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SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-7-29

ANALYSIS OF ECLSS PERFORMANCE DURING REENTRY AFTER LOSS OF ONE AMMONIA TANK

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TABLE OF CONTENTS

TABLES

FIGURES

1.0 SUMMARY

An analysis has been performed to determine whether, in case of a loss of one of the ammonia tanks, the Ammonia Boiler System can provide adequate heat rejection for the Orbiter ECLSS during re-entry.

The results indicate that temperatures can be maintained as long as NH_3 is available, but that one tank does not contain sufficient NH_3 to complete all missions. A recommendation is made to investigate incorporation of onboard NH_3 quantity calculations, and/or addition of a third NH_3 tank.

2.0 INTRODUCTION

A method of providing onboard determination of Orbiter Ammonia (NH_3) quantities has been developed (Reference 1); however, there are currently no plans for implementation of this method.

In view of this, the Mission Planning and Analysis Division (MPAD) has questioned the adequacy of the Ammonia Boiler System (ABS) performance in the event of loss of an NH_3 tank. This analysis defines ABS performance under the one tank failed contingency.

3.0 DISCUSSION

This analysis has been performed to determine whether the ABS can provide adequate heat rejection for the Orbiter ECLSS during re-entry. This objective can be reduced to two major questions:

1) Can the ECLSS temperatures be maintained within limits with only one tank providing NH_3 to the boiler, and
2) Does one tank contain sufficient ammonia to support heat rejection until GSE hookup at touchdown +15 minutes.

An examination of the ABS configuration, Figure 1, (Reference 2) reveals the following:

1) The common NH_3 entry and exit headers will cause the boiler heat transfer coefficient (UA) to remain unchanged if one tank is lost. (However, this configuration does not provide the degree of redundancy called for in the Procurement Specification, Reference 3, para. 3.2.3.1.)
2) Heat transfer will be limited by the flow capability of the NH_3 flow control valves (FCV).

It is noteworthy to consider the result of an alternate design, Figure 2, to provide redundancy by eliminating the common headers. In this configuration each tank would supply NH_3 to only one-half of the boiler. In this case, if only one tank was available to supply NH_3, the UA would be reduced. This would cause the heat transfer to be limited by this reduced UA, rather than the FCV as previously noted.

In light of these considerations, system performance was analyzed with only one NH_3 tank available, both for the system as designed, and for the alternate system design.

The analyses were performed using the Consumables Analysis Section (CAS) ECLSS Computer model. This program performs a dynamic analysis of component and system flowrates, heat transfer and temperatures. The model represents the NH_3 boiler with a heat transfer coefficient (UA) of 2275 BTU/hr. deg. R., utilizing NH_3 with an effective heat capacity of 498 BTU/lb. Calculated heat rejection rates and fluid temperatures are felt to be within ±10% accuracy.

The NH_3 effective heat capacity (and thus, the amount of NH_3 required) is the most sensitive individual parameter in this type of consumables analysis. The value of 498 BTU/lb used is a nominal value based on a constant NH_3 supply temperature of 95°F, a constant NH_3 gas exit temperature of 106°F, and a constant boiler back pressure of 21 psia (references 4 and 5). Systems analyses performed by other organizations have used values ranging from 530 to 360 BTU/hr.

Two missions were analyzed: OFT Mission 4 and an orbiter 103 mission. Heat loads were specified by Reference 6 for OFT Mission 4, and by Reference 7 as a specified heat profile for orbiter 103. The analysis was performed by initiating the program two hours prior to NH_3 boiler on time. System temperatures were allowed to stabilize using H_2O flash evaporators for heat rejection. The flash evaporators were then disabled, and the NH_3 boiler enabled for the remainder of the mission.

Both missions were first run under normal conditions for reference purposes. Each was then run with the available NH_3 reduced to half of normal levels, and a maximum NH_3 flowrate of 177 lb/hr. They were then run again with the UA also reduced to half its normal value. Nominal, rather than conservative, assumptions of mission variables were made for each analyses.

The results of these six computer analyses are presented in Figures 3 through 20 and compared in Table 1. Data from the two different missions are not directly comparable because:

a) NH_3 boiler operation on the orbiter 103 mission is approximately 7 minutes longer than on OFT mission 4.
b) Although the total heat loads during NH_3 boiler operation are similar, the orbiter 103 mission has a significantly greater percentage of its load in the ARS water loop than does OFT mission 4.
c) The orbiter 103 mission has a lower heat load prior to NH_3 boiler operation, and thus stabilizes at lower system temperatures.

The relationship between the three analyses for the same mission, however, is comparable from one mission to another.

4.0 CONCLUSIONS

Inspection of the data developed by the analyses yields the conclusions itemized below. It should be noted that a more conservative analysis would have yielded more unfavorable results for items 1, 2, and 3.

1. With only one NH_3 tank available, ECLSS temperatures can be maintained within specified limits under either configuration—with minor, and probably tolerable, exceptions —— as long as NH_3 is available.

2. For either configuration there is not enough NH_3 in one tank to support ABS heat rejection until the GSE heat exchanger can be connected, if no action is taken to reduce heat loads. (There is, however, enough NH_3 to support heat rejection until the orbiter is safely on the ground). In this analyses, the following violations of temperature specifications were noted following NH_3 depletion.

ITEM	MAX TEMP LIMIT °F	INDICATED TEMP °F
NH_3 Boiler R21 Inlet Temp.	119	122.4
NH_3 Boiler R21 Outlet Temp.	34±3	121.9
IMU Inlet Temp.	85	110.9
Avionics Bay Heat Exchanger H_2O Inlet Temp.	95	100.8
Cabin Air Temp.	74	87.1

3. The NH_3 quantity in both tanks is only marginally adequate for the orbiter 103 heat profile. An analysis utilizing more conservative assumptions would result in NH_3 depletion even without loss of one tank.

4. Operation at reduced heat loads prior to NH_3 boiler operation significantly reduces the thermal load which the NH_3 boiler will have to dissipate.

5. The ECLSS and the components being cooled provide sufficient heat sink to protect the various components from excessive temperatures for several (approx. 5) minutes after NH_3 depletion.

6. For the ABS duty cycle being contemplated, the alternate design for redundancy offers no significant advantage in thermal performance. Neither configuration meets the redundancy criteria of Ref. 3.

Based on these conclusions, it is recommended that investigation of the following items be performed:

1. Determine the feasability of onboard calculation of NH_3 quantities, to be tied into the Caution & Warning System. In the event of an NH_3 tank loss this would alert the crew to reduce electrical heat loads prior to reentry, if ground communications were inadequate.

2. Determine the feasability of adding a third NH_3 tank to provide sufficient NH_3 in the event of a tank loss.

3. Determine whether the noted violations of temperature specifications would result in equipment damage.

5.0 REFERENCES

1. MDTS., TM-1.4-7-145, dated 3 December 1975, "Method for Computing Ammonia Quantity Remaining in a Storage Tank"
2. Fairchild Stratos Document ER74722-4 dated 17 October 1975, "Ammonia Boiler Subsystem Heat Exchanger Math Model"
3. R.I. Procurement Specification MC250-0005, Rev. B dated 9 December 1974, "Ammonia Boiler Subsystem"
4. NASA Memo FM 74 (75-62) dated 22 May 1975. "Requirement for Ammonia Storage Temperature Profile"
5. JSC-08934 (Vol. I), Sec. 4.6.3, Amendment 25, "Shuttle Operational Data Book"
6. MDTSCO Working Paper 1.4-7-101, dated 25 September 1975, "Shuttle OFT Conceptual Missions EPS Consumables Analysis"
7. R.I. SD72-SH-0106-3, dated 15 July 1975, "Requirement/Definition Document - Active Thermal Control System"

TABLE 1

ECLSS PERFORMANCE DATA COMPARISON AMMONIA TANK LOSS ANALYSIS

ITEM	UNITS	MAX LIMIT	MISSION: OFT 4: 2 NH_3 TNKS	OFT 4: 1 NH_3 TNK: CURRENT CONFIGURATION	OFT 4: 1 NH_3 TNK: REDUNDANT CONFIGURATION	ORBITER 103: 2 NH_3 TNKS	ORBITER 103: 1 NH_3 TANK: CURRENT CONFIGURATION	ORBITER 103: 1 NH_3 TANK: REDUNDANT CONFIGURATION
FREON LOOP								
NH_3 Boiler								
Operating Duration								
Before Orbiter Touchdown	min		7.2	7.2	7.2	12.0	12.0	12.0
After Orbiter Touchdown	min		15.0	15.0	15.0	17.0	17.0	17.0
Ammonia Quantity								
Available	lbs		97.6	48.8	48.8	97.6	48.8	48.8
Consumed	lbs		78.8	48.8	48.8	96.8	48.8	48.8
Remaining	lbs		18.8	0	0	0.8	0	0
Time from NH_3 Depletion to GSE Hookup	min		-	5.64	3.6	-	11.94	9.67
Inlet Temp (Max)	deg F	119	115.8	118.5/116.9*	119.4/116.2*	107.1	113.1/122.4*	115.5/121.9*
Outlet Temp (After Stabilization) (Max)	deg. F	34±3***	35.0	55.6/116.4*	61.7/115.5*	34.2	50.3/121.9*	59.9/121.4*
Heat Rejection (Max)	BTU/hr		113776	88456	81445	103411	88456	78320
Heat Rejection (Avg)	BTU/hr		106490	88456**	78722**	100851	88456**	73098**
Total Flow Rate (Avg)	lb/hr		5500	5500	5500	5500	5500	5500
Flowrate Through Interchanger (Avg)	lb/hr		4169	4169	4169	4169	4169	4169
Mid Body Cold Plate Disch Temp (Max)	deg F	120	89.4	91.7/94.9*	92.7/94.9*	83.9	86.1/91.7*	85.7/91.9*
WATER LOOP								
Interchanger Discharge Temp (Max)	deg F		36.5	58.4/114.2*	64.0/112.0*	36.0	53.3/119.5*	62.2/119.4*
IMU Inlet Temp (Max)	deg F	85	67.7	68.8/100.5*	73.4/90.2*	66.7	67.8/110.9*	72.8/110.2*
Avionics Bay Heat Exchangers								
Inlet Temp (Max)	deg. F	95	81.0	88.4	89.4	81.9	82.6/100.8*	87.3/98.8*
Outlet Temp (Max)	deg F	105	95.2	96.3	97.2	94.5	97.3	98.3
Avionics Bay Cold Plates								
Inlet Temp (Max)	deg F	105	95.2	96.3	97.2	94.5	97.3	93.3
Outlet Temp (Max)	deg F	120	110.3	111.4	112.0	108.5	110.4	111.1
CABIN ATMOSPHERE								
Air Temp (Max)	deg F	74	70.3	78.0	77.6	71.1	72.7/37.1*	76.5/85.5*
Dew Point (Max)	deg F	64	47.6	51.9	52.1	49.3	60.3	60.5

