GENERAL ATOMIC

GA-A13742
UC-77

STATUS REPORT ON RESERVE SHUTDOWN SYSTEM

by
PROJECT STAFF

Prepared under
Contract E(04-3)-633
for the San Francisco Operations Office
U.S. Energy Research and Development Administration

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CONTENTS

INTRODUCTION

This report has been prepared by General Atomic Company to justify the usage of the reserve shutdown system (RSS) in its present condition. The report is divided into three parts: the status of the system, any effects on the reserve shutdown system performance, and reactor performance following a reserve shutdown system dump.

SUMMARY AND CONCLUSIONS

During a poison loading conversion of the reserve shutdown system, crystalline deposits were found on the surfaces of several reserve shutdown balls. An extensive inspection and analysis program was performed to characterize the crystals, to determine the source and extent of crystallization, and to determine the effect of the crystals on both the reserve shutdown system and the reactor itself in the event that the system is activated.

The reserve shutdown balls consist of B_4C particles intermixed with graphite. The specification for the material allows a small amount (0.15%) of B_2O_3 to be present in the balls. The analysis performed on balls taken from a typical hopper indicates that approximately 25% of the B_2O_3 has been leached out of the balls and crystallized into harmless boric acid crystals. None of the boron carbide (B_4C) has been affected. The crystalline deposits are contained within the reserve shutdown hoppers either on the hopper surfaces or on the ball surfaces.

The performance of the reserve shutdown system has been evaluated and found to be unaffected by the presence of the boric acid crystals. There is insufficient quantity of B_2O_3 in the balls to cause any stability problems with this material and the balls will remain intact throughout their 30-year life. A reserve shutdown system dump test was run which indicated no change in the release capability of the system. Laboratory tests were run to deliberately allow crystal growth between balls. Results showed negligible bond strength and all the balls separated from each other when the experiment tray was moved. Crystals which have been deposited on the hopper surfaces will have no effect on its integrity.

An evaluation has been made on the performance of the reactor following a reserve shutdown system dump. The crystals on the balls will either

dehydrate and convert back to B_2O_3 or they will vaporize and diffuse into the surrounding graphite and then convert to B_2O_3. Either consequence will not cause any effect on the reactivity which would compromise safety of the reactor core or cause degradation of the primary coolant system components.

It can, therefore, be concluded that the leaching out of B_2O_3 from the reserve shutdown balls and the subsequent crystal formation on the balls and the hopper does not change in any way the capability of the system to perform its function, nor does it compromise the safety of the reactor in the event that the system is activated.

PART I - STATUS OF RESERVE SHUTDOWN SYSTEM

An unusual event has been identified in the reserve shutdown system. Part I of this report is the investigation which has been undertaken to describe the event, determine the environmental history of the system, and define the cause.

1. Identification of Unusual Event

On September 19, 1975, during the modification of the 37 control rod drive assemblies to minimize the bypass of primary coolant flow from the orifice valve, CRD SN-028 was being converted for use in an outer core region. This conversion requires replacing the control rods and the reserve shutdown balls contained in the reserve shutdown system hopper. In the outer 18 core regions, reserve shutdown balls containing 40 wt % boron are used instead of those containing 20 wt % boron. While removing the boron carbide balls from the reserve shutdown hopper, it was noted that there was a deposit of white crystals on the surface of several of the balls. The presence of the crystals did not appear to affect the operability of the reserve shutdown system. This was subsequently identified as an unusual event per FSV Technical Specification AC 7.6.

2. History of the Environment in the Reserve Shutdown Hopper

The reserve shutdown hopper is vented to the PCRV environment as shown in Fig. 1.* The PCRV environment from January 1974 to March 1975 was described in detail in Ref. 1. Since the hopper is connected to the PCRV through the vent system, transport

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*Figures appear at the end of the text.

of the PCRV environment into the hopper has occurred via ordinary diffusion. Also, this transport was greatly enhanced during periods of large pressure swings, which occurred during the time period of interest.

Sometime in January of this year, approximately 4250 gallons of water were inadvertently admitted into the PCRV. This was reported in Ref. 1. Subsequent to the water ingress, water was removed from the PCRV through the helium purification coolers of the helium purification system from January 23 through February 15. During that process, with the moisture level in excess of 10,000 ppm, the reactor pressure was cycled between 50 and 250 psig twice to create a pumping action in order to remove the water from the PCRV liner insulation. The reactor was then pumped down and evacuated to less than 10 mm of Hg to complete the water removal. This was completed on March 10 and the reactor taken critical on March 21 to establish the integrity of the fuel and core components and ensure that the water had been completely removed.

It can, therefore, be concluded that between mid-January and March 10, 1975, the environment inside the reserve shutdown hopper was essentially the same as the PCRV. The dry helium was replaced by helium saturated with water during the pressure oscillations. This saturated helium was subsequently removed during the final PCRV evacuation and replaced again with dry helium on March 10, 1975.

The temperature of the hopper, reserve shutdown balls, and the helium within the hopper is assumed to follow the temperature of the helium within the PCRV since considerable bypass of helium into the penetration area was shown to occur during startup testing.

3. Inspection of Reserve Shutdown System

Upon discovery and identification of the crystallization, extensive inspection and tests were run at the reactor site. The reserve shutdown hoppers of five separate control rod drives (CRD) were inspected to determine the extent of crystal formation. Table 1 lists these CRDs and their location in the reactor prior to removal.

