| | |
|---|---|
| LABORELEC<br>RODESTRAAT 125<br>B-1630 LINKEBEEK | Tel 02/38.20.211<br>Telex 22297<br>Fax 02/38.20.241 |

21 pages

| | |
|---|---|
| HEADING | STEAM GENERATOR PWSCC IN SERVICE LEAKAGE EXPERIENCE IN BELGIUM |
| SUMMARY | Belgium has a large experience of operating steam generators with PWSCC through-wall axial defects in the tube roll transitions.<br><br>The service behaviour has nevertheless been very good, with a rather low primary to secondary leakage.<br><br>This report documents the available data and investigates the reasons for the observed leakrate variability and discrepancy with respect to theoretical models and laboratory experiments. |
| ANNEXES | |

| REVISION INDEX /DATE | 0/ May, 1990 | | 1/ August 21, 1990 | | / | |
|---|---|---|---|---|---|---|
| EMISSION | NAME | Visa | NAME | Visa | NAME | Visa |
| Author | P.HERNALSTEEN | | P.HERNALSTEEN | [signature] | | |
| Verification<br>Approval | | | D.DOBBENI<br>P.HERNALSTEEN | [signature] | | |

| DISTRIBUTION OF COPIES | NAME(number) | C° Div. | NAME(number) | C° Div. | NAME(number) | C° Div. |
|---|---|---|---|---|---|---|
| | P.DOZINEL | ELNUC | B.GEERAERT | ADM | | |
| | S.ULENS | EBES | D.DOBBENI | S.M. | | |
| | W.DE ROVERE | KCD | J.STUBBE | S.C. | | |
| | A.MARCHAL | CNT | | | | |
| | JACQUET | CNT | | | | |
| | G.FREDERICK | TBL | | | | |
| | C.LEBLOIS | TBL | | | | |
| | S.GREEN | EPRI | | | | |
| | C.WELTY | EPRI | | | | |
| | L.WILLIAMS | EPRI | | | | |
| CIRCULATION (initials) | | | | | | |

| | | |
|---|---|---|
| STATUS | Quality Assurance | ☐ yes ☒ no |
| | Documentary (key words) | |
| | Confidentiality | ☐ free ☐ limited to co-operators<br>☐ intern at L/E ☒ limited to beneficiary |

| REFERENCES LABORELEC | |
|---|---|
| Document | M00-90-022/R-PH/SD |
| Task/Beneficiary | M00/00339/ELNUC |

TABLE OF CONTENTS



REFERENCES


[1] "Belgian Approach to Steam Generator Tube Plugging for Primary Water Stress Corrosion Cracking", Belgatom, EPRI report NP-6626-SD, March 1990.

[2] "PWR Steam Generator Tube Plugging Limits-Technical Support Document for Expansion Zone Primary Water Stress Corrosion Cracking in Roll Transitions", Mechanism-Specific Defect Management Committee, EPRI Report NP-6864 (draft), April 1990.

[3] "Part Depth Rolled Plants - Status of the Doel 2 Unit", R. Houben and P. Hernalsteen, EPRI Workshop on PWSCC remedial measures, Clearwater (FLA), February 1989.

[4] "Comparison of Hydrostatic and Helium Leak Test Results with RPC Crack Length Measurements", R. Houben, P. Hernalsteen and C. Leblois, EPRI Workshop on PWSCC remedial measures, Clearwater (FLA), February 1989.

[5] "Doel 2 - rapport de la réunion tenue à Laborelec le 19.3.90 au sujet des G.V.", P.V. TRACTEBEL 4RV-0000351.

[6] "Doel 2 Leak Outage/February 1990", P. Hernalsteen presentation to the MSDM Committee Meeting, Charleston, March 1990 (PV Laborelec M00-90-005/R-PH du 5.3.90).

[7] "Lek in stoomgenerator A op 12.02.90", Doel NPP report KCD12/2422/85, dated 11.06.90

[8] "Roll Transition Inspection of Doel 2 SG Tubes" vol. 1, June 1989 Inspection, EPRI report NP-6716-L.

[9] "LABOLEAK : Laborelec Leakrate Probabilistic Assessment Program for PWSCC in SG Tube Roll Transitions - User's Manual" LABORELEC report M00-90-023/R-PH, May 1990.

## 1. INTRODUCTION

The issue of Steam Generator (SG) leakrate during Normal Operating conditions (NOP) is still unresolved. Theoretical models and laboratory experiments often overpredict the actual field behaviour. But the field experience is frequently ill-defined ; the best documented data are from (pulled) leaking tubes and may bias the average behaviour of the tubebundle.

In Belgium, the early deviation from the "40 % plugging limit", in favour of a length based acceptance criterion of through-wall cracks [ref 1], has resulted in long term operation of SG with a large number of roll transition PWSCC through wall cracks, especially for the units Doel 2 (part depth rolled tubes), Doel 3 and Tihange 2 (full depth rolled tubes).

The service behaviour was nevertheless very reliable, with but a rather low level of primary to secondary leakage.

The object of this report is
- to document this field experience
- to discuss some particular leakage incidents
- to investigate the reasons of discrepancy with respect to theoretical and experimental predictions.

The report has been more particularly aimed at providing support information for the work of the EPRI Mechanism-Specific Defect Management (MSDM) Committee, in charge of providing guidance for Alternate Tube Plugging Criteria (ATPC) in the USA [ref. 2].

## 2. DOEL 2 SERVICE EXPERIENCE

### 2.1 Cracking status

The two steam generators of Doel 2 are inspected by ECT/bobbin coil only ; because the roll transition cracks are located deep within the tubesheet, this type of inspection is considered sufficient as there is no safety problem and, as a consequence, no plugging limit for axial cracks.

On this basis it was considered, until the June 1989 outage, that for the worst affected steam generator (SG-A) nearly all tubes were affected by PWSCC in the roll transition [ref. 3].

However, during the June 1989 outage, an ECT/RPC inspection was performed by Laborelec, on behalf of EPRI [ref. 8], on 1060 tubes of SG-A ; this allowed to establish the actual percentage of cracked tubes at a somewhat lower level of 74 % and to characterize the axial cracks as follows :

| Statistics on 614 tubes | average | maximum |
|---|---|---|
| maximum length in roll transition | 5,5 mm | 26 mm |
| number of cracks in roll transition | 2,5 | 10 |

The crack length distribution is illustrated by figure 1 ; it should be noted that about 20 % of the cracks are relatively long (> 10 mm).

Almost all cracks indicate a depth of (close to) 100 %. This does not imply that all are physically through-wall ; however previous experience from pulled tubes shows that most of them are effectively through-wall.

## 2.2 Leak history

The technical specification applicable to the Doel 2 Unit allowed a maximum primary to secondary leak of 28 l/h per SG (0.12 gpm) ; it is but recently that this figure has been revised to the same value (79 l/h) as for the further Belgian units.

The early plant policy was to plug (or repair) any detected leaker (secondary side pressure test with fluoresceine). From 1980 this constraint was relaxed and tubes were plugged only to the extent considered necessary to maintain (or reduce) the service leak below the Tec. Spec. limit. However this change in policy did not result in significantly higher in service leakage.

The first service leak was detected in October 1977 (at a level of about 0.1 l/h) and the leak remained usually within the following ranges from 1979 up to 1989 :

SG-A : 2 to 7 l/h (1)
SG-B : less than 1 l/h

There were eight cases of the technical specification limit being exceeded, leading to either a forced outage or an advanced regular outage but none of them was caused by roll transition cracking.

The cases were :

| | |
|---|---|
| - tube rupture (first row U bend) | : 1 case |
| - SWSCC (crevice axial crack) | : 1 case |
| - loose part damage (from SS) | : 1 case |
| - circumferential crack from minisleeve repair | : 1 case |
| - leaking plugs (W explosive type) | : 4 cases |

## 2.3 Leakage incident of February 1990

### 2.3.1 Description [ref. 5, 6 and 7]

After a long unscheduled outage from November 1989 to February 1990 (replacement of cracked turbine blades), the plant could not restart because of a large leakage from SG-A, increasing rapidly from 8 to 70 l/h (0.035 to 0.3 gpm) at the time the plant was shutdown (after only 2 days of full power operation).

The time history of the event is described by figure 2, where the initial B and Li levels are respectively 1000 and 0.2 ppm.

---

1. A transient increase to 17 l/h was observed in november 1989, at the time of addition of 780 ml $LiOH.H_2O$

After shutdown initiation, the still increasing level of SG-A blowdown activity was indicative of a leak rate in the range of 140 l/h (0.6 gpm).

A secondary side pressure test (at 12 bar) was performed and indicated 143 leakers in SG-A (+3 in SG-B) of which 85 were plugged. The plant restarted with a leak rate of 12 l/h which stabilized at a level of about 20 l/h one month later.

An ECT/bobbin coil inspection of the leakers (before plugging) indicated no significant increase of the defect signal amplitude previously registered.

