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REPORT TITLE

HNPf STEAM-SODIUM REACTION TESTS.

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		ABSTRACT <p>Two series of development tests (Phase I and II) were performed using steam-nitrogen gas mixtures to react various quantities of sodium.</p> <p>In Phase I, sodium thicknesses of 0.5 and 2 inches, and fixed steam volume percentages of 10 to 80 percent, were used. The tests demonstrated the feasibility of the steam-nitrogen gas mixture method for reacting sodium and served as the basis for establishing a preliminary procedure for reacting the residual sodium in the HNPF Reactor Vessel.</p> <p>Phase II was performed to evaluate the preliminary procedure established for Phase I tests. A sodium thickness of 0.5 inches and steam volume percentages varying from 20 percent initially to 80 percent at the end were used in a simulated HNPF system. No unusual conditions were encountered and the sodium was completely reacted when the test was terminated after 59.5 hours of operation.</p>

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HNPf STEAM-SODIUM REACTION TESTS**I. INTRODUCTION**

The most common method for cleaning materials and components containing sodium is the use of superheated or saturated steam followed by water rinse. With this method the steam reacts with sodium to form sodium hydroxide and hydrogen gas. For normal applications the water is then used to wash away the hydroxide solution. The initial use of steam results in a less violent reaction than water and tends to minimize possible physical damage. AI has used this method extensively in small test loops for sodium and NaK cleaning and in the component and fuel cleaning cells of the HNPf and SRE.(1)(2) This method has also been used for sodium and NaK system and component cleaning at other installations.(3)(4)(5) Where large volumes of residual sodium are encountered, AI has modified the procedure to reduce the reaction rate by introducing moistured inert gas as the initial cleanup step. The moisture content is slowly increased as the reaction proceeds. This method was used successfully for cleaning HNPf cold traps and has been used or studied by others as a less violent method for cleaning.(5)(6)(7)

Due to this extensive experience with steam-sodium reactions, the suitability of gaseous mixtures for reaching inaccessible areas, the residue (sodium hydroxide) being relatively noncorrosive with stainless steel, and the steam and nitrogen being readily available at the reactor site, the use of steam-nitrogen gas mixtures is the method presently proposed for reacting the residual sodium in the HNPf Reactor Vessel.(8)(9) Thus, a test program was performed with a simulated reactor system to evaluate this method for use at the HNPf.

II. TEST PROGRAM

The overall objectives of the steam-sodium reaction test program were:

1. To determine the requirements and effects of using steam-nitrogen gas mixtures to react the residual sodium in the HNPf Reactor Vessel.
2. To demonstrate that the use of steam-nitrogen gas mixtures is a safe and effective method for reacting the residual sodium.

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To satisfy these overall objectives, the test program was divided into two separate phases (Phase I and Phase II) - each with its own specific objectives as described below:

A. Phase I

Phase I was a series of tests in which a fixed volumetric ratio of steam and nitrogen was used throughout the duration of each test. The objectives of this series were:

1. To determine any gross problems which might be encountered during the steam-sodium reaction operation.
2. To determine, if possible, a volumetric ratio of steam and nitrogen which could be used during the majority of the HNPF steam-sodium reaction operation to maintain a controlled and effective reaction rate.
3. To determine the effect of varying the sodium thickness.

B. Phase II

Based on the information obtained from Phase I, a preliminary procedure was devised for reacting the residual sodium in the HNPF Reactor Vessel.⁽¹⁰⁾ Phase II testing was performed to evaluate and modify, if necessary, this procedure in order to allow a final procedure to be established for use at HNPF.

III. SUMMARY

A. Phase I

A series of eight tests were performed during Phase I with sodium sample thicknesses of 0.5 and 2 inches and steam volume percents varying from 10 to 80. For each test, a constant steam to nitrogen volume percent was maintained throughout the duration of the run. The results of these tests are summarized in Table I.

The test results indicated that with steam volume percentages of 50% or less the sodium reaction rate was relatively constant as determined by sodium temperature profiles. However, in the case of one 2-inch thick sodium sample (Test #3), sodium temperatures spiked from 400°F to between 500 and 550°F during the period of 1-1/2 to 2-1/2 hours after initiation of steam flow; and, after 4.5 hours of operation a 1200°F temperature

TABLE I
SUMMARY OF PHASE I TEST RESULTS

Test #	Sodium		Flow Rate		Mass Flow Rate of Water (lbs/min)	% Steam by Vol. (approx)	Steam/N ₂ Inlet Temp. (°F)	Reaction Vessel Gas		Average Steady State Na Temp (°F)	Duration of Test (hrs)	Lbs of H ₂ O Passed thru Reaction Vessel (approx)	% Na Reacted (approx)	% H ₂ O Reacted with Na (approx)
	wt (lbs)	Approx. Thick. (in.)	N ₂ (cfm)	Steam (cfm)				Temp (°F)	Press					
1	0.31	0.5	1	1	0.0373	50	260	250	1 atm	(1)	5	11	100 ⁽²⁾	(2)
2	0.31	0.5	3	0.3	0.0112	10	260	250	1 atm	240	4.75	3	67	5
3	1.27	2	1	1	0.0373	50	260	250	1 atm	400	4.5 ⁽³⁾	10	50	5
4	1.27	2	1	1	0.0373	50	260	250	2"H ₂ O	370	5	11	33	3
5	0.31	0.5	1	1.5	0.056	60	260	300	1 atm	(4)	1	3.4	100 ⁽⁵⁾	(5)
6	0.31	0.5	1.2	0.3	0.0112	20	280	300	1 atm	250	5	3.4	50	3.5
7	0.31	0.5	0.4	1.6	0.06	80	280	300	1 atm	(6)	1.5	5.4	100 ⁽⁵⁾	(5)
8	1.27	2	1.5	1.5	0.056	50	300	350	2"H ₂ O	340	16	53.8	70	1.3

- NOTES:
- (1) Not recorded in Test #1.
 - (2) Sodium was 100% reacted and thick liquid, assumed to be sodium hydroxide, was in sample container.
 - (3) Test terminated when smoke was noted streaming from the exhaust. This was possibly sodium monoxide since sodium temperature spiked to 1200°F and sodium can react with sodium hydroxide to form the monoxide above 700°F. No reaction vessel pressure or temperature surges were noted.
 - (4) Sodium temperature spiked to greater than 1500°F shortly after introducing steam, oscillated above 700°F for about 15 minutes and then decreased to about 320°F before steam was terminated. Smoke was noted streaming from the exhaust during the 15-minute period (possibly sodium monoxide - see note (3)). No reaction vessel pressure or temperature surges were noted.
 - (5) Sodium was 100% reacted and solid material assumed to be sodium hydroxide was in sample container.
 - (6) Sodium temperature spiked to greater than 1500°F shortly after introducing steam, oscillated above 1300°F for about 10 minutes, dropped to about 550°F in next 10 minutes and then decreased to about 300°F before steam was terminated. Smoke was noted streaming from the exhaust during the 10-minute period above 1300°F (possibly sodium monoxide - see note (3)). No reaction vessel pressure or temperature surges were noted.

