

HYDROGEN SOURCE TERM FOR BWR
DEGRADED CORE ACCIDENTS

BY

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BETHESDA, MARYLAND

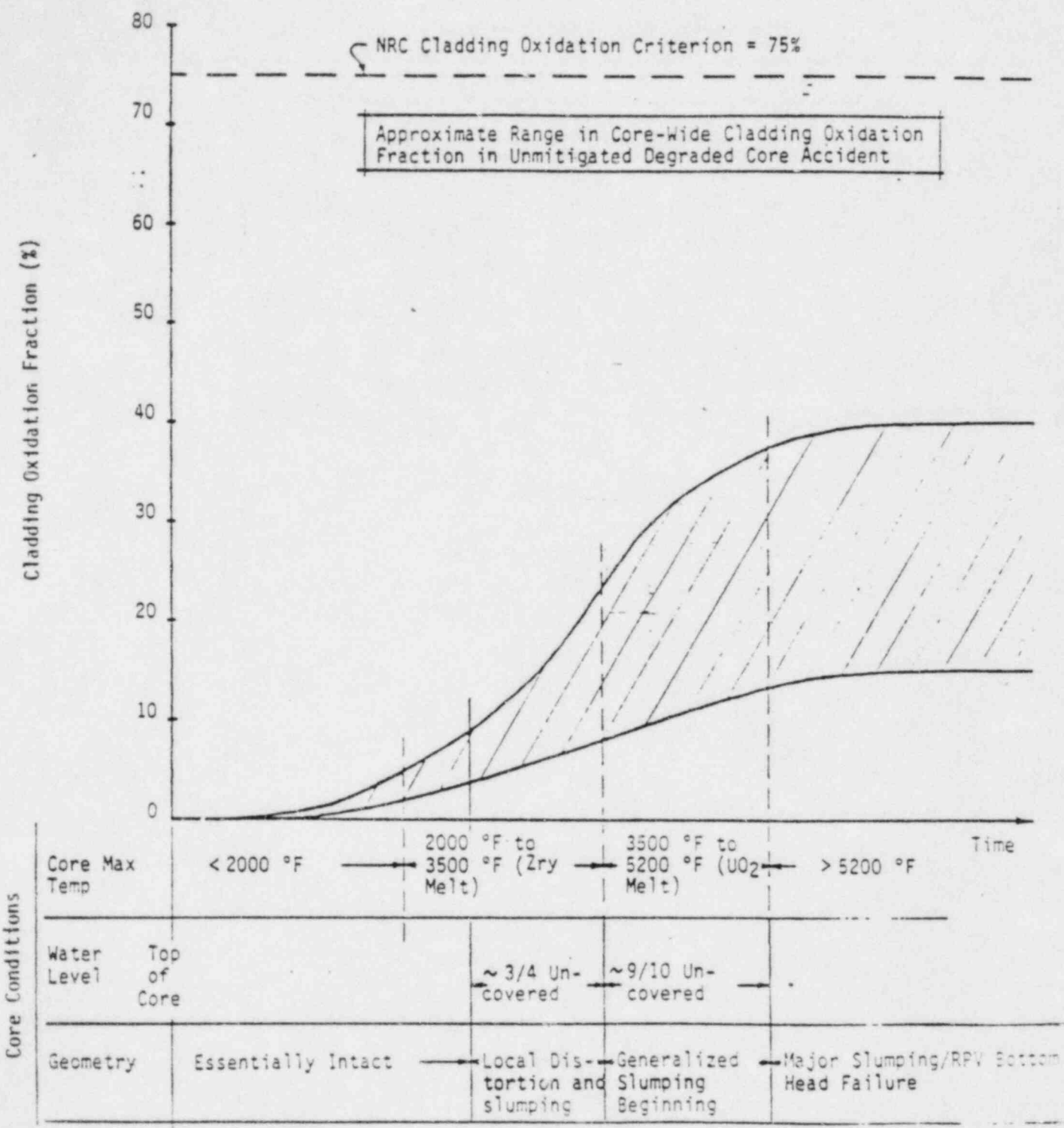
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DEGRADED CORE PHENOMENA

