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March 19, 1946.

REVIEW OF BLISTERED SLUG INVESTIGATIONS.

This memorandum reviews the work which has been done by the Slug Investigation Committee, a committee appointed to investigate the causes of slug blistering. More detailed accounts of the activities of this committee may be found in the secret documents 7-2856, 7-2960, 7-3038, 7-3075 and 7-3468. These documents contain the minutes of the meetings of this committee.

HISTORY.

The first blistered slugs noticed came from high concentration tubes discharged at B Area on October 30, 1945. The slugs from these tubes had been isolated for visual examination for corrosion. The distortions noticed on these and subsequent slugs may be divided into two classes: a) the blistered ones, where a random sprinkling of small abrupt bumps are found and b) the swollen ones, where swelling is found over relatively large areas of the slugs.

Following the discovery of the blistered slugs in the high concentration tubes at B, the following special work has been done: all high concentration material in storage at D and F was inspected for blisters; all production slugs discharged at the three areas are examined for blisters as the slugs are picked up from the discharge basin and placed into buckets; six to eight tubes of high concentration material are discharged every month at B, the slugs isolated and inspected for blisters; the canning data, stamped on the end of each slug, is recorded for every blistered slug and, up until February 8, 1946, approximately every twentieth good slug.

In an attempt to determine the cause of the blistering, the tops of two blisters were filed off. The aluminum can was filed through to the base metal in each case but no evidence of corrosion product or any cavity could be found. After experimenting with unprocessed slugs, it was decided to strip a portion of the aluminum can from a blistered slug under water by using what amounted to a long handled cold chisel. It was found that the stripping of the can from an irradiated slug was much more

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difficult than stripping the can from an unprocessed slug, indicating that exposure in the unit makes the bonding layer harder. It also appeared that the base metal of an irradiated slug is much harder than that of an unprocessed slug. A sufficient portion of the can of a blistered slug was stripped however, so that it could be seen that the surface of the base metal was blistered similar to that of the can and that the cause of blistering was in the base metal and not in the can or the bond.

A blistered slug was then sent to the 200 Area for special processing to dissolve the aluminum can from the base metal. This left a very clean base metal surface which definitely showed the same blistered appearance which had been on the can surface (see Figure 1).

A small machine lathe was then adapted to be driven by ^{air motor} hand and to be used under water for cross sectioning a blistered slug. Considerable difficulty was experienced in attempting to machine a slug under water. Some of these difficulties were those one would expect to encounter in operating equipment under about twenty feet of water but the apparent hardness of the base metal of the slug also made the operation very difficult. The cutting edge of the carbide-tipped tool became badly worn after machining a small portion of one blistered slug while a similar tool is used to machine many unprocessed slugs in the 300 Area. This worn cutting tool was replaced with a new one and further machining performed on the chemically stripped slug (see Figure 2). Some machining was also done on a badly swollen slug which had been difficult to discharge from a tube. When a groove about 1/4 inch deep had been cut on this slug, the cutting tool became quite dull and the driving gears of the lathe stripped. This slug was then placed with each end resting on a lead brick and the center of the slug, where the groove had been cut, was hit three blows with a lead brick fastened to a pipe. These blows broke the slug in two (see Figures 3 and 4). The fact that the slug broke so readily is an indication that the irradiated base metal is considerably more brittle than unexposed metal.

An attempt was later made to similarly break the chemically stripped blistered slug which had been partially machined. This attempt was unsuccessful, probably because no deep groove was machined on the slug.

RESULTS.

A summary of the number of blistered or swollen slugs found in each Area is given in Table 1. In Figure 5 are summarized the canning dates of the blistered or swollen slugs as well as the canning date of approximately every twentieth good slug. It may be seen from the curves in Figure 5 that a relatively large number of the blistered slugs were canned the last nine days of

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December 1944. Analysis of the manufacturing data for this period indicated that during this period penetration, warping and auto-clave failure were above average. However, close examination of data on the raw material used during this period brings to light no significant facts.