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spike was noted and smokelike material (possibly sodium monoxide) was observed emitting from the exhaust line. The steam flow was terminated and a second temperature spike to 600°F was noted. The sodium temperature then slowly dropped to about 300°F. No change in the reaction vessel temperature or pressure was observed during the run. Thus, except for the smokelike material, no effect on the overall system was noted due to the sodium temperature spikes.

For the runs in which steam volume percentages of greater than 50% were used rather violent steam-sodium reaction rates were indicated by sodium temperature measurements. Sodium temperatures oscillated between 700°F and 1500°F during the majority of the reaction period. Also, smokelike material (possibly sodium monoxide) was observed emitting from the exhaust line. However, as in the case of the runs with lower steam volume percentages, no other effects on the overall system were noted.

B. Phase II

For the Phase II test, a 0.5 inch thick sodium sample with about a 50 sq. in. surface area (0.8 lbs sodium) was placed in the reaction vessel. Based on the ratio of the HNPF Reactor Vessel volume to the test reaction vessel volume this was equivalent to about 700 lbs of sodium, 0.5 inch thick in the bottom of the HNPF vessel. Steam-nitrogen gas flows were then introduced into the reaction vessel. Steam volume percent was varied from 20 to 80 percent during the operating period as follows:

1. Initially 20 percent by volume steam was introduced for 2 hours (equivalent to 100 cfm nitrogen, 25 cfm steam at HNPF).
2. Steam volume percent was then increased to 50 percent over a 30-minute period and held constant for 6 hours (equivalent to 60 cfm nitrogen, 60 cfm steam at HNPF).
3. Total steam-nitrogen gas flow was then increased over a one-hour period but with the total steam volume percent remaining at 50 percent (equivalent to 150 cfm nitrogen, 150 cfm steam at HNPF). This total flow was held constant for 32.5 hours. Sufficient moisture had passed through the reaction vessel at this point to completely react the sodium even if only 5 percent of the moisture was utilized.

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4. The steam volume percent was then increased in 30 minute steps to 60, 70, 75 and finally 80 percent (equivalent to 60 cfm nitrogen, 240 cfm steam at HNPF). After 15.5 hours at 80 percent steam, the test was terminated, since sodium container temperatures were continuously decreasing and little or no hydrogen was noted with the hydrogen detector.

Following a 3 hour nitrogen purge at about 350°F, the system was cooled to ambient temperature and visually inspected. The sodium was completely reacted and a thick liquid (assumed to be sodium hydroxide) remained in the sodium container. In addition, some solid reaction product material was floating on the surface of the thick liquid. This was possibly sodium oxide or sodium carbonate. In any case, it would not react with water. Three sodium samples located on the top baffle plate, each 3/4 inch in diameter and 1/4, 1/2 and 1 inch thick, respectively, were also completely reacted.

The reaction vessel gas temperature remained relatively constant in the 300-350°F range and the reaction vessel pressure remained at 1 to 2 inches water throughout the operating period.

IV. CONCLUSIONS

Based on the results of the test program, it is concluded:

1. Steam-nitrogen gas mixtures are effective in reacting bulk quantities of sodium.
2. The use of a procedure similar to that used in Phase II will result in the successful and safe reaction of the residual sodium in the HNPF Reactor Vessel.
3. Sodium temperature and hydrogen evolution rate are satisfactory indications of reaction rate. Thus, the steam rate can be reduced or nitrogen rate increased to allow control of the reaction.
4. Even if excessive sodium temperatures are encountered, there should be little or no effect on the bulk gas temperature and pressure providing the system is continuously vented.
5. The combined use of sodium samples in the Reactor Vessel and hydrogen measurement of the exhaust gas (properly filtered and dried to remove any reaction products or moisture) will adequately indicate completion of the steam-sodium reaction.

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V. SYSTEM DESCRIPTION

A. Phase I

The system utilized for Phase I testing is shown schematically in Figure 1 and consisted of a reaction vessel (about 7.3 cu. ft.) complete with a grid plate, baffles, and a sodium container; steam and heated nitrogen supply lines; a mixing chamber for the steam-nitrogen combinations; and instrumentation for data procurement and control. A barrel heater was placed around the reaction vessel for temperature control. The sodium container was 5 inches in diameter and 2 to 4 inches high depending upon the depth of sodium sample. A separate heater was installed on the sodium container to insure melting of the sodium.

Figures 2 and 3 show the various components of the actual test system. Figure 4 shows the system ready for testing.

In operation, a predetermined quantity of sodium was placed in the sodium container and the system purged with nitrogen. When the oxygen concentration was below 1/2% in the reaction vessel, the system was preheated to about 350°F. Melting of the sodium was determined by thermocouples located in the sodium. The reaction vessel was then valved-off and the proper steam-nitrogen mixture was established through a bypass line located at the entrance to the reaction vessel. To perform the test, the steam-nitrogen mixture was introduced into the reaction vessel and the bypass line closed. Temperatures were continuously recorded during the test operation as shown in Figure 1.

B. Phase II

For Phase II testing some modifications were made to the initial test system to more closely simulate the conditions which could be encountered at HNPF. These modifications included (1) adding a moisture separator to the steam supply line to insure against moisture carryover, (2) replacing the existing steam flowmeter with a lower range flowmeter to allow lower steam flows to be used, (3) adding a seal pot on the exhaust line to maintain a slight positive pressure on the reaction vessel, (4) adding a water condenser and hydrogen detector on the exhaust line to aid in determining completion of the steam-sodium reaction, (5) using a larger sodium sample container (about 5-1/2 inches wide, 9-1/2 inches long and 1-1/2 inches high) to have a direct ratio of the HNPF Reactor Vessel bottom sodium surface area, (6) increasing the grid plate void area to have a closer simulation to the HNPF grid plate, and (7) adding instrumentation for better system control and data acquisition. The modified system is shown schematically in Figure 5. Figure 6 shows the modified grid plate. The remainder of the system was generally as shown in Figures 2, 3 and 4.