TABLE 1
CONTROL ROD DRIVES SELECTED FOR RESERVE SHUTDOWN SYSTEM HOPPER INSPECTION

Control Rod Drive Serial No.	Core Region Prior to Removal
028	13
037	2
011	21
021	30
027	22

The following inspections were performed on each of the hoppers:

Control Rod Drive	Inspections and Results
SN-028	Reserve shutdown balls were vacuumed out and a random sample of ~500 balls (650 g) was sent to San Diego for tests. Tests were also conducted by PSC Chemistry which determined that the crystals were water soluble boric acid crystals.
SN-037	Boric acid crystals were found on the inside surface of the filler plug as seen in Fig. 2. About 30 reserve shutdown balls (40 g) and samples of the crystals from the filler plug were sent to an

Control Rod Drive	Inspections and Results
	independent lab for identification. They confirmed that both were boric acid crystals (Appendix 1). These samples were later sent to GA San Diego for X-ray diffraction analysis to determine the chemical form. The balls in the hopper were vacuumed out in layers and random samples of each layer were sent to GA San Diego for quantitative analysis. The rupture disk was removed and photographed (Fig. 3). Crystals can be seen on the balls which were left on the disk and on the disk assembly. The inside of the hopper was inspected from the top and bottom using a mirror and a borescope. The only crystals seen were near the top as shown in Fig. 4.
SN-011	The filler plug and top surface of balls in hopper indicated similar crystalline deposit as seen in previous hoppers.
SN-021	Filler plug and top surface of balls in hopper indicated the same crystalline deposit. Trace crystals were also found in hopper vent system.
SN-027	Filler plug and top surface of balls in hopper indicated the same crystalline deposit. Successfully performed test No. RT-351 to verify performance of reserve shutdown system (Appendix 2). The inside of the hopper was examined after the dump test and it appeared similar to the CRD SN-037 hopper which was previously inspected and is described in Fig. 4. Typical RSS balls photographed after RT-351 are shown in Fig. 5.

4. Characterization of Crystals

Several samples of reserve shutdown balls were sent to GA at San Diego for analysis and characterization and these results are discussed below.

4.1. Reserve Shutdown Balls From CRD SN-028

The RSS for CRD SN-028 originally contained balls with >20 wt % boron in the form of B_4C and 0.15 wt % as B_2O_3. Of the sample of balls sent to San Diego, 128 out of 497 (26%) had more than 10 crystals on their surface. Of these 128, approximately 120 were analyzed to determine their chemistry and to quantify the crystallization.

The white crystals found in the first sample of balls from CRD SN-028 were identified to be boric acid crystals (H_3BO_3) and anhydrous boric acid crystals (HBO_2). Further analysis of the crystals revealed only trace amounts of Fe, Si, and Mg in addition to the H_3BO_3/HBO_2. The traces of Fe, Si, and Mg were present in the crystals to the same concentration as in the as-manufactured balls.

The average crystal (H_3BO_3/HBO_2) concentration was found to be 0.1% of the ball weight and the maximum on any ball was 0.5% of the ball weight. The average B_2O_3 concentration of these balls was 0.1% of the ball weight. An analysis of the total boron in the balls showed 20.9 wt %, well over the specified 20 wt %, indicating that no B_4C was affected by the leaching process.

Since the as-manufactured balls originally contained 0.15 wt % B_2O_3 and since the balls having more than 10 crystals on their surface had an average of 0.1 wt % B_2O_3, it can be

concluded that some of the B_2O_3 was leached out of the balls and deposited on the surface as H_3BO_3 or HBO_2. Since the balls contained well over the specified quantity of boron and since there was a definite decrease in the weight of the B_2O_3 in the ball, it can further be concluded that none of the B_4C was affected.

4.2. Reserve Shutdown Balls From CRD SN-037

The crystals on balls taken from the CRD SN-037 hopper were found to be a mixture of HBO_2 and H_3BO_3 crystals. The crystals taken from the face of the shield plug were H_3BO_3. The samples of reserve shutdown balls from the hopper were random samples taken from different levels within the hopper. This allowed a determination of the axial distribution of crystalline deposits within the hopper and aided in understanding the mechanism which took place. The distribution of crystals on the ball samples removed from the hopper is given in Table 2.

The analysis of this hopper indicated that 6.75% of the balls exhibited more than 10 crystals on their surfaces. The quantitative analysis of such balls showed that the boron present as HBO_2 or H_3BO_3 on the surface of those balls averages 0.1% of the ball weight. The analysis also indicated very clearly that crystallization was concentrated at the top and bottom areas of the hopper. Additionally, the clean balls from the middle of the hopper showed boron remaining as B_2O_3 inside the balls to be 0.15% of the ball weight which is equal to the measured as-manufactured level.

4.3. Laboratory Experiments

Several laboratory experiments were undertaken to simulate the reactor conditions. Boric acid crystals were grown on balls by dripping liquid saturated boric acid over a stack of balls

TABLE 2
AXIAL DISTRIBUTION OF CRYSTALLIZATION WITHIN
RESERVE SHUTDOWN HOPPER OF CRD SN-037

Axial Level	Balls With >10 Crystals		Balls With Any Crystals		Sample Size, No. of Balls
	%	No.	%	No.	
1	23	7	43	13	30
2	6	1	11	2	18
3	0	0	0	0	21
4	0	0	4	1	24
5	0	0	0	0	25
6	0	0	4	1	27
7	0	0	0	0	30
8	0	0	3	1	29
9	0	0	0	0	27
10	23	6	27	7	26
11	22	4	44	8	18
All	6.75	18	12.4	33	275

followed by heating in a furnace. At ∿150°F H_3BO_3 crystals were formed; at ∿325°F HBO_2 crystals were formed. Subsequently, crystals of HBO_2 were grown between adjacent balls. However, the crystals were so weak the bond was broken with only the slightest movement of the specimen dish.

Another experiment was performed to simulate the hopper environment; its configuration is shown schematically in Fig. 6. In this experiment, distilled H_2O was vaporized at ∿250°F below a bed of reserve shutdown balls. The water saturated vapor in the closed system condensed on the top surface (∿150° to 200°F) and dripped back onto the balls. After ∿30 hours the balls were examined and found to have white crystalline deposits spattered on the surfaces (Fig. 7). The system was dried out by venting to the atmosphere. The white crystals on the ball surfaces remained and were identified to be H_3BO_3.

This simulation experiment demonstrates that boron can be leached by water vapor from the B_2O_3 that is present in the balls after manufacture.

4.4. Postulated Mechanism

The chemistry of the reactions of interest are defined to help understand the mechanism which took place in the reserve shutdown hoppers between mid-January and March 10, 1975:

(1) $3H_2O + B_2O_3 \rightarrow 2H_3BO_3$ 300°F > T > 100°F*

(2) $H_2O + B_2O_3 \rightarrow 2HBO_2$ 600°F > T > 300°F

(3) $H_3BO_3 \rightarrow HBO_2 + H_2O$ 600°F > T > 300°F

*All temperatures approximate.

The qualitative identification of HBO_2 and H_3BO_3 crystals on the balls and the laboratory experiments completed in San Diego support the following mechanism:

(1) Water saturated helium (~100,000 ppm H_2O) was introduced into the reserve shutdown hopper through the vent to reactor coolant. As the temperature increased, the water vapor leached B_2O_3 out of the reserve shutdown balls in the form of boric acid as shown in reaction (1).

