Enclosure

Watts Bar Nuclear Plant

Unit 1 Cycle 1 Refueling Outage

September 1997

RESULTS OF STEAM GENERATOR TUBE INSERVICE INSPECTION
(AS REQUIRED BY TECHNICAL SPECIFICATION SECTION 5.9.9)

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INTRODUCTION

During the scheduled Watts Bar Nuclear Plant (WBN) Unit 1 Cycle 1 (U1C1) refueling outage extensive inservice inspections (ISIs) were conducted in all four steam generators (SGs) to address all potential damage mechanisms identified in the U1C1 preoutage damage assessment. The results of the inspections were classified as C-2 in SGs 1, 3, and 4, and C-1 in SG 2. Sludge lancing and a foreign object search and retrieval were performed on all four SGs. During the foreign object search and retrieval, one of the two blowdown line elbows in SGs 2 and 3 were found to be cracked at the upper edge of the elbow-to-tubesheet fillet weld. The elbow opposite the severed elbow of SGs 2 and 3 was not separated and had no visual indication of degradation. The visual inspection of SGs 1 and 4 did not reveal any separation and both ends of the blowdown pipe in those SGs are intact. An evaluation was prepared by Westinghouse to assess WBN's continued operation without repair of the cracked blowdown piping.

A foreign object was identified in SG 3 during a mid-cycle foreign object search and retrieval and dispositioned to leave in place until end of Cycle 1. However, retrieval attempts were unsuccessful during the refueling outage. Therefore, Westinghouse performed an evaluation to assess WBN's continued operation with the object lodged in the steam generator tubes.

This report fulfills the reporting requirements of WBN Technical Specification section 5.5.9 for reporting results of SG ISI. Should NRC desire to review either of the Westinghouse evaluations referred to above, copies are available onsite and will be provided upon request.

SG TUBE ISI SCOPE AND RESULTS

The WBN SG tube ISI initial sample for all SGs and all damage mechanisms included the following:

1. 69% of the full-length bobbin examination in all four SGs to bound critical areas. The areas inspected included 100% of the preheater region, 100% of the anti-vibration bar (AVB) region, 100% of the periphery tubes, and 20% random sample of the remaining tubes.

Although the EPRI Guidelines suggest 100%, this 69% inspection targeted all areas where similar design SGs have experienced degradation. Also, service-induced degradation in similar SGs have been identified after several cycles of operation.

Baseline operational data was obtained in all critical areas. Part of the basis for the EPRI Guidelines requirement for 100% bobbin examination is that most new SGs are also new designs without the operating experience of the Westinghouse Model D SGs at WBN. All unexamined tubes from U1C1 will be examined during Unit 1 Cycle 2 (U1C2), prior to anticipated degradation to obtain baseline data.

2. 20% hot leg top of tubesheet (TTS) examination in all four SGs using a mag bias plus point probe. All abnormal expansion conditions were included in the sample. 20% Row 1 & 2 U-Bend examination in all four SGs with a magnetic biased plus point U-bend probe.

   Although the EPRI Guidelines suggest 100% of Rows 1 and 2, degradation in Rows 1 and 2 have occurred in the industry after several cycles of operation. WBN Rows 1 and 2 were heat treated prior to startup, and degradation in the industry was initiated in tubes with one or more cycles of operation prior to heat treating.

3. All mechanically-induced hot leg dented intersections were examined using a mag bias plus point probe

4. All mechanically-induced freespan denting between the TTS and H02 were examined using a mag bias plus point probe

5. All test techniques were EPRI Appendix H Qualified examination techniques.

6. The following degradation was identified in three of the four steam generators:

   - Axial primary water stress corrosion cracking (PWSCC) in the roll expanded region in the tubesheet at roll overlaps and at roll transitions (SGs 3 and 4)

   - Tube wear at AVB intersections (SGs 1 and 4)

- Loose parts damage between the fifth and sixth cold leg tube support plates (TSPs), which is in the preheater at the elevation of the feedwater nozzle inlet (SG 1)

- Loose parts damage at the periphery in SG 4.

Due to the detection of axial PWSCC in the initial plus point TTS sample of SGs 3 and 4, the plus point samples were categorized as C-2 and the examination scope was expanded by 20% in both SGs. The EPRI Guidelines' 100% expansion requirement is due to safety concerns with circumferential cracks and their potential to rupture and affect adjacent tubes. The axial indications identified in SGs 3 & 4 were short indications in the tubesheet, which would cause no burst or leakage concern. Since the indications are small and since industry experience indicates that PWSCC is not a structurally significant damage mechanism in the first few cycles, it is unlikely that WBN SGs have a large number of PWSCC indications. With a 20% expansion sample (40% total inspection of the generators), if circumferential TTS PWSCC is active, it is statistically reasonable to assume that one indication would be identified. No further indications were identified.