FIGURE 1
PHASE I TEST SYSTEM

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FIGURE 2
Test System Components

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FIGURE 3
Test System Components

FIGURE 5

PHASE II TEST SYSTEM

FIGURE 7
Sodium Sample Container

In operation, 0.8 lbs of sodium was placed in the sodium container, the sodium sample container (Figure 7) was placed on the upper baffle, and the system was purged with nitrogen. When the oxygen concentration was below 1/2 percent in the reaction vessel, the system was preheated to about 300°F. A separate heater on the sodium container was then energized. This heater was installed to insure melting of the sodium and to maintain the sodium (or reaction product) temperature at about 300°F throughout the operating period. Melting of the sodium was determined by four thermocouples located in the sodium. With the sodium at about 300°F, the nitrogen flow was adjusted to about 2,300 cc/min (equivalent to 100 cfm at HNPF) and steam flow was initiated (20 volume percent equivalent to 25 cfm at HNPF). The balance of the operation was as generally outlined in Section III B, Summary, and as described in detail in Appendix A. Temperatures and reaction vessel pressure were continuously recorded during the test operations as shown in Figure 5. In addition, hydrogen evolution was monitored with the conductivity cell.

VI. DISCUSSION

A. Phase I

The initial steam-sodium reaction tests were performed primarily to determine feasibility and problem areas which might be encountered with such a process if used on a large scale such as in the HNPF Reactor Vessel. Thus, readily available instrumentation and components were used. This resulted in using a steam flowmeter with a lower limit of about 0.3 cfm. Assuming the HNPF Reactor Vessel gas volume to be about 6500 cu. ft. and with a test reaction vessel volume of only 7.3 cu. ft. (volume ratio of 890:1), this was equivalent to a lower limit of about 267 cfm of steam in the HNPF system based on obtaining similar moisture concentrations over the sodium.

Since moisture concentration is a primary factor affecting rate of reaction, it was assumed that if no major problems were encountered in the test system, the steam-nitrogen gas method would be satisfactory for use at HNPF, particularly if lower steam rates were used at HNPF. This assumption was based on the postulated manner in which the steam-sodium reaction takes place with bulk quantities of sodium. It is postulated that as the steam-sodium reaction proceeds at a relatively slow rate, a surface layer of sodium hydroxide forms over the sodium. If this layer remains unbroken, water vapor must diffuse through the sodium hydroxide layer to react with the sodium. Thus, a concentration gradient exists with dilute sodium hydroxide at the surface and concentrated sodium hydroxide at the sodium interface.

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Even though sodium hydroxide is more dense than the liquid sodium, it had been previously observed⁽⁵⁾ that with little or no agitation the sodium hydroxide remains as a layer over the sodium. However, this layer can easily be broken and mix with the liquid sodium. If some fresh sodium mixed with the dilute sodium hydroxide, a fairly vigorous reaction would take place and possibly result in temperature and/or pressure excursions in the gas volume of the reaction vessel. Indications were during the course of testing that sodium-sodium hydroxide mixing was occurring as noted by sodium temperature spikes in some of the tests. However, no reaction vessel temperature or pressure rises were noted. Thus, it was concluded that sufficient information had been obtained to allow a preliminary procedure to be established for reacting the residual sodium at HNPF.

The results of the tests performed during Phase I are discussed in detail below.

1. Test #1

For Test #1, 0.31 lbs of sodium were placed in the sodium container resulting in about a 0.5 inch thick layer. The system was preheated to 350°F for sodium melting. The system temperature was then reduced to 250°F and nitrogen containing 50% by volume of steam was introduced into the reaction vessel (1 cfm nitrogen and 1 cfm steam for a total of 2 cfm flow rate). The system was operated for about 5 hours and all temperatures were maintained between 250 and 300°F. The reaction vessel pressure remained constant at 1 atm throughout the run. The system was then allowed to cool to about 80°F and visually inspected. All of the sodium had reacted and the sodium container was filled with a thick liquid assumed to be sodium hydroxide. No sodium temperatures were monitored during this test. Thus, it was not possible to determine if sodium temperature could be used to indicate completion of the sodium-steam reaction.

Based on 1 cfm of steam for a 5-hour period, about 11 lbs of water was passed through the reaction vessel or about 40 times that necessary to react the sodium. Since all of the sodium was reacted and the NaOH solution was still liquid at 80°F, it would appear that excess water diluted the NaOH to about 54 wt.% or less (80°F being the approximate freezing point of 54 wt.% NaOH). This would also indicate that the sodium temperature, or at least the temperature at which the NaOH formed, was about 310-320°F (the boiling point of 54 wt.% NaOH being in this range at 1 atm).

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2. Test #2

For Test #2, 0.31 lbs of sodium was again used (about 0.5 inch thick layer). In addition, several 4 to 5 gram samples of sodium were placed on the top of the grid plate and the baffles. The nitrogen and steam flow rates were about 3 cfm and 0.3 cfm, respectively, or about 10% steam by volume. Figure 8 shows the temperature vs. time relationship of a thermocouple located in the sodium at the bottom of the container. The steam/N₂ and the reaction vessel gas temperatures remained constant at 260 and 250°F, respectively. The test was terminated after 4.75 hours due to failure of the steam supply. As can be seen from Figure 8, the sodium temperature had dropped to 220°F at the time of steam supply failure. The reaction vessel pressure remained constant at 1 atm throughout the run. A visual inspection of the sodium after cool-down indicated only about two-thirds (0.2 lbs) of the sodium in the container had reacted and only a portion of the small samples was reacted. The reaction products were solid.

Based on 0.3 cfm steam rate for the operating period, about 3 lbs of water had been introduced into the reaction vessel. This is about 13 times the amount required to react all of the sodium. Since about 0.2 lbs of sodium reacted, only about 5% of the water reacted with the sodium.

3. Test #3

For Test #3, the sodium layer in the container was increased to 2 inches (1.27 lbs of sodium). A 50% by volume steam flow was used for the test (1 cfm steam, 1 cfm nitrogen). The steam-N₂ and reaction vessel gas temperatures were 260 and 250°F, respectively, throughout the run. Figure 9 shows the temperature vs. time relationship of the sodium during the test. As can be seen from the figure, sodium temperature spikes were noted in the period of about 1.5 to 2.5 hours after initiation of steam flow. After a total operating time of about 4.5 hours, the sodium temperature suddenly spiked to 1180°F from 340°F and what appeared to be smoke streamed from the exhaust line. The steam flow was immediately stopped and the nitrogen gas rate was increased to 3 cfm. Within about 3 or 4 minutes the smoke was no longer visible.