* Before/After NH_3 Depletion

** Avg Calculated during time Before NH_3 Depletion

***Control range

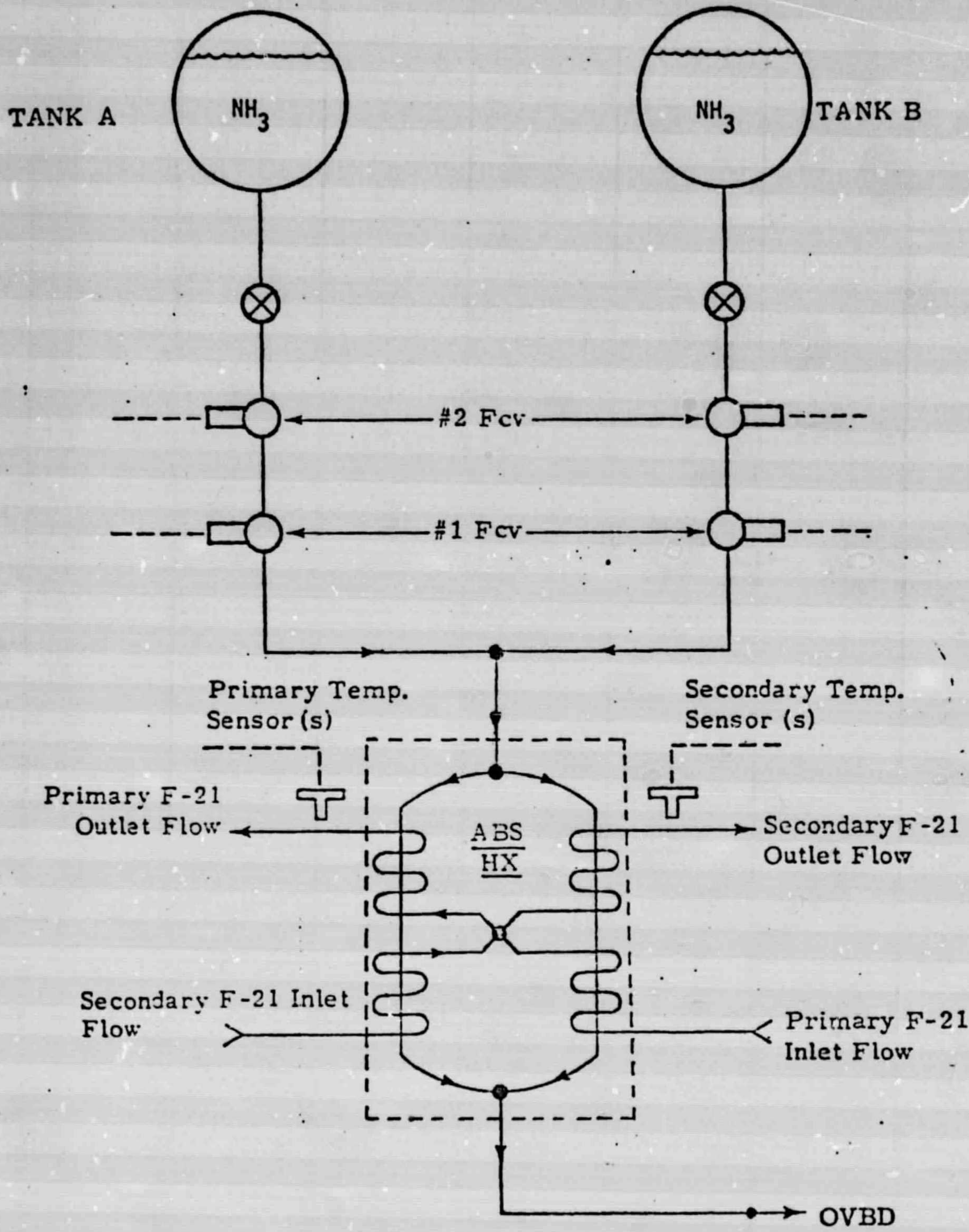

Figure 1. Ammonia Boiler System Functional Schematic - Design Configuration

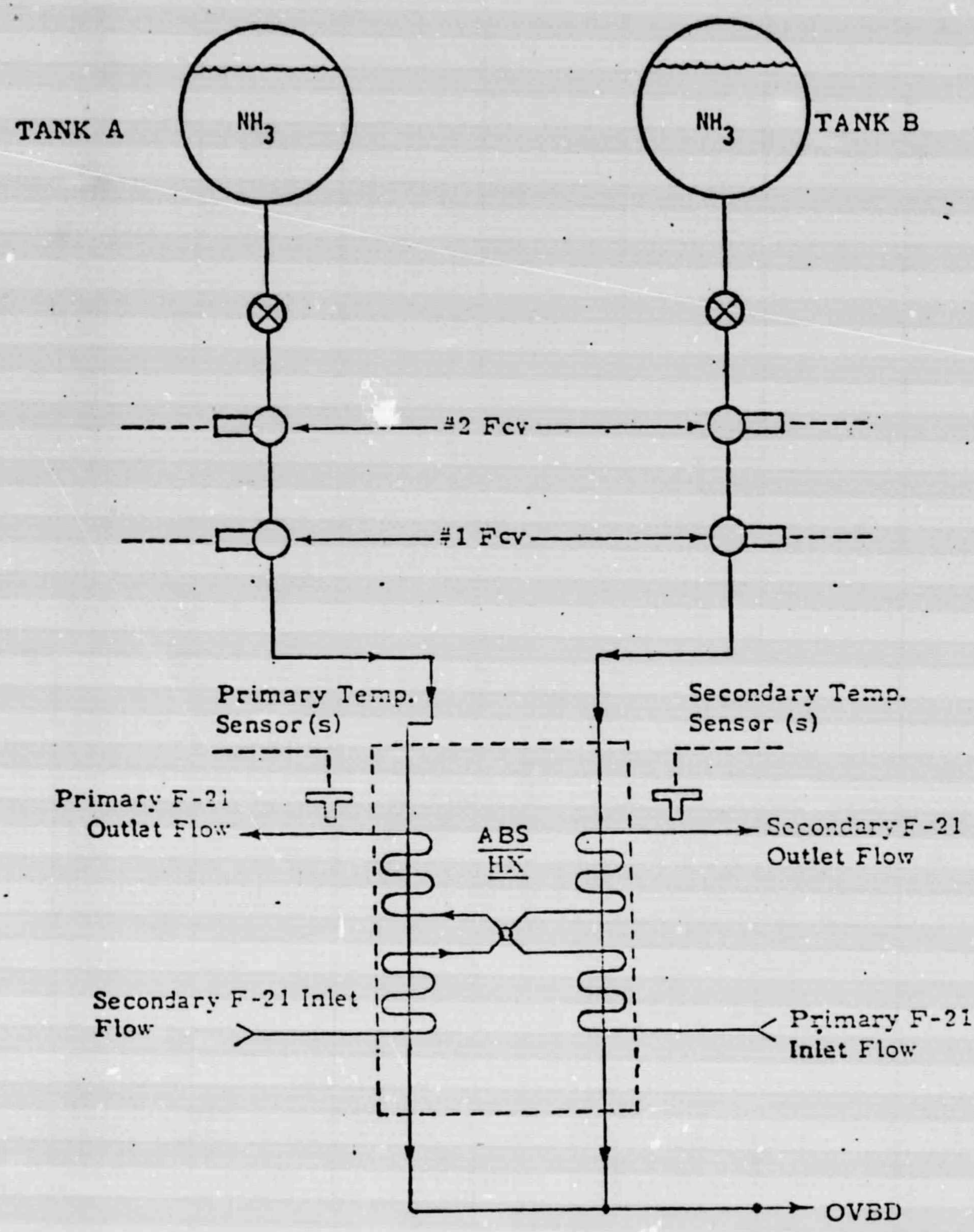

Figure 2. Ammonia Boiler System Functional Schematic - Alternate Configuration

