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INVESTIGATION INTO CAUSES AND OCCURRENCES
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October 9, 1958

INTERIM REPORT ON PT-IP-196-I
INVESTIGATION INTO CAUSES AND OCCURRENCES OF HOT SPOTS

INTRODUCTION

The hot spot investigation program was set up with four objectives in mind.

1. Establish basic information concerning hot spot frequencies at each reactor and on all types of slugs being irradiated.

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2. Develop a method of classifying hot spots and attempt to identify them with their modes of origin.
3. Determine the variation in hot spot frequencies with tube power and exposure.
4. Establish what specific actions can be taken to reduce the incidence of hot spots.

The purpose of this report is to summarize briefly the work which has been done to date and to acquaint the reader with the results of the "Hot Spot Investigation Program" as well as some of the problems encountered.

SUMMARY AND CONCLUSIONS

The observed hot spot frequencies vary considerably between reactors, and in a reactor the hot spot frequency seems to vary from month to month. Hot spot frequencies have been found to vary from 0.4 per cent hot spots (0.4 hot spots per 100 slugs examined) at KE to 15 per cent at D on BNTL solid slugs. The variation at one reactor is demonstrated by a seven-tube sample taken at KE on July 2, 1958, which showed 4.5 per cent hot spots and a 12-tube sample taken in September which showed 0.4 per cent hot spots.

The hot spot frequencies which have been established to date are shown in Table I.

All hot spots are being classified into four types: (1) a tear-drop shape on the cap end of the slug, (2) a tear-drop shape on the can end of the slug, (3) a cigar shape in the center of the slug, and (4) any other odd type.

It has been theorized that a tear-drop shape on one end of the slug indicates that the slug has been misaligned in the tube in such a manner as to bring one end of the slug within a few mils of the tube wall. A cigar-shaped hot spot is theorized to be one in which the slug is raised up against the tube or rolled over on one rib. Observations which have been made to date tend to support these theories.

The method by which the slug approaches the tube wall is still in doubt. Some of the mechanisms which appear to exist are slug cocking, bowed columns, warped slugs, and the effect of bowed tubes. It appears probable that most hot spots are caused by a combination of several of these mechanisms.

An additional object of the program has been to develop the metal inspection program sufficiently that we can make some estimate of the rupture proneness of the metal in a pile. To date it appears that we can find abnormal conditions such as gross slug warping or slug pitting, but to date we can do little to predict pile rupture performance. The greatest value of the program has been to provide basic information concerning the hot spot problem.

DISCUSSION

The variation in observed hot spot frequencies is apparent from Table I.

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TABLE I

OBSERVED HOT SPOT FREQUENCIES

<u>Area</u>	<u>Date Dis-Charged</u>	<u>Type Metal</u>	<u>No. Slug Examined</u>	<u>Average Power</u>	<u>Average Exposure</u>	<u>Per Cent Hot Spots</u>	<u>Severity*</u>
B	6-9-58	Solid	300	960	500	3.7%	-
B	7-3-58	KE-052-A Rupture Prone E	203	-	-	13.2%	1.20
C	6-20-58	I&E	256	930	800	3.5%	1.10
C	9-14-58	I&E	128	-	800	1.6%	1.00
KE	7-2-58	I&E	188	1060	800	4.8%	1.55
KE	8-5-58	I&E	456	1060	800	0.4%	1.00
D	8-14-58	BNTL	237	887	475	15.2%	1.30
DR	8-20-58	KA-121-A Rupture Prone R	167	-	-	10.2%	2.19
H	7-1-58	KE-025-A	22	-	-	32	1.00
H	7-1-58	E Metal	154	-	-	8	1.25
H	9-15-58	Solid	128	772	500	8.75%	1.18

*The severity is determined by assigning the number "1" to a light hot spot, "2" to a moderate hot spot, and "3" to a severe hot spot. The values are then averaged and the result is the average severity of the sample.

The large variation in frequency rates observed at KE is surprising. Some of the factors which could have influenced the hot spot frequency rate are: (1) a five per cent cut in power level in mid-April, (2) increase to six pumps in mid-April, and (3) flux depeaking charges were charged starting in May. It is interesting to note that from 5-20-58 until 9-25-58 KE has had only two ruptures.

The variation by tube has run from 0 to a high of 13. A typical sample of seven tubes is shown in Table II.