FIGURE B
SODIUM TEMPERATURE
TEST # 2

(0.5-INCH THICK LAYER, 0.3 CFM STEAM - 3 CFM H_2)

STEAM/ H_2 INLET - 260°F
REACTION VESSEL GAS - 250°F

TEMP. - °F

FIGURE 9
SODIUM TEMPERATURE
TEST #3

(2-INCH THICK LAYER, 1 CFM STEAM = 1 CFM N_2)

STEAM/ N_2 INLET = 260°F
REACTION VESSEL GAS = 250°F

STEAM FLOW
TERMINATED
(Na - 50% REACTED)

TEMP. - °F

1200
1100
1000
900
800
700
600
500
400
300
200
100

TIME - HOURS

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After cooling to about 80°F, the system was visually inspected. Approximately one-half of the sodium was reacted with the upper one-half portion being a solid layer of reaction products assumed to be sodium hydroxide. No visible evidence of a fire was noted in the reaction vessel.

On the basis of 1 cfm steam rate for 4.5 hours, about 10 lbs of water had been introduced into the reaction vessel or about 10 times that required to react all of the sodium. Since only about one-half of the sodium had reacted, again only about 5% of the water reacted with the sodium.

A review of the data to determine the cause of the smokelike material exhausting from the system resulted in two possible explanations. The first possibility is that some air inleakage was encountered. However, up until the smoke streamed from the exhaust, steam was visible exhausting from the reaction vessel and no leaks were located in the system. The second possibility is that the sodium hydroxide reacted with sodium to form sodium monoxide which would have the appearance of smoke. This reaction proceeds at a significant rate at temperatures above 700°F. In either case, of particular importance is the fact that the reaction was readily controlled by shutting off the steam flow.

4. Test #4

Since one possibility for the smokelike material being encountered in Test #3 was air inleakage, this test was repeated with a slight (2 inches of water) back pressure in the reaction vessel. Figure 10 shows the temperature vs. time relationship for the sodium. After an initial slow increase to about 500°F, the temperature decreased to about 380°F and no temperature spikes were noted during the test run (about 5 hours duration).

After cooling to 70°F, the sodium sample was visually inspected. Figure 11 shows the sodium container in the reaction vessel after the test. Figure 12 shows the container removed from the reaction vessel. After removal, the container was peeled away to expose the sodium cross-section (Figure 13). Figure 14 shows the chunks of reaction products separated from the sodium. Figure 13 gives further evidence that even though the sodium hydroxide is more dense it tends to remain above the sodium during the reaction as discussed above.

FIGURE 10

SODIUM TEMPERATURE
TEST #4

(2-INCH THICK LAYER, 1 GPM STEAM + 1 GPM N_2)

STEAM/ N_2 INLET = 260°F
REACTION VESSEL GAS = 250°F

TEMP - °F

TIME - HOURS

FIGURE 11
Sodium Container in Reaction Vessel after
Test #4
(2-inch Thick Na Sample - 50% Steam)

FIGURE 12
Sodium Container after Test #4

FIGURE 13

Sodium Sample after Test #4 with Sample
Container Peeled Away

FIGURE 14

Sodium Sample after Test #4 with Sodium
and Reaction Products Separated

The sodium remaining after removal of the reaction products was weighed to determine the extent of the reaction. About 0.42 lbs of sodium had reacted (about 1/3 of initial weight). For the 5-hour period about 11 lbs of water were passed through the reaction vessel or about 11 times that required to react all of the sodium. Thus, about 3% of the available water was reacted with the sodium.

5. Test #5

Test #5 was run to have a comparison with Tests #1 and #2 as to the effect of further increasing the mass flow rate of water through the reaction vessel. For this test a 0.5 inch layer of sodium (0.31 lbs) was used and steam and nitrogen flow rates were 1.5 and 1.0 cfm, respectively. While this was 60% by volume steam flow, the mass flow rate of water was 50% greater than in Test #1 (0.056 lbs/min vs. 0.0373 lbs/min for Test #1). Figure 15 shows the temperature vs. time relationship of the sodium. As can be seen from the figure, the temperature spiked to greater than 1500°F shortly after steam introduction and continued to oscillate between 900 and 1200°F for about 15 minutes before dropping. Smoke (possibly sodium monoxide) was noted to be streaming from the exhaust for the 15-minute period. The steam rate was continued for one hour to determine if any major problems would develop with the system. However, no pressure surges were noted and the reaction vessel gas temperature was only about 350°F.

After cool-down to 80°F, a visual inspection was made. The sodium had completely reacted and solid reaction products (assumed to be sodium hydroxide) remained in the sample container. Pieces of sodium (4 to 5 gram) which had been placed on the grid plate and baffles were also completely reacted.

Based on a steam flow rate of 1.5 cfm, about 1.1 lbs of water were passed through the reaction vessel in the first 20 minutes of operation (probably the period in which the majority or all of the sodium reacted) or about 4.5 times that required to react all the sodium. For the full one hour of operation about 3.4 lbs of water were introduced.

6. Test #6

Test #6 was run with a sodium sample size and mass flow rate of water comparable to Test #2. The nitrogen flow rate was reduced, however, to increase the steam volume percent to 20 (0.3 cfm steam - 1.2 cfm nitrogen). Figure 16 shows the temperature vs. time relationship of the sodium. The test was operated for 5 hours and the steam flow was terminated. At the time the steam flow was terminated, the sodium temperature spiked to over 1500°F and a small amount of white smoke was emitted from the exhaust. No pressure surges were noted and the reaction vessel gas temperature was only about 300°F.

A visual inspection after cool-down indicated that about 50 percent of the sodium had reacted in the 5-hour period. This compared to 67 percent over a 4.75 hour period in Test #2. Thus, except for the temperature spike noted at the end of Test #6, there appeared to be little difference between the results of Tests #2 and #6.

7. Test #7

Since the results of Test #5 (60 percent steam by volume, 0.31 lbs sodium) indicated a violent sodium reaction but no pressure or gas temperature surges, Test #7 was run with 80 percent steam by volume to see if excessive pressures or gas temperatures would be encountered. For this test a 0.5 inch layer of sodium (0.31 lbs) was used and steam and nitrogen flow rates were 1.6 and 0.4 cfm, respectively. Figure 17 shows the sodium temperature vs. time relationship. For all practical purposes, the test results were similar to Test #5. The sodium temperature spiked to greater than 1500°F shortly after introducing the steam, oscillated above 1300°F for about 10 minutes, dropped to about 550°F in the next 10 minutes, and then decreased to about 300°F before the steam was terminated after about 90 minutes of operation. Smoke was noted streaming from the exhaust during the 10 minute period above 1300°F. No reaction vessel pressure gas temperature surges were noted.

