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# Reliability Assessment on Decay Heat Removal System of a Fast Reactor

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## ABSTRACT

The reliability of a decay heat removal system (DHRS) is influenced by the success criteria, the components which constitute the system, the support systems configuration, and the mission time. Assessments were performed to investigate quantitatively the effects of these items. Failure probabilities of DHRS under forced or natural circulation modes were calculated and then components and systems of large importance for each mode were identified.



## INTRODUCTION

Power Reactor and Nuclear Fuel Development Corporation (PNC) has been performing Probabilistic Safety Analysis (PSA) on a fast reactor plant for nearly ten years. Meanwhile a reliability database for fast reactor components was organized, a network of computer codes for PSA was developed and a technical base for PSA on a fast reactor was established.

PSA is effective even in a conceptual design stage to pursue a rationally well balanced design by identifying weak points in design and by comparing it with alternative designs. In this study a typical loop type LMFBR of 600MW class was chosen as a model plant and a reliability analysis was performed on DHRS. Effects of success criteria, system configuration, and others were analyzed and discussions were made on rational methods to improve the reliability which include the effect of decay heat removal by natural circulation. When we discuss reliability in this paper, failure probability of DHRS per demand is considered, and the effect of initiating events which bring about the demands are not considered.

### 1. System Model

The system model analyzed is, as shown in Figure 1, the Intermediate Reactor Auxiliary Cooling System (IRACS) type that branches out of the Intermediate Heat Transport System (IHTS). The decay heat is transferred from the Primary Heat Transport System (PHTS) to the IHTS through the IHX, and released to the atmosphere via the Air Cooler in the IRACS. The water-steam system that serves as the heat sink under power operation is not considered as part of the DHRS in the assessment. The frontline system of each DHRS loop consists of the components shown in Table 1. Among the components shown in Table 1, PHTS pony motor, IHTS pony motor, air cooler blower, stop valves at the inlet and outlet of Steam Generator (SG) are necessary only in the Forced Circulation (FC), and other components are needed also in the Natural Circulation (NC). The stop valves need to be closed to isolate the water-steam system from the DHRS in the FC mode. The support systems of the DHRS considered include, as shown in Table 2, Vital AC Power Supply, Emergency Power Supply, and Component Cooling System (CCS). In the NC mode only Vital AC Power Supply is needed to control the valves, the dampers, and the vanes. In the FC mode Emergency Power Supply and CCS are needed for the active components such as pumps and blowers. The interdependency among the support system is shown in Table 3 and Figure 2. CCS is supported by Component Cooling Water System (CCWS), and CCWS by Cooing Seawater Service System (CSSS).

### 2. Failure Probability of the DHRS per loop

The unavailability and the unreliability of the system are calculated with a data base which was developed using CREDO. CREDO (Centralized REliability Data Organization) is a reliability database for fast reactor components which has been developed under cooperation of US DOE and PNC. Unavailability of a component is defined as the probability that a component fails to respond as required upon demand. Unreliability of a component represents the probability that a component fails during a certain time duration termed the mission time.

The failure probability of the DHRS FC and NC per loop when the mission time is set 168 hours is shown in Table 4. The failure probability of one loop in NC is approximately one sixth of that in the FC. The unavailability and the unreliability of the accessories of the components such as cables and breakers are also included. The unavailability includes the effect of the maintenance outage. The effect of the recovery action by the plant personnel is not included. These are both conservative assumptions. Periodic tests are assumed to be performed once a month, but the the test outages are not considered because of the test override function. Fault trees for the support systems were constructed based on the design of the prototype fast reactor plant because the detailed design of the model plant was not available.

Figure 3 shows the importance of the frontline system components and the support systems. In the FC mode the importance of the unreliability of the CCS and the pump are large. This indicates that the importances of active component and its support system are large. The failure probability of NC is much smaller than that of the FC because the active components such as pumps and blowers and their support systems are not necessary, but the importance of the unavailability of the frontline system (e.g. Damper fails to open) is relatively large. In order to improve the reliability of the DHRS, it is necessary to strengthen the test on those important components and keep the unavailability low. The test override function would be very effective to avoid the test outages.

The components which constitute the DHRS differ slightly with the type of the DHRS, but the important components and support systems (e.g. pumps, dampers, and CCS) are always necessary and the effect by the difference of the DHRS type is relatively smaller than that caused by the success criteria and the system configuration mentioned below.

