CORE SHUTDOWN REPORT: SUBCYCLE K-14.1 (U)

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CORE SHUTDOWN REPORT: SUBCYCLE K-14.1 (U)

BY:

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ISSUED: May 1992

Verification of Data
(To be completed prior to discharge of heat generating assemblies)

AUTHOR: ___________________________ DATE:_______

APPROVED BY: ________________________ DATE:_______
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Manager, Lead Engineer, Core Performance
INTRODUCTION

When a reactor is shut down, there is a set of rules that must be followed to guarantee that the reactor remains in a safe shutdown state. Some of these rules involve the cooling of heat generating assemblies before, during, and after charge-discharge (C&D) operations. These rules ensure that C&D operations will not endanger the integrity of the fuel or targets by allowing them to overheat. DPSOL 105-1225, Assembly Discharge and Forced Cooling Requirements, is the primary operations procedure that governs these cooling rules. The specific shutdown cooling limits that are input into this procedure are contained within this report.

The original Core Shutdown Report for K-14.1 [14] was issued in October 1991. That report assumed a 350 day irradiation at 1.754 MW/assembly. Since that time, the schedule for the K-14.1 subcycle has changed. Now, only the Startup/Power Ascension (SUPA) tests will be performed, after which the reactor will be shutdown for the cooling tower outage. Therefore, this revised Core Shutdown Report has been issued assuming an irradiation history representative of the SUPA tests. (Reference 20 provides an estimate of the irradiation intervals during the SUPA tests; the assumed irradiation history given in Data Sheet 1 includes a conservative margin from the reference 20 intervals).

This revision also introduces the air-cooling limit and the Infinite In-Air Wait Time (see In-Air Time section).

SUMMARY

Based upon the conservative assumptions (bounding the Startup/Power Ascension tests) stated in Data Sheet 1, the Minimum Wait Time Until Discharge is 5 hours for "one-for-one" discharge of heat generating assemblies in the K-14.1 subcycle. The Forced Cooling Limit for the heat generating assemblies is 14.3 hours, and the minimum time which must pass before other types of discharge may begin (i.e., full core discharge) is 14.3 hours. The Corrected In-Air Time graph is included as Figure 2. Using the bounding assumptions given in Data Sheet 1, the time which must pass after reactor shutdown before the in-air time becomes infinite is 1053.3 hours (43.9 days). Using the best-estimate irradiation history given in reference 20, the time which must pass after reactor shutdown before the in-air time becomes infinite is 15.4 days.

The limits in Table 1 and Figure 1 will be used to establish the shutdown process water forced cooling requirements for the K-14.1 subcycle, and to complete DPSOLs 105-1225 and 105-1255, as necessary. The limits in Tables 2 through 6 and Figure 2 will be used to govern the
discharge of heat generating assemblies for the K-14.1 subcycle, and to complete DPSOL 105-1225.

DISCUSSION

Because the Core Shutdown Report is issued prior to reactor startup, operating history data are not available during its preparation. Therefore, predictions of the operating data are used to prepare the shutdown cooling limits. The predicted data used in this report are presented in Data Sheet 1, and were used with the methods contained in references 3 thru 5 and 13 to calculate the shutdown cooling limits included herein. The operating data were predicted using engineering judgement and the data contained in references 6, 7, 16, and 20.

During operation, the appropriate reactor data will be collected in Data Sheet 2 by the Reactor Core Cognizant Engineer (from the Reactor Technology Section). After the cycle/subcycle is complete, the actual reactor operating data will be examined to verify the assumed data resulted in appropriate shutdown limits. At that point, the last two approval signatures will be entered in the Verification of Data section of the cover sheet, and the shutdown cooling limits contained herein may be used to govern C&D operations. If the assumptions turn out to be invalid, the Verification of Data section will not be completed, and a revision of this report will be issued. If the Verification of Data section is not completed, do not use these limits to govern C&D operations, or to complete DPSOL 105-1225. Note that Data Sheet 2 will not be included in copies of the Core Shutdown Report distributed prior to data verification, but will be included in the final distribution.

Note that the limits contained in this Core Shutdown Report govern C&D operations only for the sub-cycle indicated. In addition, note that the minimum required process water flow is provided by the motor and rotovalve settings specified in DPSOL 105-1231.