After cool-down to ambient, a visual inspection indicated that the sodium was 100 percent reacted and a crystalline sludge (assumed to be sodium hydroxide) remained in the sample container.

FIGURE 16
SODIUM TEMPERATURE
TEST # 6

(0.5-INCH THICK LAYER, 0.3 CFM STEAM - 1.2 CFM N₂)

STEAM/N₂ INLET = 280°F
REACTION VESSEL GAS = 300°F

TEMP - °F

TEMP - °F

TIME - MINUTES

8. Test #8

Test #8 was run with a 2-inch thick sodium sample (1.27 lbs) to determine the length of time required to completely react this amount with 50 volume per cent steam (1.5 cfm steam - 1.5 cfm nitrogen). This information was desirable in the event it was not possible to drain the HNPF Reactor Vessel to less than 2 inches. Due to manpower limitations, however, the test was only operated for 16 hours. During this period the sodium temperature remained relatively constant at about 350°F as shown in Figure 18. The reaction vessel pressure remained constant at 2-inches of water and the gas temperature was constant at 350°F.

Visual inspection of the system after cooling to ambient indicated that about 70 percent of the sodium had reacted and a thick liquid (assumed to be sodium hydroxide) was on top of the remaining sodium.

For the 16-hour period about 54 lbs of water had passed through the reaction vessel and only about 1.3 percent had reacted with the sodium. Comparing this data with the results of Tests #3 and 4 (in which 30 to 50 percent of the sodium was reacted with only about 1/5 the amount of water passing through the reaction vessel) indicated that the increase in reaction product liquid level considerably decreased the rate of reaction as would be expected.

No further attempts were made to react 2-inch thick layers of sodium since it was determined practical to drain the HNPF Reactor Vessel to less than 0.5 inches of sodium.

B. Phase II

A review of the Phase I test results indicated that with steam volume percentages of 50 percent or less the steam-sodium reaction was relatively controlled. In addition, it was determined that the maximum practical nitrogen rate obtainable at HNPF would be 150 cfm. Thus, a preliminary procedure for steaming the HNPF Reactor Vessel was devised in which the steam volume percent was varied from 20 to 80 percent; but, with the majority of the operation taking place at 150 cfm nitrogen and 150 cfm steam (50 volume percent steam).

For the Phase II testing, the volume ratio of 890:1 was used as the factor for scaling the test system flows to simulate the HNPF moisture concentration conditions. In addition it was assumed that a 0.5-inch thick layer of sodium would remain in the HNPF Reactor

FIGURE 18
SODIUM TEMPERATURE
TEST # 8

(2.0-INCH THICK LAYER, 1.5 CFM STEAM - 1.5 CFM N_2)

STEAM/ N_2 INLET = 300°F
REACTION VESSEL GAS = 350°F

TEMP. - °F

600

500

400

300

200

100

0

0

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

STEAM FLOW
TERMINATED
(Na - 70% REACTED)

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Vessel after draining. This thickness was simulated directly but the surface area was scaled by the 890:1 factor. Thus, for equivalent volumes of sodium, the time required to react the sodium in the test system would be similar to that required at HNPF.

The Phase II test was performed as described in detail in Appendix A. Figure 19 shows the change in the four sodium container temperatures vs. operating time and lists various events during this period. Several items of interest were noted as follows:

1. The widest temperature spread was less than 100°F, except for five temperature spikes to 1300°F indicated on the Near Side thermocouple only. The spikes may have been instrumentation errors but the recorder had been calibrated prior to the test and continued to give accurate readings for the remainder of the test.
2. After about 23 hours of total operation, the bottom thermocouples were generally decreasing and the sodium container heater power was increased to maintain the temperatures above 300°F.
3. After the power increase, the bottom temperatures tended to come together and the temperatures 1/4 inch above the bottom tended to come together, but at a slightly lower value. This would generally be the case if the heat were being supplied by the sodium container heaters rather than heat of reaction. This possibility is further indicated by the fact that all temperatures came together and dropped to 240°F when the sodium container heater failed after about 34 hours of operation.
4. All temperatures increased slightly when the steam volume percent was increased from 50 to 80 percent in the 42 to 44 hour operating time period. This could have indicated a moderate additional steam-sodium reaction; since, after 48 hours of total operation, all temperatures again started to decrease.

During the test, attempts were made to determine the completion of the steam-sodium reaction by monitoring the hydrogen evolution rate with a conductivity cell. This was considered unsuccessful at the time of the test due to difficulties encountered with the detector, i.e., inability to establish flow through the detector at times, what appeared to be very erratic readings at times, etc. In fact, at the time the test was terminated, the hydrogen detector still gave a slight indication. Thus, the decision to terminate the

FIGURE 19
SODIUM TEMPERATURES VS. TIME
HNPF SIMULATION TEST (PHASE II)
(0.5-INCH THICK N_2 LAYER)

NOTES

- ① - Initiated Steam Flow at 20% by Volume - Equivalent to 100 cfm N_2 , 25 cfm Steam at HNPF.
- ② - Increased steam to 50% by volume - equivalent to 60 cfm N_2 , 60 cfm steam at HNPF.
- ③ - Increased total N_2 /steam flow to equivalent 150 cfm N_2 , 150 cfm steam at HNPF (50% by volume steam).
- ④ - Three successive temperature spikes to 1300°F noted on Near Side T/C only.
- ⑤ - One temperature spike to 1300°F noted on Near Side T/C only.
- ⑥ - One temperature spike to 1300°F noted on Near Side T/C only.
- ⑦ - Increased sodium container heater power due to general decrease in sodium temperature.
- ⑧ - Sodium container heater failed.
- ⑨ - Increased steam to 60% by volume - equivalent to 130 cfm N_2 , 190 cfm steam at HNPF.
- ⑩ - Increased steam to 70% by volume - equivalent to 90 cfm N_2 , 210 cfm steam at HNPF.
- ⑪ - Increased steam to 75% by volume - equivalent to 80 cfm N_2 , 230 cfm steam at HNPF.
- ⑫ - Increased steam to 80% by volume - equivalent to 60 cfm N_2 , 240 cfm steam at HNPF.
- ⑬ - Steam flow terminated.