Among the 143 leakers, 47 were inspected by ECT/RPC during the regular June 1989 outage and it was thus possible to relate them to the measured maximum crack length in roll transition.

The results are illustrated by figure 3 (from ref. 5) and indicate that, while a larger percentage of the longer cracks did leak, this percentage did not exceed 25 % for crack lengths in excess of 10 mm and did not include all of the cracks in excess of 15 mm ; in fact the longest cracks (25 and 26 mm) were not detected as leakers. This is also illustrated by figure 4 (from ref. 6).

2.3.2 Discussion

One week before the tentative restart, a decontamination process (UKAEA development, called "COMBAT" after Cobalt Management Boric Acid Treatment) was applied to the primary loops, involving circulation of a high boron (2600 ppm) solution, for 5 days, at a temperature of about 120°C ; this was the first industrial application of the process, aimed at reducing the Co60 dosis by removal of a .1 to .2 μm thick oxyde layer.

The large leak experienced at plant restart is attributed to crack leak area cleaning as a side effect of the COMBAT decontamination process ; this effect has been clearly enhanced by the injection of Li (which was realized in a "one shot" operation, instead of the usually more progressive adjustment).

In order to correlate the measured leakrate (the abovementionned 140 l/h extrapolation) to the known crack characteristics of the individual leakers, use was made of the "mean divided by 10" leak curve from figure 2.6 of the EPRI guidelines for Alternate Tube Plugging Criteria [ref. 2] ; this figure is appended to table 1.

For the population of 1060 tubes inspected by RPC, the expected leakrate was calculated

. for all tubes with crack length > 10 mm
. for the subset of the observed 35 leakers.

These results were multiplied by 3 for extrapolation to the total tubebundle.

The results are shown in table 1. There is a reasonable agreement of the total in service leakrate (140 l/h) with the predicted leakage from the actual leakers (340 l/h). However the predicted leakrate associated with all known cracked tubes would have been larger by one order of magnitude (1600 l/h).

The tentative conclusions are :

- if and when tubes actually leak, the behaviour is consistent with the lower bound (mean/10) expectations,

- a majority of the cracked tubes do however not leak in a detectable way : this may be due to :
  . the crack not being entirely through-wall.
  This is very unlikely for the considered "long" cracks (> 10 mm), especially for Doel 2 where tube pull experience supports OD lengths hardly shorter than ID lengths for defect lengths down to 6 mm,

  . the tubesheet crevice acting as a flow limiter if clogged by oxydes or other foreign material ; however :
    - two "crevice cleaning" operations, performed in 1983 and 1986, did not show any subsequent effect on leakage,
    - the behaviour of the actual leakers does not support this assumption,

  . the denting at the top of the tubesheet acting as a leaktight barrier ; this is apparent from the tubesheet map where the 135 inspected leakers are mostly outside the sludge/dent area (see figure 5),

- the extreme variability of service leakrate and, more particularly, the very low leakage from some long cracks are likely to result from a process of crack obstruction by cruds and/or precipitates.

- Some fluid (chemical) environments may lead to (partial) cleaning of the crack leakage area, leading to unpredictable evolution.

## 3. DOEL 3 SERVICE EXPERIENCE

### 3.1 Cracking status

The three steam generators of Doel 3 are inspected by ECT/RPC, for 100 % of the roll transitions, since 1988.

The tube plugging limit for axial cracks in roll transitions is 14 mm ; however tubes have occasionally been plugged at a lower level of 13 mm.

The results from the 1989 inspection are illustrated by figure 6 and summarized in the following table (only PWSCC cracks in roll transition)

| SG # | | R | G | B |
|---|---|---|---|---|
| Number of cracked tubes | | 40 % | 35 % | 57 % |
| Crack length | average | 5 mm | 5,5 mm | 7 mm |
| | max. | 11 mm | 15 mm | 15 mm |
| Crack number (in same RT) | average | 4 | 4,5 | 5 |
| | max. | 11 | 11 | 12 |

Almost all cracks indicate a depth of (close to) 100 %. This does not imply that all are physically through-wall ; however experience from pulled tubes and helium leak test (see § 5.2.1) shows that most of them are effectively through-wall.

## 3.2 Leak history

The technical specification applicable to the Doel 3 Unit allows a maximum primary to secondary leak of 79 l/h (0.35 gpm).

The plant was commissioned in 1982 and no significant leakage was experienced until 1985 ; from thereon, and until the May 1987 forced outage, the leakrate of SG-B was in the range of 5 to 10 l/h while remaining non significant for the other SG's.

In May 1987, the leakrate of SG-B increased rapidly up to a level of 70 to 90 l/h, leading to an emergency shutdown. A secondary side pressure test evidenced 2 major leakers ; the ECT/RPC inspection detected crack lengths of respectively 18 and 22 mm (no 100 % RPC inspection was performed at that time and it happened that the tube with the longest crack had never been inspected while the other was inspected two years before) ; after plugging those tubes, the plant was restarted with a total leakrate of about 2 l/h.

Since July 1987, SG-B behavior was dominated by the "ghost" leak history (see § 3.3) while a low leakrate was experienced for SG-R and SG-B in the range of 1 to 5 l/h.

## 3.3 THE "GHOST" LEAK OF SG-B

A very special and mysterious leak affects SG-B since July 1987. This leak is power dependant ; it stays very low under 30 % power and then increases to a maximum value at 100 % power. It has been impossible to locate the leak by any of the many detection methods that have been used such as secondary and primary hydrotests, RPC inspection and Helium leak test [ref. 4]. It is suspected that the leakage is entirely coming from a single tube but it is not sure whether it is related to PWSCC ; it has not been eliminated by plugging about 40 tubes (from 1987 to 1989) nor by sleeving (in 1988) some 50 tubes with the longest roll transition cracks.

This "ghost" leak is still present after 3 full operating cycles but its value has steadily decreased with time.

| | |
|---|---|
| August 1987 | : 20 to 150 l/h |
| September 1987 | : 25 l/h |
| 1988 | : 20 to 15 l/h |
| 1989/90 | : 15 to 10 l/h. |

## 4. TIHANGE 2 SERVICE EXPERIENCE

### 4.1 Cracking status

The three steam generators of Tihange 2 are inspected by ECT/RPC for 100 % of tube roll transitions since 1988.

The tube plugging limit for axial cracks in roll transitions is 14 mm ; however tubes have usually been plugged at a lower level of 13 mm.

The results from the June 1990 inspection are illustrated by figure 7 and summarized in the following table (only PWSCC cracks in roll transition)

| SG # | | 1 | 2 | 3 |
|---|---|---|---|---|
| Number of cracked tubes | | 45 % | 39 % | 48 % |
| Crack length | average | 7 mm | 6 mm | 6 mm |
| | max. | 14 mm | 14 mm | 14 mm |
| Crack number | average | 3 | 3 | 3 |
| (in same RT) | max. | 11 | 10 | 12 |

Almost all cracks indicate a depth of (close to) 100 %. This does not imply that all are physically through-wall ; however experience of PWSCC from Doel 2 and Doel 3 indicates that most of them are probably through-wall.

### 4.2 Leak history

The technical specification applicable to the Tihange 2 unit allows a maximum primary to secondary leak of 79 l/h (0.35 gpm).

The plant was commissioned in 1982 and no significant leakage was experienced until February 1985. At that time the leakrate of SG-3 increased rapidly (at a rate of about 5 l/h per hour) up to a level of 60 l/h, leading to an emergency shutdown. A secondary side pressure test evidenced 3 leakers that were correlated to severely out of tolerance holes in the tubesheet ; the ECT/RPC inspection detected several axial cracks within the tubesheet height, up to a maximum length of 9 mm. The position of the defects indicates a lack of contact between tube and tubesheet hole, a condition known to promote complex crack morphologies (circumferential components might not be detected by RPC).

With the exception of two large leaks related to first row U bends (May 1987 and March 1988), the inservice leakrate remained rather low (not exceeding 10 l/h) until February 1989 where the leakrate of SG-1 increased from 10 to 40 l/h in essentially 2 steps associated respectively with a 50 MW load adjustment and a "return to house load" transient. An unscheduled outage was decided because of a still increasing rate (about 1 l/h per day). A secondary side pressure test evidenced one leaker which was plugged. This plug was removed for RPC inspection in June 1990 ; multiple (12) axial cracks were detected in the roll transition, with a maximum length of 11 mm.

## 5. GENERAL OBSERVATIONS

Some general observations are applicable to all operating belgian units.

### 5.1 Service behavior

- Leakrate variations often appear stepwise in association with operating transients (even some minor ones).
- Leakrate at plant startup is usually higher than after some stable operation period.
- Leakrate tends to increase slowly at the end of cycle (stretch out period).
- Lithium addition has a marked transient effect on the leakrate. A temporary increase, by a factor of 2 to 3 (for instance from 7 to 20 l/h), is progressively recovered over a matter of days or weeks. An extreme case was that associated with the somewhat massive (but not abnormal) Li injection during the Doel 2 February 1990 restart (see § 2.3). To avoid such leakrate transients, some plant operators have now choosen to use special injection devices allowing a very progressive Li adjustment.

