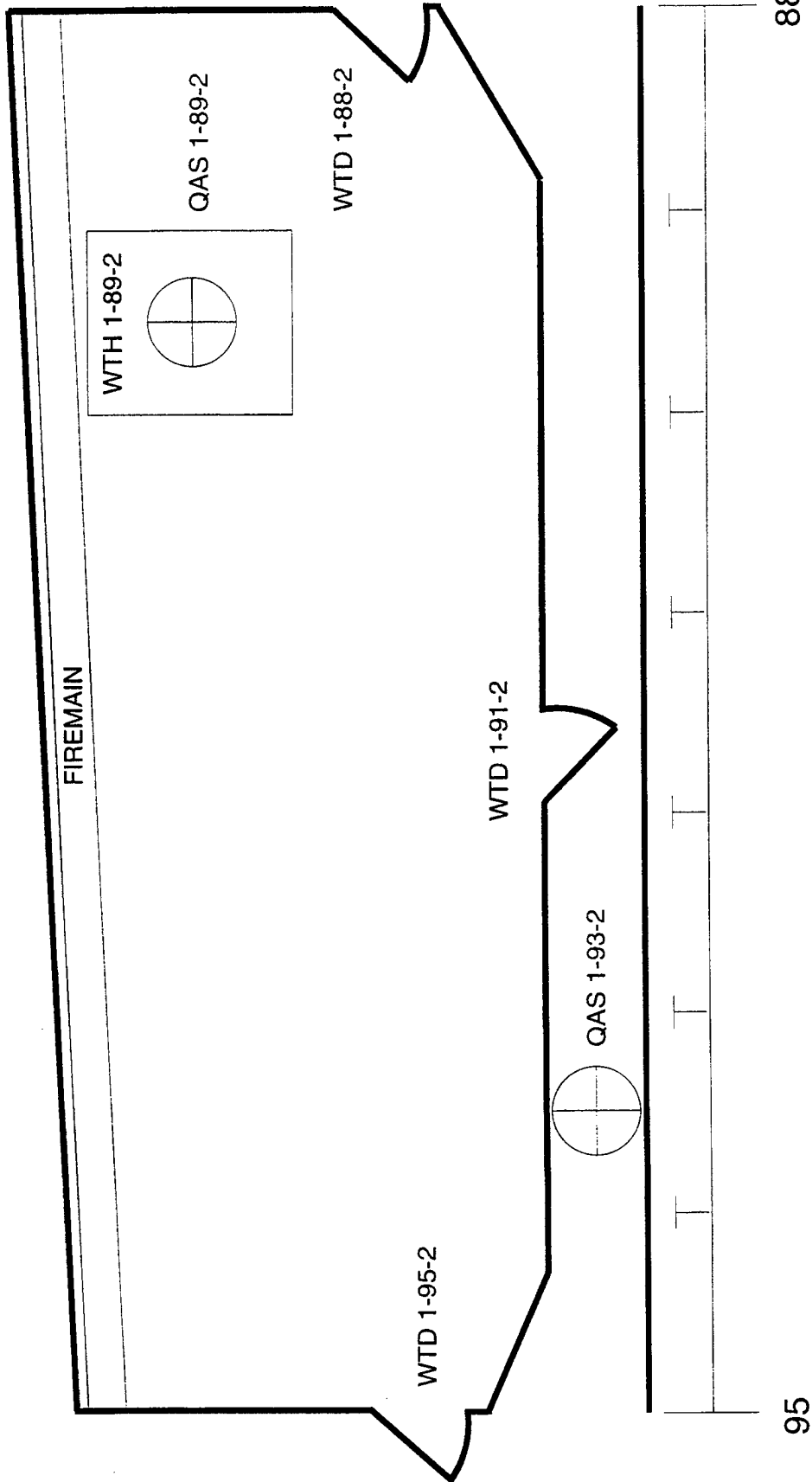
A-4

88

81

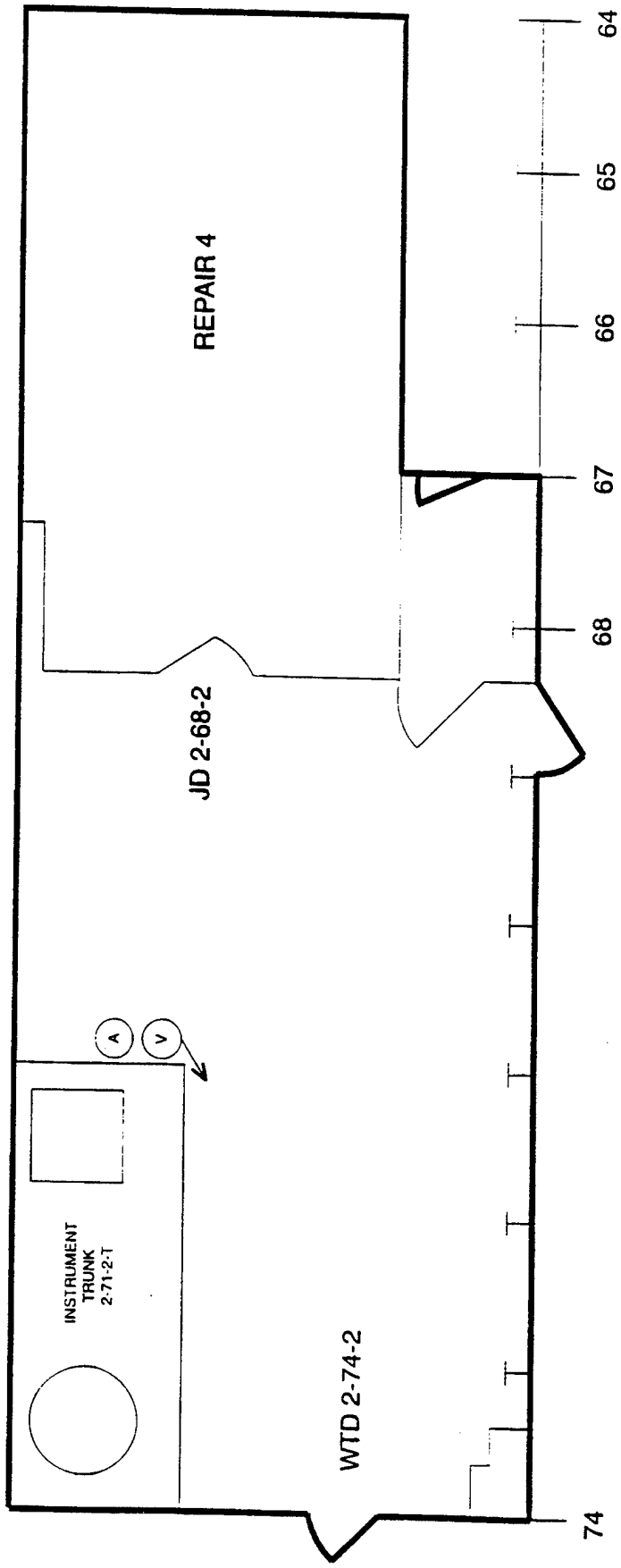
1ST PLATFORM	REV: 7/5/95
FILE: SUB1-88N	DATE: 11/29/94

