Westinghouse Electric Corporation

Energy Systems

Box 355
Pittsburgh Pennsylvania 15230-0355

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

ATTENTION: T. R. QUAY

SUBJECT: REPORT ON AP600 FAN COOLER EFFECTIVENESS AT AEROSOL REMOVAL IN SUPPORT OF RAI 470.25

Dear Mr. Quay:

The enclosed report provides an evaluation of the capability of the AP600 non-safety containment fan cooler to remove activity from the containment atmosphere during a postulated Loss-of-Coolant Accident. This report was prepared in support of the Westinghouse response to RAI 470.25. The response to RAI 470.25 is scheduled for completion by March 29, 1996.

Please contact John C. Butler on (412) 374-5268 if you have any questions concerning this transmittal.

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

/nja

Enclosure

cc: T. Kenyon, NRC
W. Huffman, NRC
J. Lee, NRC
R. Emch, NRC
J. Kudrick, NRC
M. Snodderly, NRC
N. J. Liparulo, Westinghouse (w/o Enclosure)

Enclosure to Westinghouse Letter NSD-NRC-96-4666

Impact of Fan Cooler Operation on AP600 Aerosol Removal Rates and on Post-LOCA Aerosol Releases from Containment

Background

The AP600 design differs from currently operating pressurized water reactors in that there is no safety grade active system provided to aid in the removal of airborne activity in the event of a postulated Loss-of-Coolant Accident (LOCA) with degraded core. Instead, the AP600 takes credit for sedimentation and deposition onto containment surfaces. The deposition process is driven by the heat transfer from the containment to the environment by way of the passive containment cooling system. Steam condensing on the containment shell causes airborne particulates to be carried to the shell and to be deposited there (diffusiophoresis). Likewise, there is heat transfer to the containment shell that does not involve condensing steam; this thermal gradient also causes particulates to be transported to the shell where they deposit (thermophoresis).

These removal processes combine to provide reliable aerosol removal in the event of a core degradation accident without depending on active components. The aerosol removal that is provided is sufficient to assure that the offsite doses resulting from the design basis LOCA are within the dose acceptance criteria for the reference site identified for the AP600. However, it is recognized that there is the potential to further reduce the amount of activity released to the environment if credit is taken for the operation of the non-safety grade fan cooler units. Operation of the fan coolers would provide additional aerosol removal capability. The fan coolers would also remove aerosols using the mechanisms of diffusiophoresis and thermophoresis but the removal would be promoted by forced air flow past the cooling coils; the forced air flow would also provide improved mixing of the containment atmosphere which would enhance aerosol removal. There are two fan cooler units in the containment - each of these fan cooler units has two fans.

Analysis was performed to evaluate the effect of operating one of the containment fan coolers (with only one of the two fans in the unit in use) on the amount of activity that would be released. The limitation to only one fan in operation is due to temperature rise limitations in the chilled water system that serves the fan coolers. As part of this analysis a determination was also made of the impact of fan cooler operation on the overall aerosol removal rates during a design basis accident.

The methodology for the analysis was to calculate the containment aerosol removal for the large LOCA without fan coolers operating and then to compare the result to that with one fan cooler operating. The modeling took into account the thermal-hydraulics associated with the LOCA but not those associated with the core melt sequence itself. The NUREG-1465 [1] defined core activity releases were superimposed on these LOCA thermal-hydraulics. Since this aerosol removal calculation was performed to assess the effect of a fan cooler on aerosol removal from the containment atmosphere, as opposed to assessing the absolute aerosol removal rate, the use of DBA thermal-hydraulics is acceptable. The steps in the calculation were as follows:

- Using the STARNAUA code, the DBA thermal-hydraulics, and an aerosol source corresponding to the NUREG-1465 source term [1], the suspended aerosol concentration in containment as a function of time was calculated with no fan cooler operating. The STARNAUA code is briefly described in Addendum A.

- Similarly, the suspended aerosol concentration vs. time was calculated for the case of one fan cooler operating (with one of two fans in use).

- The aerosol leaked mass and the lambda were evaluated for the cases with and without the fan cooler in operation and the results were compared to identify the effects of fan cooler operation.