### 5.2 Leak detection during outages

#### 5.2.1 Secondary side hydrostatic tests

Whenever significant in-service leakage (even below the Technical Specification Limit) is observed, a secondary side water pressure test is performed (in the range of 12 to 45 bar), generally with addition of fluoresceïne (50 ppm) and visual observation of the tubesheet under UV lighting.

The number of leakers detected by a secondary pressure test (with fluoresceine) depends on the prior shutoff delay of the channel head ventilation system and on the waiting time before the observation (variable from 2 hours up to 2 days). It is typically of the order of a few tens of tubes (up to 50) ; however any significant leaker (such as leading to a service leak in excess of the technical specification limit) has been directly detected by significant dropping (without any need for fluoresceine).

It has been generally observed that a significant in service leak (> 10 l/h) was associated with but one or two leakers (dripping behavior) ; the only exception is the February 1990 Doel 2 case (see § 2.3.1) which resulted in a large number of such "major leakers".

#### 5.2.2 Secondary side helium leak test

This very sensitive leak detection method was used only once on SG-B of Doel 3 in an (unsuccessful) attempt to locate the "ghost leak" (see § 3.3)

The test was performed, at a five bar overpressure, by INTERCONTROLE who is routinely applying it in France and some other countries [ref. 4].

The helium test detected 335 leaking tubes (none of them large enough to correlate with the observed in service leakrate). A plot of the He leakrates versus the crack lengths (measured by ECT/RPC) is illustrated by figure 6, which mimics the distribution curve of crack lengths, thus suggesting no strong correlation between leakrate and crack length. Moreover only one of the 27 "larger" He leakers (> 5 cc/hr) did coïncide with one of the 49 "longest" cracks (> 10 mm).

## 6. DISCUSSION OF SERVICE EXPERIENCE

The Belgian in-service experience of SG leakrate, which is similar to that of other countries (like France) that operate steam generators with TWD cracks, indicates low leakage values which is inconsistent with laboratory data (even performed on pulled tubes).

The total number of cracks in the 3 considered Belgian units is estimated to be in the range of 80,000 of which about 1,000 have lengths in excess of 10 mm.
Despite the fact that most of these cracks are effectively through-wall the integrated leakrate (for all 3 units, i.e. a total of 8 affected SG) is only a few tens l/h (in the range of 0.1 gpm).

The most likely explanation of such a low leakrate is

- in some particular cases :

  . the tightness of the crack, which is prevented from opening (in width) by some small remaining ligament(s) ; as an extreme case a very long crack made up of (almost) aligned individual components may not leak at all,

  . the constraining effect of the environment (such as hard sludge pile), preventing the crack to open up (in width) and/or providing a flow limiting effect,

- in the more general case :
  The process of clogging the crack leak path by primary water impurities (cruds and/or precipitates).

The last assumption is supported by the following observations :

  . Unclogging is observed in association with the chemical environment (decontamination solution, lithium addition) and plant transients.

  . The relatively rapid development of the few in service leaks (in a matter of hours or days) cannot be explained by physical crack extension (and widening) ; also failure of crack ligament(s) would lead to a more immediate (and probably larger) leakrate increase.

It should be realized that the rather limited data basis for leakrate of stress corrosion cracks (as documented by figure 2.6 of ref. 2) is significantly biased

- in the case of laboratory produced cracks, by the lack of any representative process of leak path clogging,

- in the case of laboratory testing of pulled tubes with actual SCC, by the unclogging that is likely to result from cleaning and decontamination operations,

- in the case of field data (correlation of in-service leak with NDE characterization of the crack(s) ), by the non representative consideration of leakers ("outliers" within the population of tubes with TWD cracks).

Thus the so-called "data basis" yields a gross overestimation of the average leakage effectively experienced under actual service conditions.

Even in the case that significant leaks develop in service, the best correlation appears to be with the lower bound (mean/10) of the data basis. Obviously a very large number of tubes with lower leakrate (typical of actual in-service leakage) do not show up and cannot be properly documented.

The same arguments of reduced leakrate do not apply in case of a rapid crack widening as would result from a sudden increase of differential pressure (case of a large secondary side accident such as FWLB). Thus no correlation can be expected between the leakrates under the nominal and accidental conditions.

## 7. CONCLUSIONS

The large scale field experience from SG operating with TWD cracks indicates very low leakage, considerably lower than predictable from theoretical assumptions or laboratory experiments.

This detracts from the reliability of the existing data basis of leakrates as a function of crack lengths and does not allow

- to demonstrate LBRB behavior,
- to extrapolate the leakrate under accidental conditions from the actual in service observations.

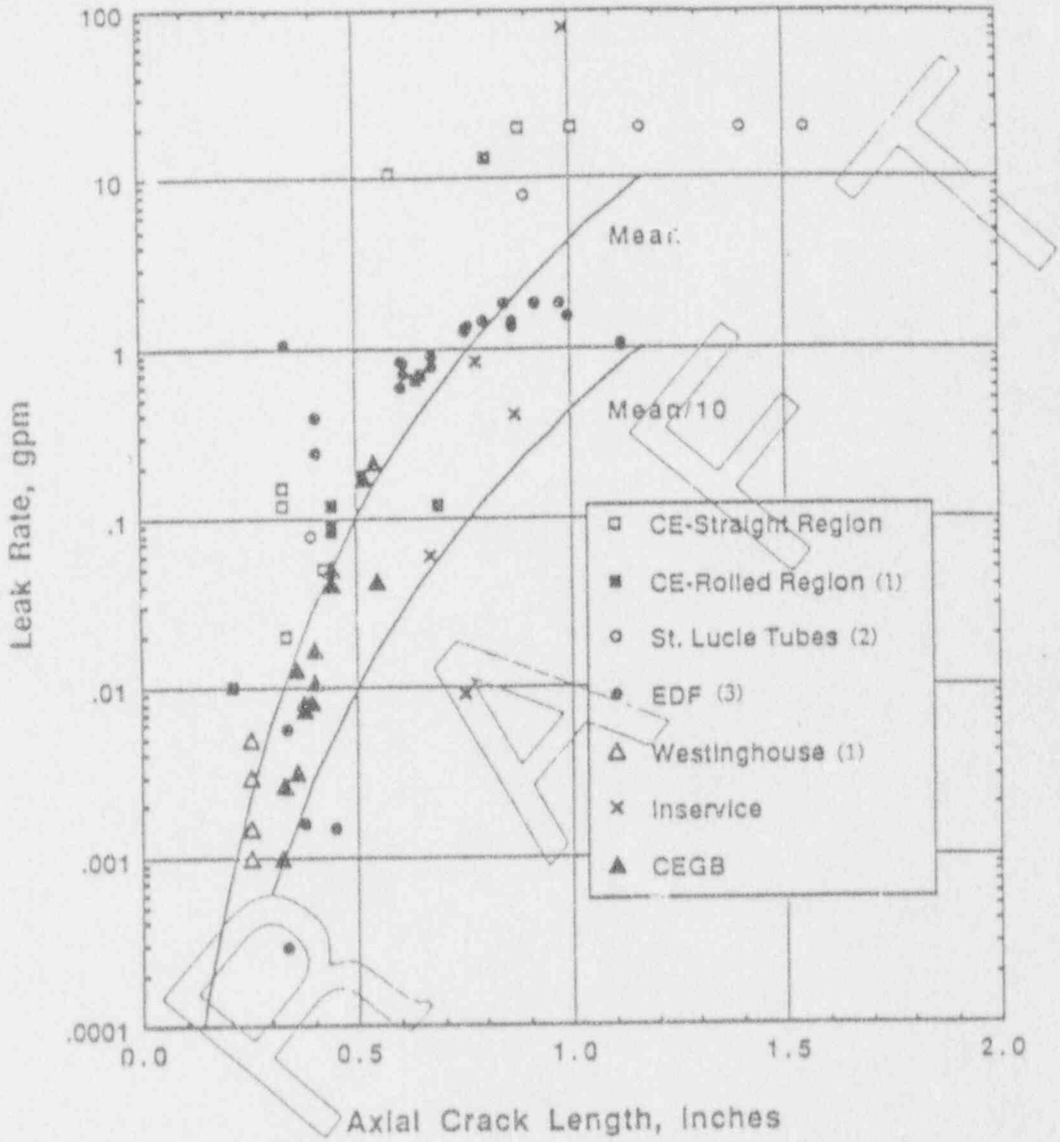
This justifies the Belgian management approach of the PWSCC problem in roll transitions, based on :

- routine 100 % RPC inspection of all steam generators (with full depth roll) at each outage,
- probabilistic assessment of the SG leakrate under postulated secondary side pipe rupture (FWLB), by using the LABOLEAK software program [ref. 9].