(2) In the saturated environment some liquid H_3BO_3 settled with liquid H_2O in the bottom of the hopper, while the vapor permeated the entire hopper condensing on the top and cooler side surfaces of the hopper and crystallizing as H_3BO_3.

(3) H_3BO_3 crystals were formed on the upper layers of the reserve shutdown balls either from H_3BO_3 liquid condensation dripping from the top inner surface of the hopper or from condensation of boric acid directly onto the balls from the surrounding vapor.

(4) As the temperature of the balls increased during the B-series startup test to 250°F to 350°F, HBO_2 was formed on the reserve shutdown balls per reactions (2) and (3).

The vapor pressure of both forms of boric acid is very high in this temperature range and as temperature increases, equilibrium would shift toward HBO_2 formation which is consistent with the observations of these experiments.

(5) As the reactor coolant was dried out, the crystals remained on the reserve shutdown balls and the hopper wall.

5. Present Status of Reserve Shutdown System

The characterization of the crystallization in laboratory tests and analyses at San Diego, which is confirmed by the inspections performed at the reactor site, allows us to understand the present status of the 37 reserve shutdown systems of the FSV reactor.

It has become obvious from the inspections and tests that some of the B_2O_3 was leached out of the RSS balls by moisture which was present in the hopper between January and March of this year. It has also been determined that the B_4C has not been affected by the moisture.

Based on the various analyses performed, it is estimated that approximately 2 to 5 g of boron may be present as crystals on balls and that another 2 to 5 g may be deposited as crystals in the hopper. The upper limit of boron present as boric acid crystals in any one hopper is estimated to be 15 g boron. The total amount of B_2O_3 estimated to be in a single hopper is 60 g. Therefore, it can be concluded that approximately 25% of the B_2O_3 has been leached out of the balls and crystallized into boric acid crystals onto the surfaces of the hopper and the balls.

PART II - PERFORMANCE OF RESERVE SHUTDOWN SYSTEM

Part I of this report presented the results of an extensive investigation to determine the present status of the reserve shutdown system. In summary, it was concluded that because of moisture ingress into the reserve shutdown hopper, B_2O_3 was partially leached out of the boronated graphite balls and that the resultant boric acid condensed onto cool surfaces of the hopper forming boric acid crystals. Part II of this report will show that this unusual event will have no effect on the performance of the reserve shutdown system.

Since the reserve shutdown system is a passive system during normal operation, it must be determined that this unusual event will have no effect on negative reactivity worth or the mechanical performance of the system over its entire lifetime. The system must be ready to perform its function at any time during its lifetime.

1. <u>Negative Reactivity Worth of Reserve Shutdown System</u>

The majority of boron in the balls (>99%) is present as B_4C, and the quantitative analysis confirmed that this material was not affected; very little of the boron has been removed from the balls. The reactivity worth of the reserve shutdown material was calculated on the basis of the B_4C present and thus the reactivity worth has not changed. The minimum boron loading in any hopper is 5400 g and with this heavy boron loading, the reserve shutdown column is neutronically black to thermal neutrons. It would require greater than a 10% loss of boron to change the reactivity worth of the reserve shutdown system by 1% of its present worth. Therefore, from the reactivity control consideration, no change has occurred.

2. Long-Term Behavior of Reserve Shutdown Material

Under normal operating conditions, the reserve shutdown material, boronated graphite balls, is stored in hoppers located in the control rod drive assembly. The balls remain stored, ready for use at any time, during the reactor's 30 year lifetime. The long-term behavior of this material, even with crystallization of B_2O_3, will not affect the system's capability of performing its design function if and when needed.

Over the long term, while the material is in the hopper, 99.85% is in the form of graphite and boron carbide (B_4C) and 0.15% is in the form of boron oxide or boric acid crystals. In a water saturated environment, the B_4C remains unaffected below 600°F (Ref. 1). The material in the form of B_2O_3 will remain in its present form at the expected operating conditions. If moisture levels were to exceed 1000 ppm, additional B_2O_3 might be converted to boric acid crystals. The existing boric acid crystals will be affected by temperatures above 300°F, changing from H_3BO_3 to HBO_2 as water is driven off by the temperature increase.

Crystal formation or changes in chemical form of these crystals will not result in bonding of balls. Crystals grown in the laboratory tests between balls had such negligible bond strength that all balls broke apart when the experiment tray was moved. Further examination at PSC indicates that no bridging was caused by any crystal formation on the balls. The quantity of B_2O_3 (0.15 wt % average) is insufficient to produce massive crystal growth between the balls.

In summary, only the B_2O_3 or the boric acid crystals can be affected over the long term if temperature and moisture levels allow further changes in these materials. The total quantity of

these materials was limited during manufacture through specifications to a small amount. It is therefore concluded that the behavior of the reserve shutdown material over the long term will be entirely satisfactory.

3. <u>Effect of Crystal Growth on Reserve Shutdown System Components</u>

The reserve shutdown system consists of a carbon steel tank 6 in. in diameter and 8 ft long, a carbon steel plug at the top end, and a graphite rupture disk at the bottom end. Two separate 3/8-in. lines are connected to 90° elbows at the bottom of the tank above the rupture disk. One line is used for pressurization of the tank during reserve shutdown initiation. The other is a vent to the PCRV environment. Both lines are approximately 15 ft long extending up to the primary closure of the CRD. Of concern is whether the boric acid either in the form of crystals or as a liquid would have an adverse effect on these steel components.

Between mid-January and March 10, 1975 the boric acid vapor could have been condensed on the steel to a soluble solution of boric acid and water or deposition of these crystals could have been by a dry transport process. Boric acid crystals in the absence of water are not corrosive to steel. In the presence of water it is mildly corrosive and could cause negligible surface pitting.

Tests conducted at GA San Diego confirmed the pitting mode of attack. They also revealed that wet crystals or a solution of boric acid reacted with the steel as evidenced by the bright orange color produced in the corrodant. At FSV only white crystals were removed from a hopper, which suggests that the deposition of crystals was by a dry transport process. Examination of the hopper did not disclose any discoloration of the

steel; hence, corrosion of the steel apparently did not occur. However, even if some pitting had occurred, the walls of these hoppers are approximately 0.280 in. thick. The ASME Pressure Vessel Code only requires a 0.090-in. wall for the pressure rating of the container; therefore, it is concluded that, even if the surfaces were wetted with boric acid solution, the resultant corrosion would have a negligible effect on the serviceability of the hopper.