The Minimum Wait Time Until Discharge included in this report is intended to govern "one-for-one" C&D operations (discharge a single irradiated assembly, charge a new assembly to that position, discharge another irradiated assembly, etc). For this type of C&D operation, the minimum wait time until discharge may commence is equal to the most restrictive of the following three wait times: the Horizontal-in-Basin Wait Time, the 25°C Discharge Machine Wait Time, and the Zero In-Air Time.

There are other types of C&D operations that may be performed, however. For example, in the event of a full core discharge, the irradiated assemblies of the old charge are discharged without being immediately replaced by fresh assemblies. Before these types of C&D operations may begin, the forced cooling limit must expire for all heat generating assemblies in the reactor tank. Note that this requirement is in addition to the wait times listed above. The minimum wait time until discharge for these types of C&D operations is equal to the most restrictive of the following four limits: the Forced Cooling Limit, the Horizontal-in-Basin Wait Time, the 25°C Discharge Machine Wait Time, and the Zero In-Air Time.

Finally, note that the minimum time derived for any shutdown cooling wait time is five hours. This practice maintains an extra level of conservatism by avoiding the high (but quickly
declining) levels of decay heat produced by the assemblies in the first few hours after shutdown. Discharge operations are not restricted, however, since it takes longer than five hours to prepare the charge and discharge cranes.

Heat Generating Assemblies (HGAs)

Any fuel or target assembly that has undergone neutron irradiation during reactor operation and requires water for cooling is termed a heat generating assembly [1]. For K-14.1, prior to initial criticality, no assemblies in the core are HGAs. Once initial criticality has been achieved, all Mk22 assemblies in the core will be HGAs. No other assemblies (Mk60Bs, control rods, safety rods) in K-14.1 are considered HGAs.

Forced Cooling Limit and Moderator Heat-Up Graph

The Forced Cooling Limit [Technical Specifications 3.4.3.3, 3.4.3.4, and 3.4.3.5] (also known as the forced cooling time) is the length of time after shutdown which must pass before natural convective cooling will be adequate to prevent the assemblies from overheating. At this point, it is possible to discontinue forced circulation of the moderator. However, in the absence of forced circulation, the heat generated by the assemblies will collect in the moderator. This will cause the moderator temperature to increase until forced circulation is resumed.

This limit is used primarily to determine the setting of the Diagnosis of Multiple Alarms (DMA) selector switch. During reactor shutdown with heat generating assemblies in the reactor, the selector switch must be set to “Table 2: RX Shutdown - Forced Cooling Required, if the time after shutdown is less than the Forced Cooling Limit. If the time after shutdown is greater than or equal to the Forced Cooling Limit, the selector switch must be set to “Table 3: RX Shutdown - Forced Cooling Not Required.”

The switch position helps the DMA system in determining the correct response to certain incidents. In addition, by looking at the DMA selector switch during an anomalous event, the reactor operator is directed to the correct section of the appropriate Abnormal Condition Control procedure (DPSOL 105-MC-2), where the possible existence of a Reactor Incident can be confirmed.

The Forced Cooling Limit is also used to determine when forced circulation can be temporarily suspended to allow for tank inspections, DC motor inoperability, etc. During these temporary circulation suspensions, the moderator will increase in temperature. The Moderator Heat-Up Graph, a graph of moderator temperature increase rate during a flow suspension versus time after reactor shutdown, helps to ensure that this increase will not cause any bulk moderator temperature limit to be violated while forced circulation is inactive. This graph would be used as input for DPSOL 105-1255, Process Water Flow Shutdown - Reducing Below Normal Charge-Discharge Flow, the operations procedures that would be used to suspend forced circulation. However, while Technical Specifications allow the suspension of forced cooling when the Forced Cooling Limit has expired, current procedures do not allow this suspension if there are HGAs in the reactor. Nevertheless, analyses have been completed
[5] demonstrating the bulk moderator heat-up times, and procedural changes to allow the suspension of forced cooling with HGAs in the tank may be implemented in the future.

The Forced Cooling Limit is normally presented for three different bulk moderator temperature ranges. However, for Mk22 assemblies, the same limit applies for all ranges. Therefore, the following Forced Cooling Limit (Table 1) may be used for any bulk moderator temperature less than or equal to 47°C.