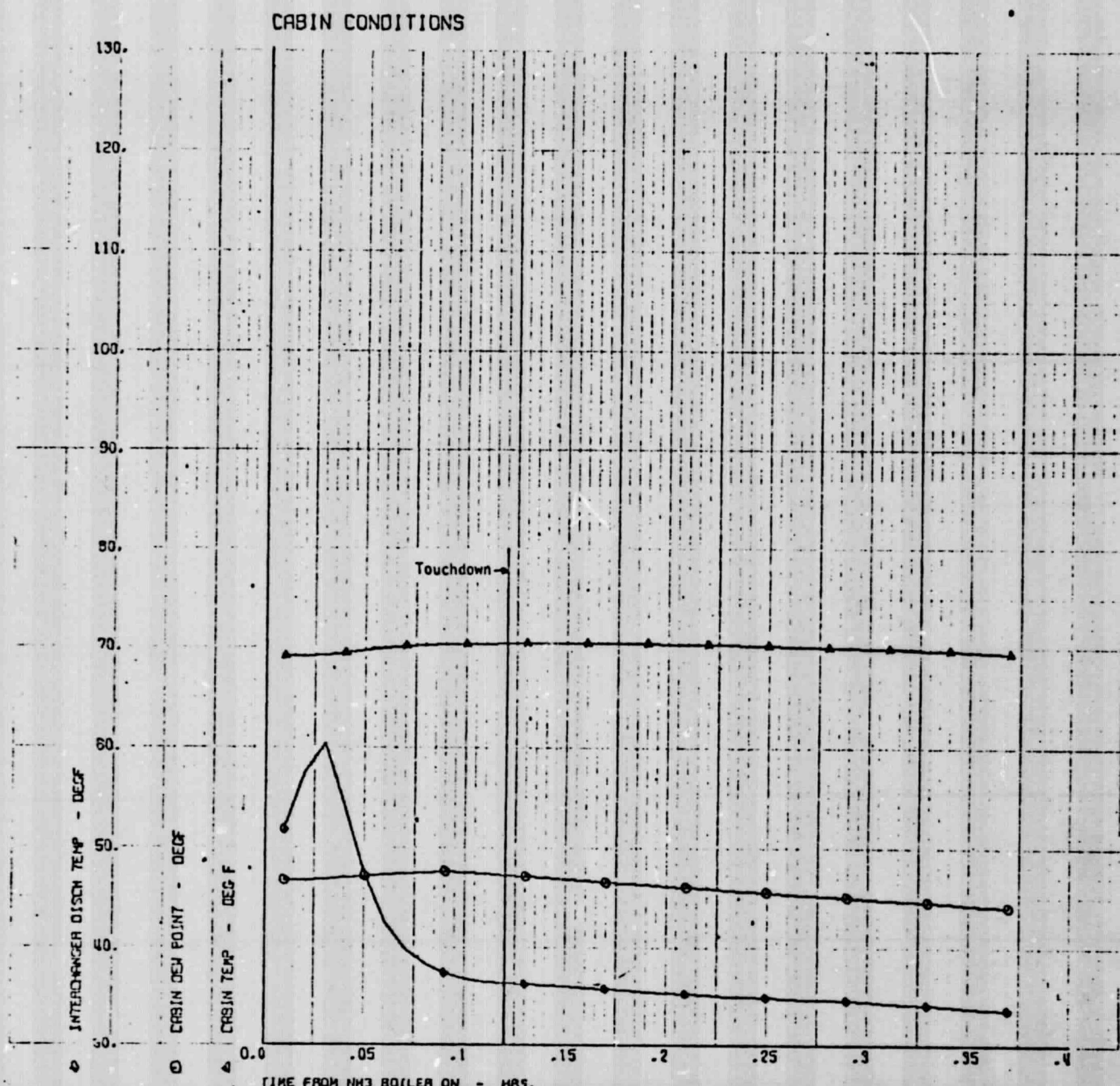

Figure 3. OFT Mission No. 4, Normal Operation - Cabin Conditions

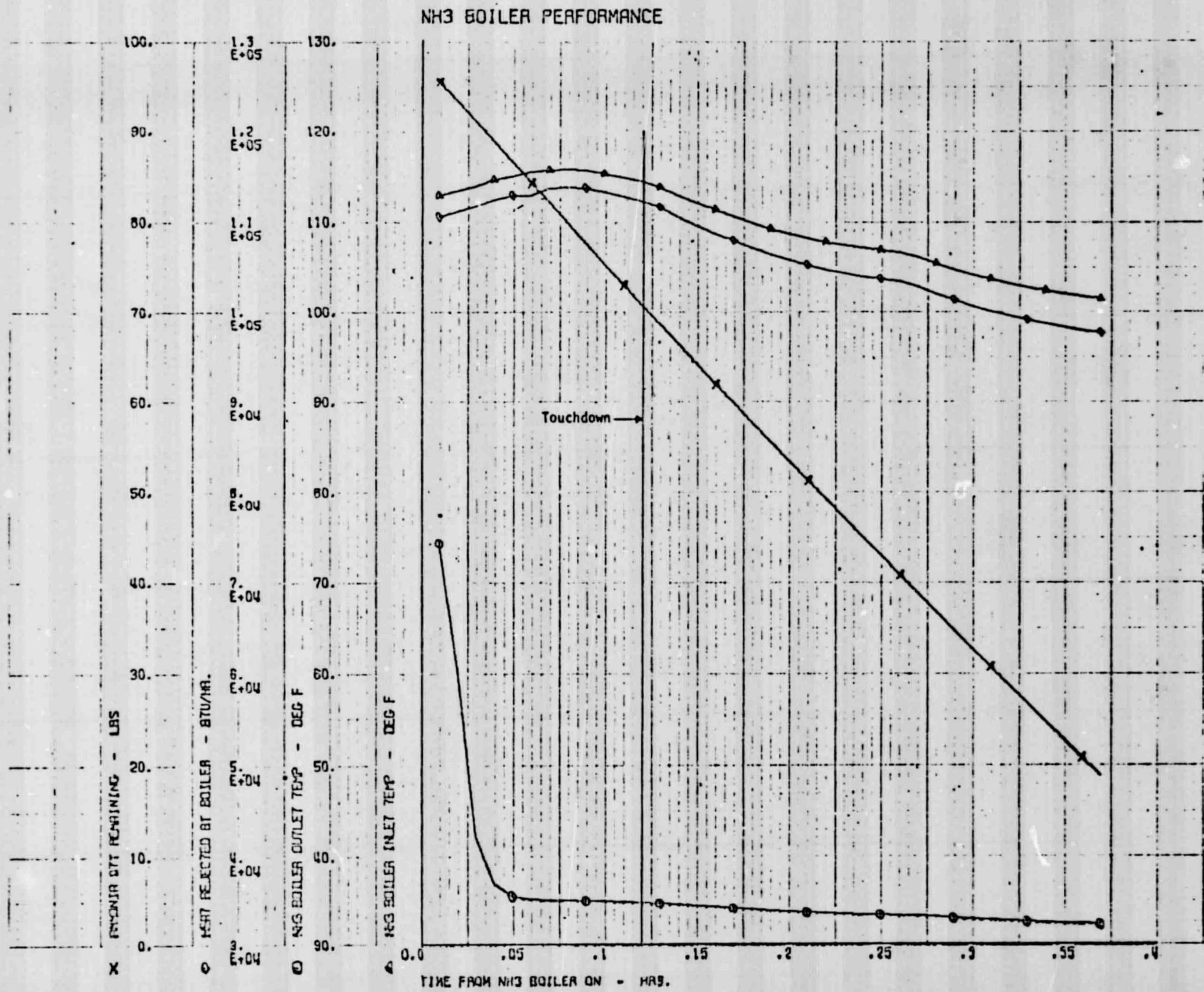

Figure 4. OFT Mission No. 4, Normal Operation - NH_3 Boiler Performance

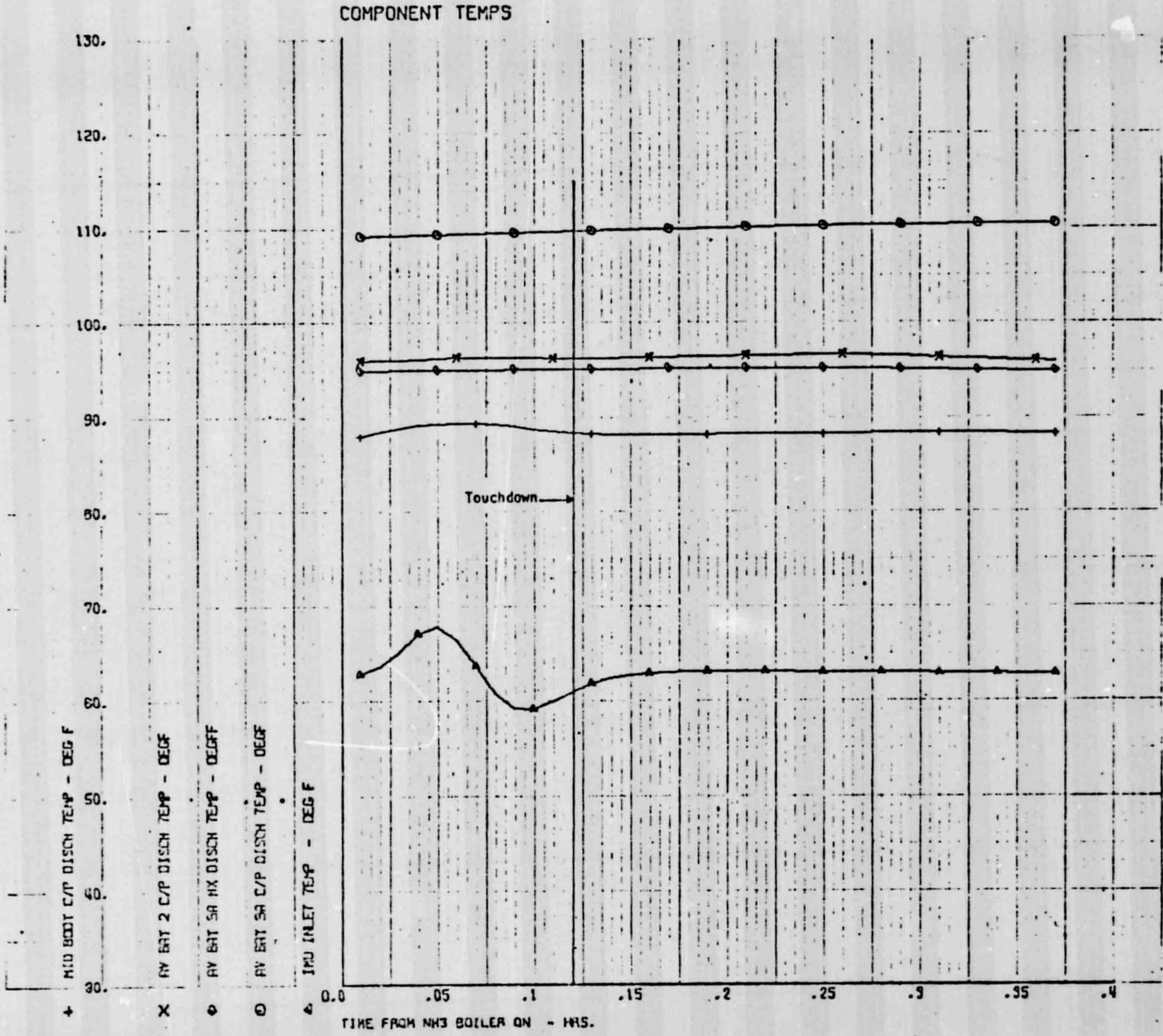

Figure 5. OFT Mission No. 4, Normal Operation - System Temperatures

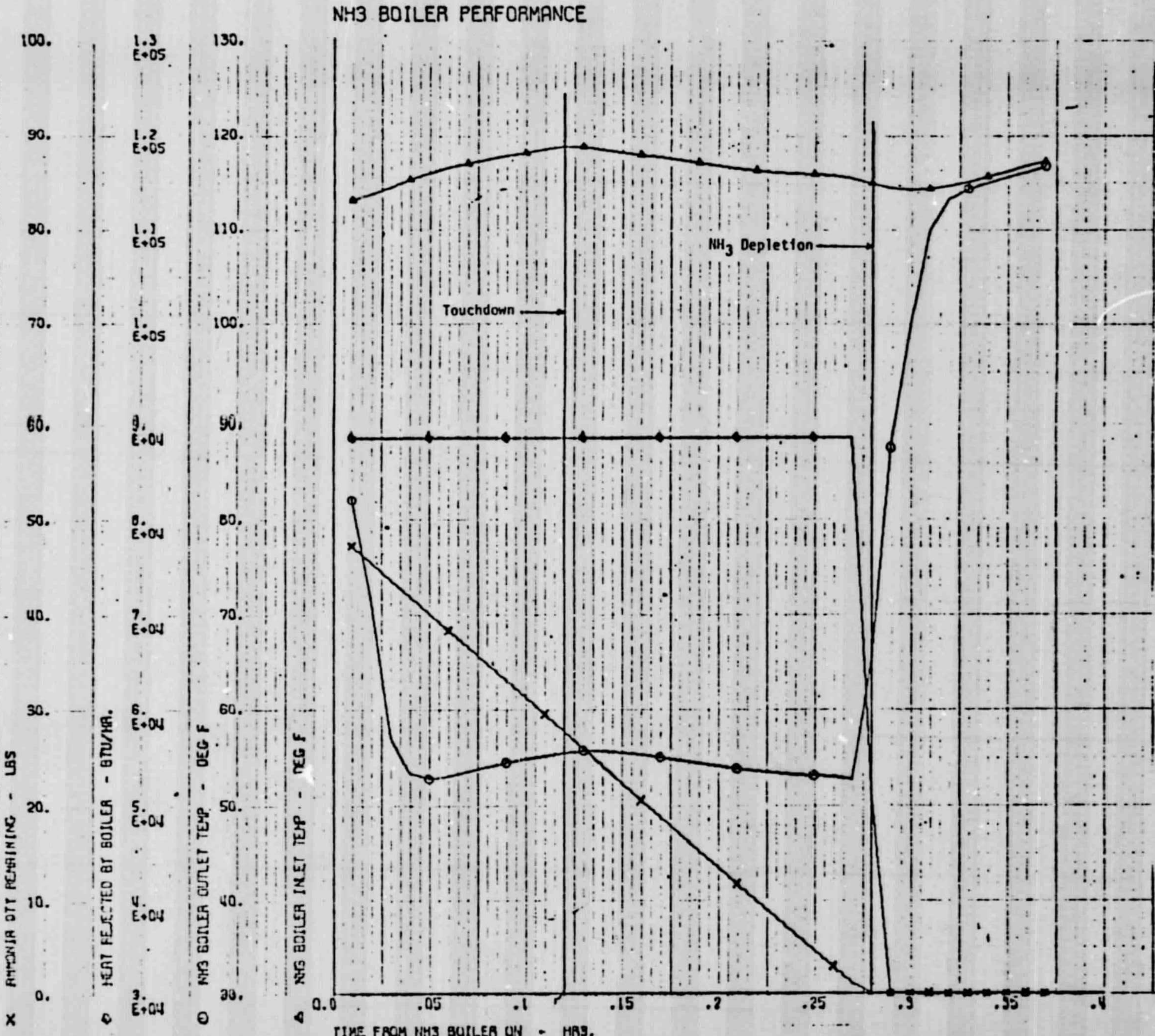