Due to bobbin loose parts damage indications that exceeded the 40% plugging limit in SGs 1 and 4, the initial bobbin samples were categorized as C-2 and the examination was expanded by 6% in both generators. No further indications were identified.

Table 1 summarizes the WBN U1C1 eddy current testing ISI exams and the results of exams conducted. Table 2 provides a summary of the tube damage detected and a characterization of the damage morphology.

The Cycle 1 total days at power was 440 with 407 total effective full power days (EFPD). The expected days at power for Cycle 2 is approximately 450, with an expected 439 EFPD. The Cycle 2 licensed length is 495 days at power.

Acceptance Criteria

Using a bounding $3\Delta P_{normop}$ value of 3780 psi for WBN, the single, 100% through wall flaw length which provides burst capability using lower tolerance limit (LTL) material properties for ¾"

Westinghouse-supplied tubing is 0.51." Any freespan indication with a length of less than 0.51," regardless of the through wall extent, does not represent a burst concern at the applied margins suggested by Draft Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes." Due to strain hardening of the U-bend regions, the limiting flaw length for Row 1 and 2 tubes is significantly greater than 0.51."

For an AVB wear flaw, a structural limit value representing a burst potential at 3ΔP of 3780 psi can be qualitatively established using historical Westinghouse data for burst tests of tubes with machined flats. For a flat length of ½," depth of 76% through wall, flow stress of 76.5 Ksi, and tube dimensions of 0.75" OD x 0.054" wall thickness, a burst pressure of 5900 psi was recorded at room temperature conditions. Adjusting this data point for Model D3 tube dimensions and LTL material properties, a ½" flat of 58% through wall would represent a burst potential of 5000 psi at operating conditions. The AVB width for a Model D3 SG is 0.296," therefore, a structural limit applied to AVB wear scars for WBN would be substantially greater than 58% through wall when a flat length adjustment and adjustment to the 3ΔP burst pressure of 3780 psi are made. It is judged that this value would be approximately 70% through wall.

Degradation Mechanisms Detected

Axial PWSCC TTS

Condition Monitoring

Axial PWSCC at the TTS was predicted in the preoutage damage assessment due to the Model D-3's high susceptibility to PWSCC. However a small number was predicted since this was WBN's first cycle, and industry experience indicates that PWSCC is not structurally significant in the first few cycles. Also rotopeening of the hot leg tubesheet region was performed prior to startup, along with skip roll repair and subsequent repeening of skip roll repaired tubes.

Two tubes in SG 4 and one tube in SG 3 were affected by axial PWSCC. The two indications in SG 4 were located within the tubesheet, one (R16 C19) at approximately 1" below the TTS at the first roll overlap region and one (R33 C39) at approximately 2"

below the TTS. The maximum axial length detected using the +point probe was 0.25" in R16 C19, which is well below the freespan limiting flaw length of 0.51." Additionally, the tubesheet restraint effectively precludes burst of axial flaws independent of length, provided the indication exists below the bottom of the roll transition.

The axial PWSCC flaw in R19 C62 SG 3 was located in an oversized hole in the roll transition and the upper flaw tip was identified at the TTS. The length of this indication was 0.13." As this indication is significantly less than the limiting freespan through wall flaw length of 0.51" for WBN, it would not have represented a burst potential if it were assumed that the flaw were through wall over its entire length. The +point voltage of this indication was only 1.01 volts; therefore, it is unlikely that this indication was 100% through wall for any length. It is concluded that this indication would not have represented a leakage potential during any plant condition. All three indications were located in abnormal expansions; therefore, it is assumed that rotopeening was not 100% effective in this area. This could explain the early detection of PWSCC in peened expansion transitions. All indications met Regulatory Guide 1.121 tube integrity requirements at the end of Cycle 1.