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TABLE II

BNTL MATERIAL FROM D AREA

<u>Lot No.</u>	<u>Tube No.</u>	<u>No. of Hot Spots</u>	<u>Tube Power</u>
CA-076-C	3279	5	929
KA-113-C	3382	3	922
KA-122-D	3765	8	871
KA-102-C	3264	7	920
KA-098-C	3388	5	881
KA-103-C	3784	6	818
KA-090-C	3973	0	872

Due to the method used to identify each tube, the variations in the number of hot spots per tube is coupled with the variation per lot. As yet these two variables have not been adequately separated and evaluated.

Rupture-prone lots have in general been found to have high hot spot incidence rates. Lot KE-052-A was a solid E metal lot which sustained six ruptures. At H Area, 22 slugs from this lot had 32 per cent hot spots, and a 154 slug sample of solid E metal from other lots irradiated at the same time showed 8 per cent hot spots. At B Area, 203 slugs were inspected from lot KE-052-A and were found to have 13 per cent hot spots. Examination of rupture-prone lot KA-121-A (two ruptures) from DR revealed a frequency of 10.2 per cent. If rupture-prone lots do in fact have high hot spot frequency rates, one would expect the rate to vary with the degree of rupture proneness. Since we do not have any method of determining the degree of rupture proneness, we would expect the hot spot frequency of lots which are declared rupture prone to vary from a normal frequency to some as yet undefined high frequency rate.

The Blunt Nose True Line slugs which were proposed as a method of improving the alignment of solid slugs are being irradiated at D Area. A 237 slug sample was examined. The sample revealed a hot spot frequency of 15 per cent. These hot spots were mostly light in appearance, and 28 out of the 35 hot spots were on the downstream end of the slug.

METHOD OF FORMATION OF HOT SPOTS

One of the objectives of this program has been to determine the causes of hot spots. All observations to date have supported the theory that a slug must approach within a few mils of the tube wall in order to develop a hot spot. The "critical" distance from tube to slug varies with the local water temperature, slug heat generation rise, and local heat transfer coefficients.

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The exact mechanism by which the slug approaches the side of the tube is still a mystery. It has been demonstrated that a hot spot can be caused by a severely warped slug. A notable example of this is tube 4985-KW, in which the ninth slug from the upstream end of the charge was warped 76 mils and had a hot spot on it. The same tube had a slug with 50 mils of warp which was the highest powered slug in the column, and did not have a hot spot. Many slugs with hot spots are not warped significantly, which indicates that warp is not the sole contributor to the hot spot problem.

It has been shown by PT-105-634-A that a cocked slug will produce a hot spot, and the appearance of many of the hot spots which have been observed indicate that they were caused in this manner. Another possibility is movement of the entire metal column either by bowing or by rolling the column on to one rib. One factor in this connection, which has not been evaluated, is the effect of bowed tubes on the hot spot frequency rate at the old piles. It seems logical that a combination of many factors are involved in the formation of many hot spots.

The mechanism by which a hot spot becomes a failure has not been defined. There are several theories proposed. One theory proposes that the hot spot eventually causes a brittle bond beneath the hot spot, thermal shock then breaks this bond and the hot spot is then a cold spot which then fails at its edge due to the resultant high temperature at the edge of the unbonded area. Some hot spots do fail at the edge of the hot spot but others fail in the center. Some hot spots which fail in the center are probably caused by intergranular attack which reaches an Al-Si spire or a small unbonded area. It is possible that these mechanisms exist and probable that many others which have not been defined also exist.

An additional objective of the program has been to develop our metal inspection program to the point where we could make some prediction as to the rupture proneness of the metal in the pile by the examination of a sample of the metal. Our experience to date indicates that we are able to find abnormal conditions such as a particular type of metal which is subject to high warpage, or a particular type of can which is subject to pitting or high corrosion rates. As far as predicting normal rupture rates is concerned, it appears that at present we can do little in this respect.

The value of the program has been largely of a basic research nature. It has long been a basic premise of engineers and scientists that basic research on a problem is the first step to its solution. It is in this respect that the hot spot investigation program has been of greatest value and can be of greater value in the future.

FUTURE PLANS

It is felt that the slug inspection program has been very beneficial and continued examination of slugs is desirable. Plans for the immediate future include examination of slugs with X-8001 (M-388) jackets. The effect of hand seating on the hot spot frequency will be determined. Examination of old pile I&E slugs will be made when they become available. A program to determine the hot spot frequency at one pile by examination of a large number of slugs is being considered. We will continue to attempt to evaluate the many variables which are included in the formation of hot spots and in the failure of a hot spot.

N. E. Guller

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