Fig. A2 – Control room instrumentation layout



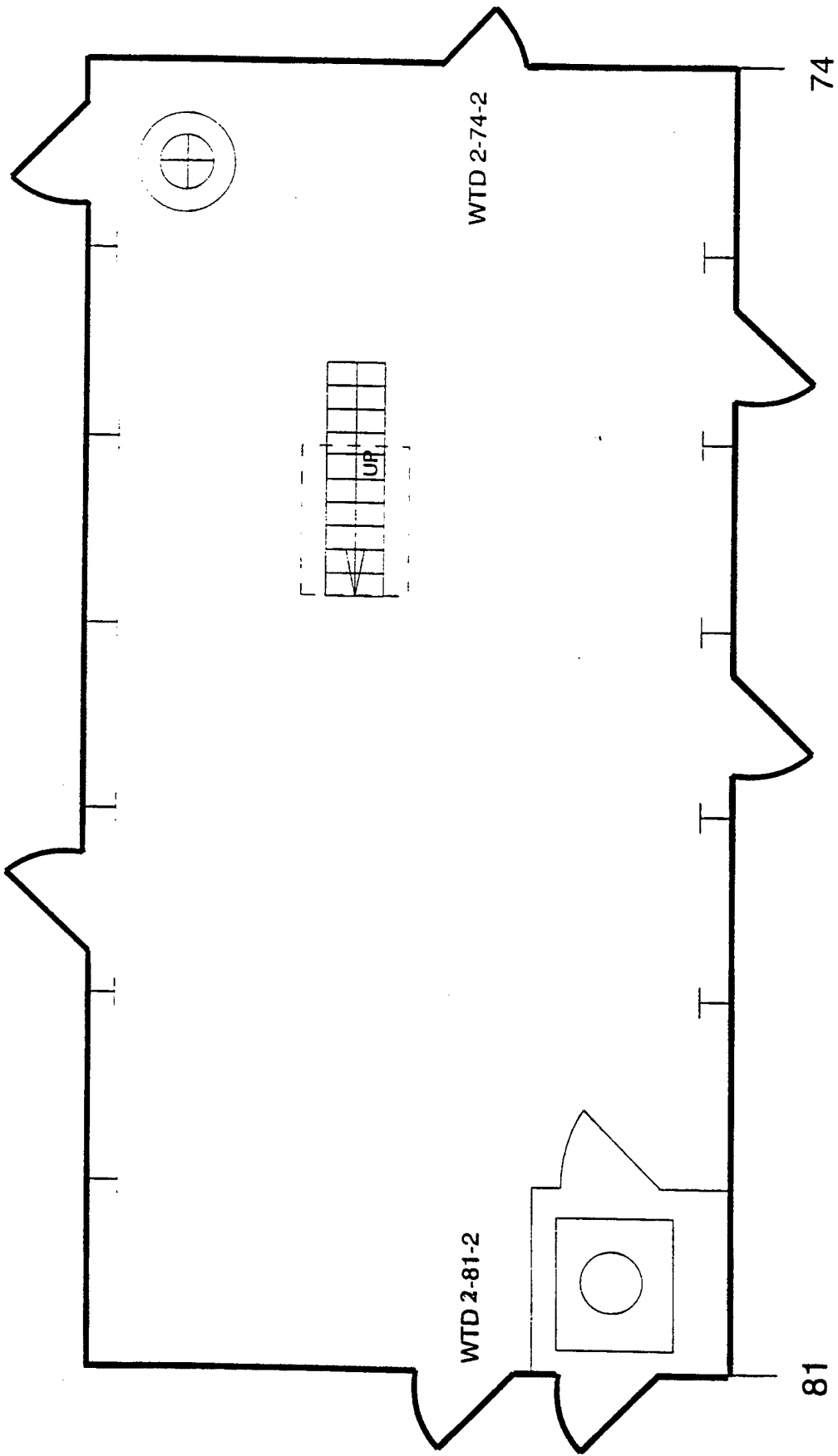
A-5

Fig. A3 - Fan room instrumentation layout



2ND PLATFORM	REV: 7/5/95
FILE: SUB2-74	DATE: 4/19/94

Fig. A4 – CPO living quarters instrumentation layout



2ND PLATFORM	REV: 7/5/95
FILE: SUB2-81	DATE: 4/19/94

A-7

Fig. A5 – Crew living instrumentation layout

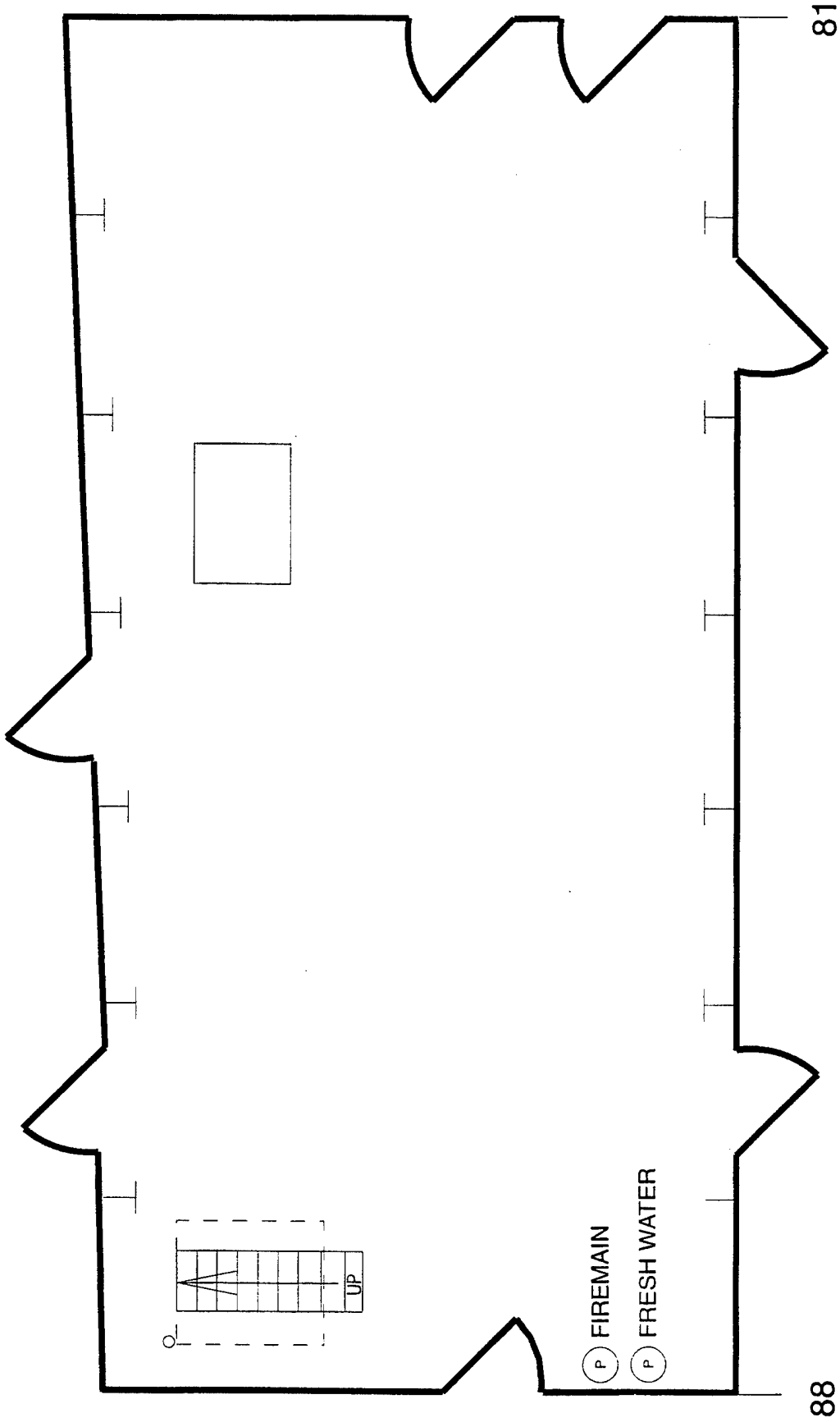
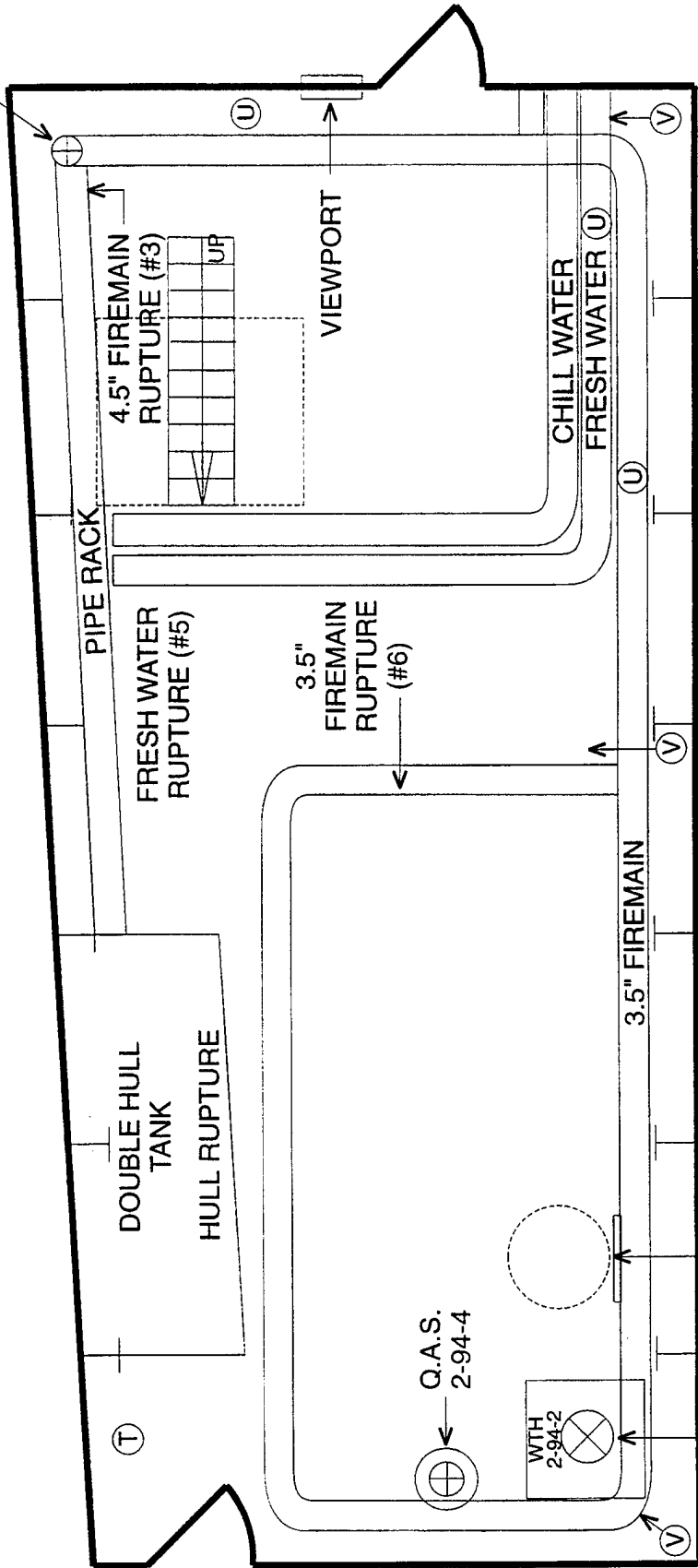


Fig. A6 - Wardroom instrumentation layout

FM RISER
2-88-4



88

95

2ND PLATFORM	REV: 8/23/95
FILE:SUB2-95	DATE: 4/19/94

Fig. A7 - Upper Wet Compartment layout

Appendix B
Instrumentation Listing

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location		REMARKS
			(x/y/z)	Frame No.	
COMBAT SYSTEMS (1-79-2)					
1	Pressure	34.5 bar (0-500 psi)	--	1-79-2	Firemain pressure.
2	Flow meter	0-1891 lpm (0-500 gpm)	--	1-79-2	Firemain flow, ultrasonic.
PASSAGEWAY (2-68-2)					
3	Video (camera)	N/A	2.5/0.0/2.0	2-77-1	Mount high on inboard bulkhead, looking aft at Repair 4 doorway.
4	Audio (microphone)	N/A	5.0/2.5/2.5	2-70-0	Mount in overhead such that it does not interfere with personnel movement.
UPPER "WET" COMPARTMENT (2-88-2)					
5	Video (camera)	N/A	8.5/1.0/2.0	2-88-1	Mount high on forward bulkhead, toward inboard side, looking at aft-centerline. Camera must be enclosed/protected from water spray.
6	Pressure	17.2 bar (0-250 psi)	8.6/1.0/2.2	"	Actually mounted <u>OUTSIDE</u> compartment in fresh water supply piping.
7	Pressure	17.2 bar (0-250 psi)	8.6/1.0/2.2	"	Actually mounted <u>OUTSIDE</u> compartment in firemain supply piping.
8	Flow Meter	0-945 lpm (0-250 gpm)	--	2-88-0	Ultrasonic on FM.
9	Flow Meter	0-945 lpm (0-250 gpm)	--	2-90-1	Ultrasonic on FM.

INSTRUMENTATION LISTING - Damage Control Testing

[Note: For coordinate system (x/y/z), measurements are from: aft bulkhead/starboard bulkhead/deck level, within each space (exempt Bridge Access Trunk and Bilge level spaces). "+" is forward, port, up. All dimensions are in meters.]

Item No.	Instrument Description	Output Range	Location		REMARKS
			(x/y/z)	Frame No.	
10	Flow Meter	0-756 lpm (0-200 gpm)	--	2-89-2	Ultrasonic on fresh water piping.
11	Video (camera - Wide Angle Lens req'd)	N/A	5.0/0.0/2.0	2-91-1	Mount high on inboard bulkhead, looking across compartment in the "aft" direction. Camera must be enclosed/protected from water spray.
12	Thermocouple	0-100°C	0.1/3.3/2.1	2-94-2	Use <u>EXISTING</u> T/C string.
13	"	"	0.1/3.3/1.8	"	"
14	"	"	0.1/3.3/1.5	"	"
15	"	"	0.1/3.3/1.2	"	"
16	"	"	0.1/3.3/0.9	"	"
17	"	"	0.1/3.3/0.6	"	"
18	"	"	0.1/3.3/0.3	"	"
19	Video (camera - Wide Angle Lens req'd)	N/A	0.0/0.1/2.0	2-94-2	Mount high at the junction (corner) of the inboard and aft bulkheads, looking (forward) toward the center of the compartment. Camera must be enclosed/protected from water spray.
TORPEDO ROOM (3-74-2)					
20	Microswitch	0-1	QAWTD 3-81-2		Attach to WTD frame such that; open = 0, closed = 1

Appendix C
Original Test Schedule

Table C1. Original Test Schedule

Test	Day	Team A		Team B1		Team B2	
		Damage	Repair	Damage	Repair	Damage	Repair
CW-1	1	Explosion	Patch	3.5 in. firemain	Jubilee patch	4.5 in. firemain	Banding kit
CW-2	1	Rip/Gash	Patch	4.5 in. firemain	Jubilee patch	Fresh water	Banding kit
CW-3	1	Rip/Gash	Plugs and wedges	Fresh water	Jubilee patch	3.5 in. firemain	Banding kit
CW-4	2	Explosion	Patch	4.5 in. firemain	Banding kit	Fresh water	Jubilee patch
CW-5	2	Explosion	Plugs and wedges	3.5 in. firemain	Banding kit	4.5 in. firemain	Jubilee patch
CW-6	2	Rip/Gash	Patch	Fresh water	Banding kit	3.5 in. firemain	Jubilee patch
CW-7	3	Rip/Gash	Patch	Fresh water	Banding kit	3.5 in. firemain	Jubilee patch
CW-8	3	Explosion	Patch	3.5 in. firemain	Banding kit	4.5 in. firemain	Jubilee patch
CW-9	3	Rip/Gash	Plugs and wedges	4.5 in. firemain	Banding kit	Fresh water	Jubilee patch
CW-10	4	Rip/Gash	Patch	4.5 in. firemain	Banding kit	Fresh water	Jubilee patch
CW-11	4	Explosion	Plugs and wedges	Fresh water	Banding kit	3.5 in. firemain	Jubilee patch
CW-12	4	Explosion	Patch	3.5 in. firemain	Banding kit	4.5 in. firemain	Jubilee patch
CW-13	5	Rip/Gash	Patch	Fresh water	Jubilee patch	3.5 in. firemain	Banding kit
CW-14	5	Rip/Gash	Plugs and wedges	4.5 in. firemain	Jubilee patch	Fresh water	Banding kit
CW-15	5	Explosion	Patch	3.5 in. firemain	Jubilee patch	4.5 in. firemain	Banding kit
CW-16	6	Explosion	Patch	3.5 in. firemain	Jubilee patch	4.5 in. firemain	Banding kit
CW-17	6	Explosion	Plugs and wedges	Fresh water	Jubilee patch	3.5 in. firemain	Banding kit
CW-18	6	Rip/Gash	Patch	4.5 in. firemain	Jubilee patch	Fresh water	Banding kit