Operational Assessment

Since all indications at the end of Cycle 1 met tube integrity requirements, operating cycle lengths are essentially the same, and ameliorative tube modifications such as preoperational rotopeening and skip roll repair were performed, it can be expected that all axial PWSCC indications at the end of Cycle 2 will also satisfy Regulatory Guide 1.121 guidelines. Operating experience from other Model D SGs that were peened prior to operation indicates that observance of structurally significant axial PWSCC in the roll transitions and roll expanded regions occurs after 5 to 6 operational cycles. Also, the earliest Model D3s to come on line did so in the early 1980's. These SGs were inspected using only the bobbin coil probe for several inspections. Based upon limited ability of the bobbin probe to detect short axial flaws in the roll transition and roll expansion region, it is reasonable to assume that axial PWSCC had

initiated in these units in the first or second operational cycles. This information, coupled with the tendency for roll transition PWSCC to exhibit a somewhat self limiting growth bounded by the length of the roll transition, approximately 0.25," suggest that structurally significant PWSCC indications are not expected at the end of Cycle 2 inspection.

Loose Parts Damage

Condition Monitoring

It is not unusual for plants to see loose parts damage in the first outage inspection. Also, WBN had a number of upper internals and preheater modifications after the generators were installed. For these reasons, loose parts damage was predicted in the preoutage damage assessment.

A total of 15 loose parts indications in SG 1 was detected in 14 tubes at varying elevations from 0.5" to 14" above the fifth cold leg support plate, which is in the preheater at the elevation of the feedwater nozzle inlet. Indications of wear were not detected within the thickness of the tube support plate. The tubes affected were in groupings of common rows or columns (see Figure 1). The maximum depth indication of this type was reported as 75% through wall (R47 C64) by bobbin. Based on low frequency (10 KHz) rotating pancake coil (RPC) inspection, a suspected metallic object was detected adjacent to one of the tubes (R49 C57) with a wear indication. The characterization of these indications was fairly uniform among the tubes involved. Of the 15 total indications, three exceeded the 40% depth based plugging limit and were removed from service. Based on the identification of the suspected foreign object, tube R49 C57 was preventively plugged.

The 75% maximum depth indication located in R47 C64 was at approximately 6" above the fifth cold leg plate. As the tube vibration amplitudes increase at elevations approaching the midspan, it is reasonable that largest depth indications were located away from the plate. This bounding indication had insufficient volume to present a rupture or leakage concern.

Loose parts damage was also identified in SG 4 in periphery tubes R13C3 (40% through wall) and R14C3 (25% through wall). R13C3 was taken out of service. Neither indication presented rupture or leakage concerns.

Operational Assessment

Inspections bound the affected areas, the periphery tubes and the preheater regions. Since no leakage occurred from the 75% indication in R47 C64 and its size presented no rupture concern and since 100% of the potentially affected areas were inspected, it can be concluded that no indication was left undetected at the end of Cycle 1 that would present a rupture or leakage concern. Since tubes with loose parts damage are not in a continued state of degradation, growth should not be projected in the tubes left inservice with less than 40% wall loss.

AVB Wear

Condition Monitoring

AVB wear was predicted in the preoutage assessment and pluggable indications were expected in the abnormal gaps identified by AVB gap measurements taken prior to startup. 100% of the AVB region was inspected.

A total of three AVB wear indications were detected in SGs 1 and 4. None of the indications exceeded the 40% plugging limit. The limiting depth indication was found in R36 C74 SG 4 and had a depth of 25% through wall.

Operational Assessment

The maximum detected AVB wear depth as determined by bobbin inspection was 25% through wall. This tube, R36 C74 in SG 4, was not plugged. Assuming a conservative linear wear depth of progression, this indication could exhibit a maximum depth of 50% at the end of Cycle 2. As the bobbin is expected to overcall shallow wear depths, the actual peak wear depth may be less than 25% through wall. With a structural limit representing a burst potential at a $3\Delta P$ value of 3780 psi for an AVB wear scar at approximately 70% through wall, significant burst margin is expected to be provided at the end of Cycle 2 for all AVB wear indications.

Other Inspections

Automated analysis of bobbin data was used to detect crack support plate indications, and none were identified. An upper internals visual inspection was performed on SG 3 for evidence of erosion/corrosion, cracked welds, deposit buildup, or any other service-induced degradation. No degradation was identified; therefore, no further upper internals inspections were performed. Since WBN steam generators have no support plate cracking, it can be concluded that the design basis function of the support plate has not been compromised.

CONCLUSIONS

The NDE testing completed on the WBN Unit 1 SGs and plugging of defective tubes met the Technical Specification and ASME Section XI code requirements for ISI; therefore, each SG has been demonstrated operable.