## 3. Failure Probability of the DHRS

The reliability of the DHRS varies with the success criteria, i.e. whether the FC is needed or the NC is enough, how many loops are necessary in each mode, how many hours the DHRS needs to operate. It is assumed that the plant being analyzed has three loop IHTS and each loop has a DHRS, and each DHRS has independent support systems. The success criteria is set as the following: One loop FC until one hour after reactor shutdown and one loop NC until 168 hours after that. The result is shown by the broken curve-1 in Figure 4. The increment of the failure probability between 1 hour and 168 hour is smaller than that at 0 hour. This means that the effect of the success criteria just after shutdown is the largest. The failure probability of the DHRS when the success criteria is relaxed as much as possible i.e. only one loop NC is enough throughout the mission time, is shown by the broken curve-2 in Figure 4. The failure probability is approximately one 16th at time 0 and one fourth at 168 hours of the curve-1. The points 5 and 6 in the figure correspond to the failure probability of the DHRS when the success criteria is 3-loop and 2-loop NC respectively. From the view point of the reliability, it is desirable to have a design which does not require FC of DHRS as success criteria.

## 4. The Effect of Additional DHRS Loop

It was indicated in Section 3 that the unreliability keeps increasing with time even if the success criteria is only one loop operation (300%). If the initiating event is a coolant leakage type, the mission time of DHRS can be longer. The failure probability of DHRS when the mission time is one month is also shown in Figure 4 with curves-1 and -2. Therefore in this section, an assessment was made on the effect of an additional DHRS loop. A Direct Reactor Auxiliary Cooling System (DRACS) with smaller heat removal capability was considered. "Smaller heat removal capability" means that the DRACS alone does not have enough capability right after the reactor shutdown, but it does have when the decay heat decreased some hours after reactor shutdown. It was assumed that the DRACS also has support systems which are independent from the other DHRS support systems. Also assumed is that the decay heat can be removed only by the DRACS 24 hours after reactor shutdown. The results are shown with the solid curves-3 and -4 in Figure 4. The curve-3 stands for the case that one loop IRACS FC is necessary for one hour after reactor shutdown, and the curve-4 one loop IRACS NC. The increase of unreliability between 24 hours and 720 hours is approximately one fourth of those of curves -1 and -2. It was proved that the added DRACS effectively limits the increase of unreliability.

## 5. The effect of the number of support systems

An assessment was made on the effect of the additional DHRS frontline system in the former section, and each frontline system was assumed to have independent support systems there. Here in this section, the effect of support system number is analyzed. The results are shown in Figure 5. The success criteria is assumed one loop FC or NC throughout the 168 hour mission time.

When the success criteria is one loop FC, contribution of support system is dominant. The failure probability of DHRS does not decrease drastically even if the number of frontline system is increased. For example, f(4,2) (see note) is not much smaller than f(3,2). On the other hand, f(3,3) is approximately one fifth of f(3,2). When the number of support systems is smaller than the number of frontline systems, the failure probability is dominated by the support system. Therefore the effect of adding only the frontline system loop is small.

When the success criteria is one loop NC, the contribution of frontline system unavailability is relatively larger than in the case of FC. Thus strengthening the frontline system also effectively decrease the failure probability. For example, f(4,2) and f(3,3) are both 40% smaller than f(3,2).

note: f(m,n) means the failure probability of DHRS with m frontline systems and *n* support systems

## 6. Discussions on the Reliability of DHRS

Reliability analyses on the DHRS of a fast reactor plant were performed and the following insights were obtained.

a. Failure probability of NC is approximately one sixth of that of FC per loop in the IRACS type DHRS when the mission time is 168 hours.

b. Of large importance are unreliability of CCS (40%) and pump (20%) in FC mode, unavailability of dampers at the inlet and outlet of air cooler (40 %) in NC mode.

c. The success criteria just after the reactor shutdown affects most on the failure probability of DHRS. If one loop FC is needed for first one hour, the failure probability of DHRS is approximately four times larger than the case where one loop NC is enough when the mission time is 168 hours.

d. Adding one loop DHRS with smaller heat removal capability makes the unreliability in 720 hours one fourth, and effectively limit the increase of unreliability when the mission time is long.

e. The contribution of support system is large in FC mode. Therefore adding only the frontline system loop is not very much effective.

f. In the case that the success criteria is NC, strengthening the frontline system is also effective because the contribution of frontline system unavailability is large.

g. The effect of type of DHRS on the failure probability is smaller than those of success criteria and support system configuration.