Appendix D
Actual Test Schedule

Table D1. Actual Test Schedule

Test	Date	Team A		Team B1		Team B2	
		Damage	Repair	Damage	Repair	Damage	Repair
CW-1	2/12/96	Explosion	Bucket patch with shoring	3.5 in. firemain	Jubilee patch	4.5 in. firemain	Banding kit
CW-2	2/12/96	Rip/Gash	Box patch with shoring	4.5 in. firemain	Jubilee patch	Fresh water	Banding kit
CW-3	2/12/96	Rip/Gash	Box patch with shoring	Fresh water	Jubilee patch	3.5 in. firemain	Banding kit
CW-4	2/13/96	Explosion	Bucket patch	4.5 in. firemain	Banding kit	Fresh water	Jubilee patch
CW-5	2/13/96	Explosion	Box patch	3.5 in. firemain	Banding kit	4.5 in. firemain	Jubilee patch
CW-6	2/13/96	Rip/Gash	Plugs and wedges	Fresh water	Banding kit	3.5 in. firemain	Jubilee patch
CW-13	2/13/96	Rip/Gash	Plugs and wedges	Fresh water	Jubilee patch	3.5 in. firemain	Banding kit
CW-14	2/14/96	Rip/Gash	Box patch with shoring	4.5 in. firemain	Jubilee patch	Fresh water	Banding kit
CW-15	2/14/96	Explosion	Bucket patch	3.5 in. firemain	Jubilee patch	Fresh water	Banding kit
CW-7	2/14/96	Rip/Gash	Plugs and wedges	Fresh water	Banding kit	3.5 in. firemain	Jubilee patch
CW-8	2/14/96	Explosion	Bucket patch	3.5 in. firemain	Banding kit	4.5 in. firemain	Jubilee patch
CW-11	2/15/96	Rip/Gash	Plugs and wedges	Fresh water	Banding kit	3.5 in. firemain	Jubilee patch
CW-10	2/15/96	Rip/Gash	Box patch with shoring	4.5 in. firemain	Banding kit	Fresh water	Jubilee patch
CW-12	2/15/96	Explosion	Box patch with shoring	3.5 in. firemain	Banding kit	4.5 in. firemain	Jubilee patch
CW-9	2/15/96	Rip/Gash	Plugs and wedges	4.5 in. firemain	Banding kit	Fresh water	Jubilee patch
CW-16	2/16/96	Explosion	Bucket patch	3.5 in. firemain	Jubilee patch	4.5 in. firemain	Banding kit
CW-17	2/16/96	Explosion	Bucket patch	Fresh water	Jubilee patch	3.5 in. firemain	Banding kit
CW-18	2/16/96	Rip/Gash	Box patch	4.5 in. firemain	Jubilee patch	Fresh water	Banding kit