Utilizing the criteria of Regulatory Guide 1.121, TVA concludes that the integrity of the Watts Bar Nuclear Plant Unit 1 SGs was maintained during Cycle 1 and will be maintained through full Cycle 2, and does not represent an unreviewed safety question.

Table 1

SUMMARY OF WATTS BAR UNIT 1 CYCLE 1
SG EDDY CURRENT INSPECTION/TUBE PLUGGING RESULTS

EDDY CURRENT EXAM TYPE	S/G 1	S/G 2	S/G 3	S/G 4	Totals
Full-Length Bobbin Coil	3504	3222	3217	3498	13441
Partial Length Bobbin Coil	0	0	0	0	0
U-Bend RPC	46	46	46	46	184
Top of Tubesheet RPC	941	936	1872	1872	5621
Support Plate RPC HL	16	27	16	61	120
Support Plate RPC CL	0	0	1	1	2
Free Span RPC HL	46	18	33	30	127
Free Span RPC CL	16	0	1	2	19
Total Exams Completed	4569*	4249	5186	5510	19514

INDICATIONS (Tubes)	S/G 1	S/G 2	S/G 3	S/G 4	Totals
AVB WEAR	1	0	0	2	3
BULGE	0	0	0	5	5
DISTORTED BOBBIN SIGNALS	6	0	0	1	7
UNUSUAL OD ANGLE	1	0	0	0	1
MANUFACTURING MARK	4	9	8	6	27
POTENTIAL LOOSE PART	0	0	0	5	5
LOOSE PART DAMAGE	15	0	0	2	17
PWSCC HTS	0	0	1	2	3

PLUGGING STATUS	S/G 1	S/G 2	S/G 3	S/G 4	Totals
Previously Plugged Tubes	3	0	1	4	8
Plugged Cycle 1					
Damage Mechanism					
PWSCC HTS	0	0	1	2	3
LOOSE PARTS DAMAGE	4	0	0	1	5
TOTAL TUBES PLUGGED	7	0	2	7	16

Table 2

Resolution of Defective Tubes and All Service-Induced Wall Loss Indications

Date: *30-Sep-97*

SG	ROW	COL	IND	LOCATION	CHARACTERIZATION	RESOLUTION
Sample: 0						
1	12	42	APT	H02+3.94	MFG MARK	(2)
1	21	62	UOA	H04-.08	UNUSUAL OD ANGLE	(2)
1	28	86	APT	C11+28.04	MFG MARK	(2)
1	28	86	APT	C13+36.67	MFG MARK	(2)
1	37	47	11	AV4+.00	AVB WEAR	(1)
1	39	61	22	C05+2.10	PLP DAMAGE	(1)
1	41	61	22	C05+2.61	PLP DAMAGE	(1)
1	42	61	10	C05+2.79	PLP DAMAGE	(1)
1	44	61	10	C05+.58	PLP DAMAGE	(1)
1	45	40	APT	H04+23.38	MFG MARK	(2)
1	46	61	17	C05+.61	PLP DAMAGE	(1)
1	47	61	4	C05+.58	PLP DAMAGE	(1)
1	47	63	34	C05+5.11	PLP DAMAGE	(1)
1	47	64	75	C05+5.73	PLP DAMAGE	PLUG
1	48	57	42	C05+14.22	PLP DAMAGE	PLUG
1	48	63	16	C05+5.00	PLP DAMAGE	(1)
1	48	64	32	C05+6.27	PLP DAMAGE	(1)
1	49	57	17	C05+.43	PLP DAMAGE	PLUG-PREV.PLP
1	49	57	30	C05+14.28	PLP DAMAGE	(1)
1	49	63	51	C05+5.77	PLP DAMAGE	PLUG
1	49	64	35	C05+6.95	PLP DAMAGE	(1)