TABLE 1 - DOEL 2 / SG-A / EVALUATION OF IN SERVICE LEAKAGE FOR LONG CRACKS (> 10 mm)

| POPULATION | CRACK LENGTH (mm) | UNIT LEAKRATE from Fig. 2.6* of ref.(2), at mean / 10 (gpm) | CRACKED TUBES | | | LEAKERS TUBES (february 90) | | |
|---|---|---|---|---|---|---|---|---|
| | | | number | leakrate | | number | leakrate | |
| | | | | (gpm) | % cumulative | | (gpm) | % cumulative |
| | 11 | 0.004 | 31 | 0.12 | 5 | 7 | 0.028 | 5.5 |
| | 12 | 0.006 | 33 | 0.20 | 13.5 | 6 | 0.036 | 12.5 |
| | 13 | 0.01 | 24 | 0.24 | 23.5 | 5 | 0.050 | 22.5 |
| SAMPLE | 14 | 0.015 | 18 | 0.27 | 34.5 | 5 | 0.075 | 37 |
| OF ~ 1000 | 15 | 0.02 | 20 | 0.40 | 51 | 8 | 0.06 | 68.5 |
| TUBES | 16 | 0.03 | 3 | 0.09 | 55 | 2 | 0.06 | 80 |
| INSPECTED | 17 | 0.04 | 3 | 0.12 | 60 | 1 | 0.04 | 88 |
| BY RPC | 18 | 0.06 | 1 | 0.06 | 62.5 | 1 | 0.06 | 100 |
| IN 1989 | 19 | 0.08 | 1 | 0.08 | 66 | 0 | | |
| | 21 | 0.12 | 1 | 0.12 | 71 | 0 | | |
| | 25 | 0.3 | 1 | 0.3 | 83.5 | 0 | | |
| | 26 | 0.4 | 1 | 0.4 | 100 | 0 | | |
| | TOTAL(expected leakrate) | | 137 | 2.4 | | 35 | 0.5 | |
| COMPLETE | extrapolation (x3) | | ~ 500 | 7.2 gpm = 1600 l/h | | ~ 100 | 1.5 gpm = 340 l/h | |
| TUBE BUNDLE | measurement | | | - | - | | 0.6 gpm = 140 l/h | |

* Appended to this table ; the figure is taken from ref (2), which is a draft interim version of the EPRI report NP 6864




(1) roll transition
(2) 1425 psi
(3) scaled for temperature at 1450 psi

Figure 2-6. Leak Rate Versus Nominal Axial Crack Length for Corrosion Cracked Steam Generator Tubes, 600° F (data from Appendix E)

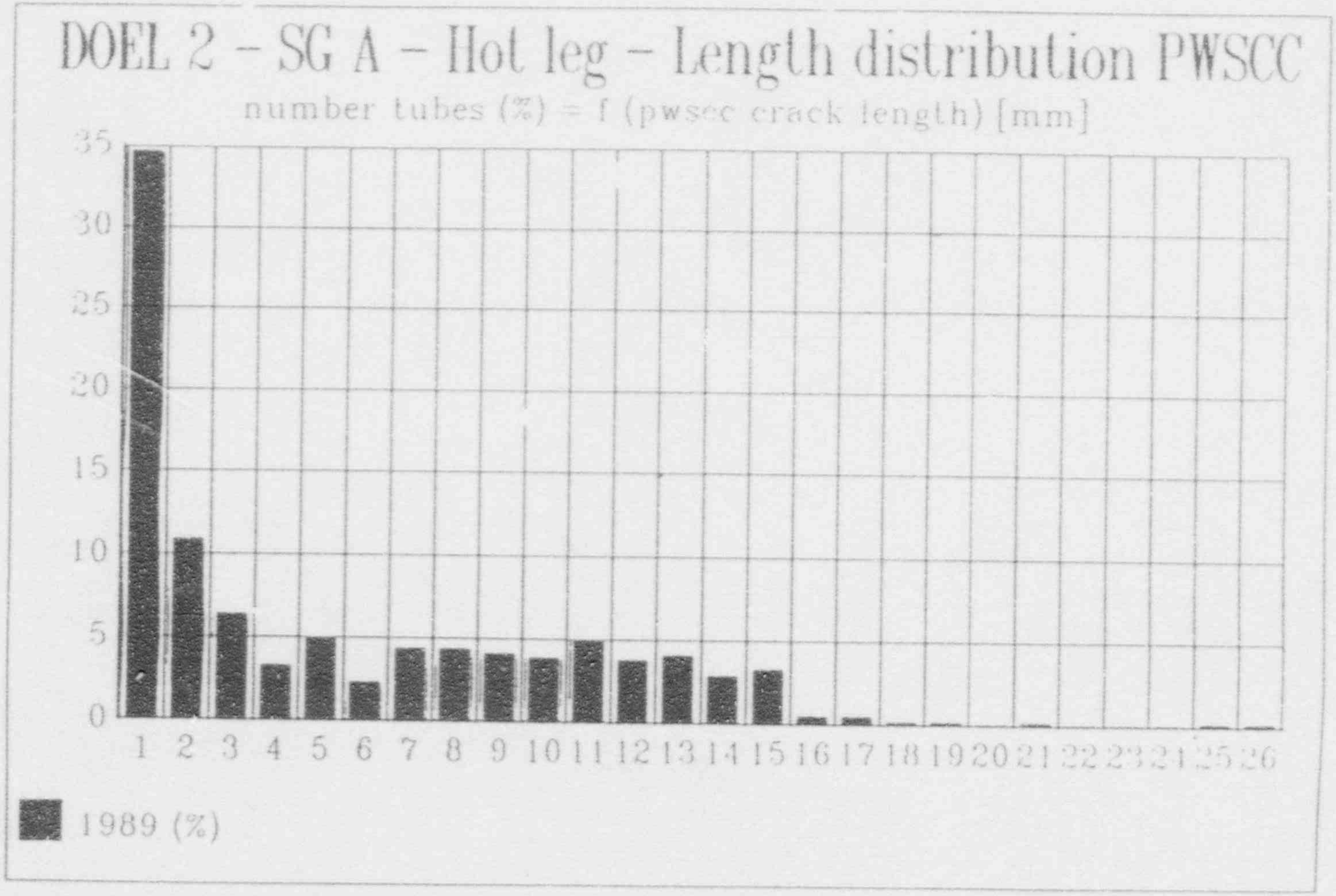
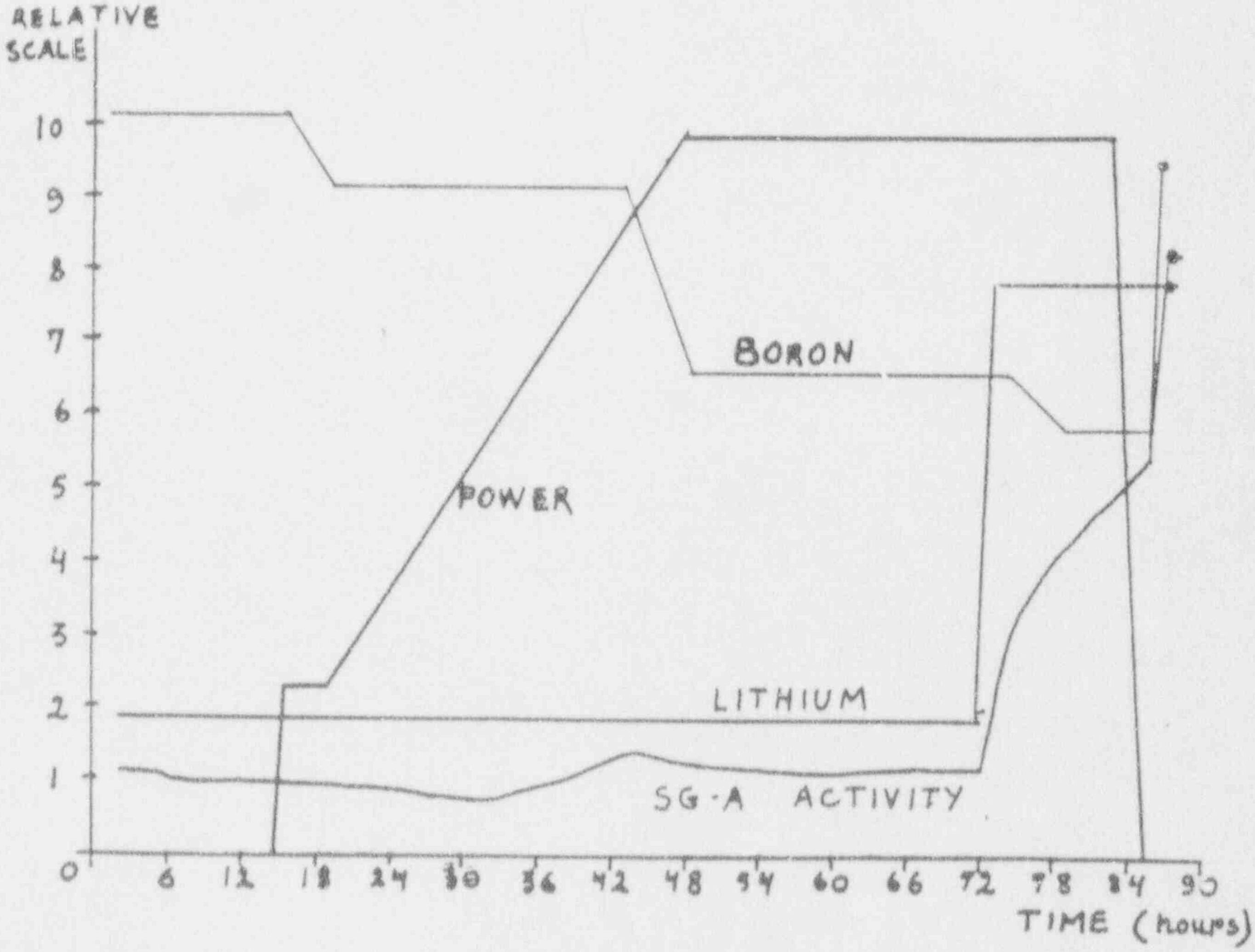