PART III - PERFORMANCE OF REACTOR FOLLOWING RESERVE SHUTDOWN SYSTEM DUMP

Part II of this report concluded that the reserve shutdown systems would function as designed if and when needed. Part III assumes a dump of the reserve shutdown hoppers into the reactor core. The consequences of having boric acid crystals as part of the reserve shutdown material have been evaluated since these crystals either as loose material or bonded to the reserve shutdown balls will also be dumped into the core. The behavior of the material in the core, its removal from the core, and the effects of residual material on reactor components and core reactivity have all been evaluated.

1. Behavior of Reserve Shutdown Material in Core

Normally, following a dump of the reserve shutdown system, the balls are vacuumed out and returned to the hoppers. The vacuum system is designed to remove all these balls from a reserve shutdown channel. In the present situation, as described in Part I, it has been estimated that 12% of the reserve shutdown balls have boric acid crystals on their surfaces. The behavior of these crystals while in the reactor core is considered in this section.

1.1. Experimental Tests

A series of tests have been performed at GA to determine the behavior of the RSS balls in the reactor core at different temperatures. The experimental procedure and a detail report on the tests is presented in Ref. 2. A summary of the important

test results is as follows:

(1) All balls were visibly clean after the anneals showing that the surface crystals had vaporized.

(2) The balls with crystalline deposits released twice as much boron as the clean balls, indicating some degree of crystalization within the ball.*

(3) The boron released was not temperature dependent.

(4) Most of the boron which was released from the balls was then absorbed by the graphite crucible used in the test. The total average boron transporting was 5.5% of the leachable boron.

(5) There are two reactions involved when HBO_2 is heated in a dry atmosphere:

(a) Vaporization: HBO_2 (crystals) → HBO_2 (gas)

(b) Dehydration: $2HBO_2$ (crystals or gas) → B_2O_3 (solid) + H_2O

Reaction (a) accounts for the removal of the crystals off the surface of the balls, whereas reaction (b) is occurring both within the ball and within the surrounding graphite.

1.2. Predicted Behavior in Reactor

Following a reserve shutdown system dump, the boronated graphite balls drop through a guide tube which is inserted into the top layer of the core. The balls continue down a blind graphite channel machined in the control rod fuel and reflector

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*The quantity of subsurface crystals has been estimated from these tests to be ~0.15 mg B, which would have no effect on the mechanical integrity of the RSS balls.

elements eventually filling it. As determined earlier, approximately 12% of the balls have a crystalline deposit of H_3BO_3 or HBO_2 on their surfaces. The remaining balls have some subsurface HBO_2 or H_3BO_3. The temperature in the core will eventually convert all of the H_3BO_3 to HBO_2. All of the surface HBO_2 will volatilize and diffuse into the graphite, while some of the subsurface HBO_2 will volatilize and the remainder will be converted back to B_2O_3 and remain in the ball. The rate of this process is temperature dependent and at lower temperatures more of the HBO_2 will remain on the surface or in the subsurface of the ball.

Any loose boric acid crystals in the hopper will also be dumped into the core and the same reactions would occur to this material. In the event that the temperature is not sufficiently high and these crystals are not completely vacuumed out, then they eventually volatilize as the reactor temperature is increased and diffuse into the graphite.

The consequences of this boron transport from the RSS balls to the core graphite is discussed in Sections 2 and 3.

1.3. Steam Distillation of Boron

In the reactor, any B_2O_3 left in the graphite core after dropping the balls would remain fixed until a steam ingress event occurred (in which case the reactor would be shut down). At temperatures below about 400°C, the water vapor would convert the B_2O_3 to HBO_2 and slowly volatilize the boron from the core. The boron would tend to condense as HBO_2 or H_3BO_3 on cooler surfaces in the circuit.

The rate of such steam volatization has been measured in some early experiments at GA. In those tests borated graphite specimens having known B_2O_3 content were exposed to flowing H_2-H_2O mixtures at three temperatures. The results of the tests are given in Table 3.

TABLE 3

STEAM DISTILLATION OF BORON[a] FROM BORATED GRAPHITE SPECIMENS[b]

Temperature		H_2O Pressure (atm)	Boron Distilled (% Leachable B/hr)[c]
°C	°F		
260	500	0.03	1.5
		0.30	2.5
178	350	0.03	0.4
121	250	0.03	0.1

(a) Volatile boron species is either HBO_2 or H_3BO_3.

(b) Specimens were chunks, 25 to 50 g each containing 100 to 1000 ppm leachable boron (B_2O_3).

(c) The rates given are initial rates. The boron release was found to be dependent on $\sqrt{time}$ which suggests a diffusion controlled process. Thus, at longer times the fractional release rates would decrease.

The results in Table 3 show that the process of steam distillation of volatile boron from graphite is relatively slow. Depending on the temperature, geometry, and steam concentration, times of 100 to 1000 hr would be required for 100% removal of leachable boron from graphite materials.

These long times indicate that no sudden boron loss could occur during a steam leak. In addition HBO_2 cannot be distilled at temperatures above about 400°C.

2. Reactivity Behavior of Core Following Reserve Shutdown Material Removal

The experimental results reported in Section 1 and discussed in detail in Ref. 2* show that not more than 5.5% of the boron leached from the balls will be absorbed by the core graphite when the reserve shutdown system is activated into a hot core. If we conservatively assume the entire 60 g of presently leachable boron per hopper is available at the time the reserve shutdown system is activated, then the total boron that can be distributed into the core is 122 g. This represents a maximum core reactivity decrease of only 0.003 Δk which can be compensated by a control rod group adjustment of approximately 1 ft of control rod group 2B, and which will disappear by neutron capture during subsequent reactor operation. Under some subsequent high moisture condition in the primary loop, it is possible that this boron could be leached from the core; however, this would be a slow process and the effect on reactor operation could again be compensated by a small control rod adjustment.

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*The data given in Table 2 (Column 11) of Ref. 2 show that less than 1% of the leachable boron was transported through the relatively thin wall test crucibles. In the reactor, because of the relatively large mass of graphite in the core, transport of HBO_2 out of the core should be negligible.