This sample's results have been classified as Category C-2

Table 2

Resolution of Defective Tubes and All Service-Induced Wall Loss Indications

Date: *30-Sep-97*

SG	ROW	COL	IND	LOCATION	CHARACTERIZATION	RESOLUTION

TVA Level III Clayton B. Webber, 9/30/97
Date

S/G Program Engineer: Philen Cathrone, 9/30/97
Date

Plant Manager: R. Purcell, 10/1/97
Date

(1) Retest Future Outage

(2) None Required

Table 2

Resolution of Defective Tubes and All Service-Induced Wall Loss Indications

Outage: WBN Unit 1 Cycle 1 Date: *30-Sep-97*

SG	ROW	COL	IND	LOCATION	CHARACTERIZATION	RESOLUTION
Sample: 0						
2	9	2	APT	H04+39.61	MFG MARK	(2)
2	13	81	APT	H05+35.36	MFG MARK	(2)
2	16	25	APT	H07+5.38	MFG MARK	(2)
2	35	35	APT	C03+4.50	MFG MARK	(2)
2	35	47	APT	C02+5.82	MFG MARK	(2)
2	38	58	APT	H01+8.05	MFG MARK	(2)
2	44	67	APT	C13+16.10	MFG MARK	(2)
2	46	41	APT	H06+35.33	MFG MARK	(2)
2	46	79	APT	C08+14.23	MFG MARK	(2)

This sample's results have been classified as Category C-1

TVA Level III Clayton B. Webber, 9/30/97
Date

S/G Program Engineer: Robert Cotton, 9/30/97
Date

Plant Manager: R. Purcell, 10/1/97
Date

(1) Retest Future Outage

(2) None Required

Table 2

Resolution of Defective Tubes and All Service-Induced Wall Loss Indications

Outage: WBN Unit 1 Cycle 1 **Date:** *30-Sep-97*

SG	ROW	COL	IND	LOCATION	CHARACTERIZATION	RESOLUTION
Sample: 0						
3	13	14	APT	H01+4.61	MFG MARK	(2)
3	17	17	APT	C13+40.06	MFG MARK	(2)
3	19	62	SAI	HTS+.00	PWSCC HTS AXIAL	PLUG
3	19	69	APT	C13+2.19	MFG MARK	(2)
3	22	59	APT	H04+37.34	MFG MARK	(2)
3	26	106	APT	H04+42.16	MFG MARK	(2)
3	27	73	APT	H03+12.55	MFG MARK	(2)
3	27	87	APT	H03+33.50	MFG MARK	(2)
3	34	40	APT	H07+4.84	MFG MARK	(2)

This sample's results have been classified as Category C-2

TVA Level III Clayton B. Walker 9/30/97
Date

S/G Program Engineer: Helen Cothron 9/30/97
Date

Plant Manager: R. Purcell 10/1/97
Date

(1) Retest Future Outage

(2) None Required

Table 2

Resolution of Defective Tubes and All Service-Induced Wall Loss Indications

Outage: WBN Unit 1 Cycle 1 **Date:** *30-Sep-97*

SG	ROW	COL	IND	LOCATION	CHARACTERIZATION	RESOLUTION
Sample: 0						
4	9	38	APT	C13+28.84	MFG MARK	(2)
4	13	3	40	H01+.00	PLP DAMAGE	PLUG
4	14	3	25	H01+.43	PLP DAMAGE	(1)
4	16	19	MAI	HTS-1.02	PWSCC HTS AXIAL	PLUG
4	22	76	APT	C05+19.60	MFG MARK	(2)
4	26	80	BLG	HTS+2.59	BULGE	(1)
4	26	81	BLG	HTS+2.42	BULGE	(1)
4	26	82	BLG	HTS+2.57	BULGE	(1)
4	26	83	BLG	HTS+2.51	BULGE	(1)
4	26	85	BLG	HTS+2.42	BULGE	(1)
4	27	37	APT	H05+2.41	MFG MARK	(2)
4	31	33	APT	H04+35.43	MFG MARK	(2)
4	31	97	PLP	H02+.69	POT LOOSE PART	(1)
4	31	97	PLP	H02+.75	POT LOOSE PART	(1)
4	32	97	PLP	H02+.82	POT LOOSE PART	(1)
4	33	39	MAI	HTS-2.06	PWSCC HTS AXIAL	PLUG
4	33	96	PLP	H02+.64	POT LOOSE PART	(1)
4	33	97	PLP	H02+.65	POT LOOSE PART	(1)
4	34	61	APT	C11+2.23	MFG MARK	(2)
4	36	74	25	AV4+.00	AVB WEAR	(1)
4	38	17	21	AV4-.12	AVB WEAR	(1)
4	48	52	APT	AV4+22.20	MFG MARK	(2)