Slugs from certain special tubes, corrosion and high concentration tubes have been isolated upon discharge and from these slugs data may be obtained on factors such as length of exposure, equivalent product concentration and rate of concentration increase. These data are summarized in Table II. From these data, length of exposure does not appear to be a factor in blistering. Concentration, however, definitely does appear to be a factor. Of the almost 200 blistered slugs which have been found to date, all but three of these have come from tubes which were discharged at concentrations considerably in excess of normal. That accounts, in part at least, for the higher number of blistered slugs found at B and F than at D, as B unit contained many high concentration tubes and F unit had several high concentration corrosion tubes while D unit has had no high concentration tubes since this special work was started. The rate of concentration increase does not appear to be a definite factor in blistering.

Further evidence that concentration is a factor in blistering may be seen in Tables III and IV. In ordinary production tubes, where the relative position of slugs in a tube is not known, the general location of the slugs may be determined by measuring their relative activities. These data for blistered slugs are given in Table III and they definitely indicate that the frequency of blistered slugs varies directly with the activity, or the product concentration, of the blistered slugs. The position of slugs in a corrosion tube is known and from Table IV it may be seen that most of the blistered slugs come from the central portion of the tube length, where the product concentration is the highest.

Blistered slugs in corrosion tubes, where gravimetric data are obtained, show a less regular weight loss than non-blistered slugs. While most of the blistered slugs show a slightly greater than normal weight loss, a few of them have shown a slightly less than normal weight loss. No very badly blistered slug has been found in a corrosion tube and the one showing the greatest weight loss over normal was only about 0.3 gms lighter than normal. Assuming that blistering is due to some sort of swelling, this would only represent an increase in volume of 0.3 cc over non-blistered slugs.

CAUSE OF THE BLISTERING.

The work done to date has revealed no obvious cause for the blistering of the slugs. The filing, stripping, machining and breaking of blistered slugs revealed no evidence of any corrosion or cavitation. The fracture surface of the slug broken in two was considerably different from that of an unexposed slug. The fracture of the exposed slug did not show the plane surfaces which are visible on the fracture of an unexposed slug and the

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structure appeared generally finer near the slug surface than is found on an unexposed slug.

Speculation regarding the possible cause for blistering of slugs assumes one or more of the following mechanisms:

- a. Movement in a manner allied to creep wherein any stress, however slight, may produce successive dislocations each "nucleated" by the violent local thermal agitation produced by fission.
- b. Production of relatively low density matter within the slug. This includes breakdown of chemical compounds found as impurities in the base metal, formation of gases, etc.
- c. Work hardening with consequent expansion, possible local stress, etc.

All of the above mechanisms have certain shortcomings in explaining the cause of blistering. The first mechanism fails adequately to explain development of abrupt blisters, blistered slugs appearing next in line to good ones, etc., while the second mechanism suggests that inclusions, pores and fissures would get relatively larger because of the greater forces acting on their greater surface and considerable cavitation could reasonably be expected to result. The third mechanism requires a means of acting in non-random fashion in order to cause blistering.

Preferred orientation of the crystal structure of the metal has been suspected of being a factor in the blistering of slugs. Such an orientation might be favorable to the deposition of migrating particles resulting in an increase in volume at the expense of a part of the slug which does not possess this orientation. Preferred orientation may result from physical factors such as extrusion temperature, extrusion pressure, etc. of the base metal.

PROGRAM.

The following program has been planned for future work:

1. The canning date will be recorded and the relative tube position determined for all blistered slugs.
2. A method will be developed to determine the hardness of exposed metal.
3. Production tests are being planned in which slugs selected for a high degree of solidity and perfection of bonding, slugs having a lower than average weight, slugs having a higher than average weight, slugs known to be somewhat porous, and slugs exhibiting a tendency to warp during fabrication

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are exposed in high activity regions of a unit. All of the above slugs will pass the existing specifications but they will have exhibited these particular properties to a greater extent than average. These slugs will upon discharge be isolated and closely examined for blisters or swelling.

4. Work will be done to devise tests and equipment necessary to study the preferred orientation theory.
5. A warp gage will be used to study warp during slug fabrication.