The presence of some boric oxide crystals remaining in the reserve shutdown holes of the core after removal of the balls by vacuuming will represent a reactivity change considerably less than the 0.003 Δk discussed above and will have a negligible effect on core reactivity. Volatization of these crystals and rapid burnup (by neutron capture) of this residual boron would occur upon subsequent power operation and any effect on reactor operation will be negligible. In the FSAR, Section 3.8.3.3, it is stated that the effect on reactor operation of even a few of the balls remaining in the core would be small.

3. Effect on Reactor Materials

The experimental results of Section 1 (Part III) indicated that most of the boron volatilized from the balls would be absorbed by the core graphite. If, however, some of the HBO_2 would diffuse through the graphite, it could enter the helium coolant flow. In the hot coolant it would eventually dehydrate to B_2O_3 and be deposited on other reactor component surfaces.

The quantity of B_2O_3 which could enter the coolant would be extremely small. However, assuming that it was present, the B_2O_3 could be reconverted to boric acid following a moisture ingress. Therefore, the effect of boric acid on various reactor materials has been considered.

3.1. Effect on Nonmetallics

There will be no detrimental effects on the alumina/silica containing ceramics (such as Masrock, Coors alumina, silica fiber, Kaowool fiber) as a result of interaction with boric acid at reactor shutdown temperatures. At reactor operating

temperatures, boric acid crystals will lose water of hydration to form boric oxide, B_2O_3, which does not interact with the ceramics in either the solid or molten state.

In regard to the latter, it should be noted that alumina is not particularly soluble in molten boric oxide, and there is no satisfactory evidence for the existence of aluminum borate. Therefore, there will be no problems in the event boric oxide comes in contact with alumina at the operating temperature of FSV.

As with alumina, silica will not react with boric oxide since silica is insoluble or only slightly soluble in fused boric oxide (Ref. 3). In a short experiment, molten boric oxide was heated in a vitreous-silica vessel without any visible effects on the silica. Phase diagrams (Ref. 4) do not show any compounds for the presence of small quantities of boric oxide in silica at upwards of 1400°C (2550°F). However, when silica is in the presence of large quantities of other oxides such as barium or calcium, lower melting compounds are formed. This is not a problem in FSV since the concentration of these oxides is very low compared to the amount of silica.

3.2. Effect on Reactor Metals

Boric acid solutions are weakly acidic with a pH of about 6; as such it is only slightly corrosive to the common metals used for reactor components. Boric acid does not react with silver which is used in the circulator seals. Boric acid crystals in the presence of water and oxygen may produce a mild form of pitting corrosion in carbon steel. In the absence of oxygen, e.g., in a helium environment, corrosion by either form of boric

acid is negligible; in the absence of both water and oxygen, (i.e., dry boric acid crystals), corrosion does not occur. It may, therefore, be concluded that the presence of boric acid in the reserve shutdown system and the small amount that might enter the primary coolant system will not cause degradation of the system's metallic components.

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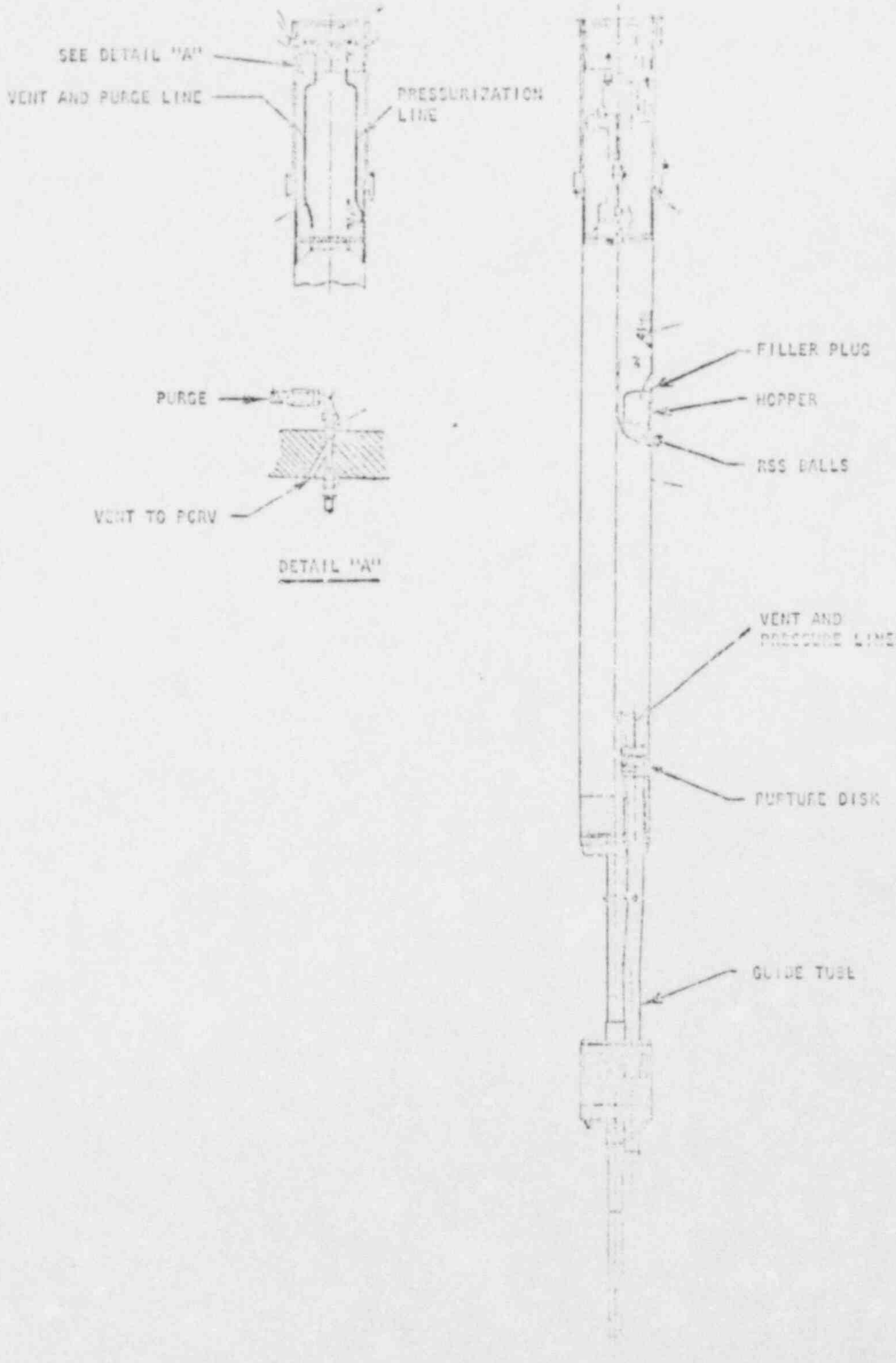