Assumptions

1. Design Basis LOCA conditions in containment
2. Passive Containment Cooling System external cooling water initiated at 660 seconds after the initiation of the accident
3. Fan Cooler Operation
   - Base Case - No fan coolers operating
   - Fan Cooler Case - One fan cooler started at 600 seconds after the initiation of the accident (one out of two fans in the fan cooler operating)
4. Aerosol source is from NUREG-1465 with the initiation of releases from the core delayed by 50 minutes [2]
5. Containment leak rate of 0.12% per day
6. All fan cooler hea transfer is assumed to be due to condensation

Results of Analysis

All times reported in the following are times after the initiation of core damage; to obtain the time after initiation of the accident, add 3000 seconds (50 minutes) to the stated times. The airborne aerosol concentrations as a function of time are provided in Figure 1. For both cases, the aerosol concentration peaks at about 8000 seconds. At 40,000 seconds the aerosol concentration is three orders of magnitude below this peak for the case with no credit for fan cooler operation and nearly four orders of magnitude below the peak for the case with one fan cooler operating. From Figure 2, it is seen that the aerosol removal is roughly 40% settling and 40% diffusiophoresis for the case with no fan cooler operating, with about 20% of the removal coming from thermophoresis. This is an expected result given the large amount of steam that will be generated in a DBA accident. For the case with an operating fan cooler, the fraction of aerosol removal by settling is reduced and the fraction removed by diffusiophoresis is increased relative to the case with no fan cooler in operation.

With the airborne concentrations as reported in Figure 1 and the design basis containment leak rate of 0.12% per day, the mass of aerosols leaked from the containment were determined to be as shown in Figure 3. From Figure 3, the aerosol leakage is seen to be essentially complete by about 30,000 seconds. At this point there is very little of the aerosols remaining airborne and available for leakage (see Figure 1). The primary result from this analysis is the determination that the leakage of aerosols from the containment is reduced by about 30% for the case with one fan cooler operating.

This reduction in leaked mass is due to the faster removal of aerosols in containment which, in turn, is due to increased heat transfer associated with operation of the fan cooler. This increased heat transfer occurs starting at 600 seconds (the time of fan cooler startup), and persists until roughly 30,000 seconds at which time the steam in containment is reduced and the fan cooler effect is no longer as significant. The aerosol removal constants (lambda values) were calculated for each case and are shown in Figure 4. As shown in the figure, the removal constant for the case with an operating fan cooler is as much as 50 percent greater than for the case with no fan cooler in operation.

The thermal-hydraulic data shows that, at 20,000 seconds, the total heat transfer with one fan cooler operating is about 50% greater than when there is no fan cooler in operation and is about 25% larger at 40,000 seconds. This supports the above conclusion that the 30% reduction in aerosols leaked from the containment is due to the increased heat transfer.

References

1. L. Soffer, "Accident Source Terms for Light-Water Reactor Nuclear Power Plants," NUREG-1465, February, 1995.

2. Westinghouse Letter NTD-NRC-94-4335 (DCP/NRC0241), 11/2/94, "Position Paper on AP600-Specific Time Delay in the Physically Based Source Term"

Addendum A

Description of STARNAUA

STARNAUA was developed by and is proprietary to Polestar Applied Technology, Inc. STARNAUA is an enhanced version of NAUAHYGROS [1] and was developed by Polestar for performing aerosol removal calculations in support of work to develop and apply a realistic source term for advanced and operating LWRs.

NAUAHYGROS is an enhancement of the NAUA - mod 4 code [2]. It models natural removal of containment aerosols by gravitational settling and diffusiophoresis and takes into account the effect of hygroscopicity (growth of hygroscopic aerosols such as CsOH due to steam condensation on the aerosol particles) on aerosol removal. In developing STARNAUA, the capabilities of the base NAUAHYGROS code were enhanced by the addition of a model for thermophoresis, a model for spray removal, and by the capability to directly input steam condensation rate or condensation heat transfer rate and total heat transfer rate (such as would be provided from an external containment thermal hydraulics code calculation). Changes to the input file and to the output plot file were also made.

The approach used for validation STARNAUA was as follows:

- Validation of STARNAUA without the added spray removal and thermophoresis models was performed against NAUAHYGROS and NAUA - mod 4.

- Validation of the STARNAUA spray model was performed against experimental data as well as other accepted code calculations.