Figure 7. OFT Mission No. 4, Current Configuration, One NH_3 Tank - NH_3 Boiler Performance

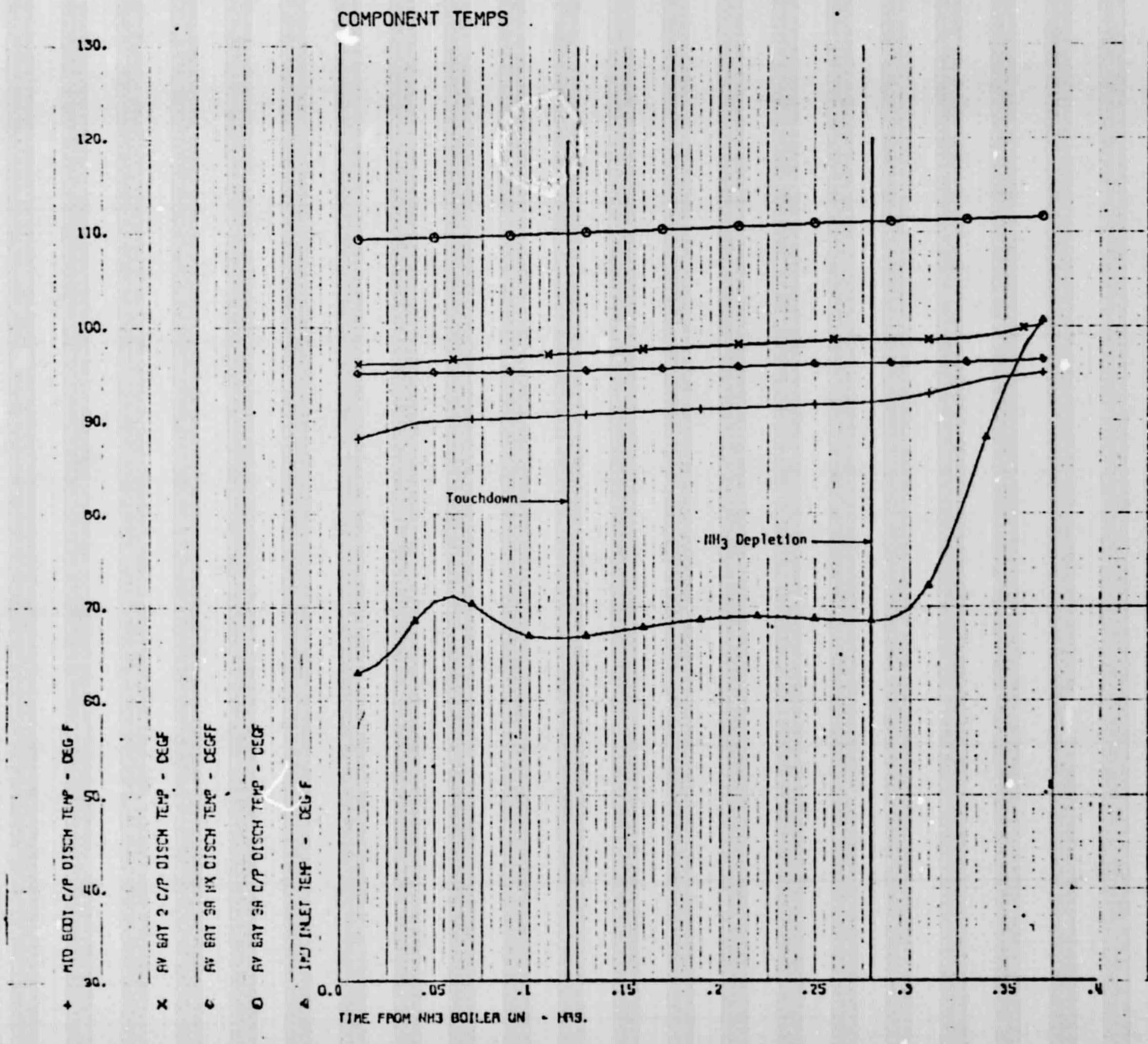

Figure 8. OFT Mission No. 4, Current Configuration, One NH_3 Tank - System Temperatures

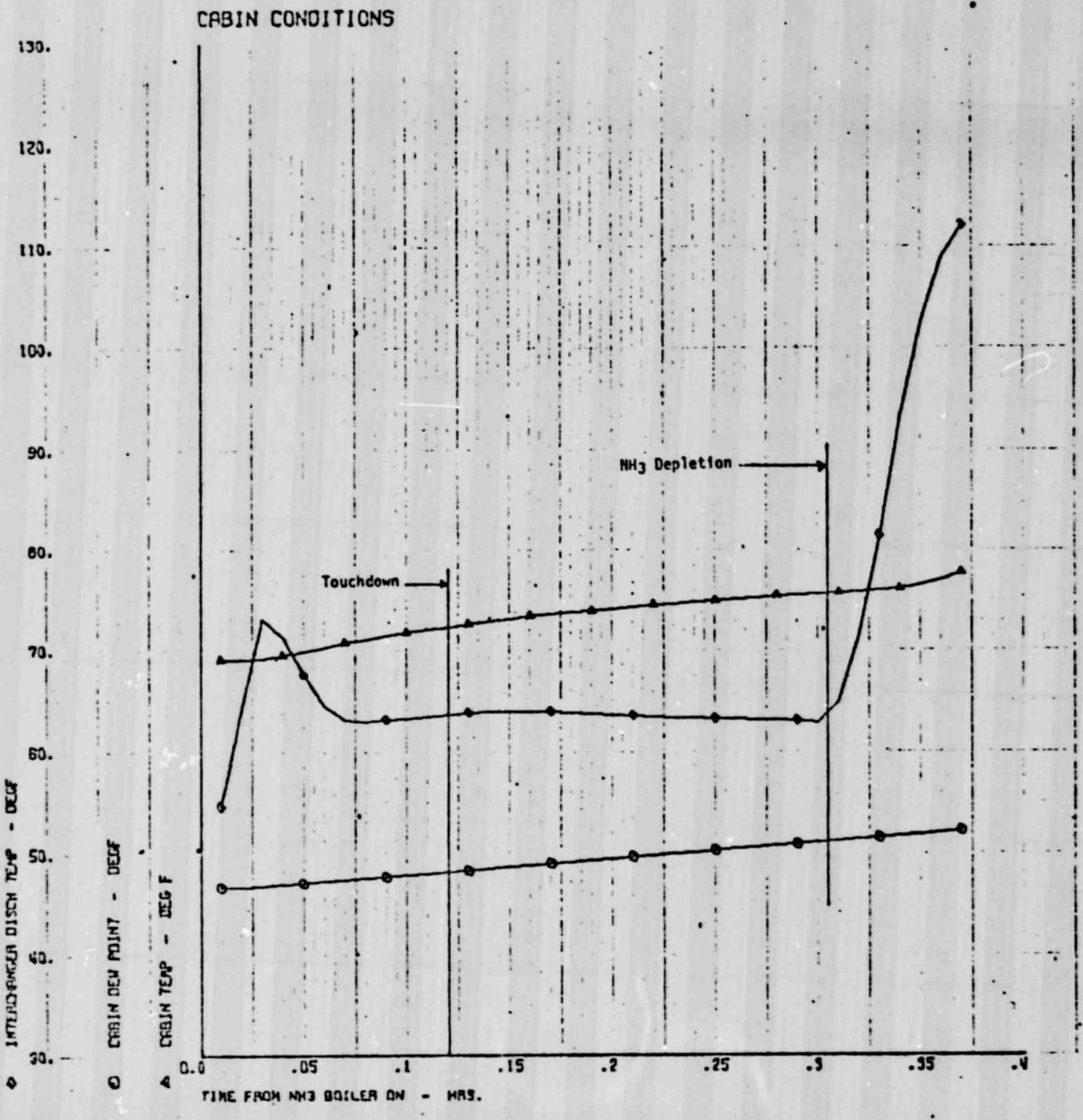

Figure 9. OFT Mission No. 4, Redundant Configuration, One NH_3 Tank - Cabin Conditions