Appendix E
Water Level Data

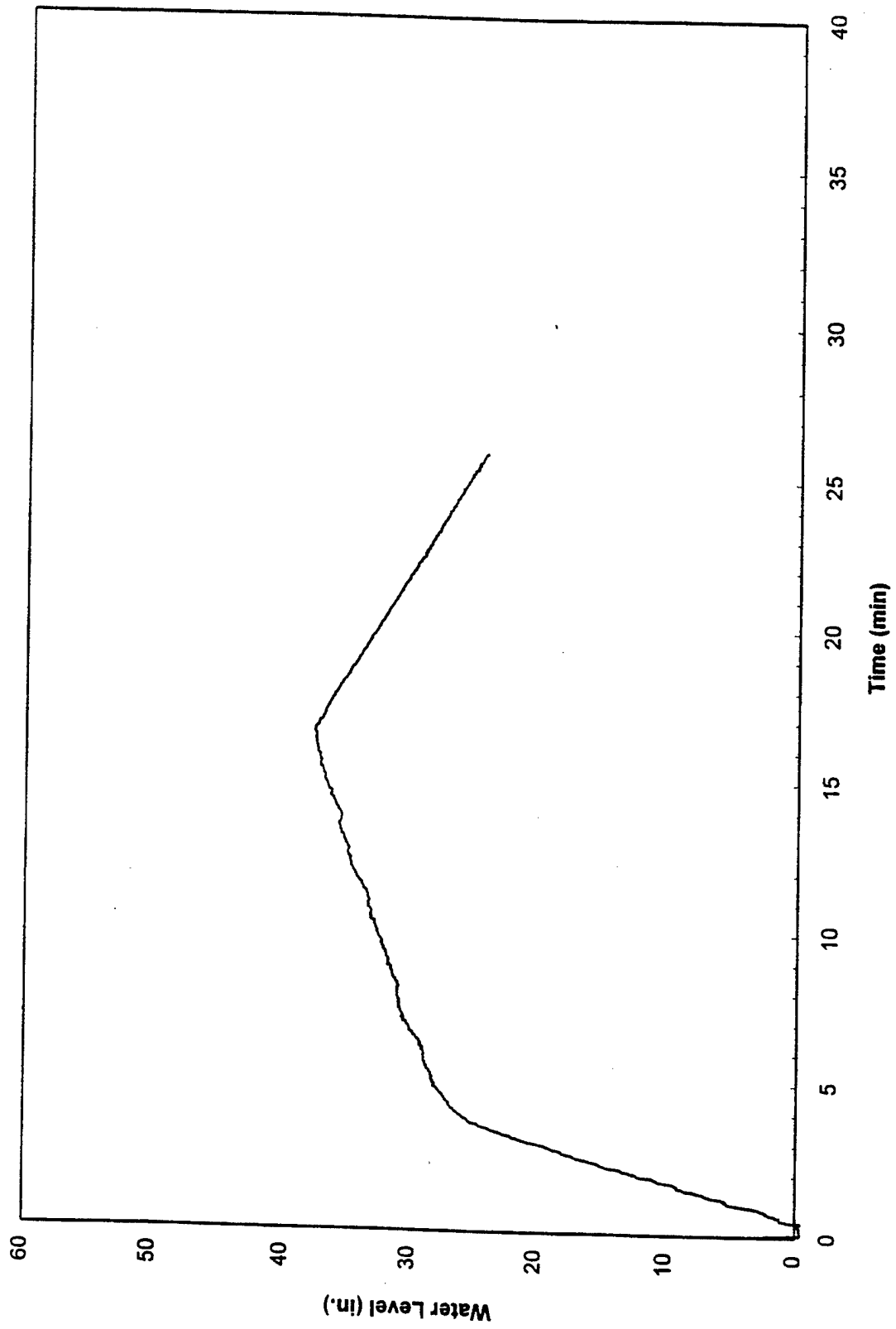


Fig. E1 - Water level in Upper Wet Compartment for test CW-1

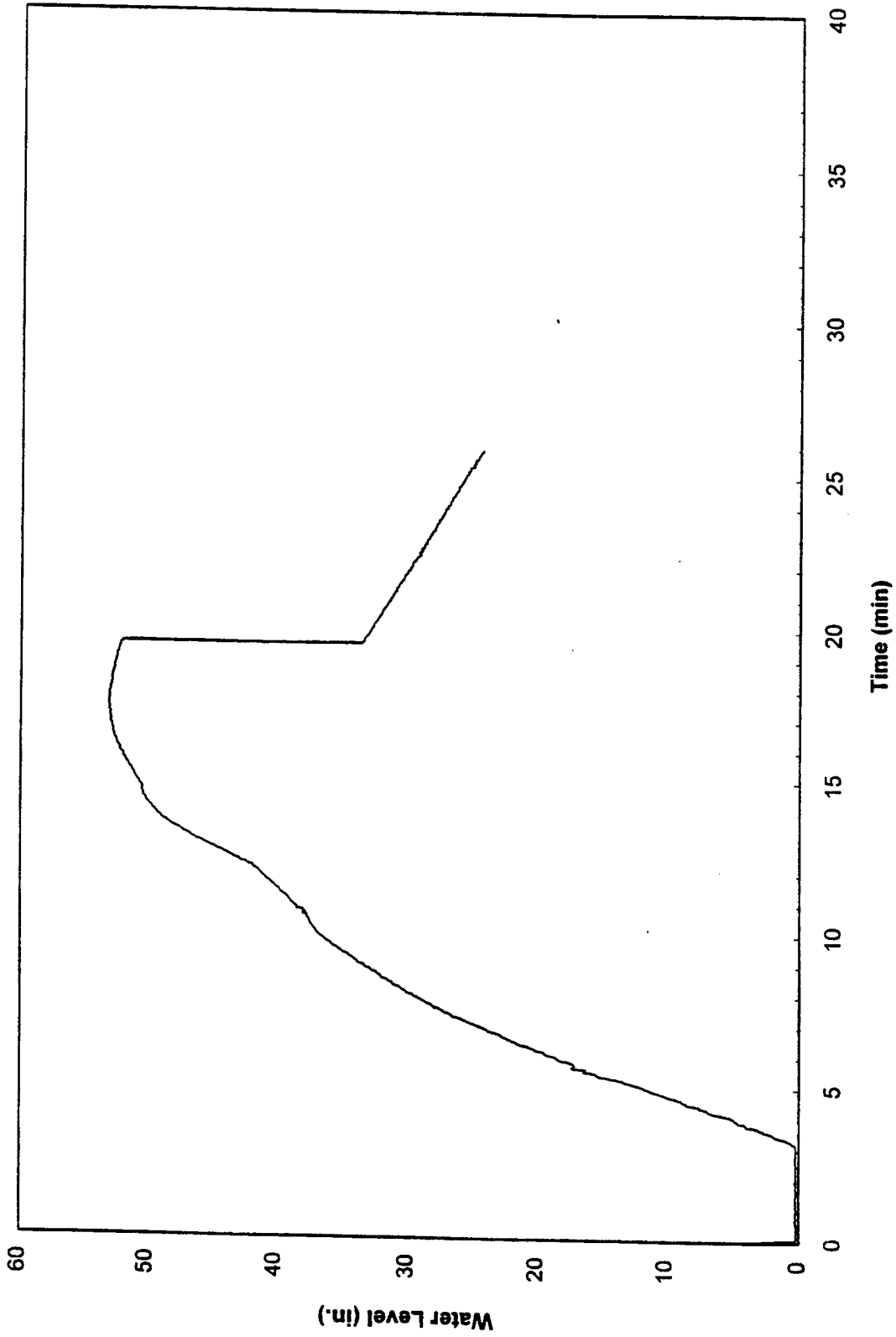


Fig. E2 - Water level in Upper Wet Compartment for test CW-2

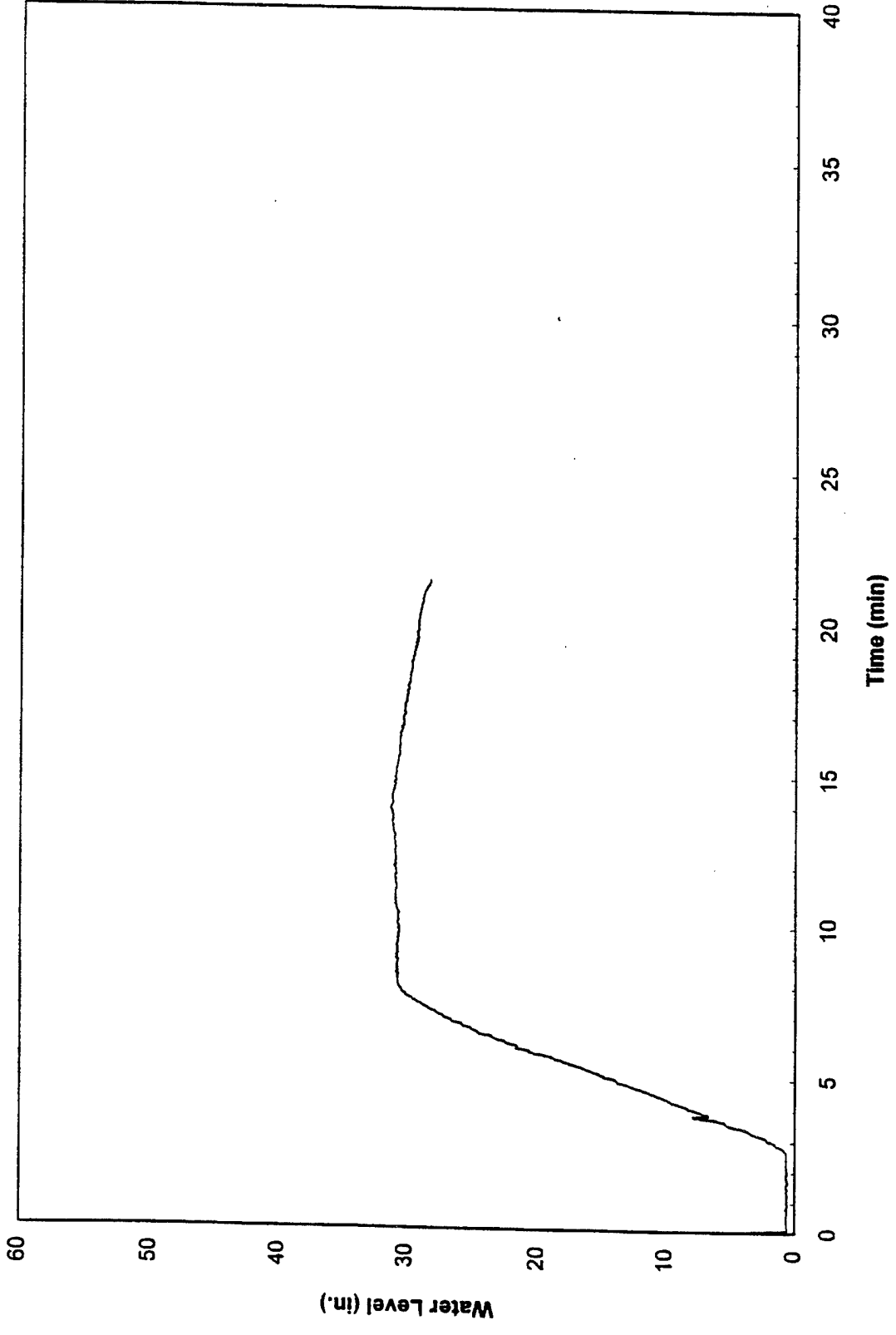


Fig. E3 - Water level in Upper Wet Compartment for test CW-3

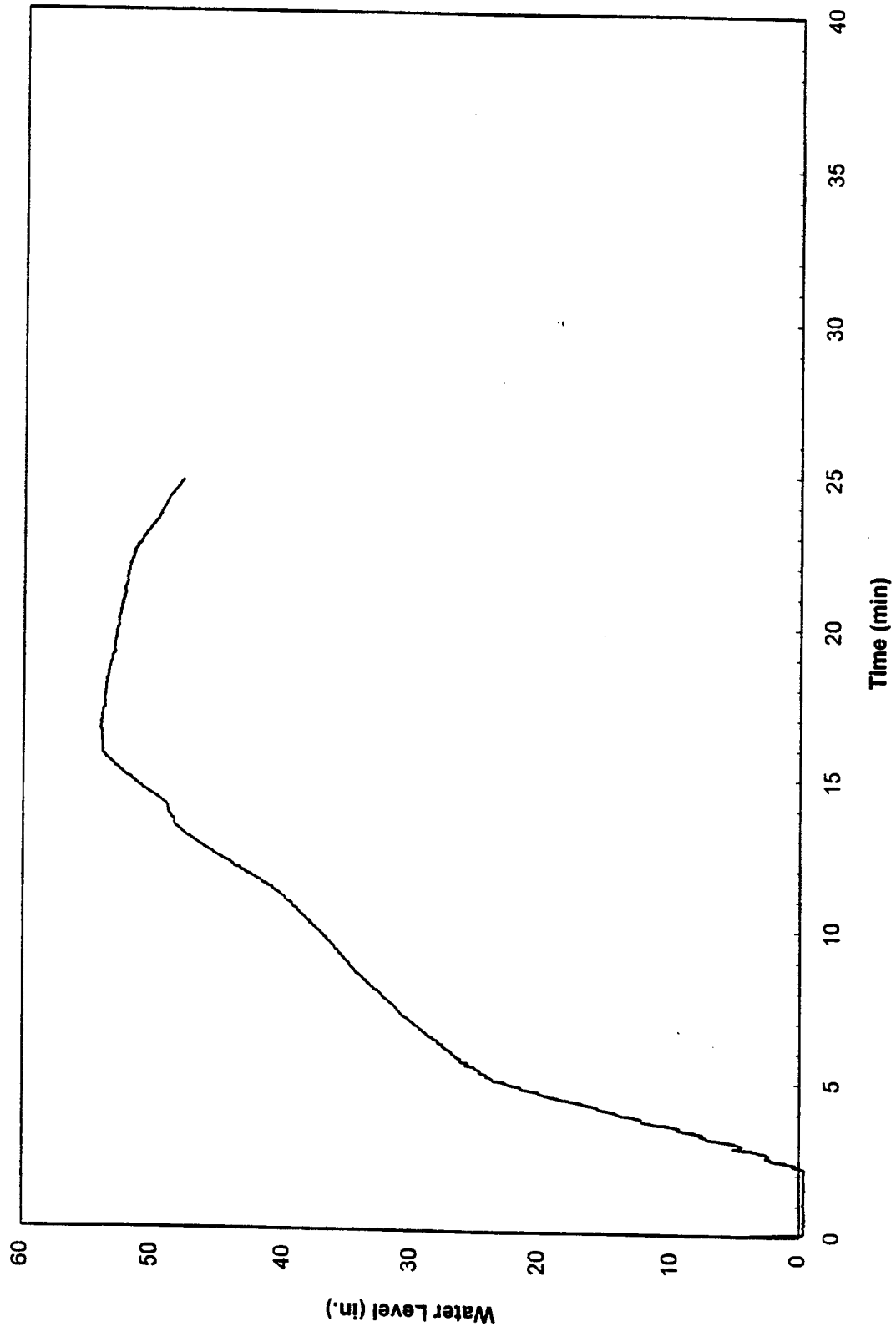