test was based on the decreasing sodium container temperatures rather than no hydrogen indication. However, after the hydrogen detector scale readings were plotted vs. operating time (Figure 20), they were compared with the sodium temperatures and events shown in Figure 19. From this comparison the following conclusions could be drawn (assuming the hydrogen detector readings were at least qualitative indications of hydrogen in the effluent gas):

1. At the time it was necessary to increase sodium container heater power to maintain temperatures (23 to 24 hours of operation) the hydrogen detector scale reading had dropped significantly from the 6-8 range to less than 1.0 (the nominal "zero" point). This could have meant that the majority of the steam-sodium reaction was complete. If this were the case, about 10 percent of the moisture which had passed through the reaction vessel had reacted with the sodium. This is not unreasonable based on previous tests.
2. When the steam volume percent was increased to 80 percent (42 to 44 hours of operation) the hydrogen detector scale readings again increased for about 4 hours. They then dropped to below about the 2 level until the test was terminated. Assuming the detector zero point had shifted to the 2 level, it is possible that some steam-sodium reaction took place during this 4-hour period which corresponded to the slight temperature increase period in Figure 19.

Visual inspection of the system at the end of testing indicated all of the sodium had reacted. Figure 21 shows the sodium container located in the reaction vessel after the vessel top was removed. Figure 22 shows the sodium container removed from the system. As can be seen from the figures some white solid material was floating on the surface of the liquid reaction products (assumed to be primarily sodium hydroxide). The solid material was probably sodium oxide or possibly sodium carbonate if some carbon dioxide was introduced with the steam. Most important was the fact that the solid material would not react with water.

From an overall system standpoint the complete operation was relatively uneventful and well controlled. No pressure oscillations and no major temperature changes were noted (except for the five sodium temperature spikes noted previously).

The successful completion of the Phase II operation indicated that the procedure used would be satisfactory for use at HNPF. Thus, a general procedure (Appendix B) was prepared to serve as a guide for establishing the operating procedure for reacting the residual sodium in the HNPF Reactor Vessel.

FIGURE 20

H₂ DETECTOR READING VS TIME
HNPF SIMULATION TEST (PHASE II)

FIGURE 21
Sodium Container in Reaction Vessel
after HNPF Simulation Test (Phase II)

FIGURE 22
Sodium Container after HNP
Simulation Test (Phase II)

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APPENDIX A

OPERATING PROCEDURE HNPF STEAM-SODIUM REACTION TEST

Run # _____
Start Date _____
End Date _____
Engineer _____

GENERAL

The objective of this test is to simulate the steam-nitrogen gas mixture process proposed for reaction of the residual sodium in the HNPF Reactor Vessel. Thus, the operating procedure listed below should be followed as closely as possible provided the steam-sodium reaction remains controlled and personnel safety is not jeopardized.

Based on previous test experience, the following general information should be used as a guide for determining if the reaction is controlled and for making process adjustments for unusual circumstances.

1. Sodium temperature, reaction vessel gas temperature and reaction vessel pressure are the main data points which indicate the status of the reaction. The reaction is assumed to be controlled if the reaction vessel gas temperature and pressure remain relatively constant even if random sodium temperature spikes are noted. However, if during steady-state operation sodium temperature spikes above 700°F are noted continuously for a period of 1 minute, reaction vessel pressure reaches 2 psig, or reaction vessel gas temperature reaches 400°F, the steam flow should be immediately reduced in an attempt to correct the situation. When normal conditions are again established for a period of 30 minutes, the steam flow should be slowly returned to the operating point.
2. During periods of changing steam-nitrogen gas mixture ratios it is possible that the above noted unusual temperature and pressure conditions may be encountered. If this is the case, the nitrogen flow should be increased or the steam flow reduced (depending upon which flow is being adjusted) to the previous set point where essentially a steady-state condition existed. When conditions are again normal for a minimum of 30 minutes, attempts should be made to continue with the procedure.

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3. If at any time the reaction appears to be uncontrollable by simply reducing steam flow, the steam flow should be completely stopped and supervision notified immediately. However, at no time should the nitrogen flow be stopped.

A laboratory notebook is to be used throughout the test to record any data and observations which will aid in establishing the final operating procedures for the actual HNPF system.

PROCEDURE

- _____ 1. Place 365 grams sodium in sodium container and 1.6 grams (1/4 inch thick), 3.2 grams (1/2 inch thick), and 6.4 grams (1 inch thick) sodium, respectively, in the 3 sodium sample containers.
- _____ 2. Purge system with N₂ until exhaust gas contains less than 1/2% O₂.
- _____ 3. Adjust N₂ gas flow to 2,300 cc/min (see Table A for equivalent HNPF flows).
- _____ 4. Energize N₂ heaters and adjust as necessary to obtain a N₂ gas temperature of 260-300°F.
- _____ 5. Energize reaction vessel heater and set TIC to control at 260°F.
- _____ 6. Energize steam line heaters and adjust as necessary to obtain a preheat temperature of 260°F.
- _____ 7. Energize sodium container heaters to melt sodium. (Melting point 208°F).
- _____ 8. After sodium is melted, continue heating sodium until the 400-600°F range is reached and hold for 2 hours. (N₂ temperature and flow to be maintained at 260°F and 2,300 cc/min, respectively).
- _____ 9. Turn off sodium container heaters and allow sodium to cool to 300°F.
- _____ 10. Take data point.
Time: _____

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- _____ 11. With sodium at 300°F, N₂ at 260°F and 2,300 cc/min, and reaction vessel at 260°F, slowly open steam control valve to establish a steam flow of 16 mm. (See Table A for equivalent HNPF flows).

NOTE: It may be necessary to readjust the N₂ heaters to insure that the steam-N₂ mixture entering the reaction vessel is 260-300°F.

- _____ 12. Operate for 2 hours, taking an initial data point and subsequently every 30 minutes.

- _____ 13. With N₂ at 2,300 cc/min and steam at 16 mm, change flow rates as follows:

Time: _____

- a. Holding N₂ flow constant at 2,300 cc/min:

_____ Slowly increase steam to 20 mm, wait 5 min.

_____ Slowly increase steam to 26 mm, wait 5 min.

_____ Slowly increase steam to 30 mm, wait 5 min.

_____ Slowly increase steam to 34 mm, wait 5 min.

- b. Holding steam flow constant at 34 mm:

_____ Slowly reduce N₂ to 1,900 cc/min, wait 5 min.

_____ Slowly reduce N₂ to 1,600 cc/min, wait 5 min.

_____ Slowly reduce N₂ to 1,400 cc/min.

Time: _____

- _____ 14. Operate at this point (1,400 cc/min N₂ and 34 mm steam) for 6 hours. Take initial data point and subsequently every 30 minutes.