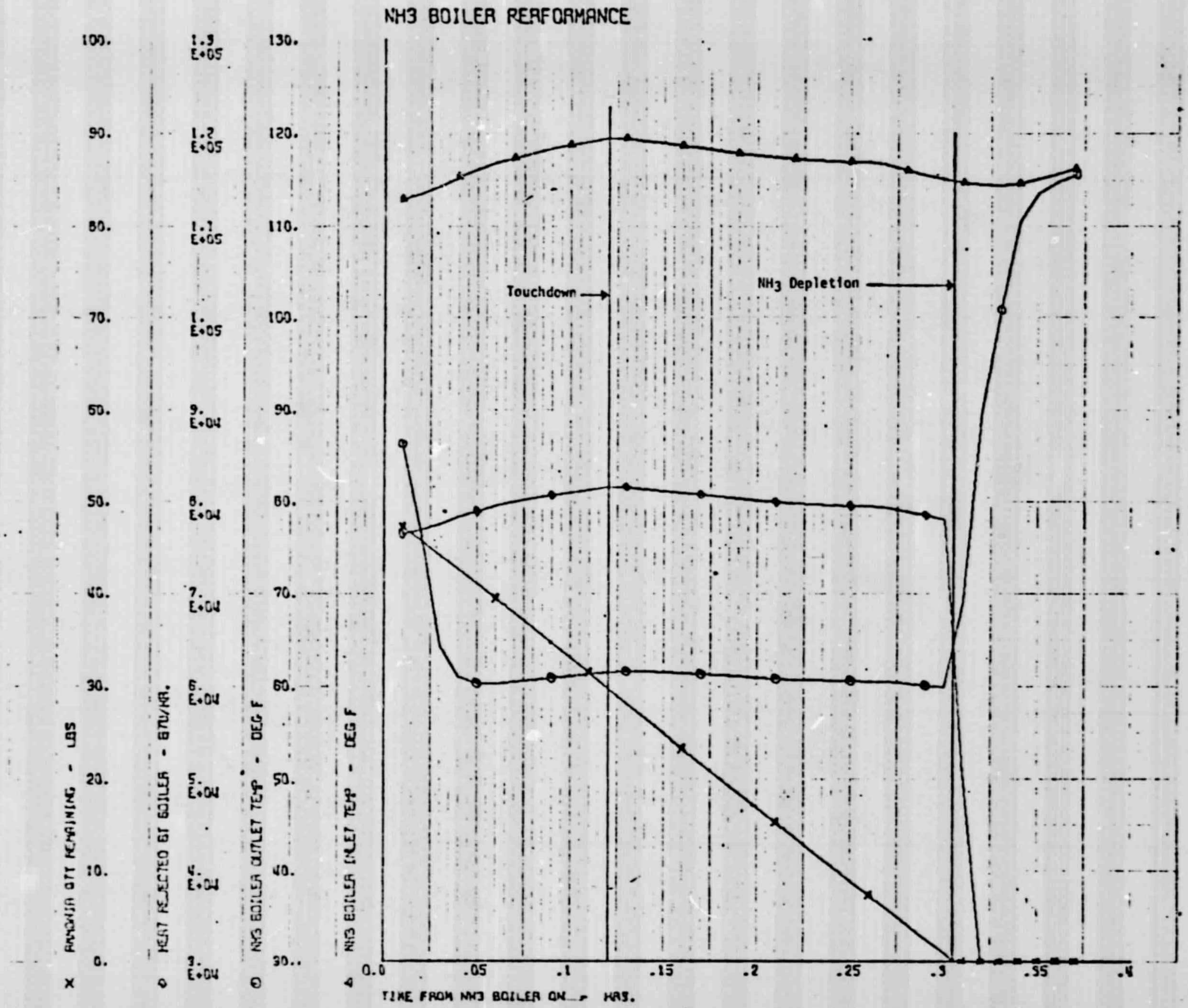

Figure 10. OFT Mission No. 4, Redundant Configuration, One NH_3 Tank - NH_3 Boiler Performance

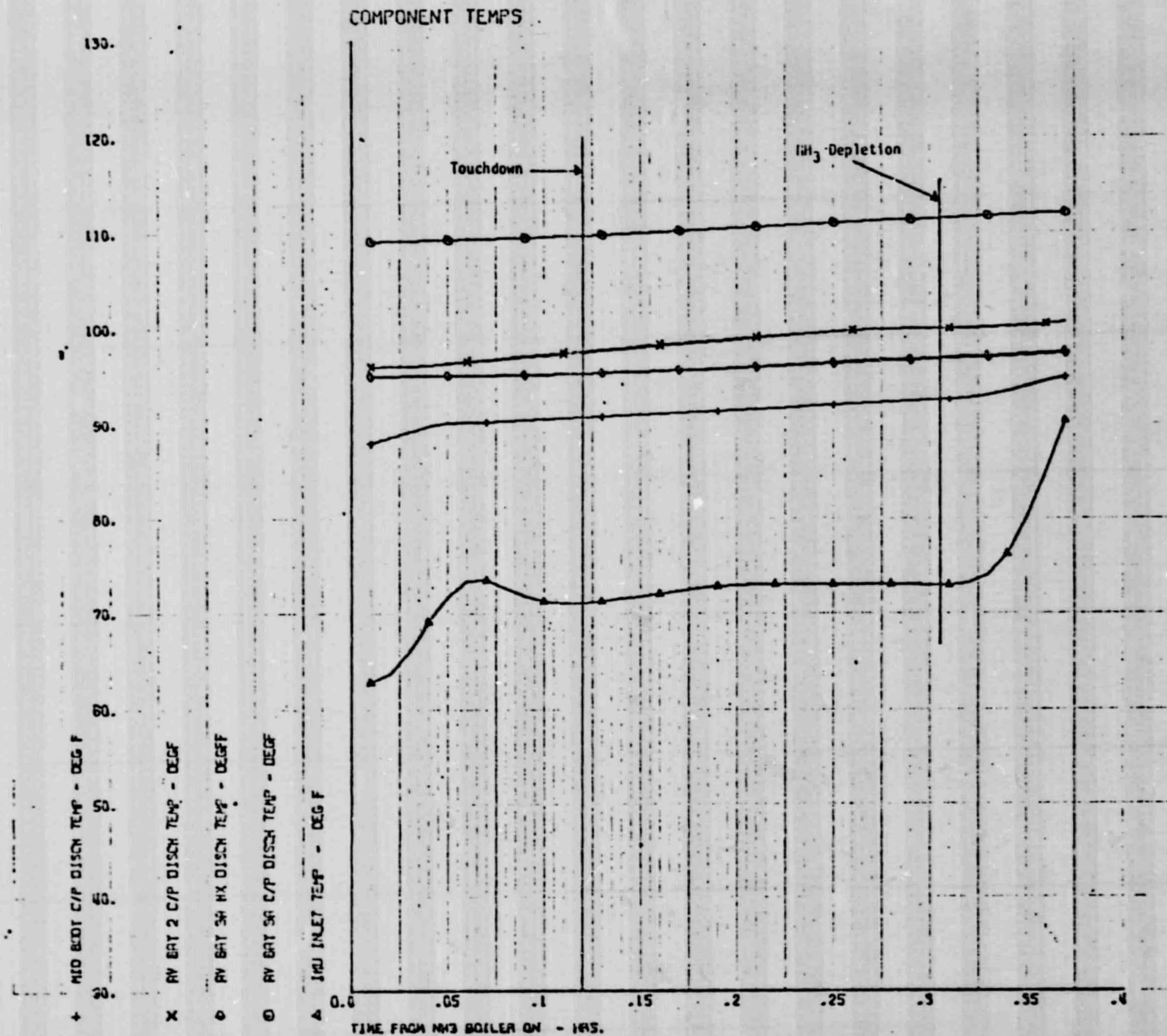

Figure 11. OFT Mission No. 4, Redundant Configuration, One NH_3 Tank - System Temperatures