FIGURE 1 : Distribution curve of maximum crack length in roll transitions

FIGURE 2

# DOEL 2 LEAK OUTAGE

## FEBRUARY 1990




LEAKRATE INCREASED FROM
8 TO 70 l/h (.035 → .30 gpm)

MIGHT HAVE DOUBLED AFTER
SHUTDOWN INITIATION

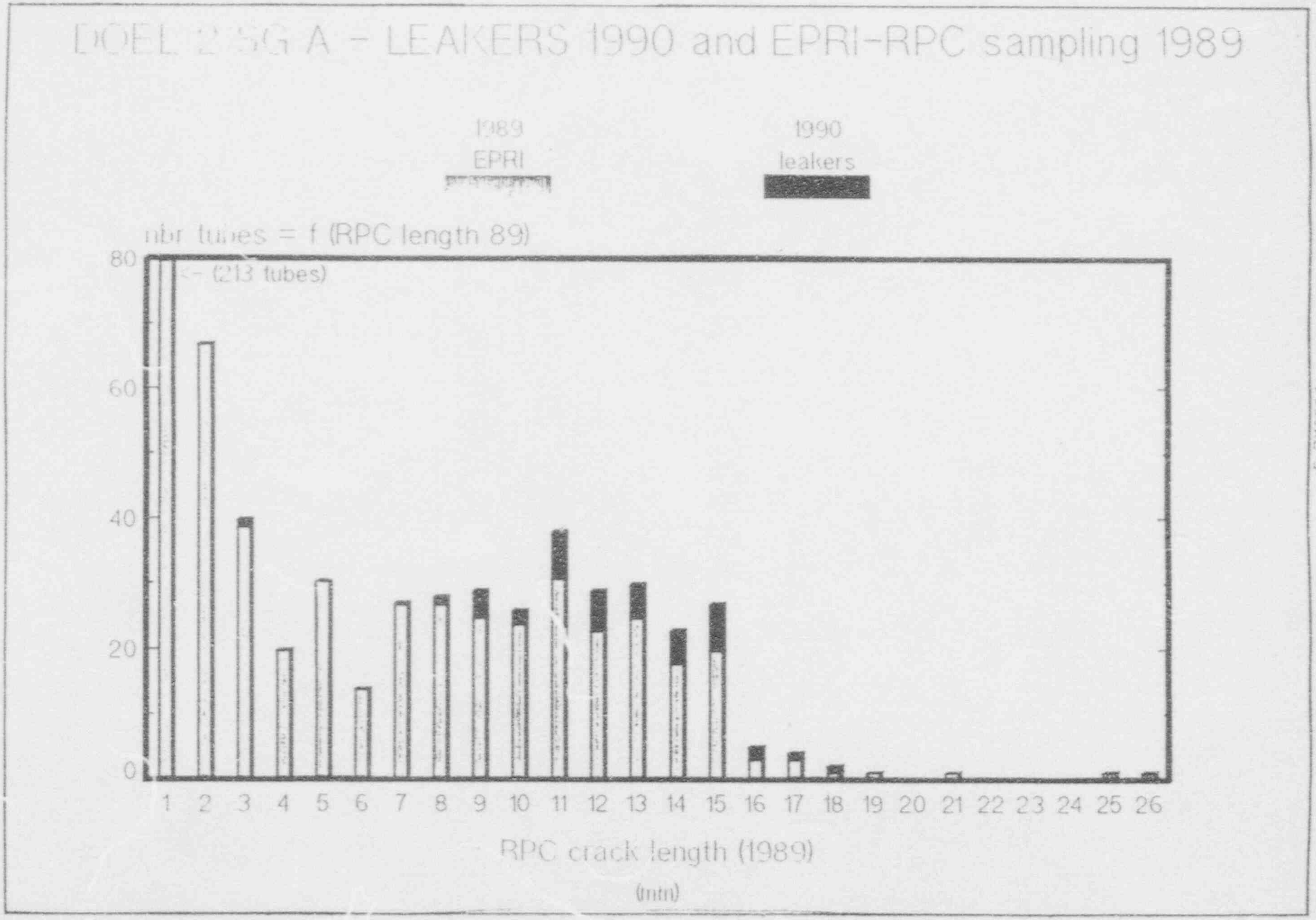

DOEL 2 SG A - LEAKERS 1990 and EPRI-RPC sampling 1989
1989
EPRI
1990
leakers
nbr tubes = f (RPC length 89)
<- (213 tubes)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
RPC crack length (1989)
(mm)

FIGURE 3

FIGURE .