NOTE: Adjust N₂ heaters to insure that the steam-N₂ mixture entering the reaction vessel is 260°F.

- _____ 15. With N₂ at 1,400 cc/min and steam at 34 mm, change flow rates as follows:

Time: _____

- a. Holding steam flow constant at 34 mm:

_____ Slowly increase N₂ flow to 3,500 cc/min and adjust N₂ heaters to maintain 260-300°F gas temperature.

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b. Holding N₂ flow constant at 3,500 cc/min:

- _____ Slowly increase steam flow to 36 mm, wait 5 min.
- _____ Slowly increase steam flow to 44 mm, wait 5 min.
- _____ Slowly increase steam flow to 48 mm, wait 5 min.
- _____ Slowly increase steam flow to 54 mm, wait 5 min.
- _____ Slowly increase steam flow to 58 mm, wait 5 min.
- _____ Slowly increase steam flow to 64 mm, wait 5 min.
- _____ Slowly increase steam flow to 68 mm, wait 5 min.
- _____ Slowly increase steam flow to 72 mm, wait 5 min.
- _____ Slowly increase steam flow to 76 mm, wait 5 min.
- _____ Slowly increase steam flow to 78 mm.

Time: _____

- _____ 16. Operate at this point (3,500 cc/min N₂ and 78 mm steam) for 40 hours. Take initial data point and subsequently every 30 minutes for the first 10 hours, and every hour for the remaining 30 hours.

NOTE: The hydrogen evolution is a key indication during this period. If the hydrogen detector indicates a significant drop or particularly if no hydrogen evolution is indicated for a period of 3 hours, notify supervision; since it may be possible to proceed to the next step prior to the end of the 40 hour period. Conversely, if the hydrogen detector still indicates a relatively high rate at the end of 40 hours, notify supervision prior to proceeding to the next step.
(Actually operated 32½ hours since sodium temperatures were dropping and little or no hydrogen evolution was noted on hydrogen detector).

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_____ 17. With N₂ at 3,500 cc/min and steam at 78 mm, change flow rates as follows:

(Adjust N₂ heaters as necessary to maintain 260°F temperature).

Time: _____

- _____ a. With N₂ at 3,500 cc/min, slowly increase steam flow to 88 mm, wait 5 min.
- _____ b. Slowly reduce N₂ flow to 3,000 cc/min, wait 5 min.
- _____ c. Slowly increase steam flow to 98 mm, wait 30 min.
(60% steam)
- _____ d. Slowly reduce N₂ flow to 2,500 cc/min, wait 5 min.
- _____ e. Slowly increase steam flow to 108 mm, wait 5 min.
- _____ f. Slowly reduce N₂ flow to 2,100 cc/min, wait 30 min.
(70% steam)
- _____ g. Slowly increase steam flow to 112 mm, wait 5 min.
- _____ h. Slowly reduce N₂ flow to 1,900 cc/min, wait 5 min.
- _____ i. Slowly increase steam flow to 116 mm, wait 30 min.
(75% steam)
- _____ j. Slowly reduce N₂ flow to 1,600 cc/min, wait 5 min.
- _____ k. Slowly increase steam flow to 122 mm, wait 5 min.
- _____ l. Slowly reduce N₂ flow to 1,400 cc/min.
(80% steam)

Time: _____

_____ 18. Operate at this point (1,400 cc/min N₂ and 122 mm steam) for a minimum of 6 hours and until hydrogen evolution has been essentially undetectable for the last 3 hours of operation. Take initial data point and subsequently every 30 minutes until operation is complete.

NOTE: Notify supervision prior to proceeding to next step.

Time: _____

_____ 19. Shut off steam flow and increase N₂ flow to 3,500 cc/min.

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- _____ 20. Increase N₂ gas temperature to 350°F and reset reaction vessel TIC to 350°F.
Time: _____
- _____ 21. Operate for 4 to 8 hours (to be determined at time of operation) to purge system and "dry" reaction products.
Time: _____ (Actually operated 3 hours)
- _____ 22. Shut off all heaters, reduce and maintain N₂ flow at 2,300 cc/min and allow system to cool to ambient temperature for visual inspection.

TABLE A

COMPARISON OF TEST FLOW RATES WITH PROPOSED HNPF FLOW RATES

Step in Operating Procedure	Nitrogen			Steam				
	Equivalent HNPF CFM (@ 260°F)	Test CFM (@ 70°F)	Test cc/min (@ 70°F)	Equivalent HNPF CFM (@ 260°F)	Test CFM (@ 260°F)	Test cc/min (@ 260°F)	Test Flow meter mm	Vol % Steam (@ 260°F)
11	100	0.083	2,300	25	0.028	800	16	20
13 ↓	100	0.083	2,300	30	0.034	1,000	20	23
	100	0.083	2,300	40	0.045	1,300	26	29
	100	0.083	2,300	50	0.056	1,600	30	33
	100	0.083	2,300	60	0.036	1,900	34	37
	80	0.066	1,900	60	0.067	1,900	34	43
	70	0.058	1,600	60	0.067	1,900	34	46
	60	0.049	1,400	60	0.067	1,900	34	50
15 ↓	150	0.124	3,500	60	0.067	1,900	34	29
	150	0.124	3,500	70	0.079	2,200	38	32
	150	0.124	3,500	80	0.090	2,500	44	35
	150	0.124	3,500	90	0.101	2,800	48	38
	150	0.124	3,500	100	0.112	3,100	54	40
	150	0.124	3,500	110	0.123	3,400	58	42
	150	0.124	3,500	120	0.135	3,700	64	45
	150	0.124	3,500	130	0.146	4,000	68	47
	150	0.124	3,500	140	0.157	4,300	72	48
	150	0.124	3,500	145	0.162	4,500	76	49
	150	0.124	3,500	150	0.168	4,700	78	50
	150	0.124	3,500	170	0.190	5,300	88	53
17 ↓	130	0.107	3,000	170	0.190	5,300	88	57
	130	0.107	3,000	190	0.213	6,000	98	60
	110	0.091	2,500	190	0.213	6,000	98	64
	110	0.091	2,500	210	0.235	6,600	108	66
	90	0.074	2,100	210	0.235	6,600	108	70
	90	0.074	2,100	220	0.246	6,900	112	71
	80	0.066	1,900	220	0.246	6,900	112	74
	80	0.066	1,900	230	0.257	7,200	116	75
	70	0.058	1,600	230	0.257	7,200	116	77
	70	0.058	1,600	240	0.268	7,500	122	78
	60	0.049	1,400	240	0.268	7,500	122	80

APPENDIX B

GENERAL GUIDE FOR PREPARING PROCEDURE FOR REACTING RESIDUAL SODIUM
IN THE HNPV REACTOR VESSELGENERAL

Based on previous test experience, the following general information should be used as a guide for determining if the steam-sodium reaction is controlled and for making process adjustments for unusual circumstances.