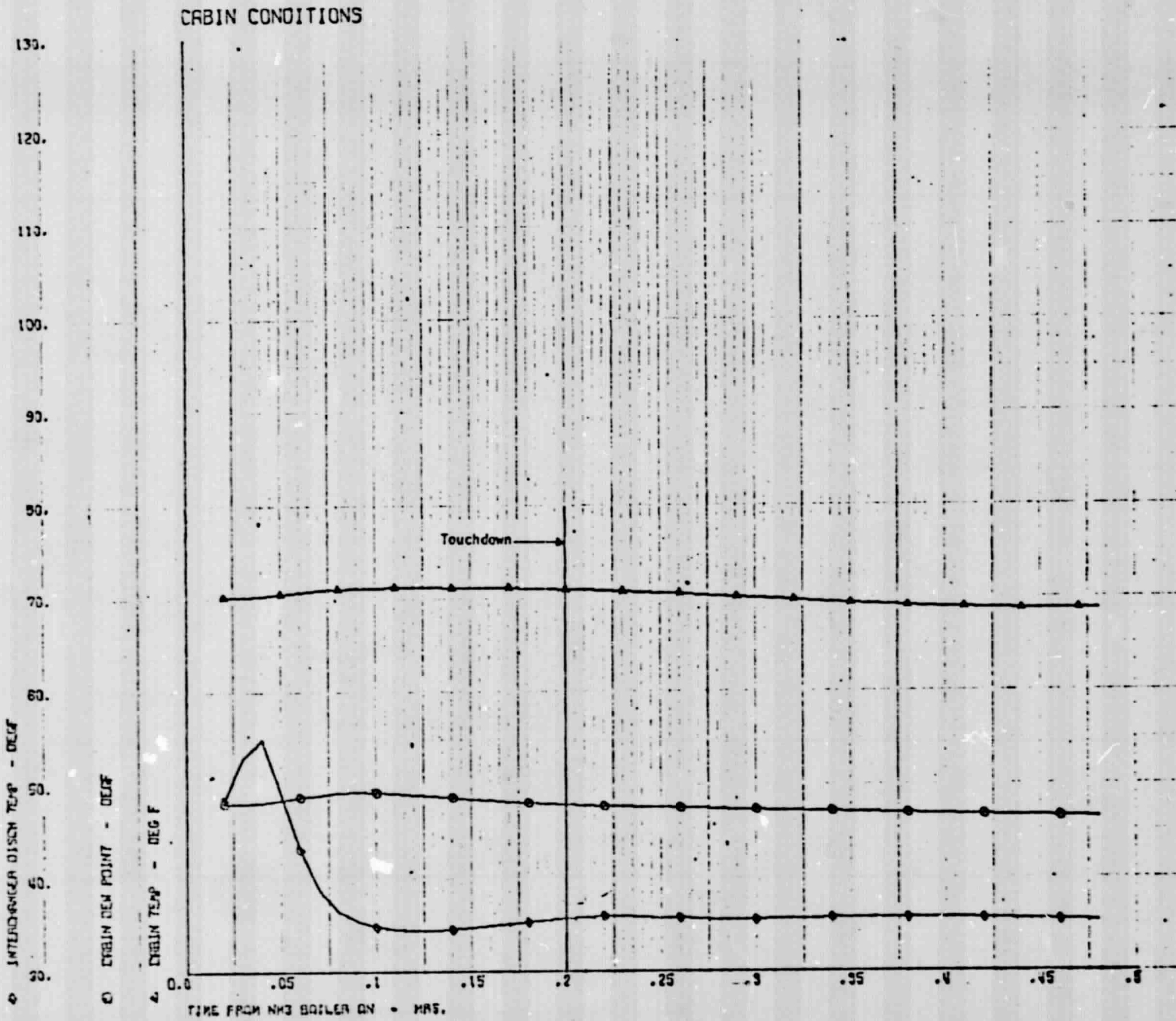

Figure 12. Orbiter 103 Mission, Normal Operation - Cabin Conditions

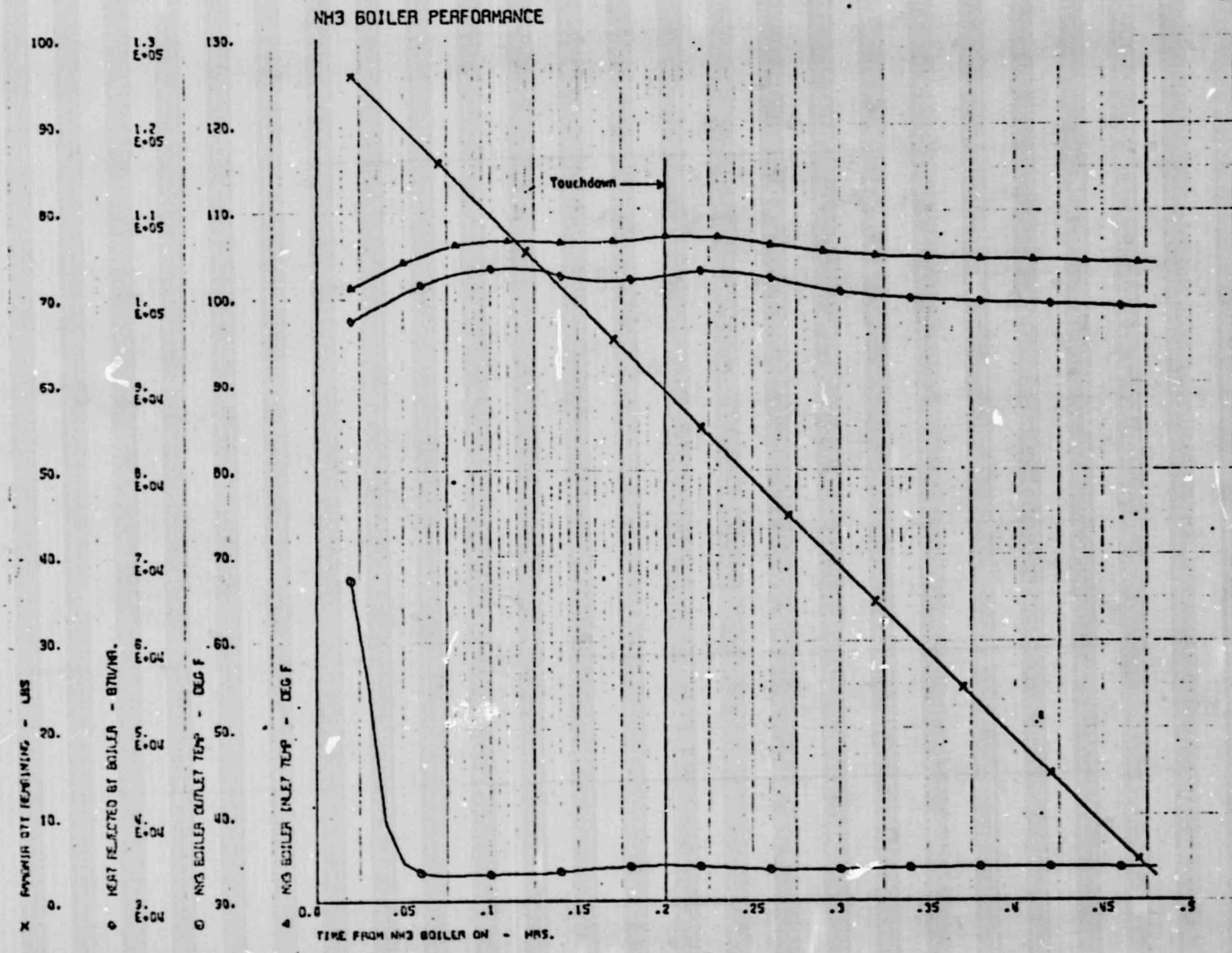

Figure 13. Orbiter 103 Mission, Normal Operation - NH_3 Boiler Performance

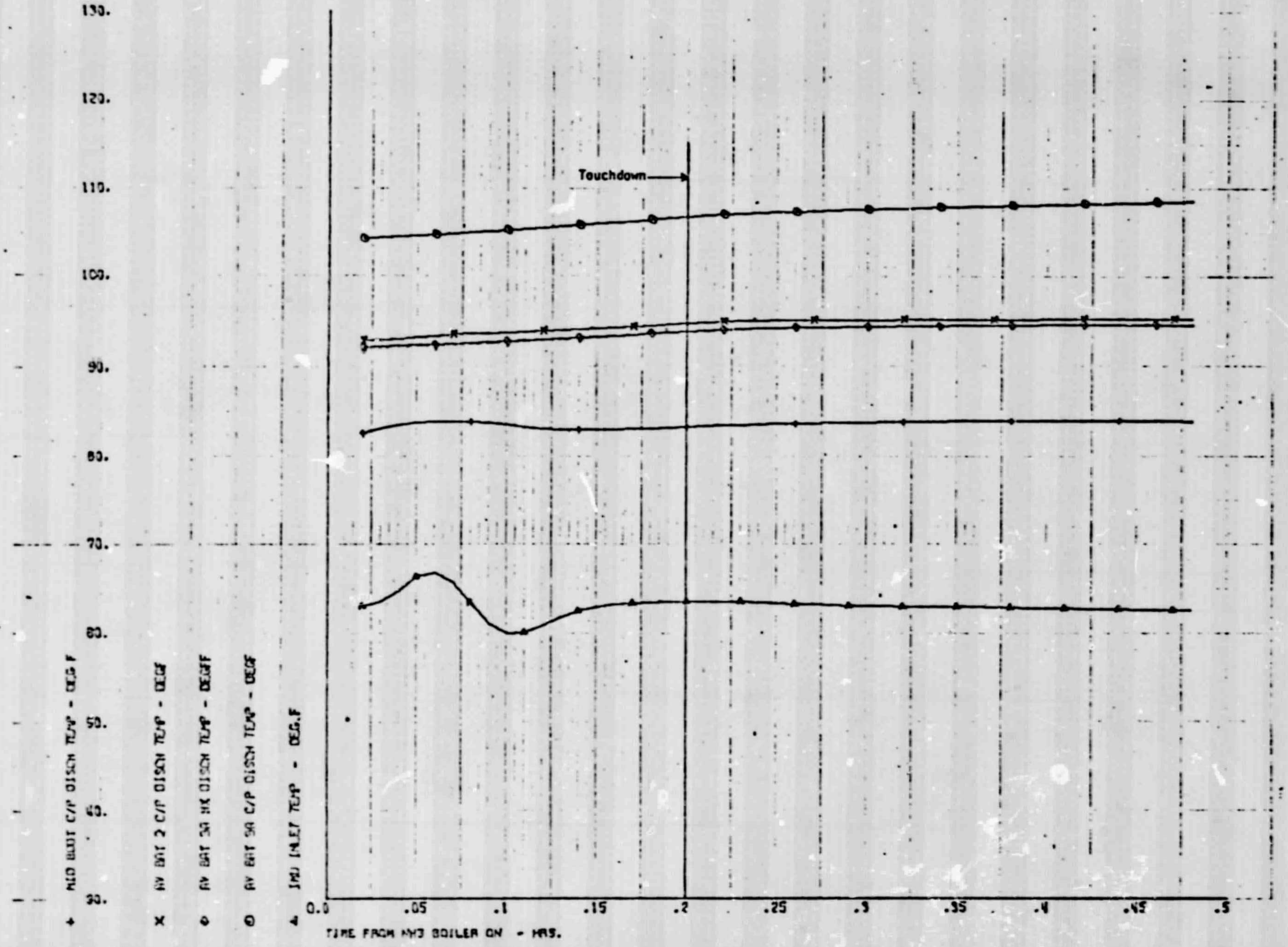

Figure 14. Orbiter 103 Mission, Normal Operation - System Temperatures

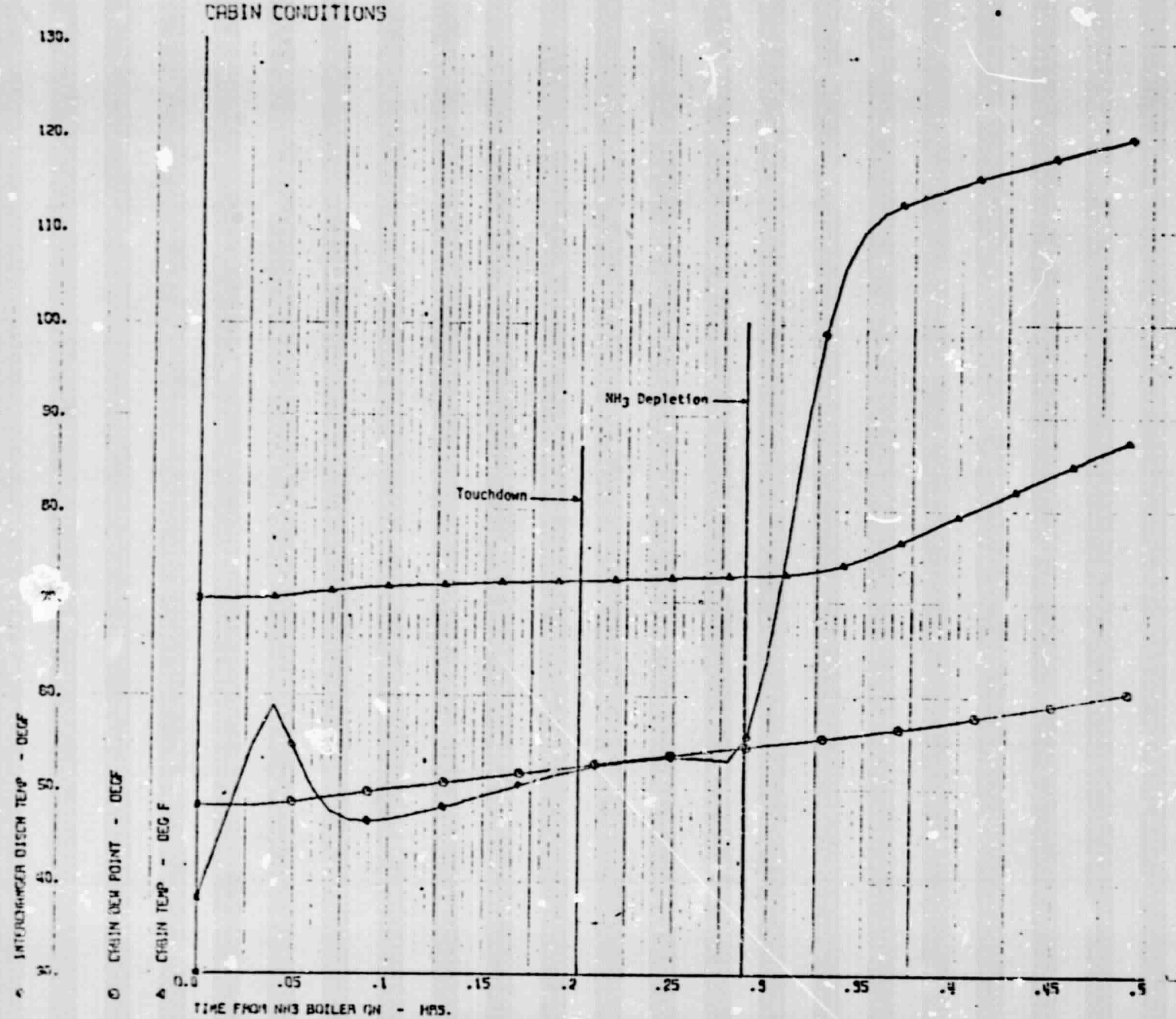