- Validation of the STARNAUA thermophoresis model was performed by comparing the thermophoresis model results against separate effects experiments. Also, sensitivity studies were performed to confirm that reasonable variations in model parameters did not cause significant changes in model predictions.

References:

1. R. Sher and J. Jokiniemi, "NAUAHYGROS 1.0: A Code for Calculating the Behavior of Aerosols in Nuclear Plant Containments Following a Severe Accident", EPRI Report TR-102775, Electric Power Research Institute, Palo Alto, July 1993.

2. H. Bunz, M. Koyro, and W. Schöck, "NAUA Mod 4 - A Code for Calculating Aerosol Behaviour in LWR Core Melt Accidents: Code Description and Users Manual", Report KfK 3554, Kernforschungszentrum Karlsruhe, August 1983.

Comparison of Suspended Aerosol Concentrations

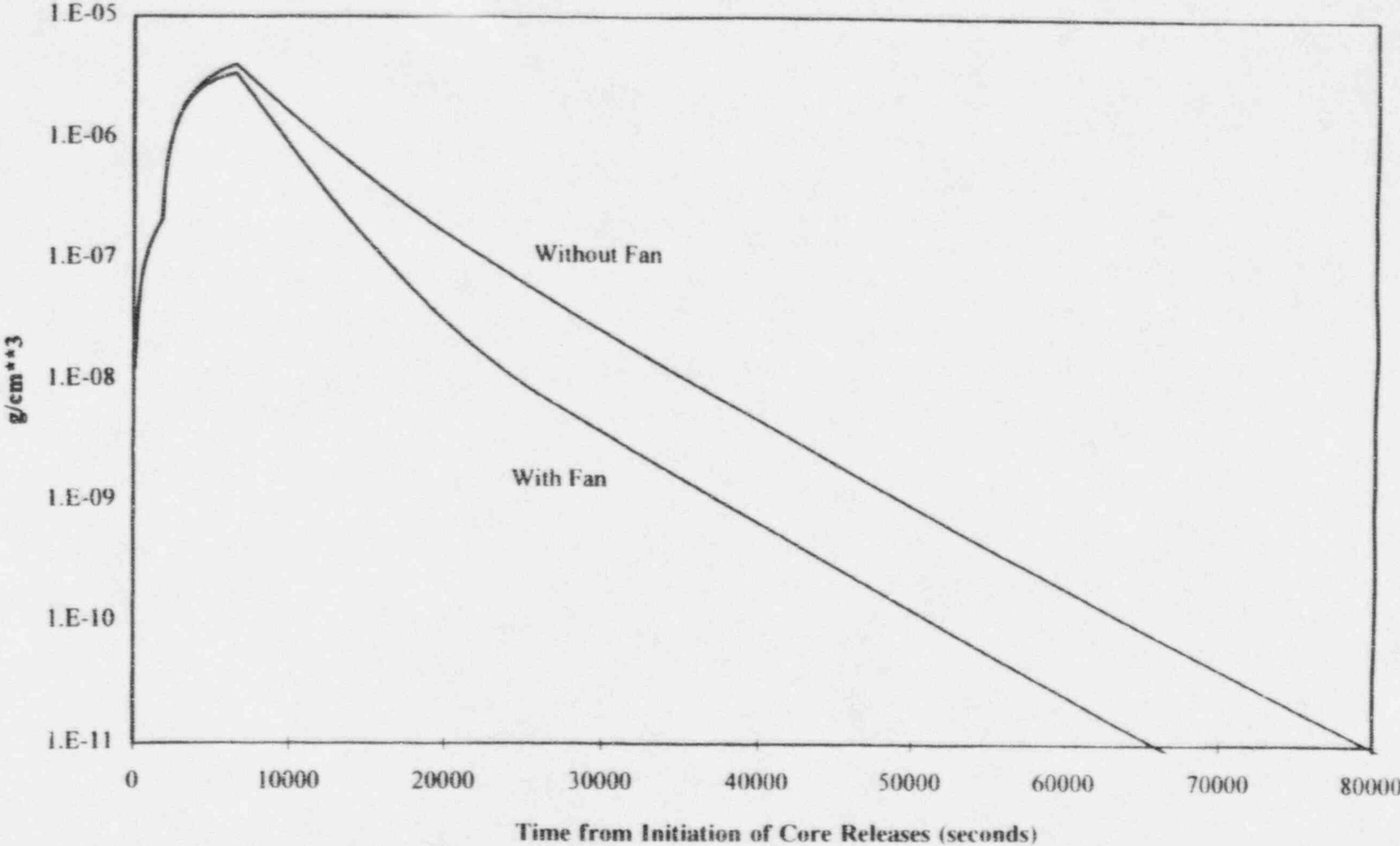


Figure 1

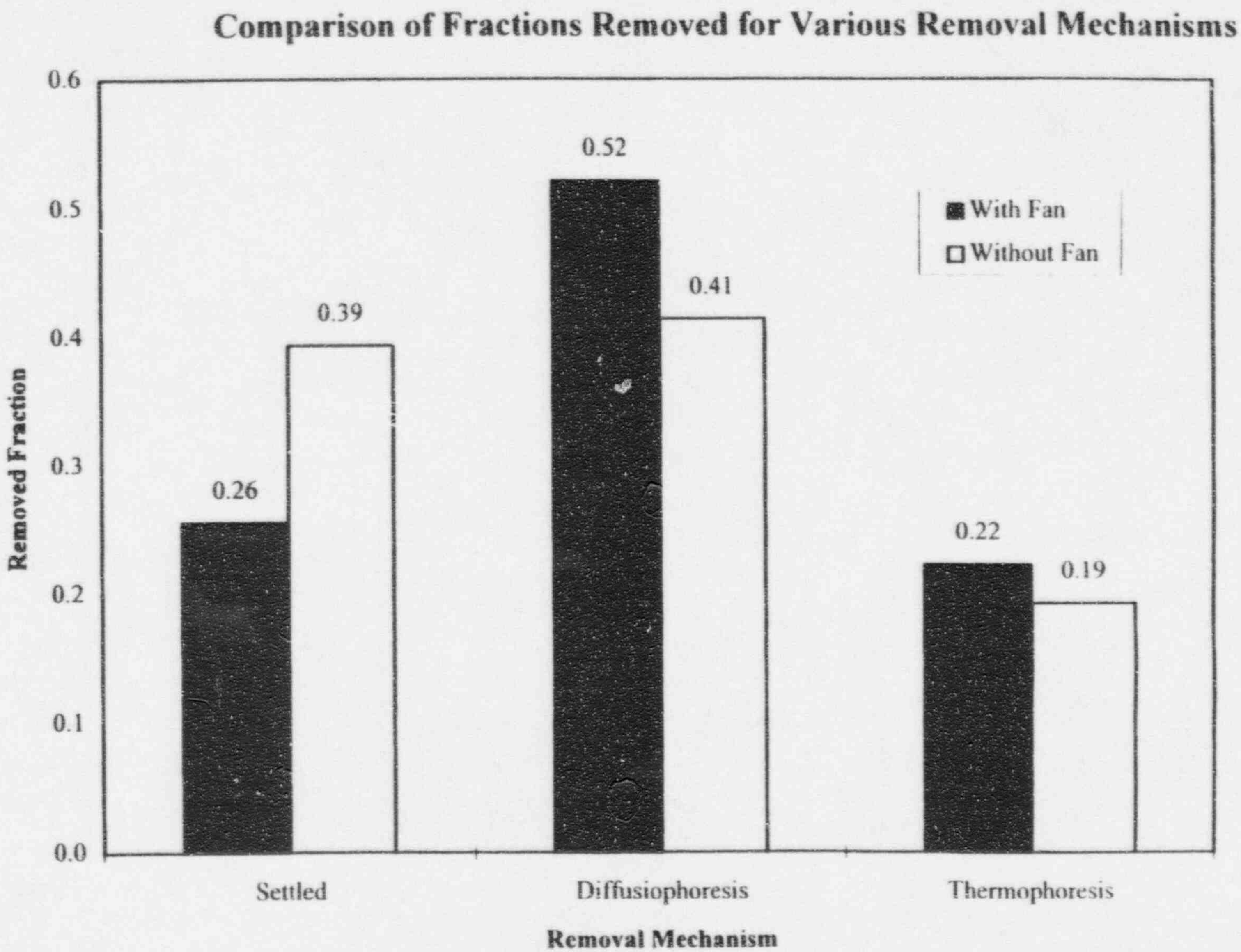
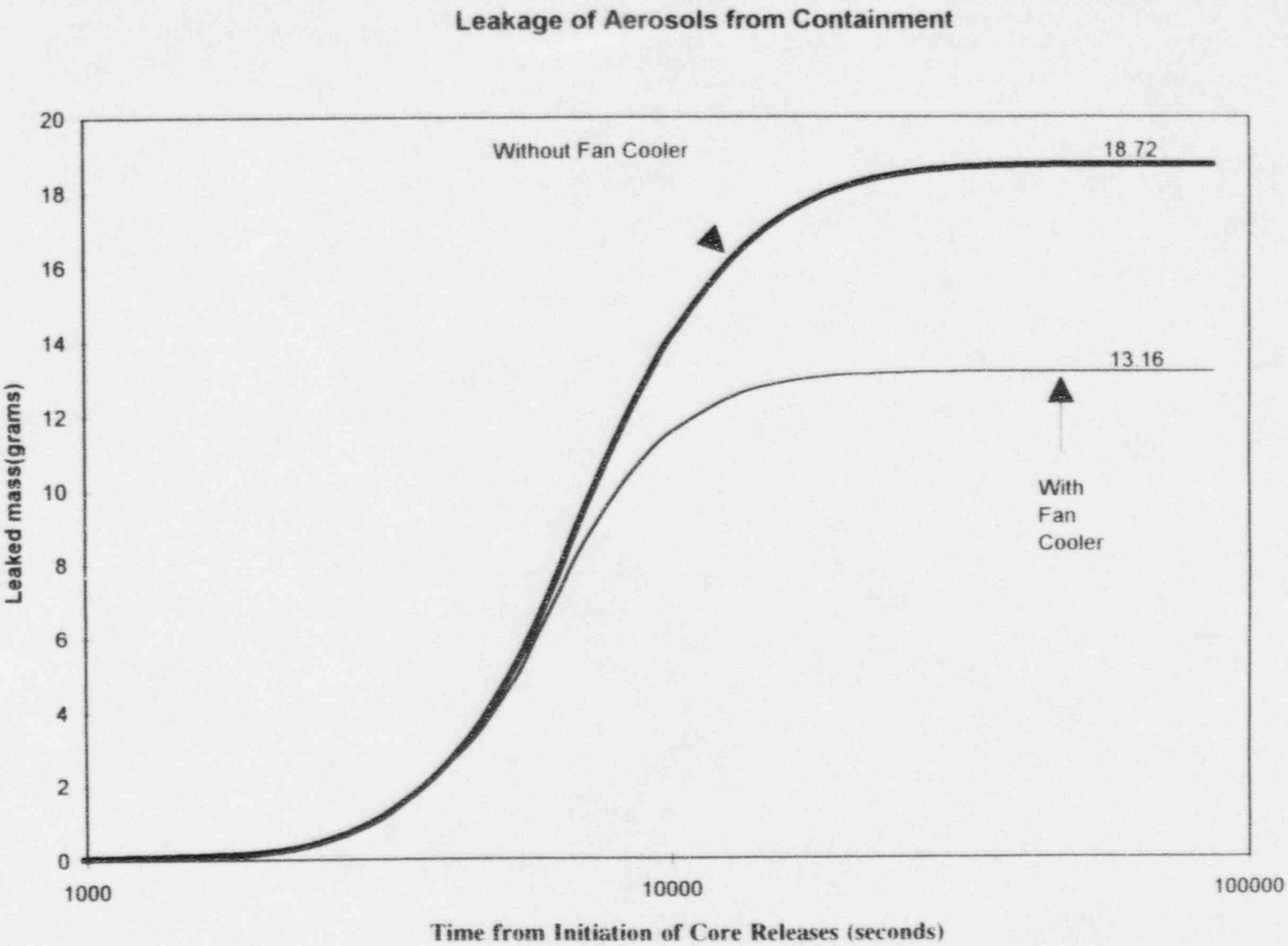