1. Reactor Vessel gas temperature and pressure and the hydrogen evolution rate are the main data points which indicate the status of the reaction. The reaction is assumed to be controlled if the Reactor Vessel gas temperature and pressure remain relatively constant. However, if during steady-state operation Reactor Vessel gas temperature reaches _____°F (to be determined), Reactor Vessel pressure reaches _____ psig (to be determined), or very high hydrogen rates are encountered, the steam flow should be immediately reduced in an attempt to correct the situation. When normal conditions are again established for a period of 30 minutes, the steam flow should be slowly returned to the operating point.
2. During periods of changing steam-nitrogen gas mixture ratios it is possible that the above noted unusual temperature, pressure, and hydrogen evolution conditions may be encountered. If this is the case, the nitrogen flow should be increased or the steam flow reduced (depending upon which flow is being adjusted) to the previous set point where essentially a steady-state condition existed. When conditions are again normal for a minimum of 30 minutes, attempts should be made to continue with the procedure.
3. If at any time the reaction appears to be uncontrollable by simply reducing steam flow, the steam flow should be completely stopped and supervision notified immediately. However, at no time should the nitrogen flow be stopped.
4. Additional limitations will probably be placed on the system such as Reactor Vessel wall temperature, radioactive gas discharge, high oxygen content of gas, etc. However, these will be determined at a later date in the detailed procedure.

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PROCEDURE (To be used as a guide only)

1. Place sodium samples (size and quantity to be determined) in Reactor Vessel and preheat system to between 260 and 300°F.
2. Flush system with nitrogen at 260-300°F and 100 cfm flow rate and insure exhaust gas is less than 1/2% oxygen. (Use nitrogen to preheat any pipe sections which do not have heaters)
3. With system and nitrogen temperatures at 260-300°F, slowly introduce steam at about 260°F temperature until a total flow of 125 cfm is established (100 cfm nitrogen - 25 cfm steam).

Note: Adjust nitrogen and steam line heaters to insure that the steam-nitrogen mixture entering the Reactor Vessel is 260-300°F.

4. Operate for about 2 hours, monitoring the system continuously for unusual events.
5. With nitrogen at 100 cfm and steam at 25 cfm, change flow rates as follows:
 - a. Holding nitrogen flow constant at 100 cfm, slowly increase steam flow over about a 20 minute period to 60 cfm.
 - b. Holding steam flow constant at 60 cfm, slowly decrease nitrogen flow over about a 10-minute period to 60 cfm.

Note: Adjust heaters as necessary to insure steam-nitrogen mixture entering the Reactor Vessel is 260-300°F.

6. Operate at this point (60 cfm nitrogen, 60 cfm steam) for about 6 hours.
7. With nitrogen at 60 cfm and steam at 60 cfm, change flow rates as follows:
 - a. Holding steam flow constant at 60 cfm, slowly increase nitrogen flow to 150 cfm and adjust heaters to maintain 260-300°F gas temperature.
 - b. Holding nitrogen flow constant at 150 cfm, slowly increase steam flow over about a one-hour period to 150 cfm.
8. Operate at this point (150 cfm nitrogen, 150 cfm steam) for about _____ hours. The actual operating time will depend upon an estimate of the amount of sodium remaining in the Reactor Vessel at the time of operation; and, for estimating purposes it should be assumed that

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8. 3 to 5 percent of the steam passing through the Reactor Vessel will react with the sodium. However, hydrogen evolution is a key indication during this period. If the hydrogen detector indicates a significant drop or particularly if no hydrogen evolution is indicated for a period of about 3 hours, some sodium samples should be removed from the Reactor Vessel, if possible, to determine the extent of the reaction. The results would determine the next step. Conversely, if a high hydrogen evolution rate is still indicated after operating for a pre-determined number of hours, it may be necessary to operate for an additional period at these flow rates before proceeding to the next step. In any case supervision should be notified prior to proceeding to the next step.
9. With nitrogen at 150 cfm and steam at 150 cfm, change flow rates as follows:
 - a. Slowly increase steam flow to 170 cfm, wait 5 to 10 minutes.
 - b. Slowly reduce nitrogen flow to 130 cfm, wait 5 to 10 minutes.
 - c. Slowly increase steam flow to 190 cfm.
10. Operate at this point (130 cfm nitrogen, 190 cfm steam - 60% by volume steam) for about 30 minutes.
11. With nitrogen at 130 cfm and steam at 190 cfm, change flows as follows:
 - a. Slowly reduce nitrogen flow to 110 cfm, wait 5 to 10 minutes.
 - b. Slowly increase steam flow to 210 cfm, wait 5 to 10 minutes.
 - c. Slowly reduce nitrogen flow to 90 cfm.
12. Operate at this point (90 cfm nitrogen, 210 cfm steam - 70% by volume steam) for about 30 minutes.
13. With nitrogen at 90 cfm and steam at 210 cfm, change flows as follows:
 - a. Slowly increase steam flow to 220 cfm, wait 5 to 10 minutes.
 - b. Slowly reduce nitrogen flow to 80 cfm, wait 5 to 10 minutes.
 - c. Slowly increase steam flow to 230 cfm.
14. Operate at this point (80 cfm nitrogen, 230 cfm steam - 75% by volume steam) for about 30 minutes.

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15. With nitrogen at 80 cfm and steam at 230 cfm, change flows as follows:
 - a. Slowly reduce nitrogen flow to 70 cfm, wait 5 to 10 minutes.
 - b. Slowly increase steam flow to 240 cfm, wait 5 to 10 minutes.
 - c. Slowly reduce nitrogen flow to 60 cfm.
16. Operate at this point (60 cfm nitrogen, 240 cfm steam - 80% by volume steam) for a minimum of 6 hours and until hydrogen evolution has been essentially undetectable for the last 3 hours of operation. If possible, additional sodium samples should be removed from the Reactor Vessel at this point to insure that the steam-sodium reaction is complete.

Note: Notify supervision prior to proceeding to next step.
17. Shut off steam flow and prepare for reaction product "drying" operation.
(To be established at a later date)