## 7. Concluding Remarks

Factors that dominate the system reliability such as the importance of support systems under FC mode operation were identified, effects of NC heat removal were analyzed, and insights were obtained into the methods to improve the reliability of DHRS. In the NC mode unavailability of active components are important to secure heat sink. In order to achieve high level of reliability i.e. 1E-7/d level, recovery actions by plant personnel should be taken into consideration. Further study needs to be performed to evaluate the effects of common cause failure, initiating event dependency etc.

## References

1. Nakai, R. et al., "Development of FREEDOM/CREDO Database for LMFBR PSA," IAEA Technical Committee Meeting on Evaluation of Reliability Data Sources, Vienna, Austria, Feb. 1988.

2. Hioki, K., "PC-based Support Programs Coupled with the SETS Code for Large Fault Tree Analysis," PSA '89, Pittsburgh, PA, USA, April 1989.

Table 1 Components in DHRS

| Component | necessary only in FC |
|---|---|
| PHTS pony motor | ○ |
| PHTS check valve | |
| PHTS piping | |
| IHX | |
| IHTS pony motor | ○ |
| IHTS piping | |
| Air Cooler outlet stop valve | |
| SG inlet stop valve | ○ |
| SG outlet stop valve | ○ |
| Air Cooler | |
| Air Cooler blower | ○ |
| Air Cooler inlet vane | |
| Air Cooler inlet damper | |
| Air Cooler outlet damper | |

Table 2 Interdependency Between Frontline System and Support System

| | | supported components | | | | |
|---|---|---|---|---|---|---|
| | | pump | blower | valve | damper | vane |
| support system | Emergency Power | ○ | ○ | | | |
| | CCS | ○ | | | | |
| | Vital Power | | | ○ | ○ | ○ |

Table 3 Interdependency Between Support Systems

| | | supported system | | | |
|---|---|---|---|---|---|
| | | Emergency Power | CCS | CCWS | CSSS |
| support system | Emergency Power | | ○ | ○ | ○ |
| | CCS | | | | |
| | CCWS | | ○ | | |
| | CSSS | ○ | | ○ | |

Table 4 Failure Probability of DHRS per loop

| operational mode | unavailability (/demand) | unreliability (/168hour) | Total (/168hour) |
|---|---|---|---|
| Forced Circulation | $1.8\times10^{-2}$ | $6.3\times10^{-2}$ | $8.1\times10^{-2}$ |
| Natural Circulation | $7.1\times10^{-3}$ | $5.7\times10^{-3}$ | $1.3\times10^{-2}$ |