Fig. E4 - Water level in Upper Wet Compartment for test CW-4

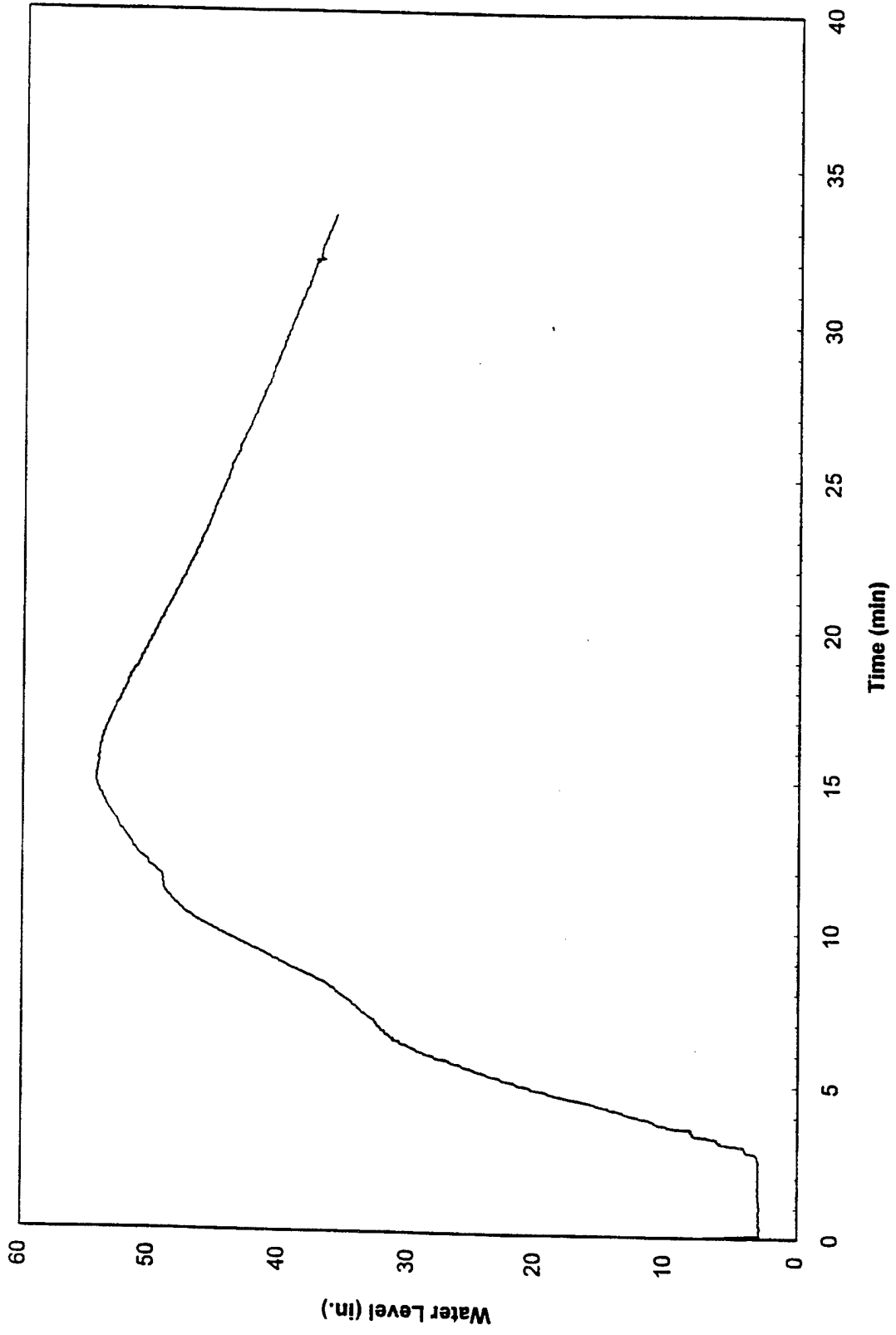


Fig. E5 - Water level in Upper Wet Compartment for test CW-5

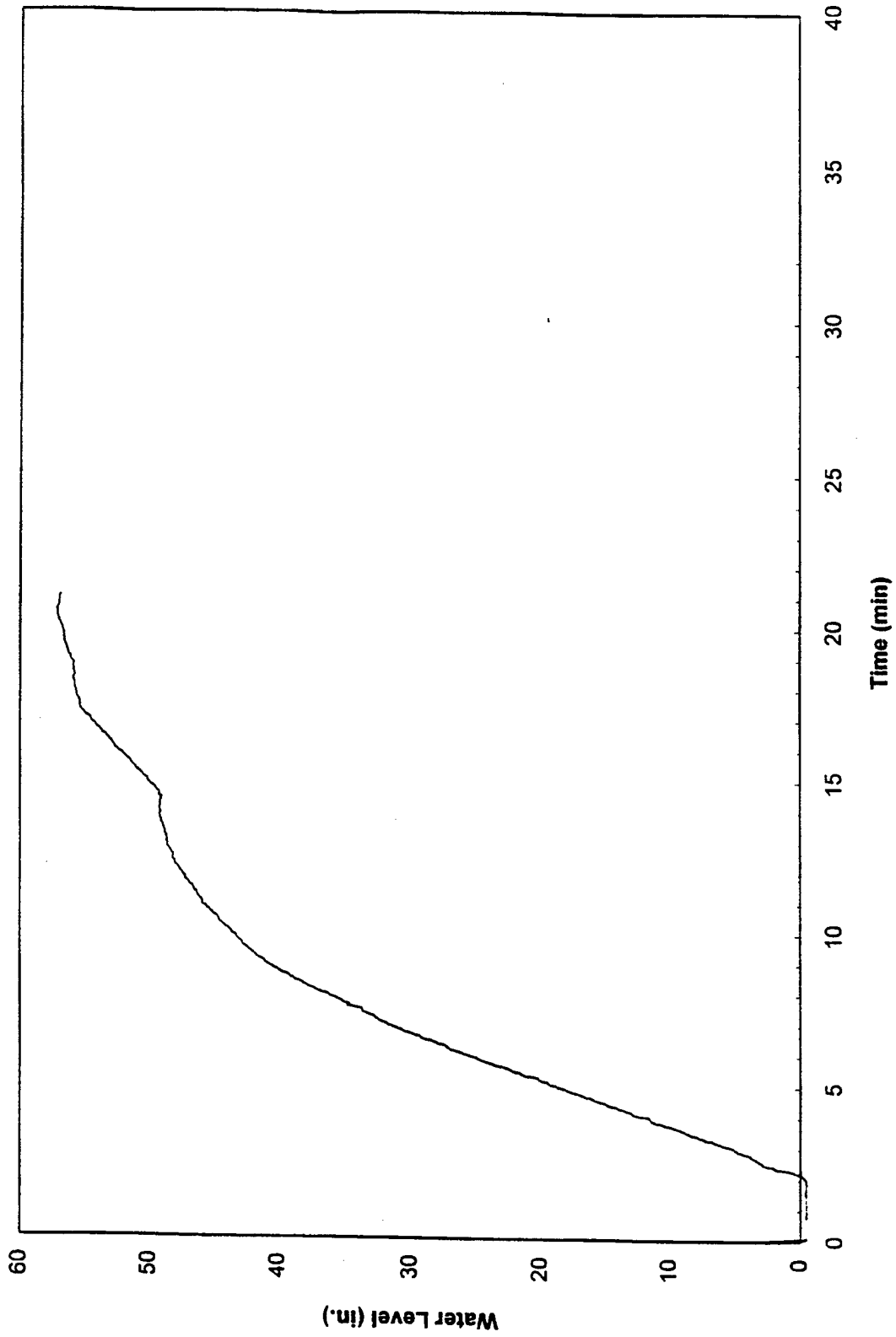


Fig. E6 - Water level in Upper Wet Compartment for test CW-6

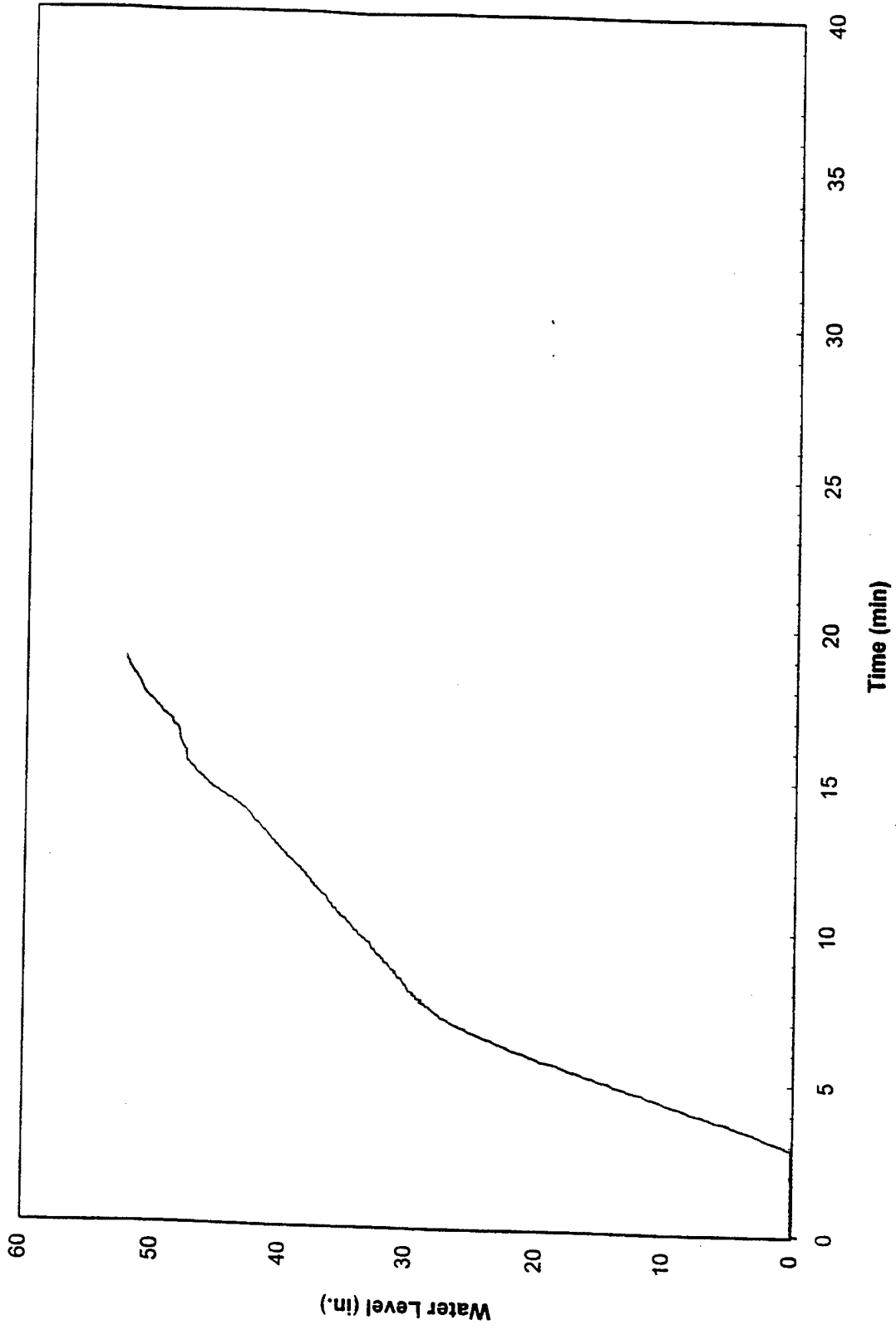


Fig. E7 - Water level in Upper Wet Compartment for test CW-7