Fig. 11. Reserve shutdown system

Fig. 2. Filler plug from control rod drive SN-037 with crystal deposit layer on cone-shaped end

Fig. 3. [illegible]

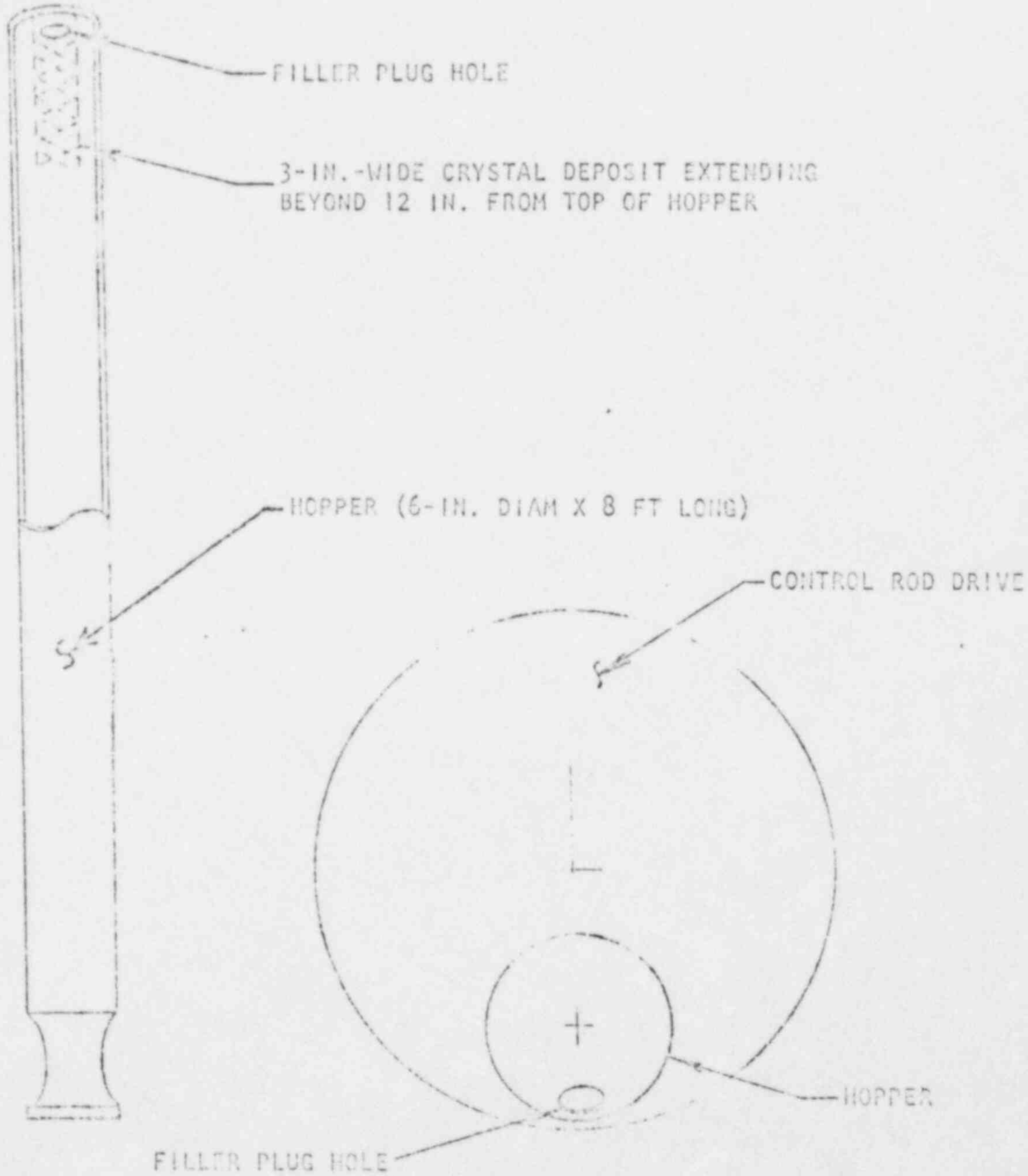


Fig. 4. Location of crystals on inside wall of CRD 3A-037 hopper

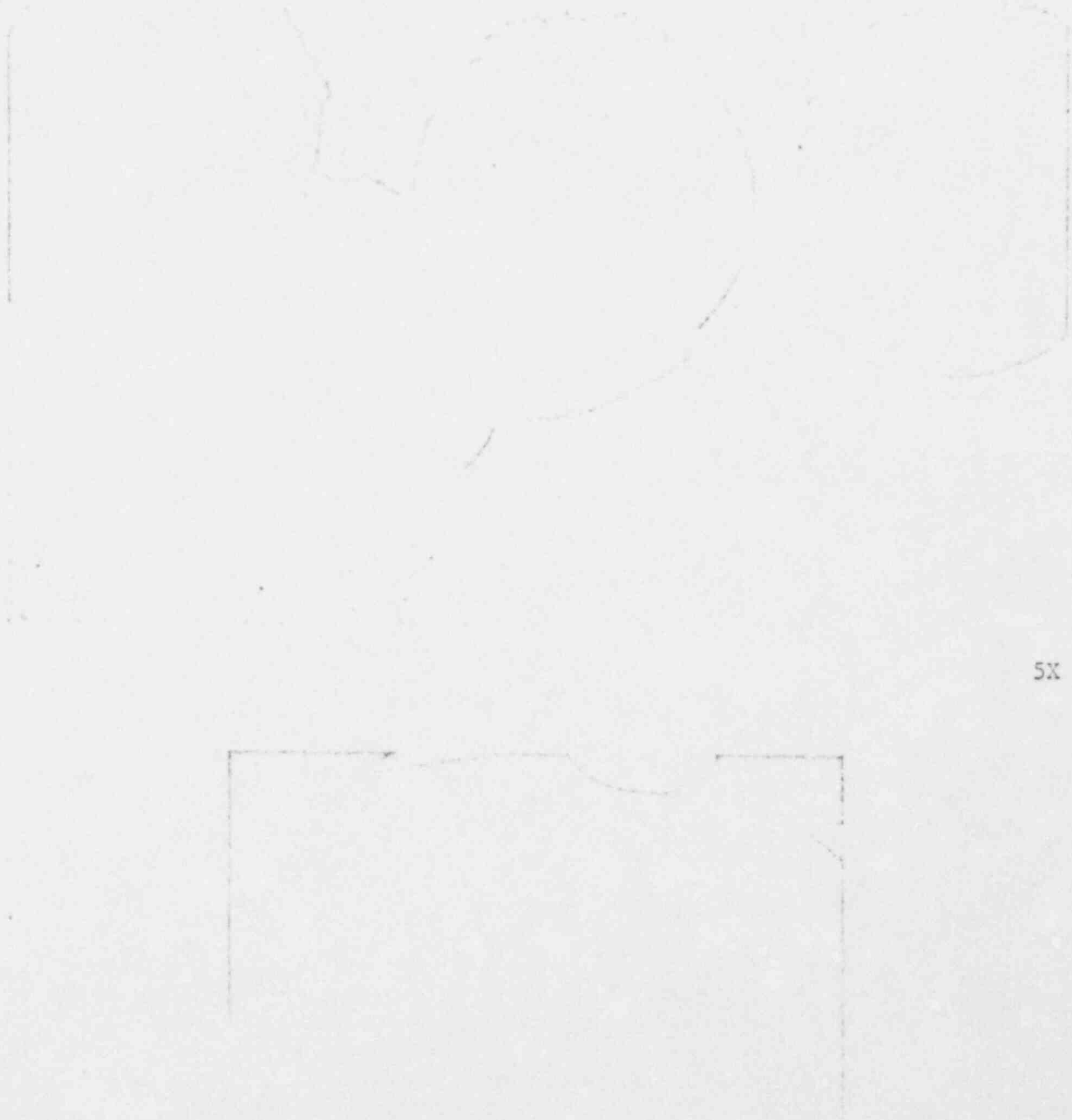


Fig. 5. Reserve shutdown system balls from control [illegible] after dump test (HT-[illegible])

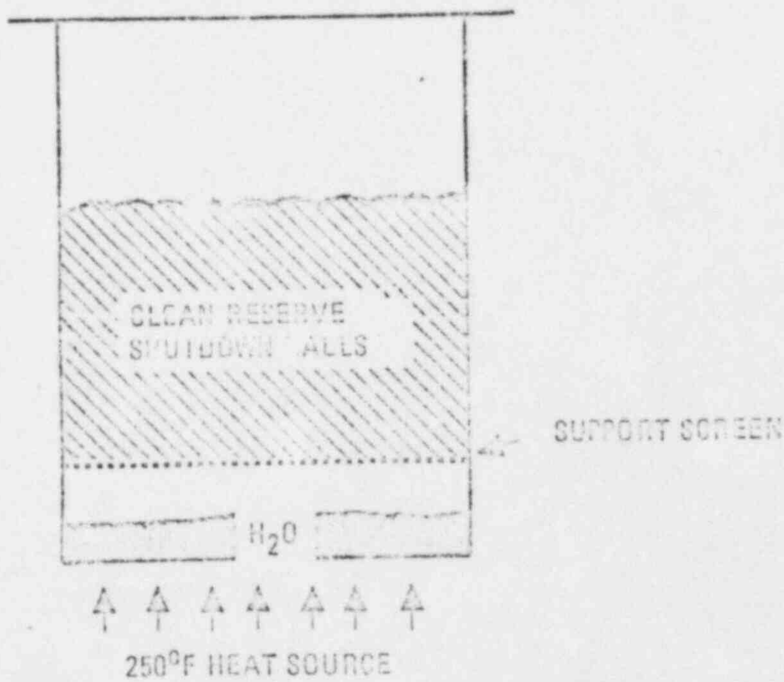


Fig. 6. Schematic of hopper simulation experiment

4.5X

Fig. 7. Boric acid crystals on reserve shutdown balls. Left: ball taken from SN-028 hopper showing worst case of crystal formation on ball; right: crystals of H_3BO_3 grown on clean ball in laboratory at San Diego.

APPENDIX 1

REPORT ON INDEPENDENT LABORATORY ANALYSIS OF WHITE CRYSTALS

ANALYSIS REPORT

REPORT TO STEARNS ROGER, INC. (Dick Nirschl) LAB. NO. I-2665

P.O. Box 404, Platteville, Colo. 80651 DATE RCVD. 9/23/75

BILL TO STEARNS ROGER, INC. COMPLETED 9/25/75

Box 5888, Denver, Colorado 80217 SPECIAL SERVICE

Req. No. Z 6152 REV R 13076

ANALYSIS REQUESTED:

#1 - White crystals
#2 - White crystals on surface of B_4C balls

CERTIFICATE OF ANALYSIS:

PERCENT:	#1	#2
Boric Acid	94.6	91.2

APPENDIX 2

REPORT ON TEST RT-351

GA RT 351

POT REF

REE Ref

DATE 9-24-75

ISSUED

REQUEST FOR TEST

REQUESTER R. D. PHELPS SYSTEM 12

PURPOSE/OBJECTIVE

To demonstrate that a typical RSD hopper will discharge its RSD material when pressurized with an 800psid source. See attached procedure...

DESCRIPTION OF TEST

1) Position CRD in HSF over special RSD mat'l receiver.
2) Pressurize hopper with 800 psig He source.
3) Observe response.
4) Replace rupture disc, RSD material & CCT.

DATA REQUIRED

Observe physical response
Record initial He bubble pressure.

ANTICIPATED RESULTS/ACCEPTANCE CRITERIA

Rupture disc must rupture; mat'l must be fully released into receiver.

REF SOP OR ABNORMAL CONDITIONS

Test to be done in HSF.