This sample's results have been classified as Category C-2

Table 2

Resolution of Defective Tubes and All Service-Induced Wall Loss Indications

Outage: WBN Unit 1 Cycle 1 **Date:** *30-Sep-97*

SG	ROW	COL	IND	LOCATION	CHARACTERIZATION	RESOLUTION

TVA Level III Clayton B. Webb 9/30/97
Date

S/G Program Engineer: Nelson Cochran 9/30/97
Date

Plant Manager: R. Purcell 10/1/97
Date

(1) Retest Future Outage

(2) None Required

SG - 1 FREESPAN PLUS POINT

5 : 14 TEST C05 THROUGH C06 +/-2" -PF

▣ : 3 PLUGGED TUBE

Plan 10 - Preheater Expanded Scope

Watts Bar Nuclear 1 .WWAT-1 SERIES D3

09-28-1997 12:49 HRS. SUPERTUBIN

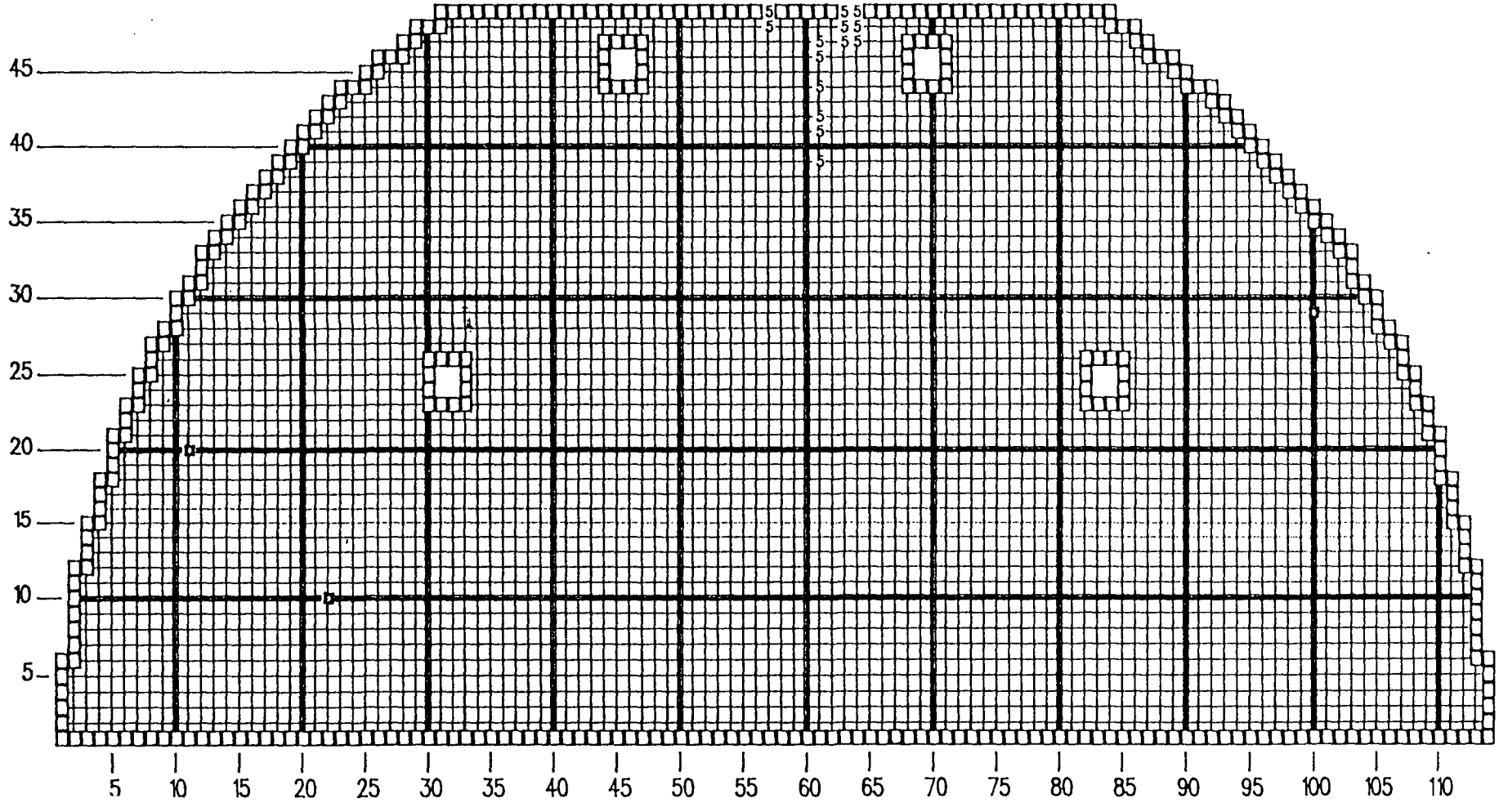

Figure 1