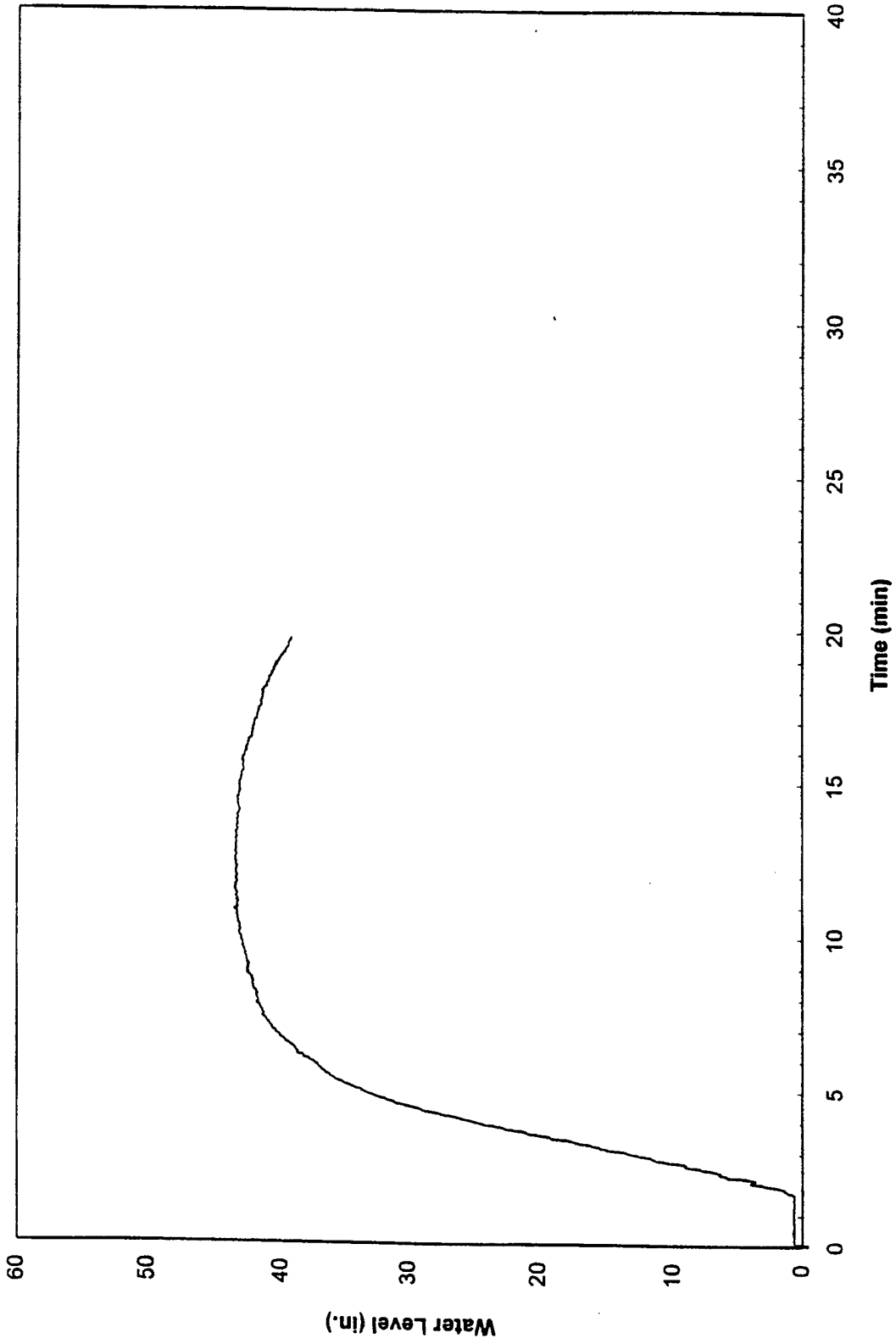


Fig. E8 - Water level in Upper Wet Compartment for test CW-8

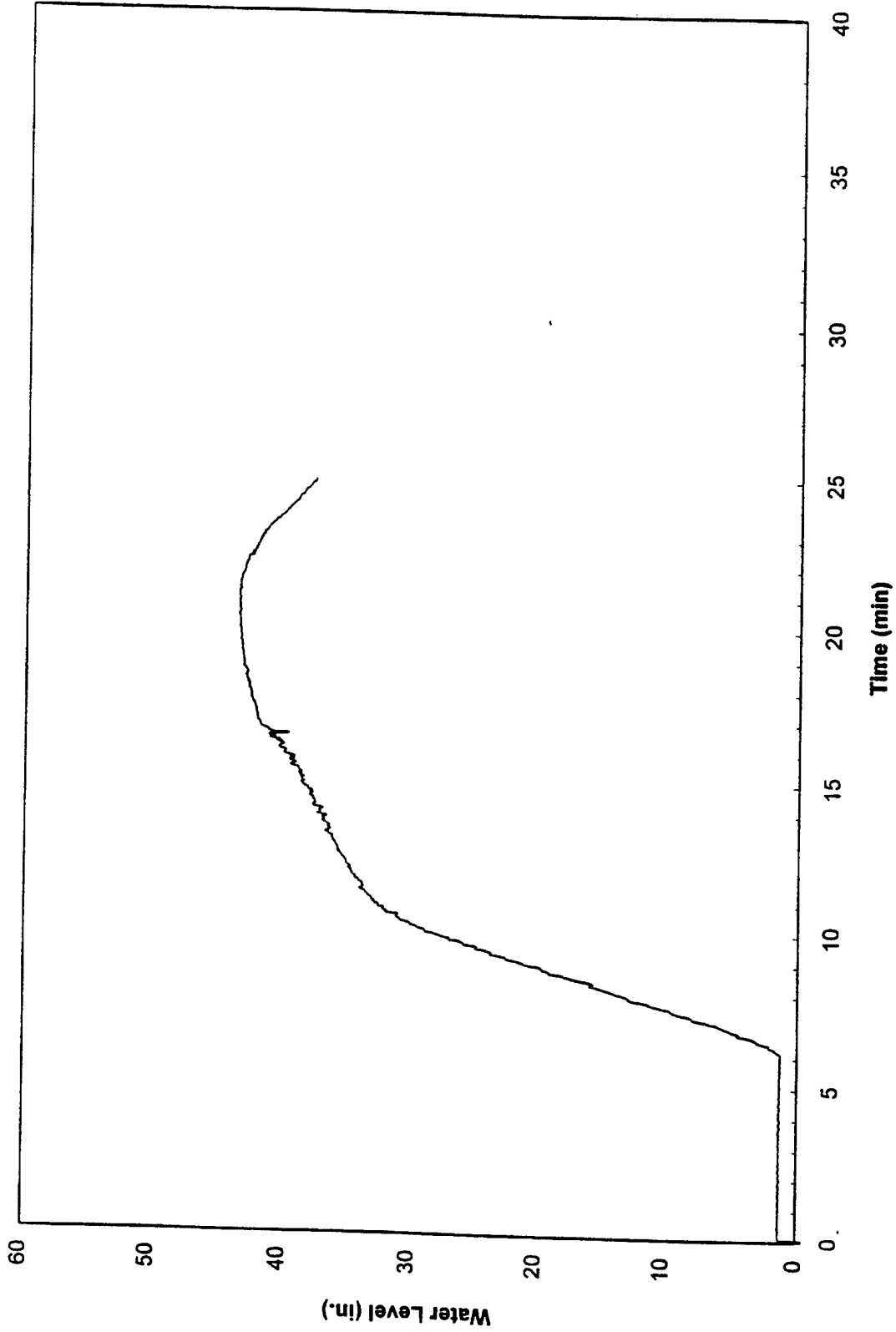


Fig. E9 - Water level in Upper Wet Compartment for test CW-9

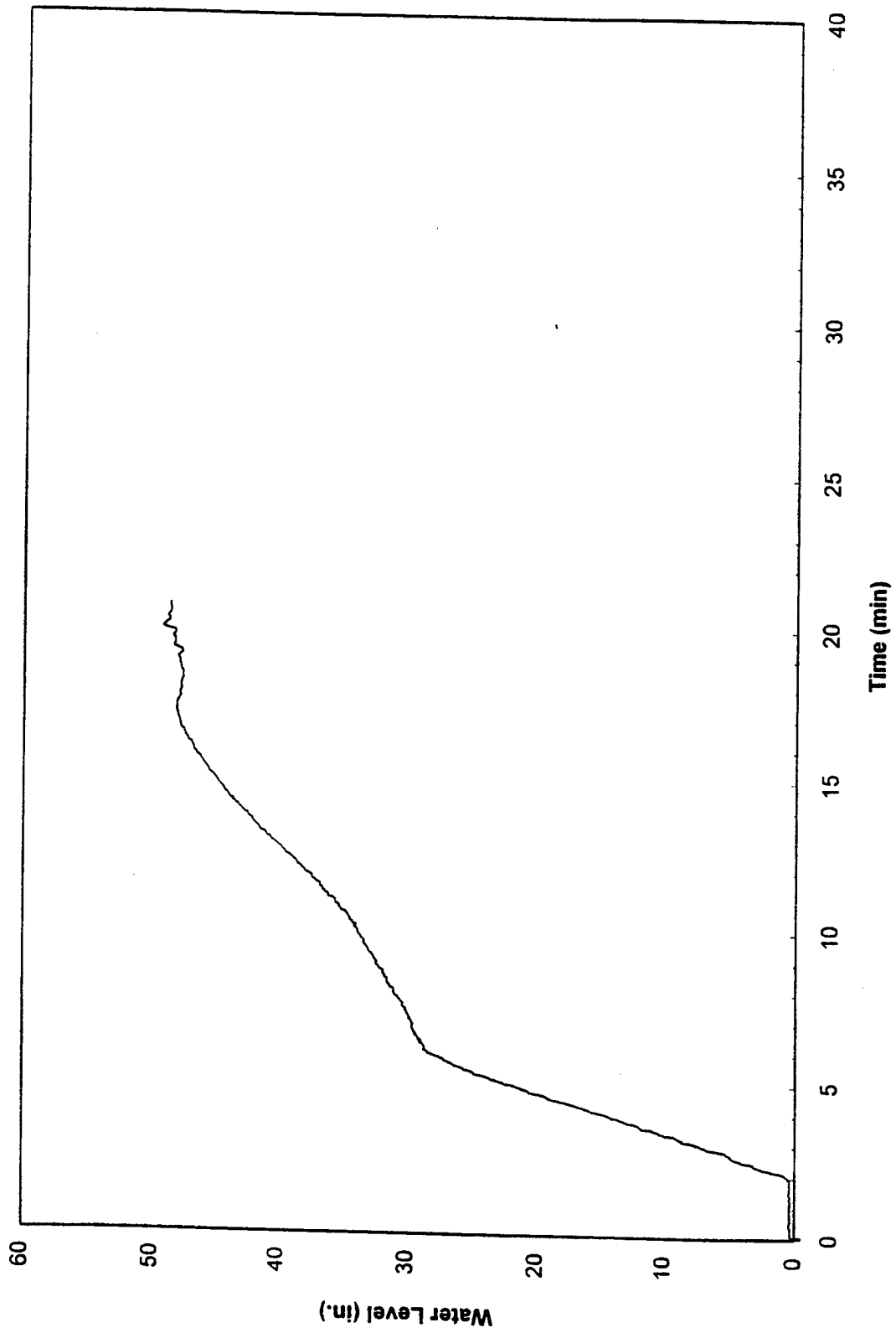


Fig. E10 - Water level in Upper Wet Compartment for test CW-10

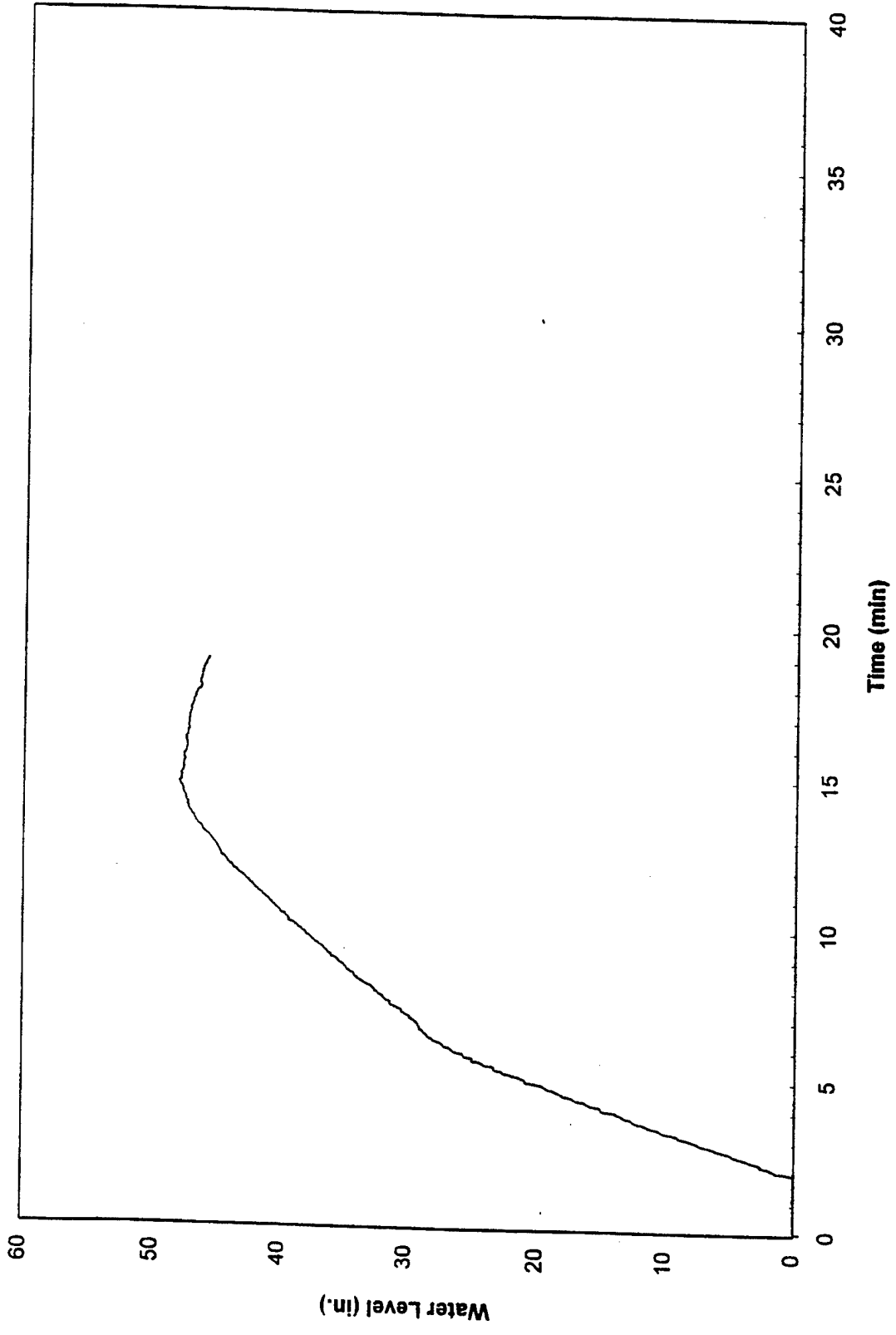


Fig. E11 - Water level in Upper Wet Compartment for test CW-11