Table 1

<table>
<thead>
<tr>
<th>Bulk Moderator Temperature (°C)</th>
<th>The Forced Cooling Limit (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T ≤ 47</td>
<td>14.3</td>
</tr>
</tbody>
</table>

The Moderator Heat-Up Graph is presented as Figure 1

In-Air Time

When a heat generating assembly is removed from the reactor and exposed to ambient air, in the absence of any water cooling, its surface temperature begins to rise. The technical limit on this assembly surface temperature is 250°C [Technical Standard 4.01]. This is the Leidenfrost limit: at temperatures above this limit, vapor film formation could interfere with discharge machine cooling. The Uncorrected In-Air time is the amount of time an assembly may remain in air without any water cooling, before its surface temperature will exceed 200°C (maintaining a 50°C conservative margin from the Technical Standard limit).

After an assembly is removed from the tank during discharge, there is a short delay before the discharge machine can begin adequate cooling for that assembly. This delay is accounted for in the calculation of the Discharge Machine Wait Time by the discharge machine delay time. This delay time is the amount of time between initiation of discharge machine cooling and full cooling flow to the assembly it is carrying, including allowances for failure of the primary cooling system, subsequent failure of automatic activation of the secondary system, and time to manually activate the secondary system. The Uncorrected In-Air time must be greater than this delay time or the assembly's surface temperature will rise above its limit before the discharge machine can begin to cool it. The delay time is 48 seconds [11].

To more easily denote this, the Corrected In-Air Time is used (also known as the allowable in-air time without cooling). The Corrected In-Air Time is defined as the Uncorrected In-Air Time minus the delay time. Thus, discharge operations may occur only when the Corrected In-Air Time is greater than or equal to zero. The time after shutdown when this point is reached is called the Zero In-Air Time. The Zero In-Air Time is given in Table 2, and the Corrected In-Air Time is presented as a function of time after shutdown in Figure 2.
During the actual discharge operation, the discharge machine cooling timer must be set for the appropriate Corrected In-Air Time, to ensure that the discharge machine cooling system is activated before the Corrected In-Air time has elapsed.

Table 2

The Zero In-Air Time is 5 hours.

The Corrected In-Air Time is presented as a function of time after shutdown in Figure 2.

For conservatism, the above in-air times are calculated assuming adiabatic heat-up. In reality, an assembly suspended alone in air will dissipate some of its heat by free convection. The maximum amount of heat that an assembly can dissipate in this manner is called the air-cooling limit. At an ambient air temperature of 40°C and a maximum assembly temperature of 385°C, the air-cooling limit for a Mk22 assembly is 465 W [13]. If an assembly is generating less than or equal to 465 W of decay power in air, it will be able to dissipate as much heat as it produces. Such an assembly could be suspended in air indefinitely without overheating (an infinite in-air time).

The maximum assembly temperature limit used here (385°C) is the technical limit noted in reference 18 for maximum surface temperature (it is equivalent to two-thirds of the melting temperature of silicon-contaminated aluminum). Since assemblies with an infinite in-air time will not need cooling from the discharge machine, the more restrictive Leidenfrost temperature limit (250°C) is not required (the Leidenfrost limit protects against vapor film formation during discharge machine cooling).

Since decay power decreases with time after shutdown, after a sufficient amount of time has passed after shutdown, each of the heat generating assemblies will have an infinite in-air time. The time that must pass, after reactor shutdown, before the in-air time becomes infinite is called the Infinite In-Air Wait Time. For the K-14.1 subcycle, the infinite in-air wait time is 1053.3 hours (43.9 days).

This wait time is based upon the conservative assumptions (bounding the Startup/Power Ascension tests) stated in Data Sheet 1. Using the irradiation intervals given in reference 20, and the decay heat calculations given in reference 19, a best-estimate value of the infinite in-air wait time is calculated: 15.4 days. The infinite in-air wait time is very sensitive to the irradiation history assumed. For a more accurate (but still bounding) value, the infinite in-air wait time should be recalculated at the end of the K-14.1 subcycle, using the actual irradiation history of the subcycle. However, if the actual irradiation history (given in Data Sheet 2 of the verified version of the CSR) is bounded by the irradiation history assumed in Data Sheet 1, the infinite in-air wait time of 43.9 days is conservative.