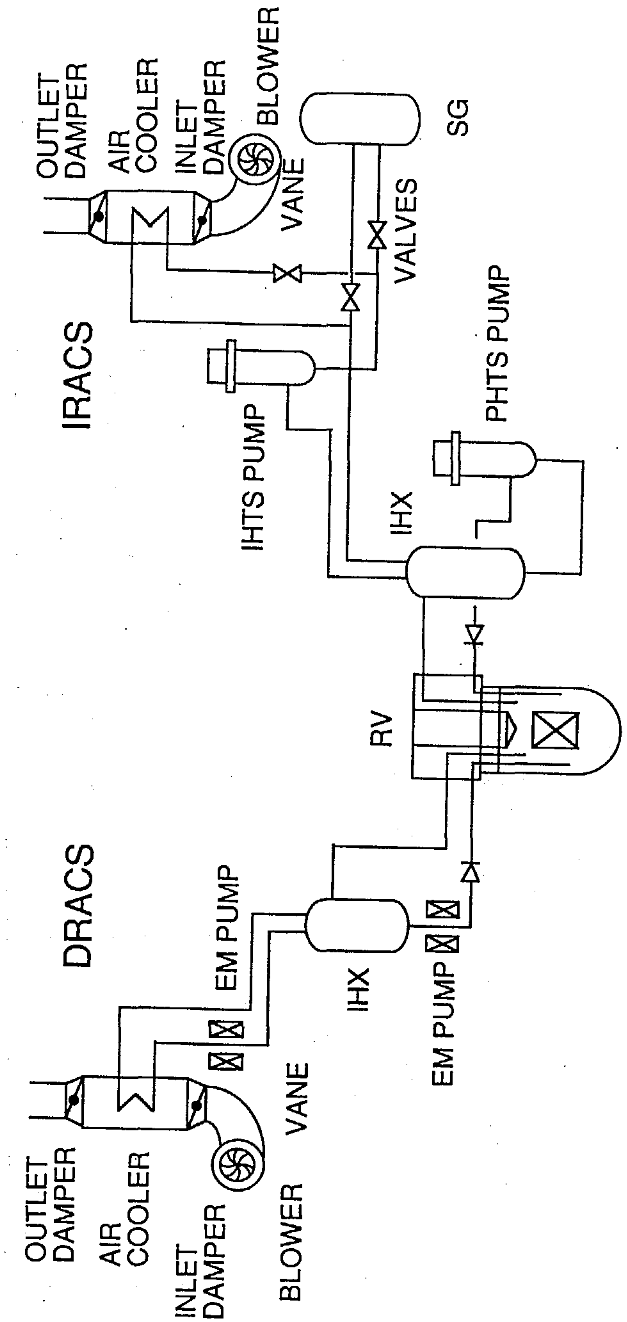


Figure 1 Schematic Diagram of DHRS

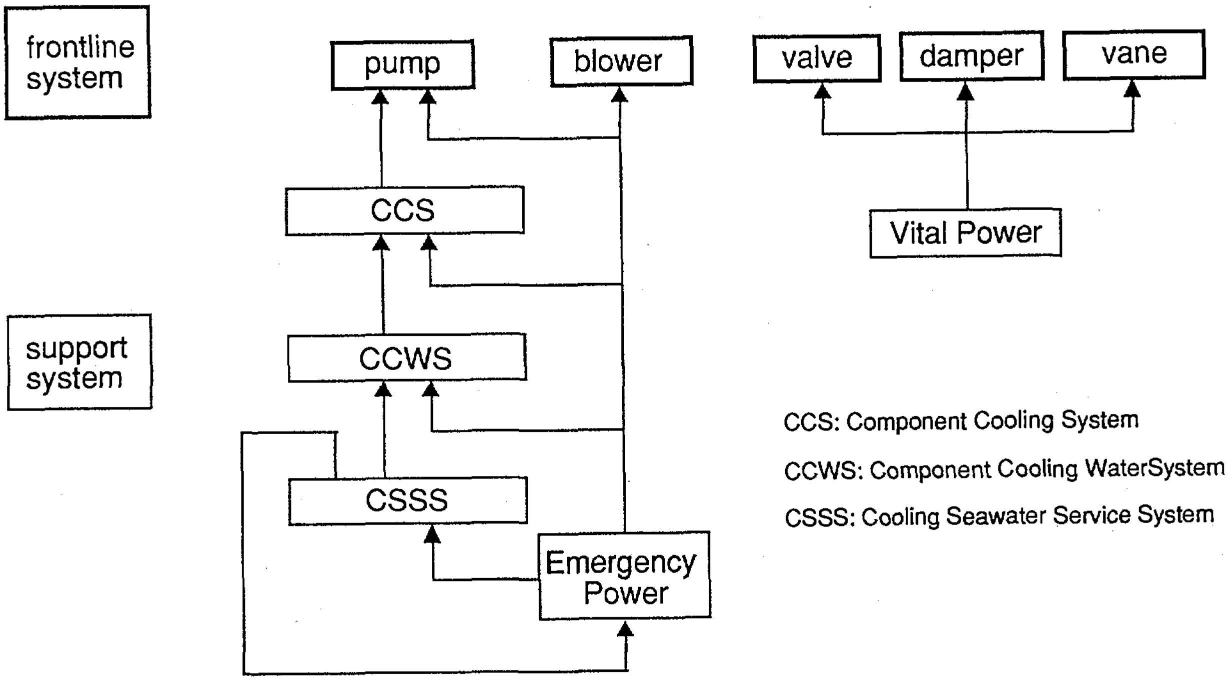


Figure 2 Interdependency bewteen frontline systems and support systems