TECHNICAL DEPARTMENT

C. P. KIDDER

Asst. Chief Supervisor

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P. A. Dahlen

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TABLE I

Blistered or Swollen Slugs Found in Each Area

Area	Number Inspected To Date	Number Blistered	Canning Range of Blistered	General Canning Range.
B.	17,691	77	Before 11/3/44 to 3/13/45	Before 11/3/44 to 8/24/45
D.	23,233	16	Before 11/3/44 to 2/21/45	Before 11/3/44 to 8/15/45
F	20,282	104	12/21/44 to 2/5/45	11/20/44 to 3/1/45

TABLE II

Tube Concentration and Exposure vs. Number of Blistered Slugs.

Area	Tube No.	Days Exposed	Conc. MWD/tube	Conc. Increase per day MWD/tube/day	No. of Blistered pieces.
B	1768	283	51.8	.183	13
B	1773	283	52.4	.185	
B	1788	398	44.3	.111	0
B	2378	298	55.5	.186	5
B	3273	298	54.2	.182	13
B	3279	298	53.6	.180	12
B	3466	413	57.4	.139	0
B	1759	413	46.5	.113	0
B	3088	413	46.5	.113	0
B	3050	413	46.5	.113	0
B	2462	264	46.3	.175	0
B	2485	264	46.3	.175	0
B	2474	264	49.2	.186	0
B	3160	434	50.7	.117	4
B	2375	280	49.1	.182	0
B	2365	285	49.1	.172	0
B	3574	278	47.6	.163	4
B	2685	292	49.5	.170	0
D	1875	264	47.0	.178	0
B	3180	441	47.4	.108	3
U	2487	292	46.4	.159	0
B	1889	441	46.4	.105	1
B	3671	278	45.3	.163	8
B	2585	320	51.5	.161	0
U	1956	469	49.9	.106	0
C	1989	469	49.9	.106	0
B	1473	306	50.6	.165	0
B	1659	481	50.2	.104	3
B	1475	278	52.2	.165	0

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B	1661	304	41.6	.137	0
B	2978	283	44.5	.157	0
B	1186	497	51.7	.104	2
B1	1373	333	54.3	.163	0
B	1472	333	54.7	.164	1
B	1477	333	54.5	.164	0
B	1688	497	52.2	.105	0
B	2457	497	53.2	.107	0
B	2557	497	52.1	.105	0
B	3473	333	54.3	.163	0
D	2465	227	43.1	.190	0
D	2469	227	41.8	.184	0
D	2479	227	42.2	.186	0
D	2483	227	43.0	.189	0
D	2369	176	31.2	.178	0
D	2574	228	38.0	.167	1
D	2974	197	34.7	.176	0
D	3885	243	30.0	.123	0
F	2376	255	39.4	.154	4
F	2478	255	40.7	.160	5
F	2375	257	41.0	.154	0
F	2473	267	40.7	.152	7
F	2475	267	41.0	.154	2
F	2575	267	41.2	.154	4
F	2580	330	53.9	.163	20
F	3576	330	54.5	.165	3
F	2274	330	49.8	.151	21
F	3586	330	46.4	.140	3

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Table III

Relative Activity of Blistered or Swollen Slugs.

<u>Activity of Blistered slugs relative to Average Activity of 4 Highest in tube.</u>	<u>Number of Blistered Slugs.</u>
.40 to .45	1
.45 to .50	0
.50 to .55	0
.55 to .60	4
.60 to .65	2
.65 to .70	5
.70 to .75	7
.75 to .80	8
.80 to .85	9
.85 to .90	14
.90 to .95	12
.95 to 1.04*	40
	<hr/> 102

* If a blistered slug happens to be one of the most active in the tube, it may have an activity greater than 1.0 compared to the average of the four highest.

TABLE IV.

Location of Blistered or Swollen Slugs in Corrosion tubes.

Location of blistered or swollen Slugs in Corrosion tubes.

<u>Position in Tube (No. 1 is most upstream)</u>	<u>Number of Blistered slugs.</u>
1-5	0
6-10	9
11-15	12
16-20	12
21-25	12
26-30	8
31-35	3

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Figure 1a
Chemically Stripped
Blistered Slug

Figure 2
Chemically Stripped
Blistered Slug
Partially Machined

Figure 3
Partially Machined Swollen Slug
Broken in Two

Figure 4

FIGURE 5
NUMBER OF REJECTED AND
GOOD PIECES VS. CANNING
DATES

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