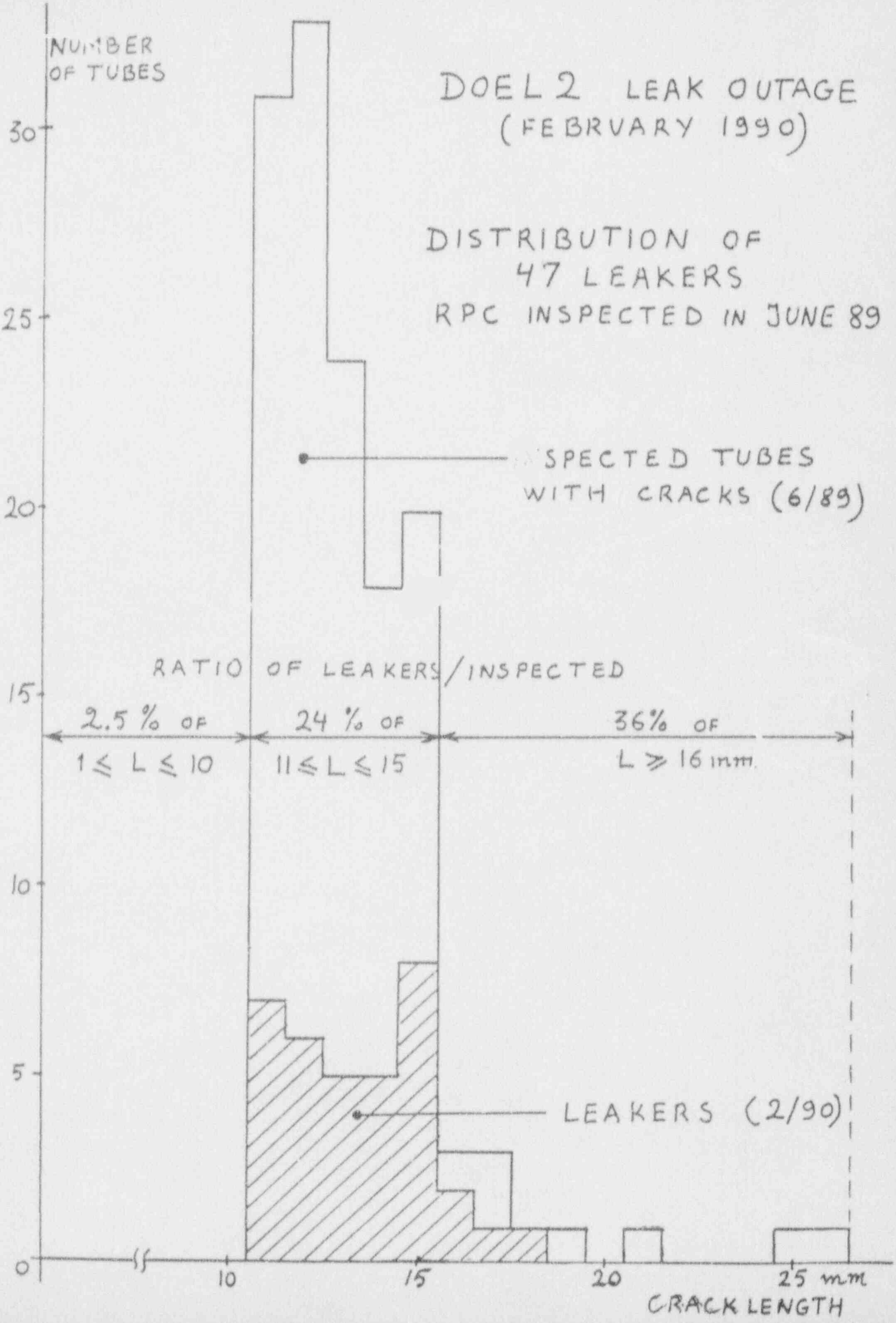
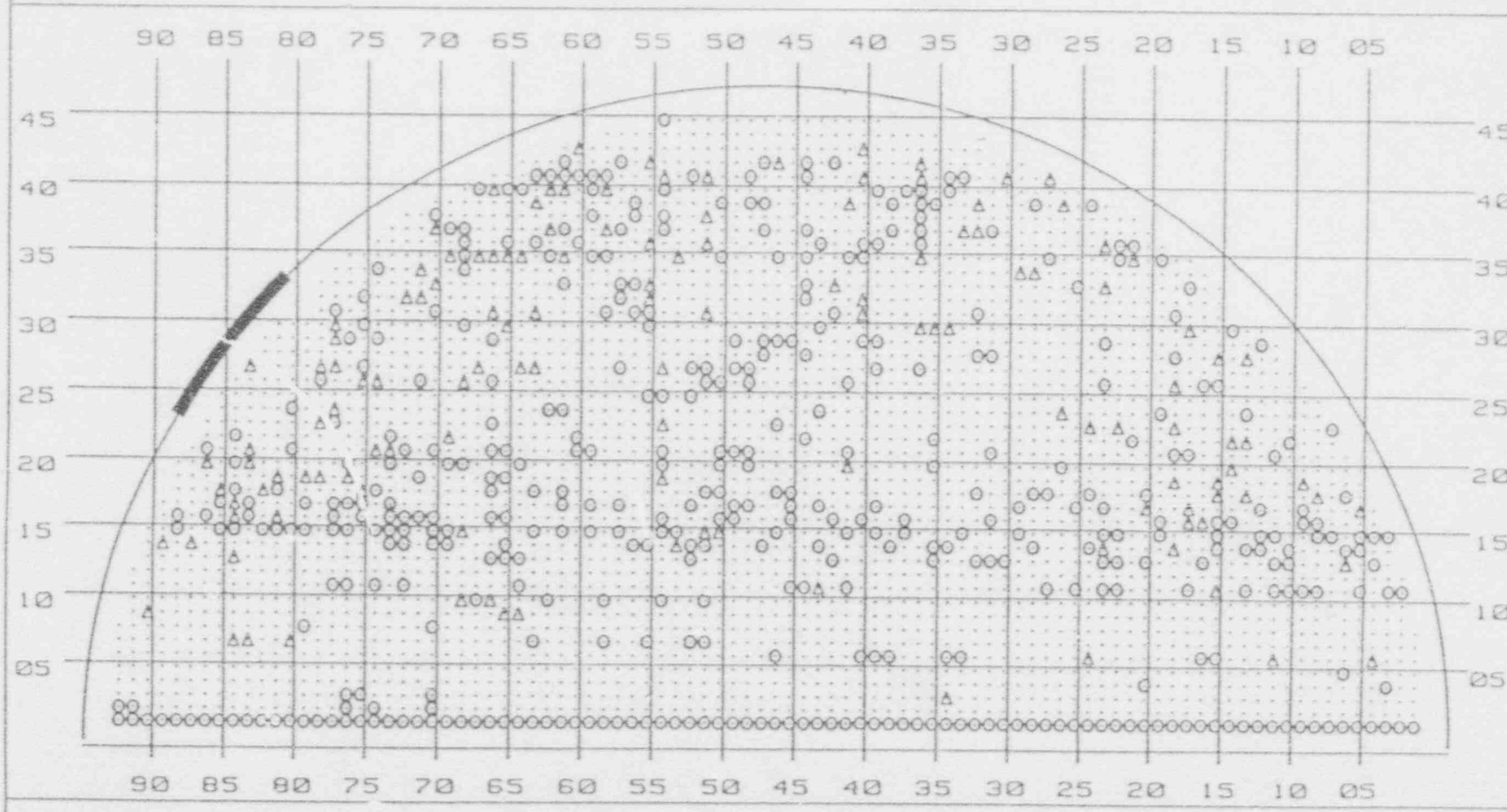

NUMBER OF TUBES
DOEL 2 LEAK OUTAGE (FEBRUARY 1990)
DISTRIBUTION OF 47 LEAKERS RPC INSPECTED IN JUNE 89
SPECTED TUBES WITH CRACKS (6/89)
RATIO OF LEAKERS/INSPECTED
2.5 % OF 1 ≤ L ≤ 10
24 % OF 11 ≤ L ≤ 15
36% OF L ≥ 16 mm
LEAKERS (2/90)
0
5
10
15
20
25
30
10
15
20
25 mm
CRACK LENGTH

FIGURE 5

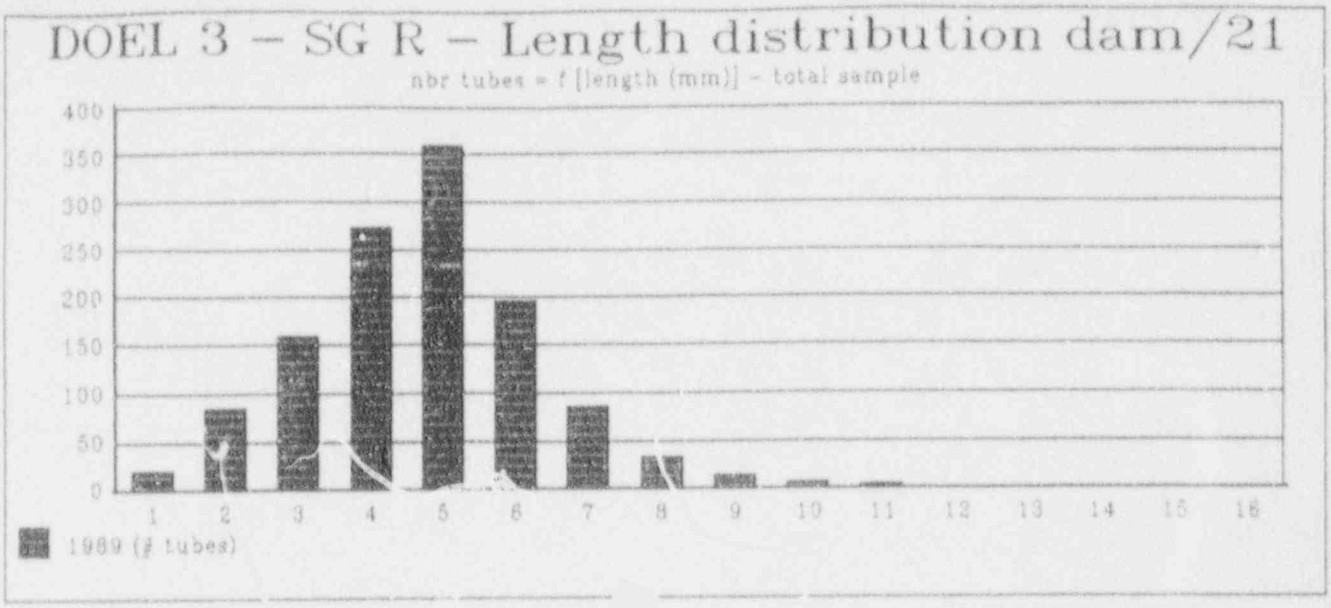
LABORELEC - SECTION M - N.D.T.