Note that these results are only valid if the ambient air surrounding the assemblies is relatively unencumbered by flow obstacles or by large external heat sources; these results are not valid for Mk22 assemblies in a dry reactor tank.
Horizontal-in-Basin Wait Time (HIB)

The HIB is designed to ensure fuel integrity during a postulated event wherein a heat generating assembly is dropped horizontally on the floor of the disassembly basin. Since natural convection in the annular channels is the primary cooling method available to an assembly in the disassembly basin, and since this natural convection is gravity driven, a horizontal assembly cannot dissipate as much heat as can a vertical assembly. However, if the time after shutdown is greater than or equal to the HIB, an assembly dropped in the basin will not overheat or melt.

This wait time is calculated for two cases: for an assembly discharged with its universal sleeve housing (USH) and for an assembly discharged without its USH (Table 3).

Table 3

<table>
<thead>
<tr>
<th>The Horizontal-in-Basin Wait Time is 5 hours. [with USH]</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Horizontal-in-Basin Wait Time is 5 hours. [without USH]</td>
</tr>
</tbody>
</table>

Discharge Machine Wait Time (DMWT)

Assemblies are removed from the reactor and brought to the discharge and exit (D&E) canal by the discharge machine, which has several sources of cooling water available to prevent the assemblies from overheating during their transit. The DMWT is the amount of time which must pass after reactor shutdown before the discharge machine can adequately cool the heat generating assemblies. It is based, in part, on the temperature of its cooling water sources. The 25°C DMWT is the DMWT based on a cooling water source temperature of 25°C, and is used to determine the Minimum Wait Time Until Discharge (see next section). The 47°C DMWT is used to determine if special water source monitoring is required. Both are given in Table 4.

If the 47°C DMWT is greater than the HIB and the Zero In-Air Time, special monitoring of the discharge machine water sources must be performed. This monitoring is described in Appendix 1, Special Monitoring For Discharge Machine Cooling Water Sources, and in DPSOL 105-1225. The monitoring methodology requires that a Discharge Machine Water Source Temperature Limit graph be used as input into DPSOL 105-1225. However, because these wait times are equal (5 hours), special monitoring is not required and it is not necessary to include the graph in this report.

In the past, DPSOL 105-1225 used a limiting discharge machine wait time based on an upper bound inlet temperature of 40°C instead of the 47°C temperature assumed here. The 40°C DMWT was determined to be non-conservative however [4]; a procedure revision request was issued to change the bounding temperature to 47°C [10]. If this change has not yet been made to DPSOL 105-1225 at the time it is filled out for the discharge of HG + s, an urgent change...
request (UCR) must be processed so that the modifications described in reference 10 are made to DPSOL 105-1225.

Note that whenever the discharge machine is handling heat generating assemblies, two sources of light water (one primary and one secondary) and one source of heavy water (either primary or secondary) must be available. Each primary source (load rod) must be able to provide 8 gpm, and each secondary source (holddown sleeve) must be able to provide 13 gpm [Technical Specification 3.9.6]. In addition, to ensure conservatism in the shutdown cooling limits during discharge operations, the vertical tube storage (VTS) basin, plenum inlet, and pump suction temperatures must not be allowed to exceed 47° C [Technical Specification 3.9.6], in addition to any other existing limits.

### Table 4

<table>
<thead>
<tr>
<th>Description</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>The 25° C Discharge Machine Wait Time is 5 hours.</td>
<td></td>
</tr>
<tr>
<td>The 47° C Discharge Machine Wait Time is 5 hours.</td>
<td></td>
</tr>
</tbody>
</table>

Appendix 1 is not required.

**Minimum Wait Time Until Discharge**

The Minimum Wait Time Until Discharge [Technical Specification 3.9.1] is the earliest time after reactor shutdown that discharge operations may begin (it is also known as the *decay time before discharge may commence*). This wait time is determined by taking the most restrictive (i.e., the maximum) of three calculated wait times: the Horizontal-in-Basin Wait Time, the 25° C Discharge Machine Wait Time, and the Zero In-Air Time.

Note that this limit is only valid for "one-for-one" C&D operations. For other types of C&D (i.e., full core discharges), the forced cooling limit must expire in addition to the other constraints. The minimum wait time until discharge for these other types of C&D is calculated as the most restrictive of the following four limits given in this report: the Forced Cooling Limit, the Horizontal-in-Basin Wait Time, the 25° C Discharge Machine Wait Time, and the Zero In-Air Time. For the K-14.1 subcycle, this wait time is 14.3 hours (for assemblies discharged with or without their USHs).