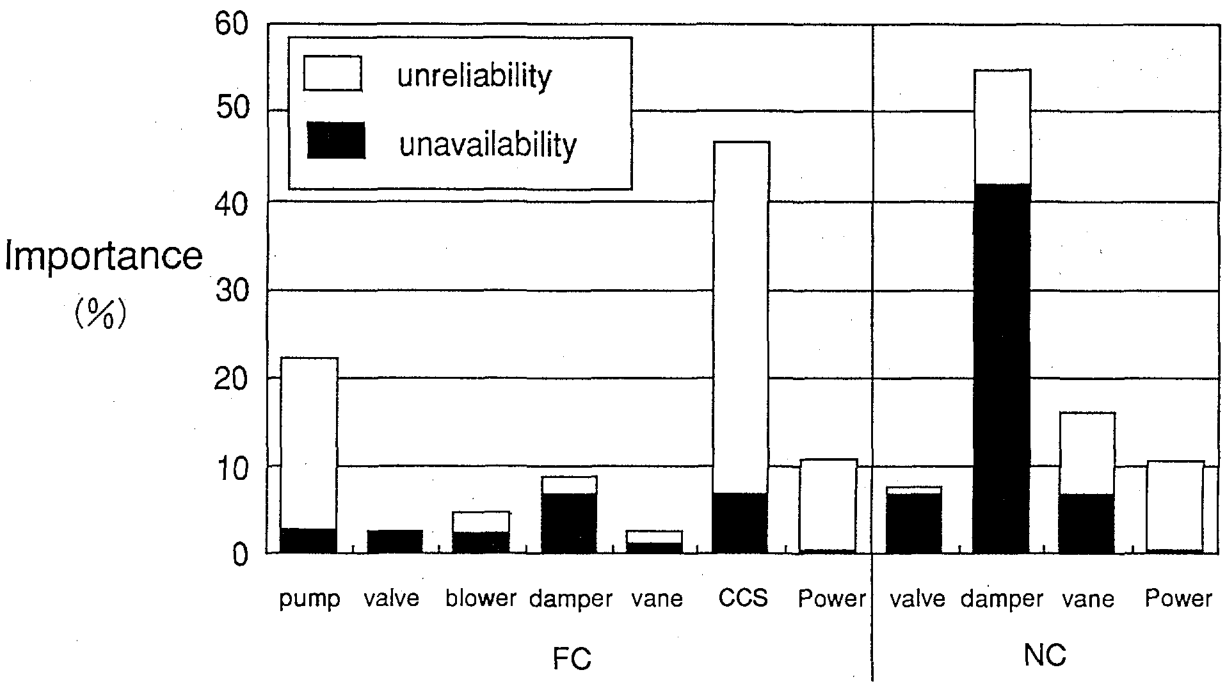


Figure 3 Importance of frontline system components and support systems per loop

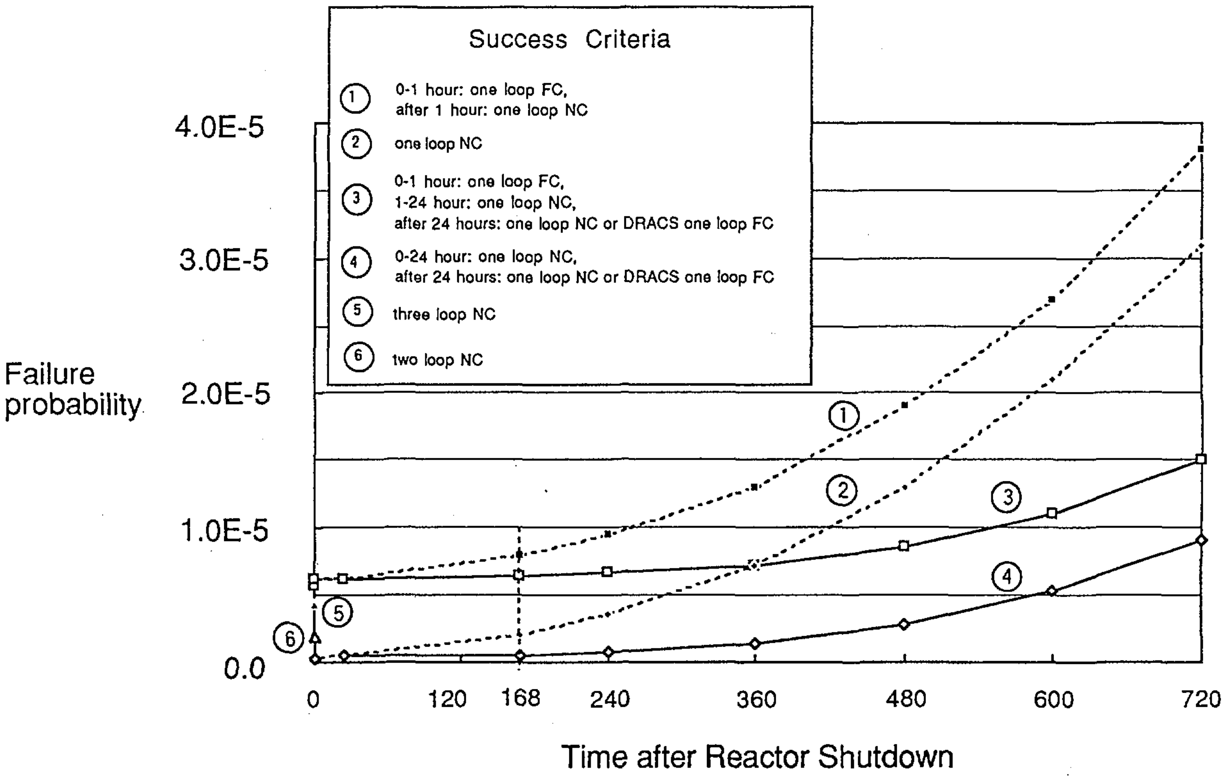


Figure 4 Failure Probability of DHRS