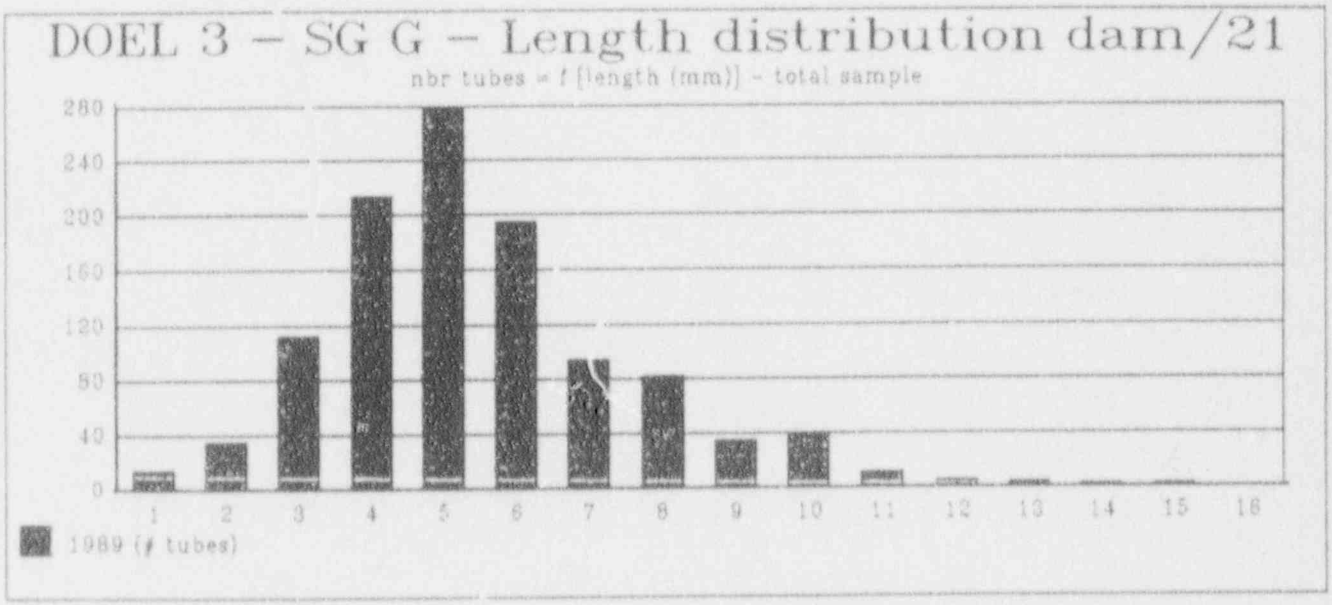
DOEL 2 - SG A - HL - SII - I - ID2AB90 - 15.FEB.1990

ALL INSPECTED TUBES DURING I.S.I. (LEAKERS)



< 135 tubes > Δ : Mandatory length (15 m).
< 461 tubes > o : Plugged tubes.


DOEL 3 – SG R – Length distribution dam/21
nbr tubes = f [length (mm)] - total sample
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
1989 (# tubes)


DOEL 3 – SG G – Length distribution dam/21
nbr tubes = f [length (mm)] - total sample
280
240
200
160
120
80
40
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
1989 (# tubes)

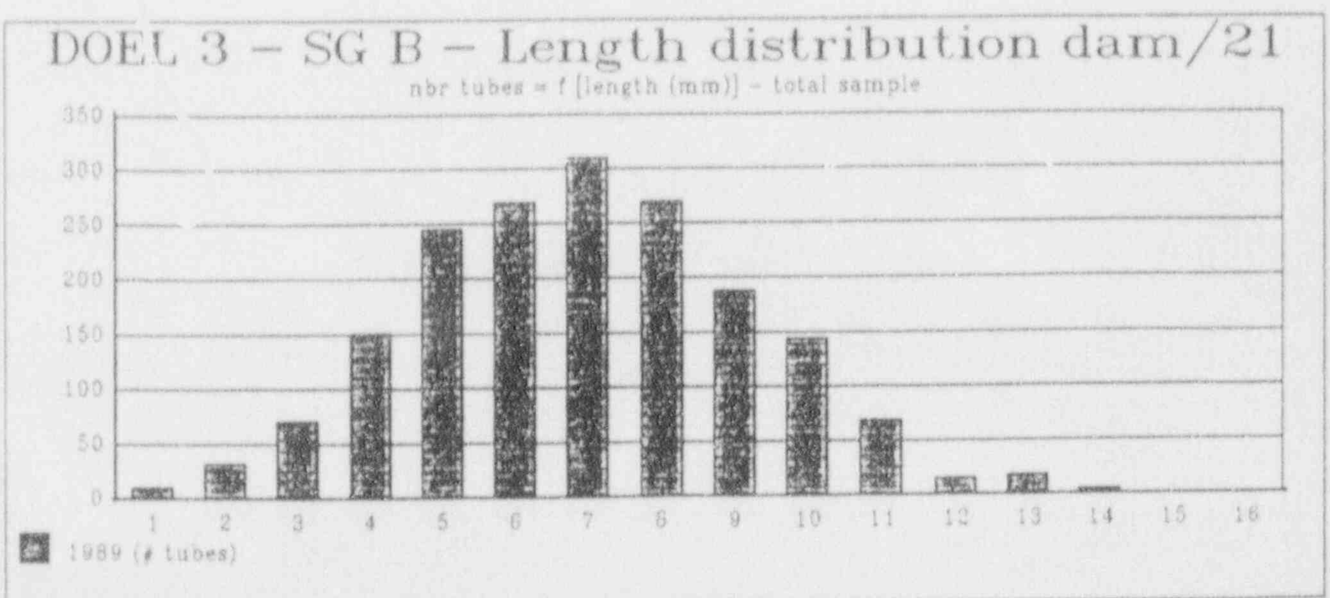
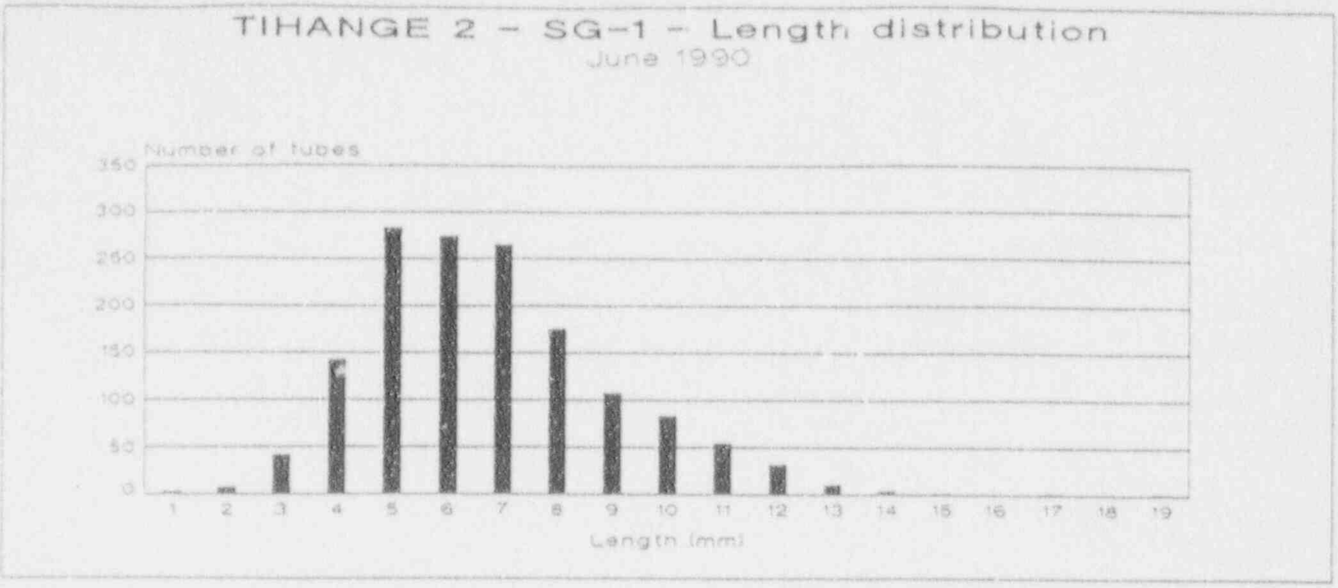
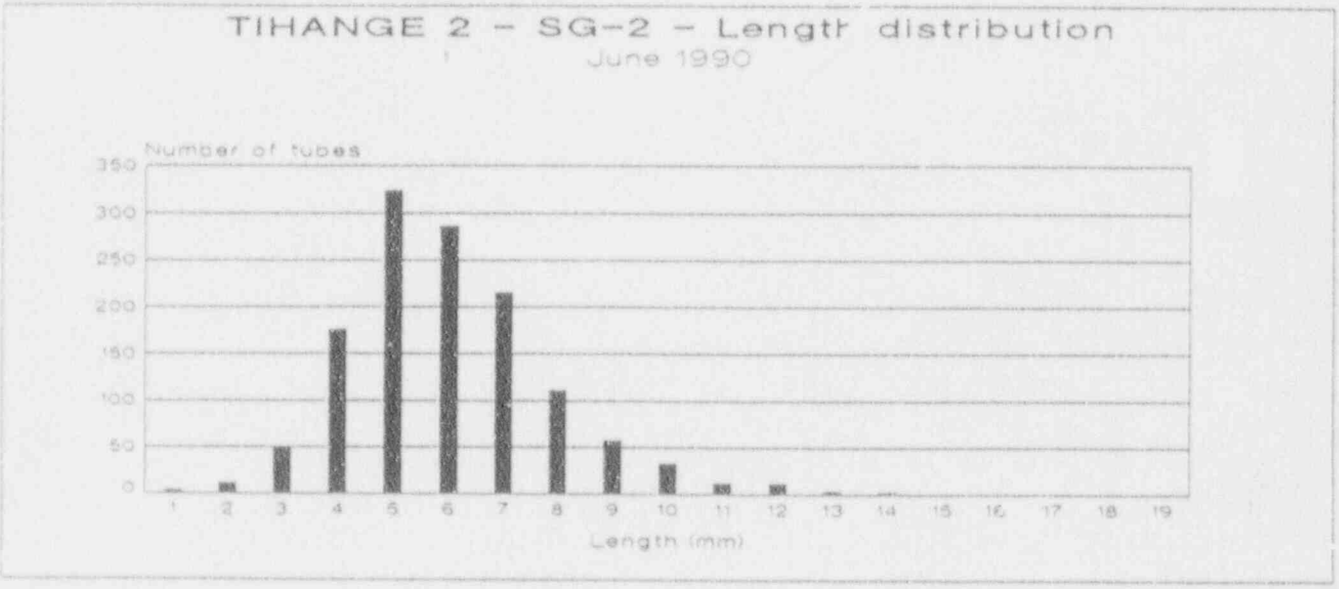