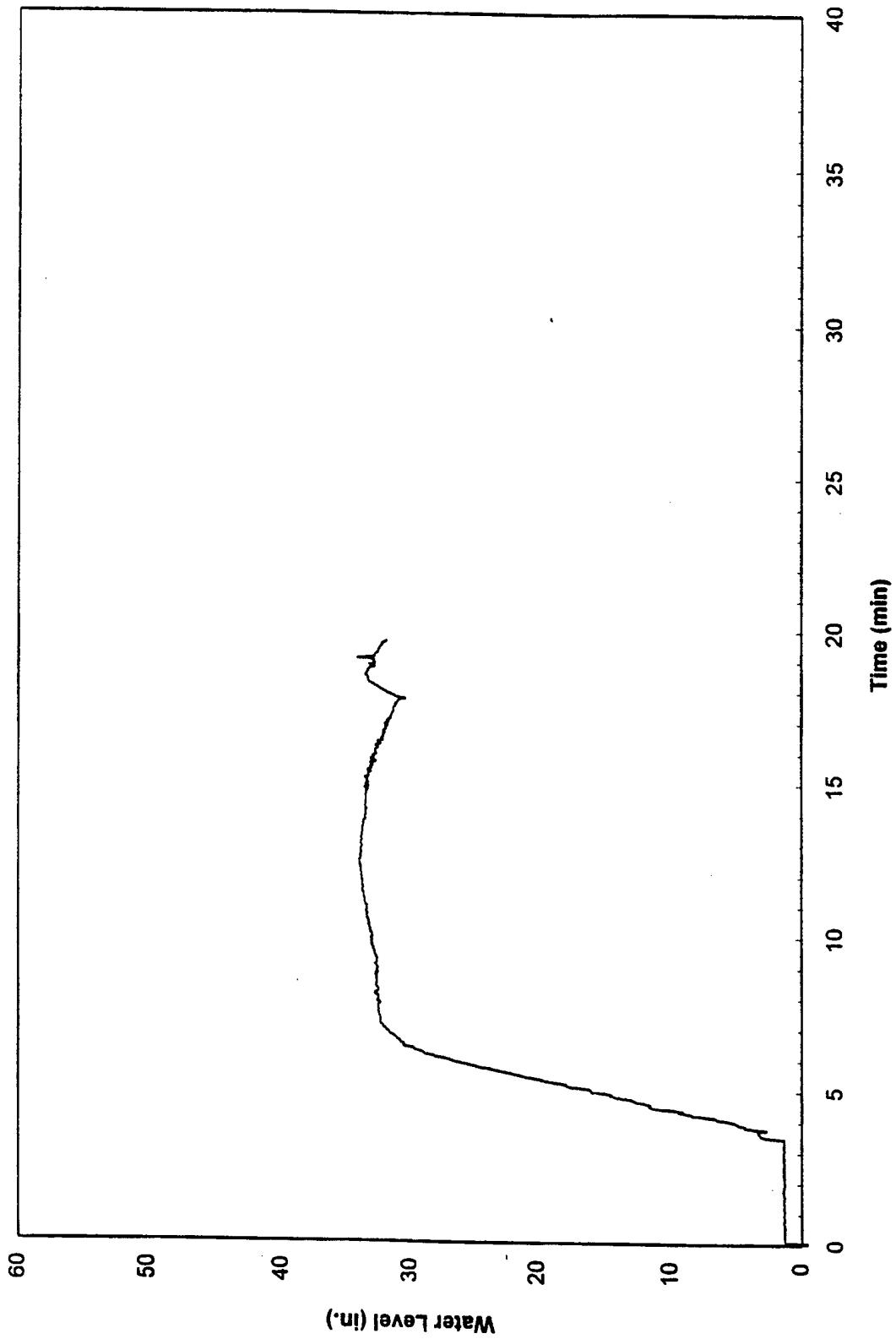


Fig. E12 - Water level in Upper Wet Compartment for test CW-12

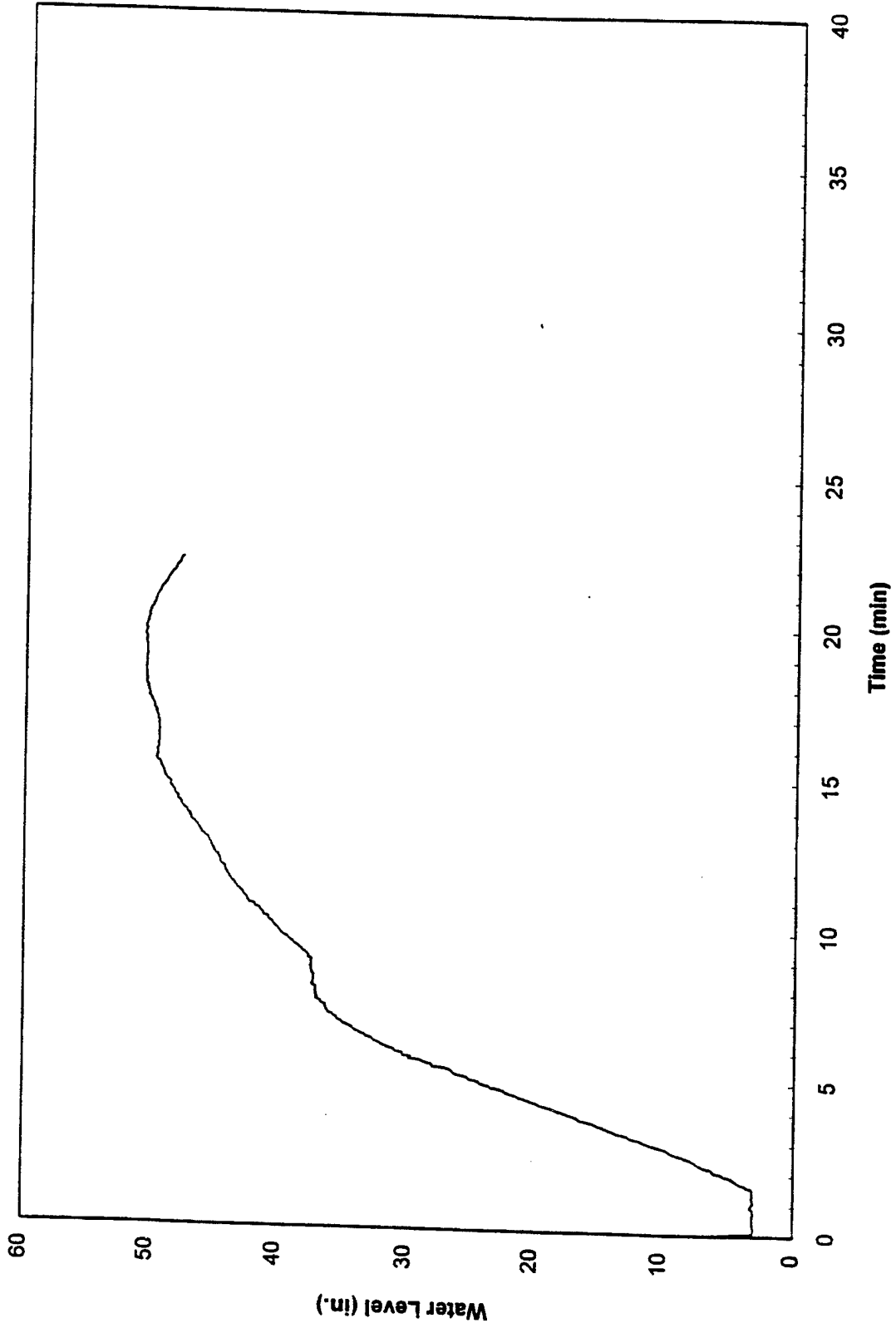


Fig. E13 - Water level in Upper Wet Compartment for test CW-13

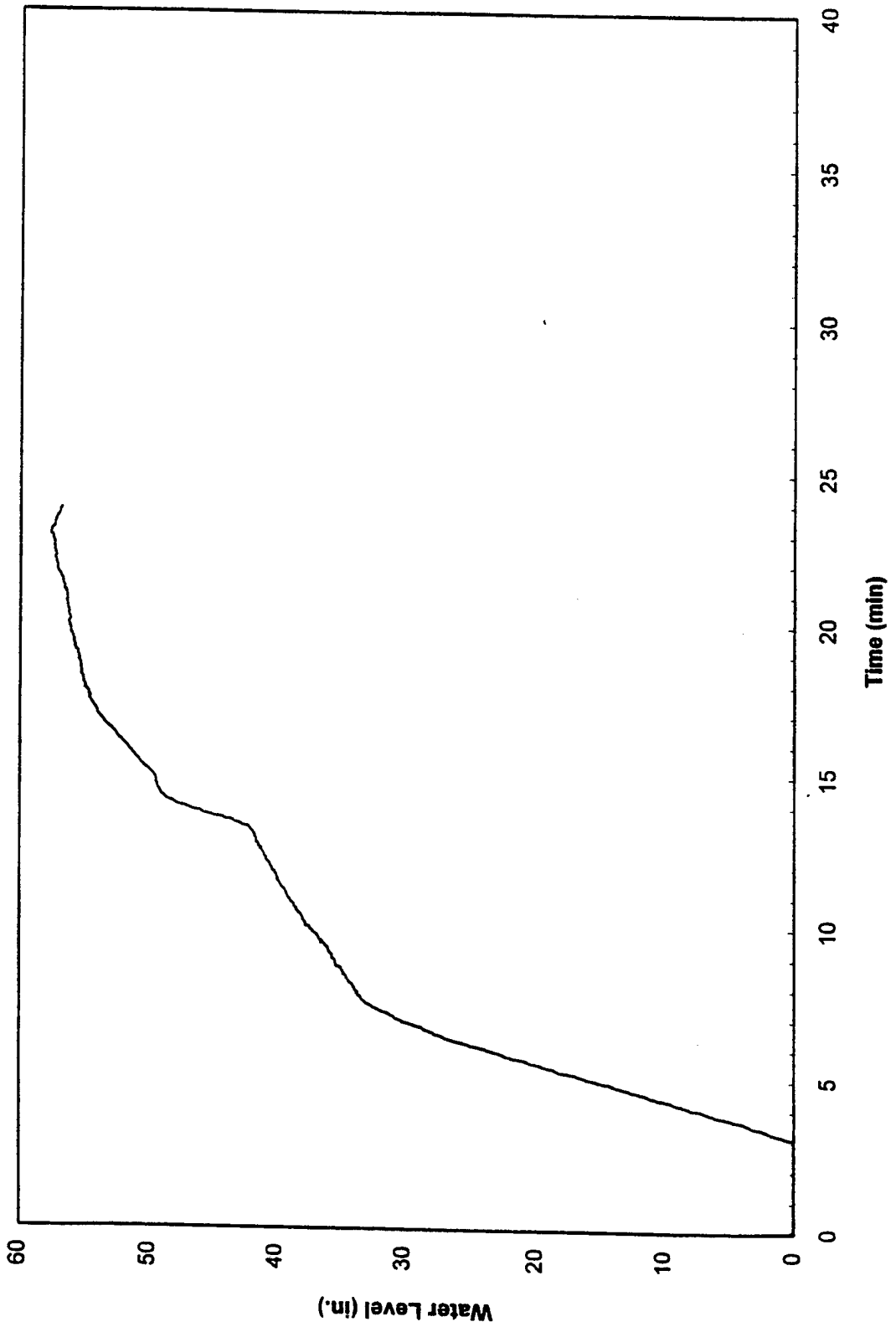


Fig. E14 - Water level in Upper Wet Compartment for test CW-14

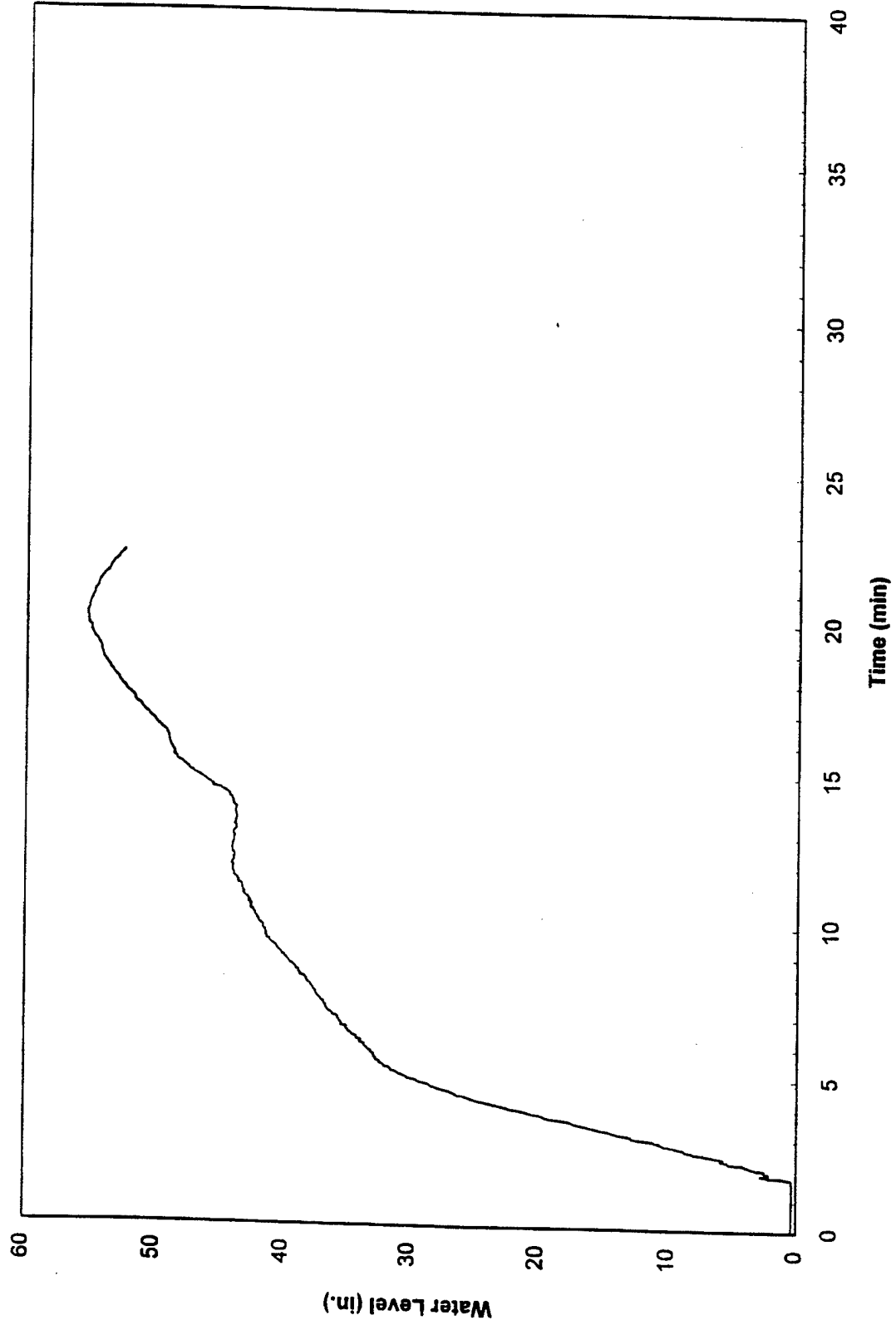