Figure 15. Orbiter 103 Mission, Current Configuration, One NH_3 Tank - Cabin Conditions

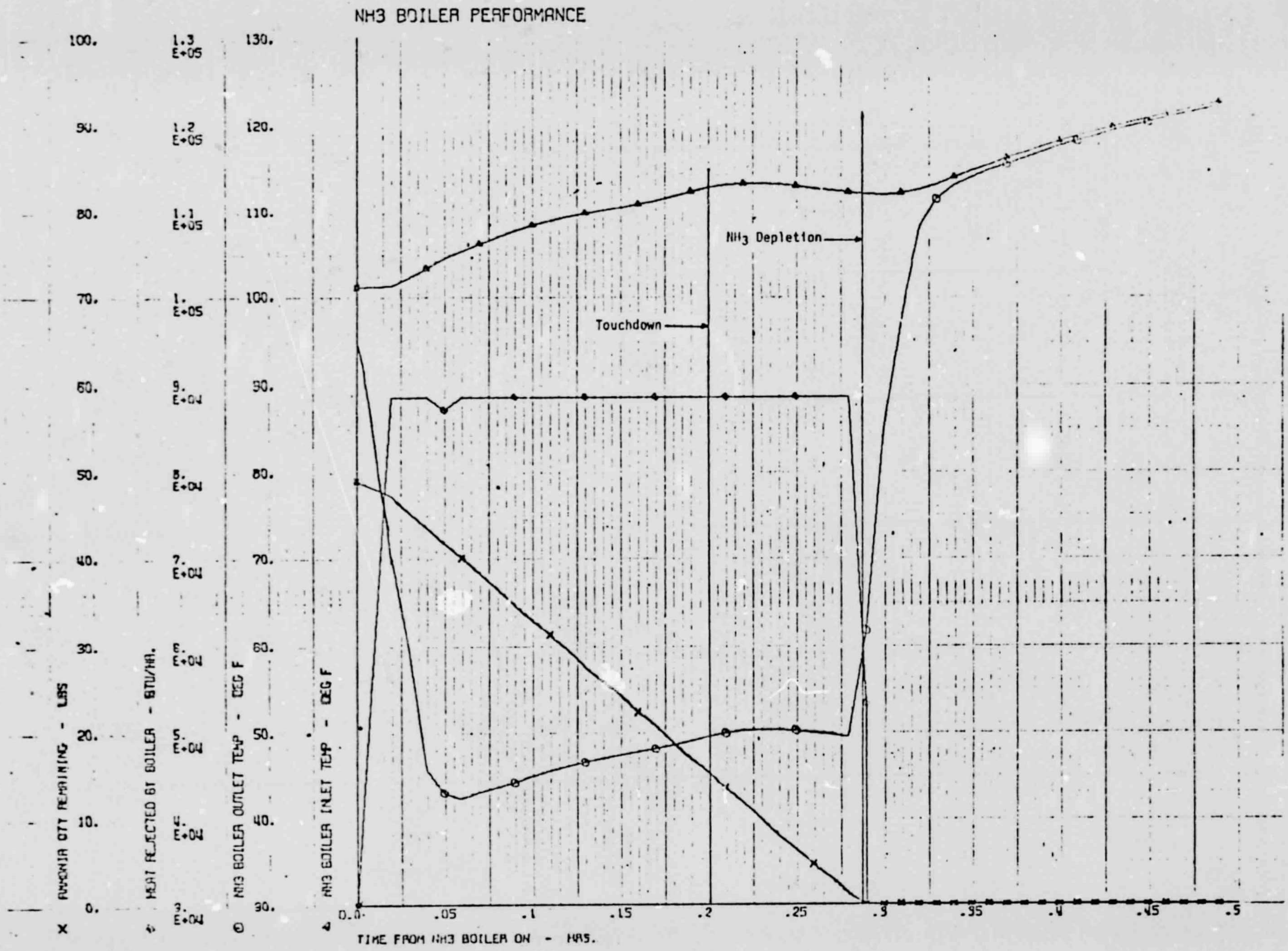

Figure 16. Orbiter 103 Mission, Current Configuration, One NH_3 Tank - NH_3 Boiler Performance

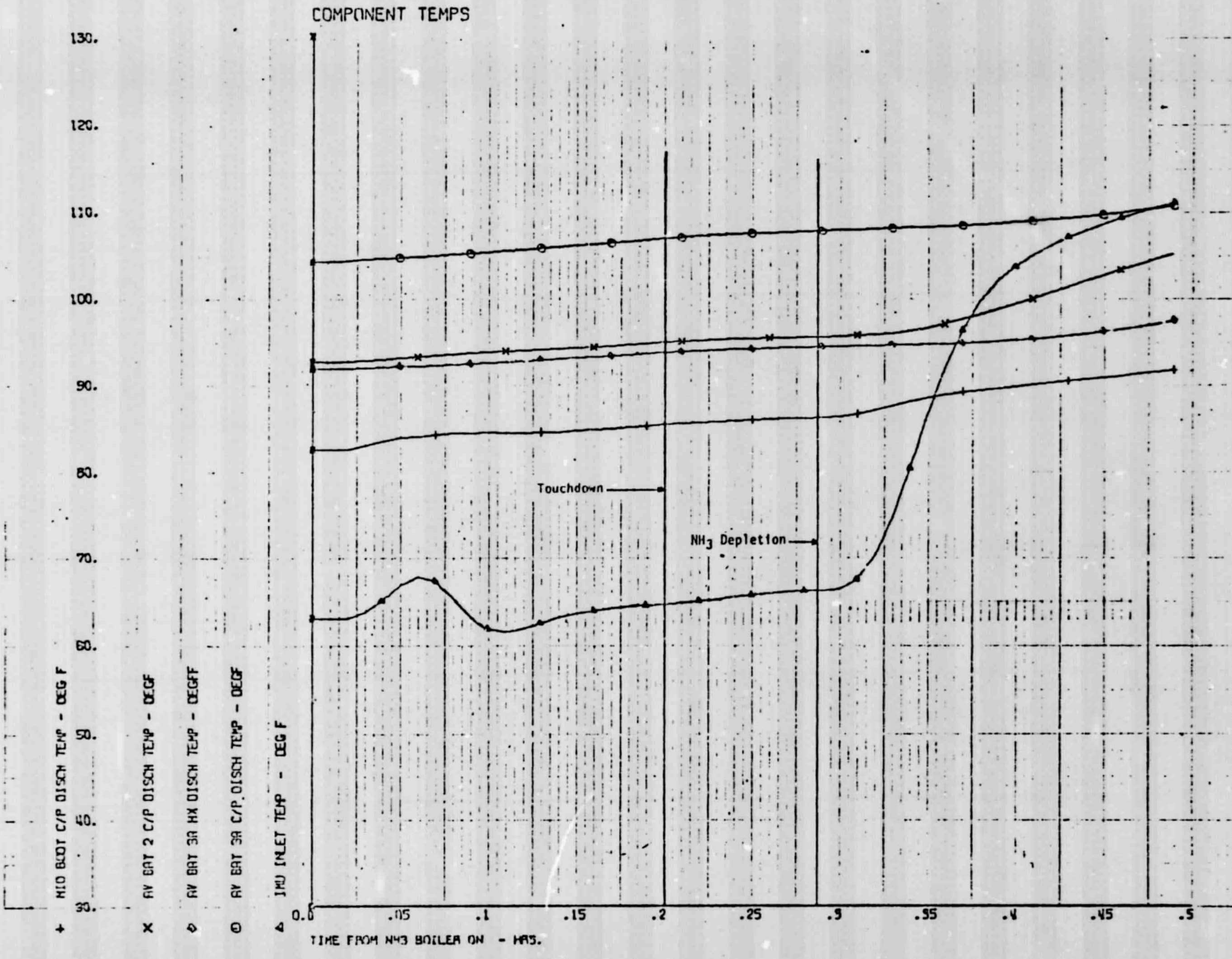

Figure 17. Orbiter 103 Mission, Current Configuration, One NH_3 Tank - System Temperatures