DOEL 3 – SG B – Length distribution dam/21
nbr tubes = f [length (mm)] - total sample
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
1989 (# tubes)

FIGURE 7


TIHANGE 2 - SG-1 - Length distribution
June 1990
Number of tubes
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Length (mm)


TIHANGE 2 - SG-2 - Length distribution
June 1990
Number of tubes
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Length (mm)

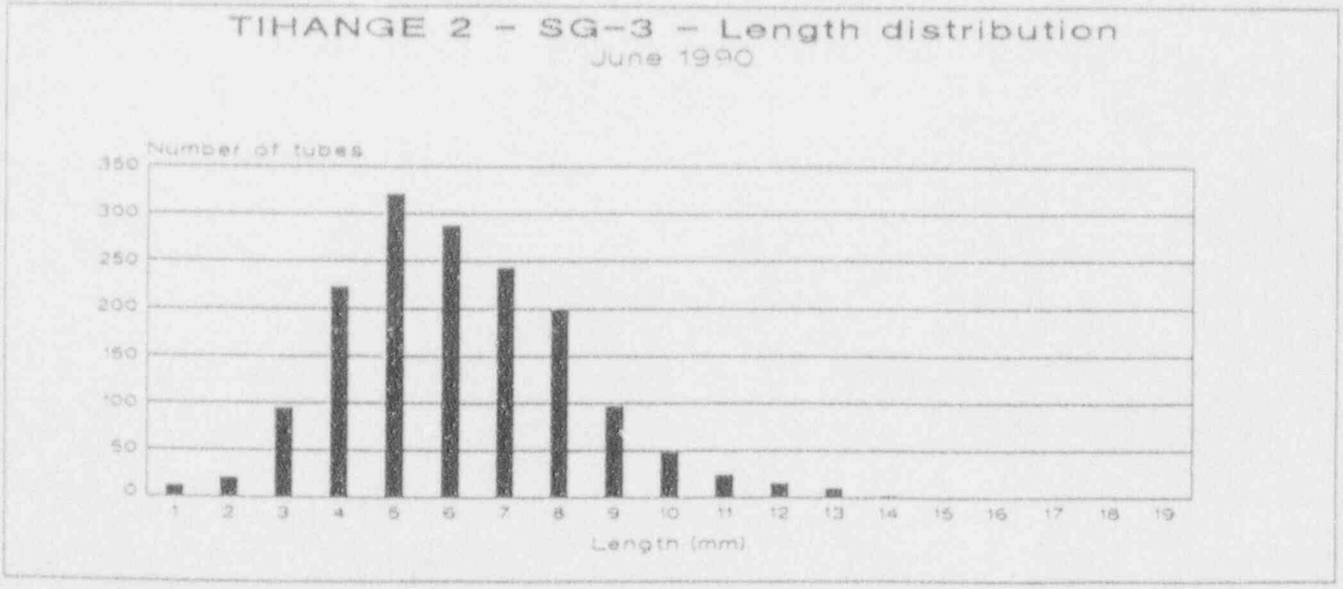
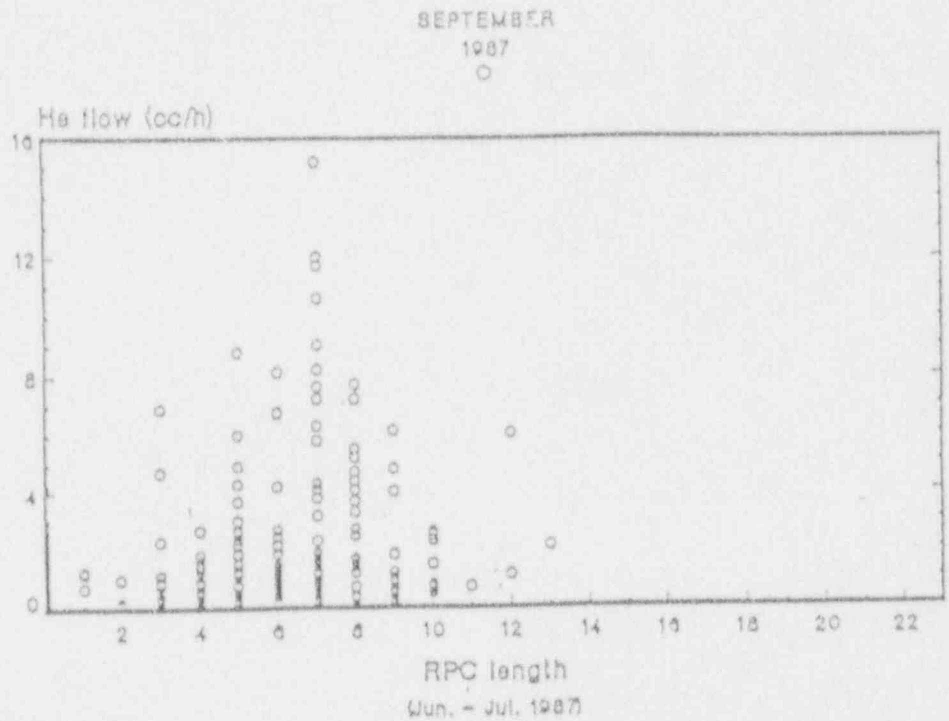

TIHANGE 2 - SG-3 - Length distribution
June 1990
Number of tubes
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Length (mm)

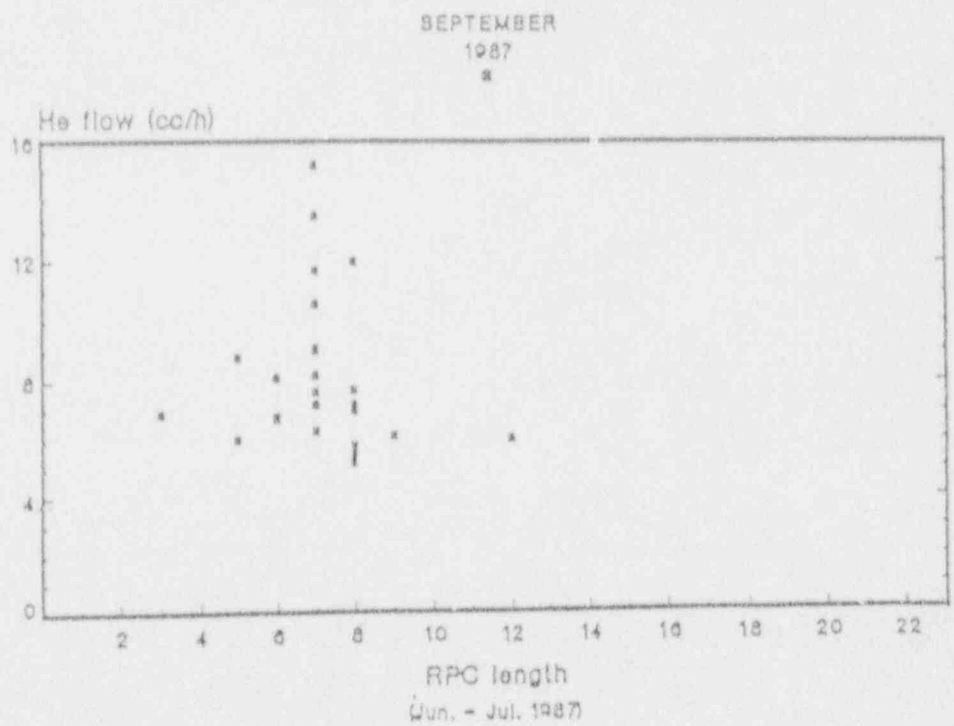
FIGURE 8

DOEL 3 : 335 TUBES DETECTED BY He LEAK TEST




HELIUM LEAK VERSUS RPC LENGTH

27 TUBES WITH He LEAK > 5 cc/h




HELIUM LEAK VERSUS RPC LENGTH