Fig. E15 - Water level in Upper Wet Compartment for test CW-15

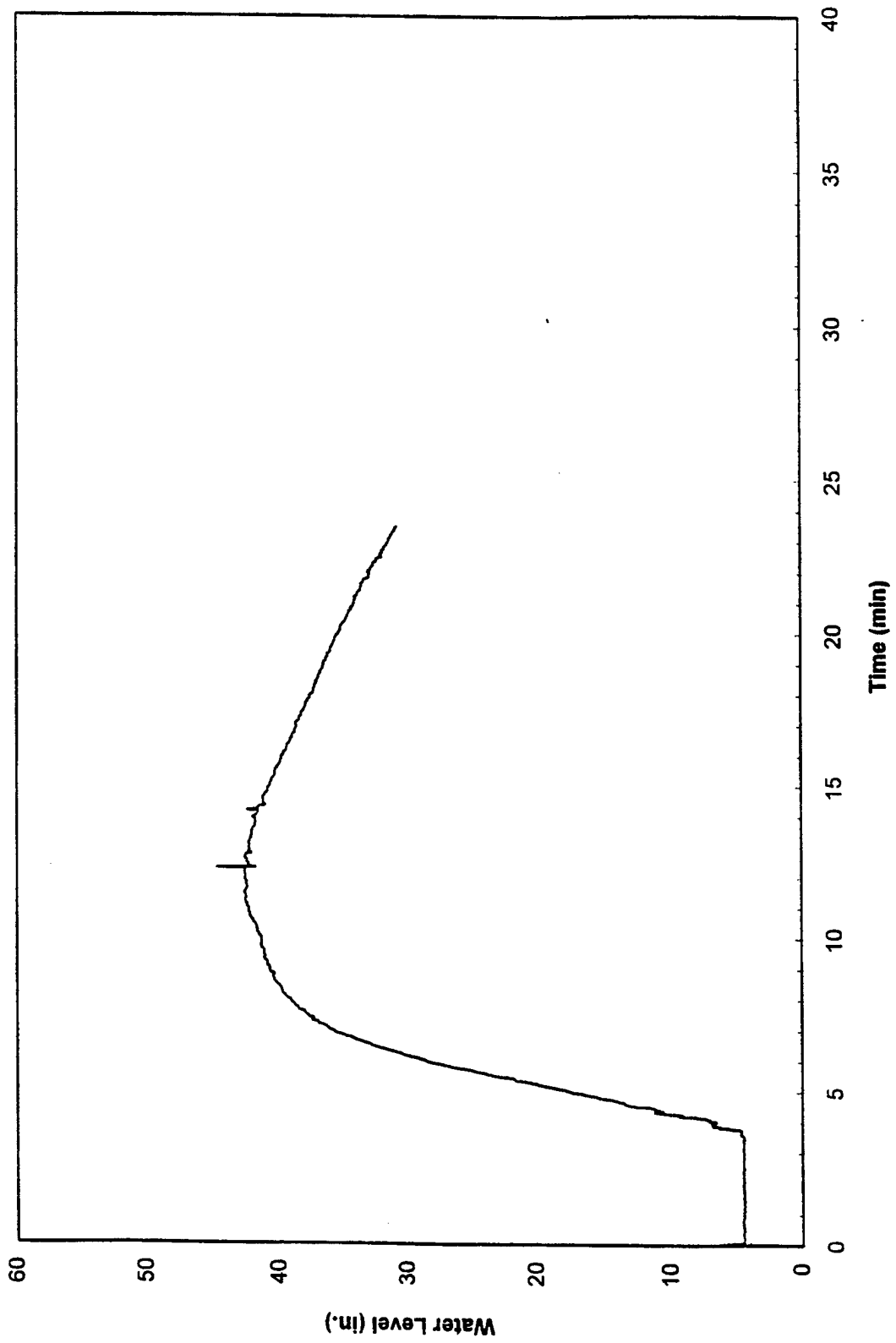


Fig. E16 - Water level in Upper Wet Compartment for test CW-16

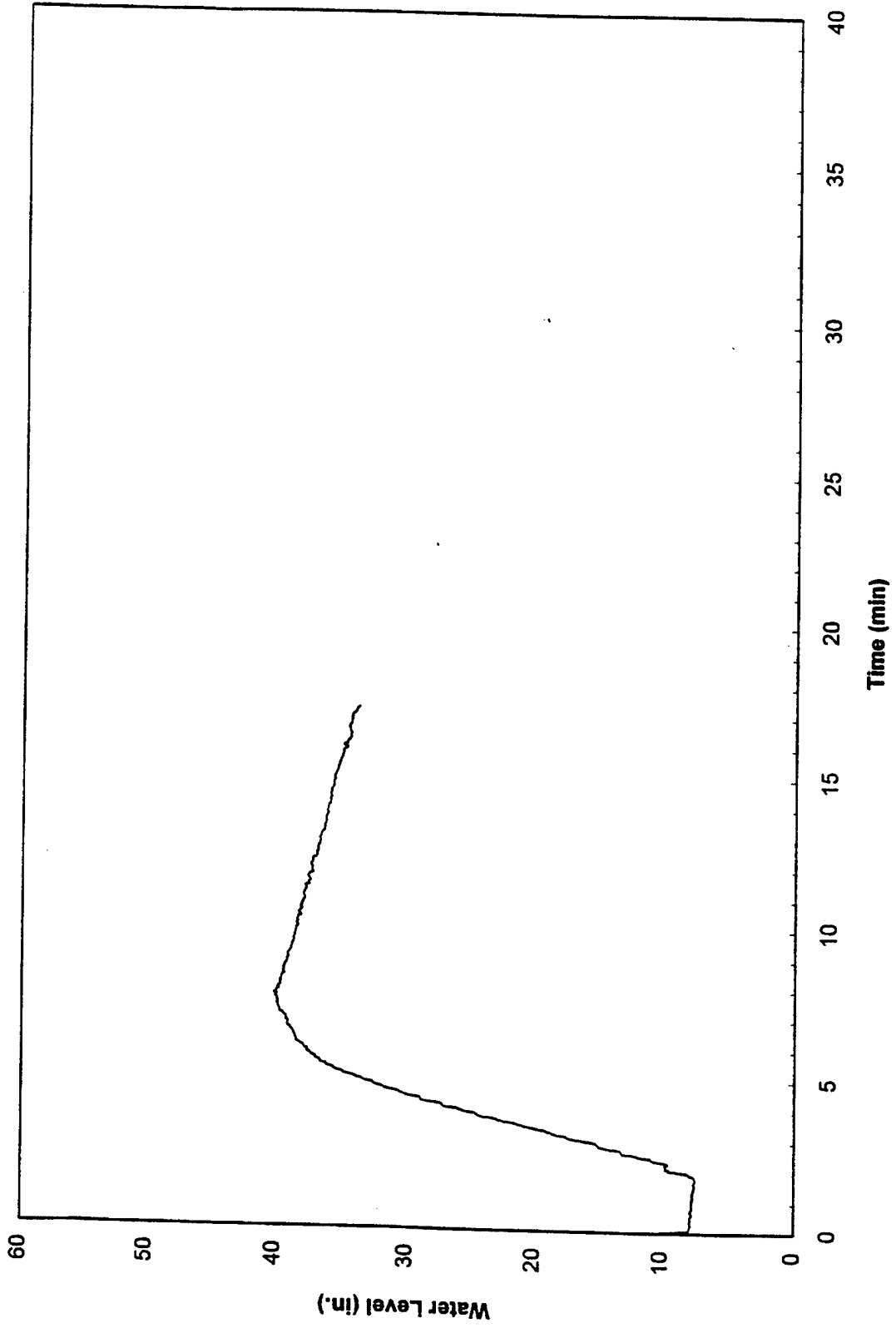


Fig. E17 - Water level in Upper Wet Compartment for test CW-17

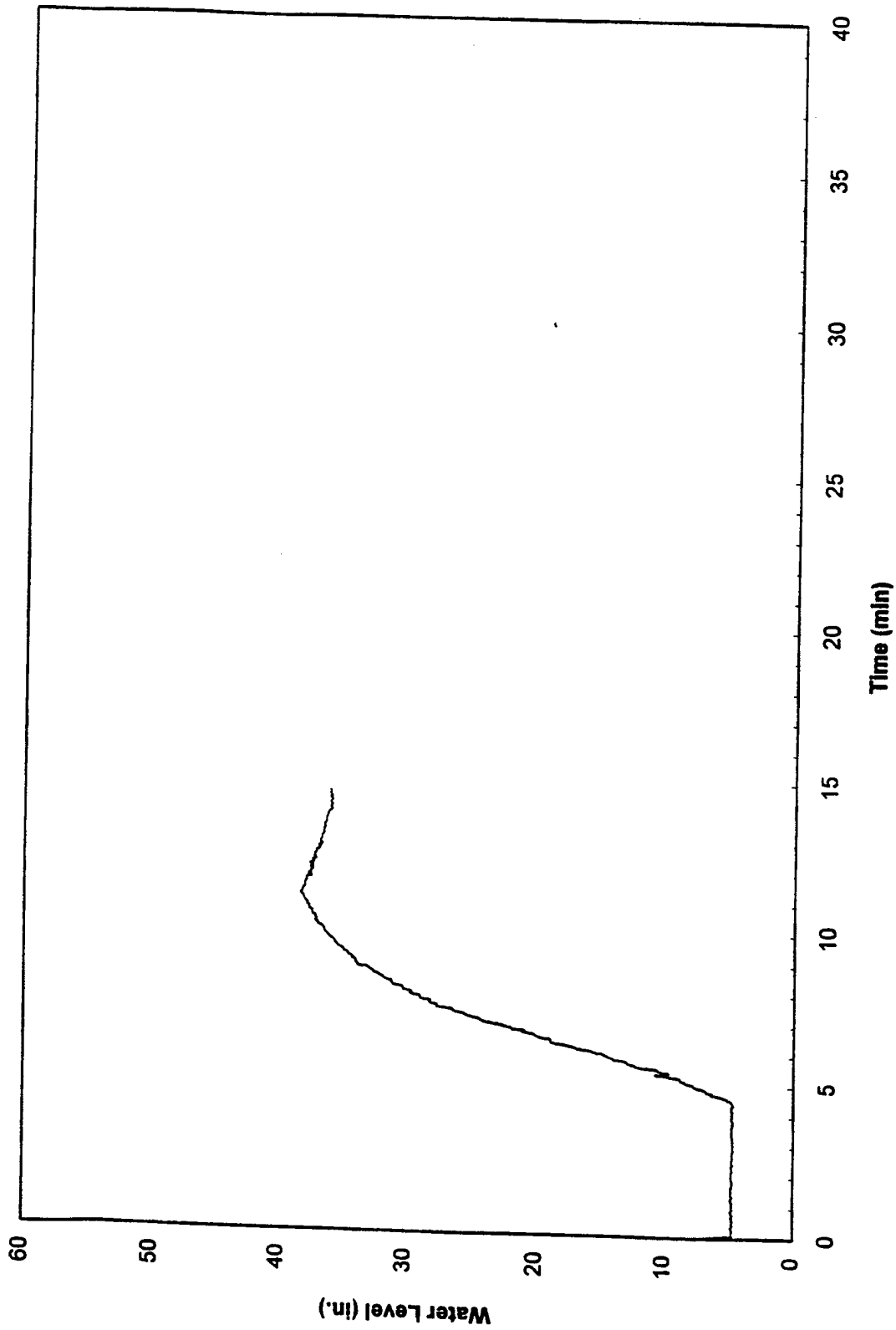


Fig. E-18 - Water level in Upper Wet Compartment for test CW-18