with various Success Criteria

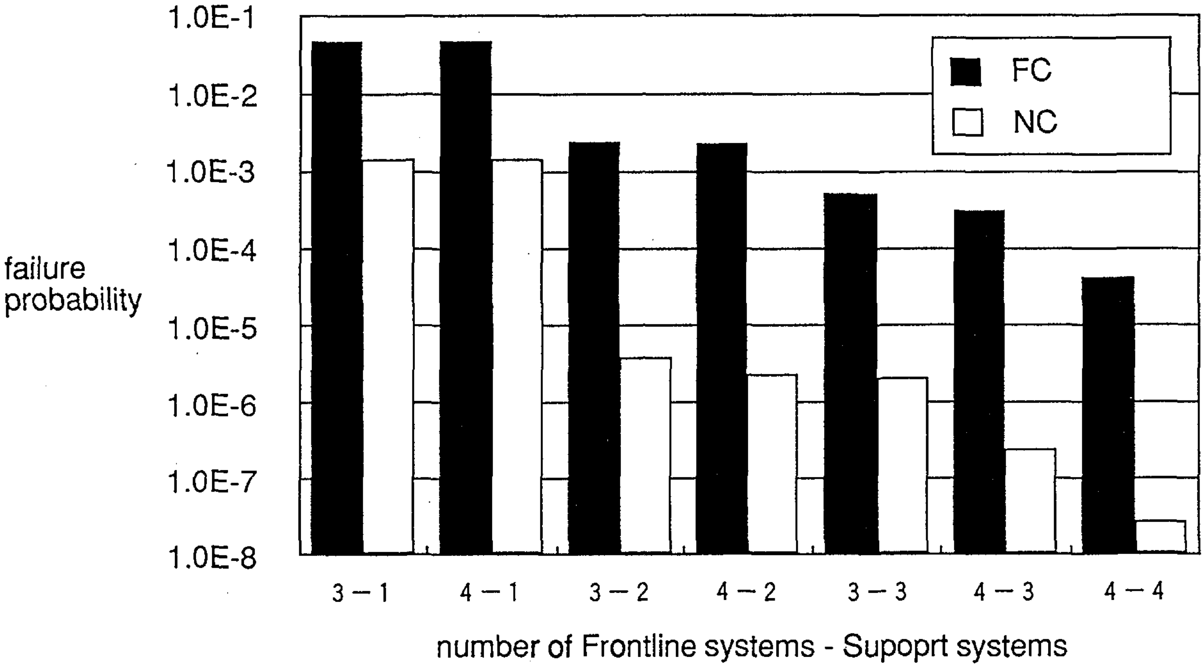


Figure 5 Failure Probability of DHRS with various number of frontline systems and support systems (mission time = 168 hours )