The "one-for-one" Minimum Wait Time Until Discharge is calculated for two cases: for an assembly discharged with its universal sleeve housing (USH) and for an assembly discharged without its USH (Table 5).
Table 5

| The Minimum Wait Time Until Discharge is 5 hours. | [with USH] |
| The Minimum Wait Time Until Discharge is 5 hours. | [without USH] |

Technical Specification References

The Technical Specifications make several references to the Core Shutdown Report. Table 6 summarizes these references, listing the specific specification number, the limit referenced in that specification as it is referred to in this document, and the value of the limit referenced.

Table 6

<table>
<thead>
<tr>
<th>Specification Number</th>
<th>Title</th>
<th>Limit Name</th>
<th>Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4.3.3</td>
<td>Process Water System - Shutdown</td>
<td>Forced Cooling Limit</td>
<td>14.3 hours</td>
</tr>
<tr>
<td>3.4.3.4</td>
<td>Process Water System - No Forced Circulation Bulk Moderator Temperature Limit</td>
<td>Forced Cooling Limit</td>
<td>14.3 hours</td>
</tr>
<tr>
<td>3.4.3.5</td>
<td>Process Water System - Natural Circulation Reactor Level</td>
<td>Forced Cooling Limit</td>
<td>14.3 hours</td>
</tr>
<tr>
<td>3.9.1</td>
<td>Irradiated Assemblies</td>
<td>Minimum Wait Time Until Discharge</td>
<td>5 hours *</td>
</tr>
<tr>
<td>3.9.6</td>
<td>Discharge Machine Water Sources</td>
<td>Plenum Inlet Limit</td>
<td>47°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pump Suction Limit</td>
<td>47°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vertical Tube Storage Limit</td>
<td>47°C</td>
</tr>
</tbody>
</table>

*Valid for 'one-for-one' C&D only

Failed Assembly Limits

If there are any assemblies that have failed and require special discharge or storage, request a Failed Assembly Core Shutdown Report from the Reactor Technology Section.
REFERENCES


Moderator Heat Up With No Forced Cooling

Figure 1

Moderator Heat Up Rate

(°C/min)

0 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50

Time After Shutdown (hours)

0 50 100 150 200 250 300 350 400 450 500 550 600 650 700
Corrected In-Air Time

Figure 2

Figure 2 assumes an adiabatic heat-up.
APPENDIX 1: SPECIAL MONITORING FOR DISCHARGE MACHINE COOLING WATER SOURCES

Applicability

This appendix is used whenever the 47° C Discharge Machine Wait Time is greater than the Horizontal-in-Basin Wait Time and the Zero In-Air Time.

Instructions

While discharge operations are in progress, and until the 47° C Discharge Machine Wait Time has expired, follow these steps once every 30 minutes (see also: DPSOL 105-1225, Appendix A):

1. Calculate P, O, and V as follows:

   P = System 1 Plenum Inlet Temperature + 2° C
   O = System 3 Pump Suction Temperature + 2° C
   V = Vertical Tube Storage Temperature + 2° C

2. Determine the time since reactor shutdown.

3. Plot P, O, and V on Figure 3*.

4. The pre-drawn curve on Figure 3 is the maximum allowed temperature for any discharge machine water source, as a function of time after shutdown. Verify that P, V, and O all fall below the curve on Figure 3. If they do not, suspend discharge operations as described in DPSOL 105-1225.

*Note: Figure 3, the Discharge Machine Water Source Temperature Limit graph is only included with this report if special monitoring of discharge machine cooling water sources is necessary (such to be determined from the main body of this report).
DATA SHEET 1: PREDICTED VERSUS ACTUAL OPERATING DATA

Note: Fission Power = Computer Power * Fission to Computer Power Ratio
Fission Exposure = Computer Exposure * Fission to Computer Power Ratio

Assembly Type: Mk22

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Predicted Value</th>
<th>Actual Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Assembly Fission Power (MW)</td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td>Maximum Assembly Fission Exposure (MWD)</td>
<td>105.6</td>
<td></td>
</tr>
<tr>
<td>Maximum Assembly APM Value</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td>Irradiation Length (days)</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Plenum Inlet Temperature (°C)</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>
END

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