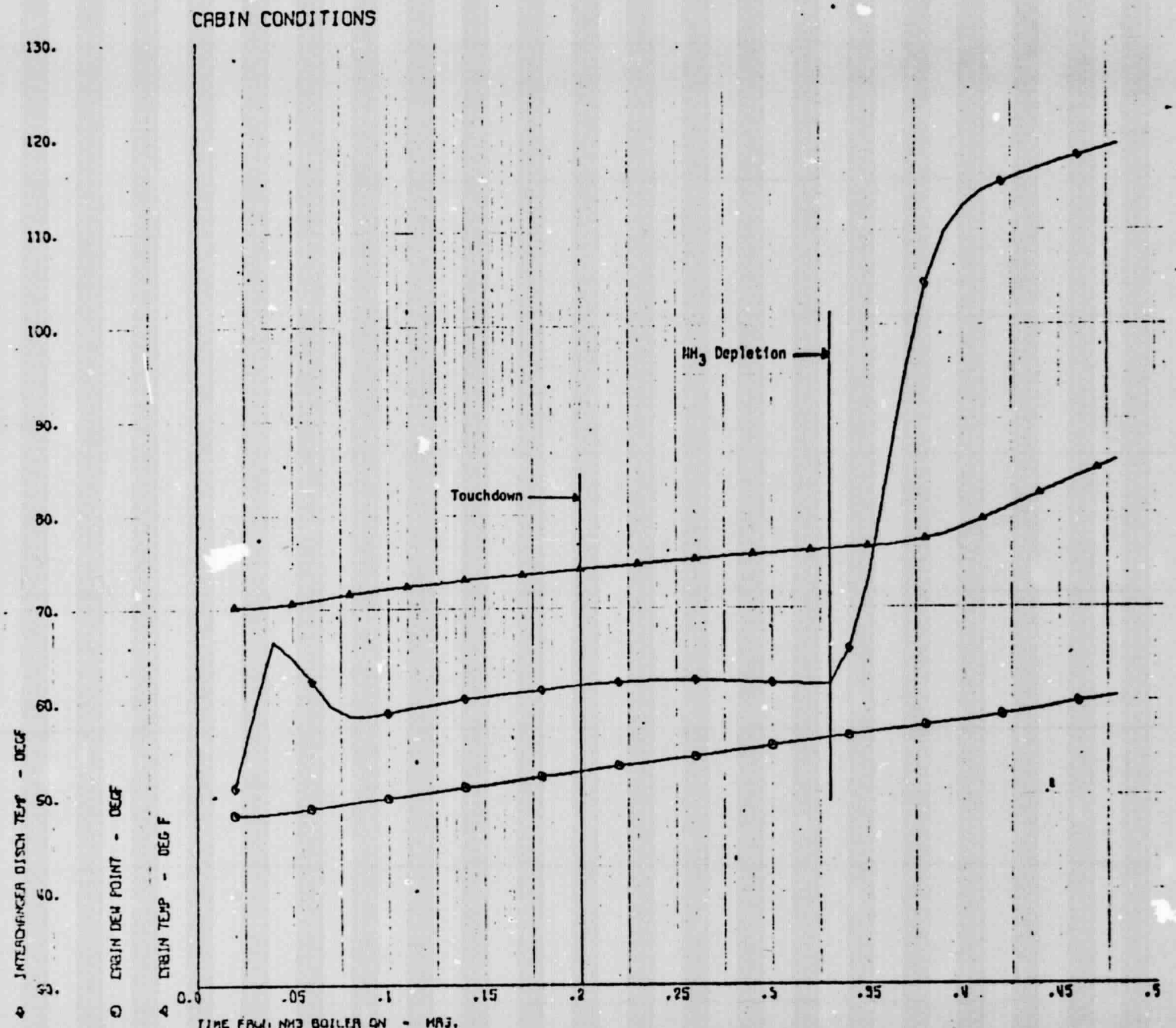

Figure 18. Orbiter 103 Mission, Redundant Configuration, One NH_3 Tank - Cabin Conditions

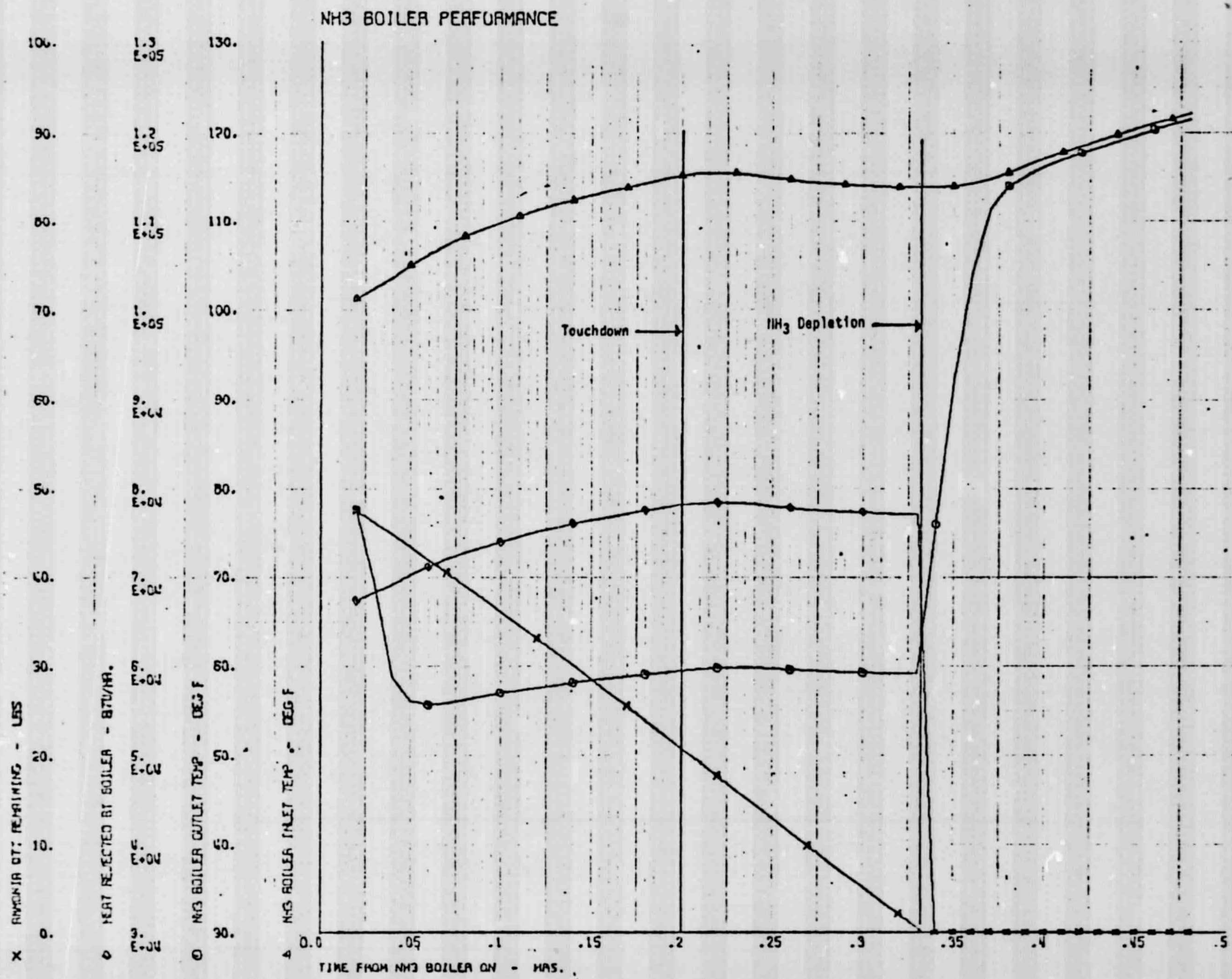

Figure 19. Orbiter 103 Mission, Redundant Configuration, One NH_3 Tank - NH_3 Boiler Performance

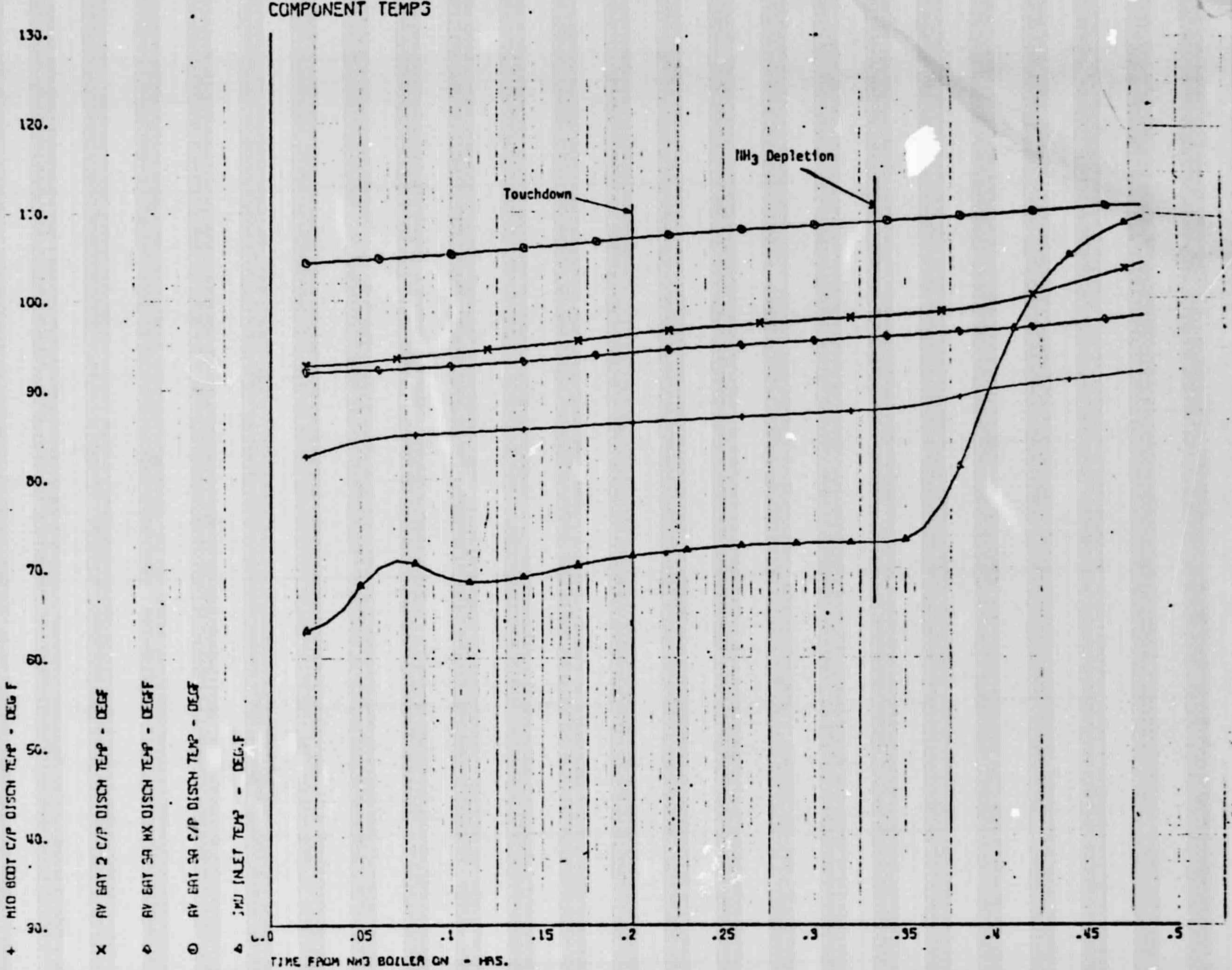

Figure 20. Orbiter 103 Mission, Redundant Configuration, One NH_3 Tank - System Temperatures