Comparison of Fractions Removed for Various Removal Mechanisms
Removed Fraction
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.26
0.39
0.52
0.41
0.22
0.19
With Fan
Without Fan
Settled
Diffusiophoresis
Thermophoresis
Removal Mechanism

Figure 2

Figure 3


Leakage of Aerosols from Containment
Without Fan Cooler
18.72
13.16
With
Fan
Cooler
Leaked mass(grams)
0
2
4
6
8
10
12
14
16
18
20
1000
10000
100000
Time from Initiation of Core Releases (seconds)

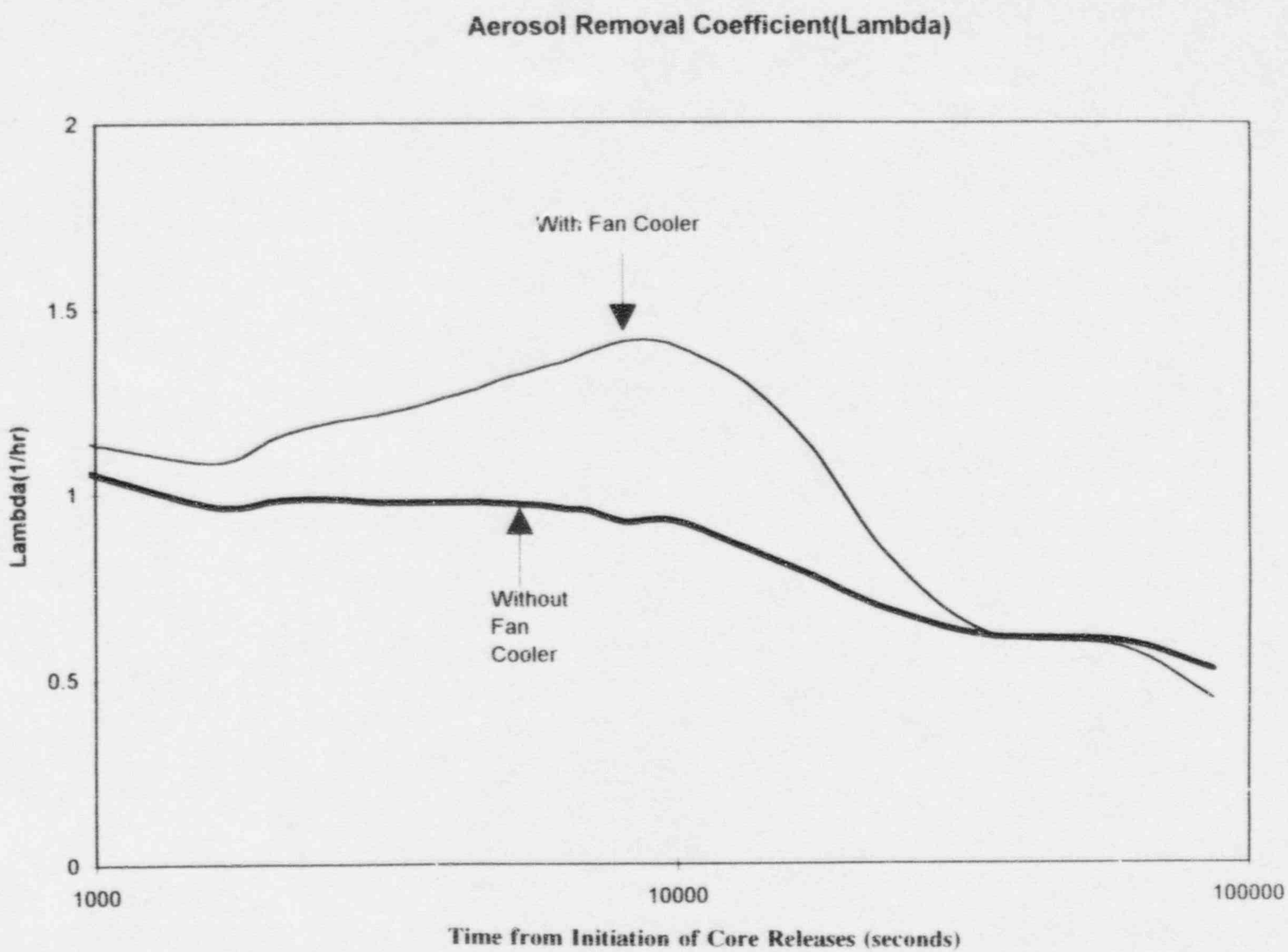

Aerosol Removal Coefficient(Lambda)
With Fan Cooler
Without
Fan
Cooler
Lambda(1/hr)
2
1.5
1
0.5
0
1000
10000
100000
Time from Initiation of Core Releases (seconds)

Figure 4