SCHEDULE REQUIREMENTS ASAP

SAR & APPROVAL SHEET ATTACHED

WORK ASSIGNED BY R.D. Phelps TO PSC Maint. / Results

DATE COMPLETED BY

Please advise FSV Engineering Office when work is completed

TEST RT-351

Procedure

1. Position catch barrel assembly in HSF, west side.

2. Install CRD unit (S/N to be established later) in the west port of the HSF.

3. Connect RSD discharge pipe to barrel by positioning work stand platform in the HSF.

4 Connect tubing, valves, and He bottle to the RSD fitting on top of CRD unit (He bottle pressure = 800 ± 100 psig).

5. Close manual actuator valve.

6. Open He bottle valve.

7. Verify test setup and clear all personnel from HSF.

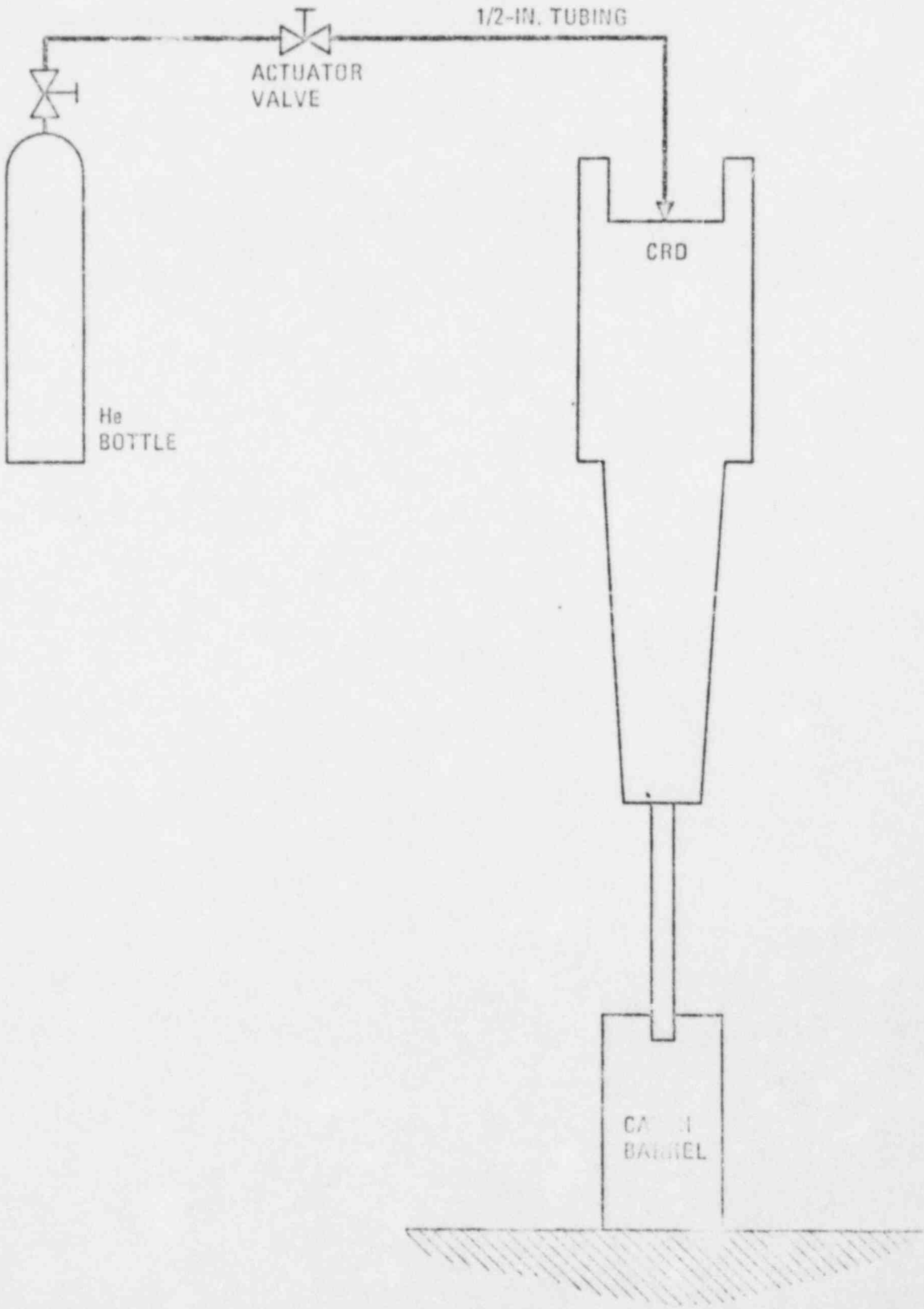
8. Quickly open manual actuator valve.

9. Observe/inspect results of test.

10. Replace rupture disc and RSD balls.

11. CCT RSD unit of CRD.

TEST SETUP FOR RT-351



INSPECTION REPORT FROM RT-351 (RSD HOPPER AND BALLS FROM CRD S/N 027 - REGION 22) R. J. NIRSCHL (OCTOBER 4, 1975)

Purpose: To demonstrate that the presence of boric acid crystals (HBO_2 and H_3BO_3) inside the RSD hopper did not affect its operability.

Description: Details of the test description are given in RT-351. The CRD selected for the test contained boron graphite balls with 40 wt % boron and a 9/16-in. O.D. Three CRDs used in the outer core regions had been inspected visually prior to the test. All three showed about equal crystalline formation on the top and side surface of the hopper, indicating that it made no difference which CRD was used in the test. An outer CRD assembly was selected because of the higher weight percent boron content and larger diameter balls. The larger diameter balls would have a greater tendency to bond and bridge.

Inspection Results: The test was performed with no unusual occurrence. Following the test, both the hopper and balls were inspected visually. The top and bottom of the hopper were inspected with a flashlight and mirror.

RSD hopper

1. No traces of crystals were found on the bottom end. Apparently any crystals there had been blown into the test receptacle.

2. The only crystalline formation present in the hopper was on the top and side surface near the top. The crystalline deposit on the filler plug and the top surface was essentially the same as it was prior to the test. No reasonable estimate could be made on the quantity of crystals.

3. The rupture disc assembly was as expected with no unusual marks.

RSD boron graphite balls

1. A significant number of the balls still had crystals on the surface. In fact, a rough estimate of the percentages showed them to be about the same as those obtained from previous hopper inspections. The crystals all adhered to the ball surface.

2. No evidence of loose crystals could be found but there was so much loose dust (black graphite) that it would have been hard to detect the crystals.

3. A random sample was taken for later analysis and the barrel was bagged up for any future quantitative analysis.