CORE DEGRADATION WITH INSUFFICIENT COOLING

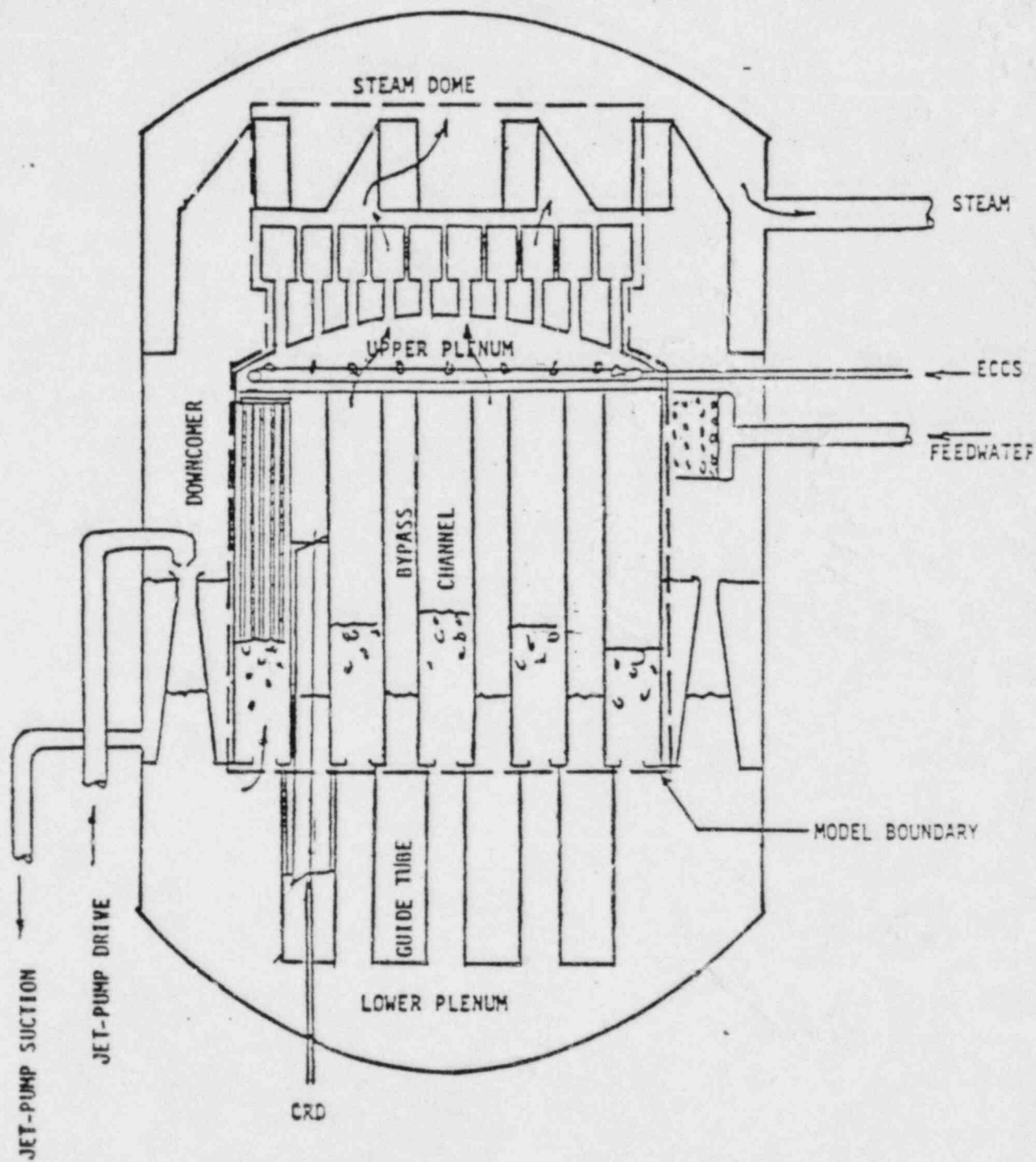
- DEGRADED CORE ACCIDENTS GENERALLY INVOLVE DECAY HEATING OF CORE DUE TO SUSTAINED INADEQUATE CORE COOLING
- CORE DEGRADATION PROGRESSION CHARACTERIZED BY:
 - RELATIVELY SLOW INITIAL HEATUP RATES WITH STEAM COOLING
 - LATER DOMINANCE OF ZIRCALOY OXIDATION EXOTHERMIC ENERGY RELEASE
 - RATE LIMITS FROM LOCAL STEAM OR STEAM/HYDROGEN CONDITIONS
 - HIGH DEGREE OF NONCOHERENCY OF CORE DAMAGE
 - SPATIAL DISTRIBUTION
 - DAMAGE SEVERITY
- RELATIVELY SMALL SYSTEM RESPONSES REQUIRED TO ADEQUATELY SUPPLY SUFFICIENT COOLANT SUPPLIES/HEAT SINKS FOR:
 - PREVENTING CORE DAMAGE DUE TO OVERHEATING
 - INTERRUPTING CORE HEATUP/DEGRADATION PROCESS



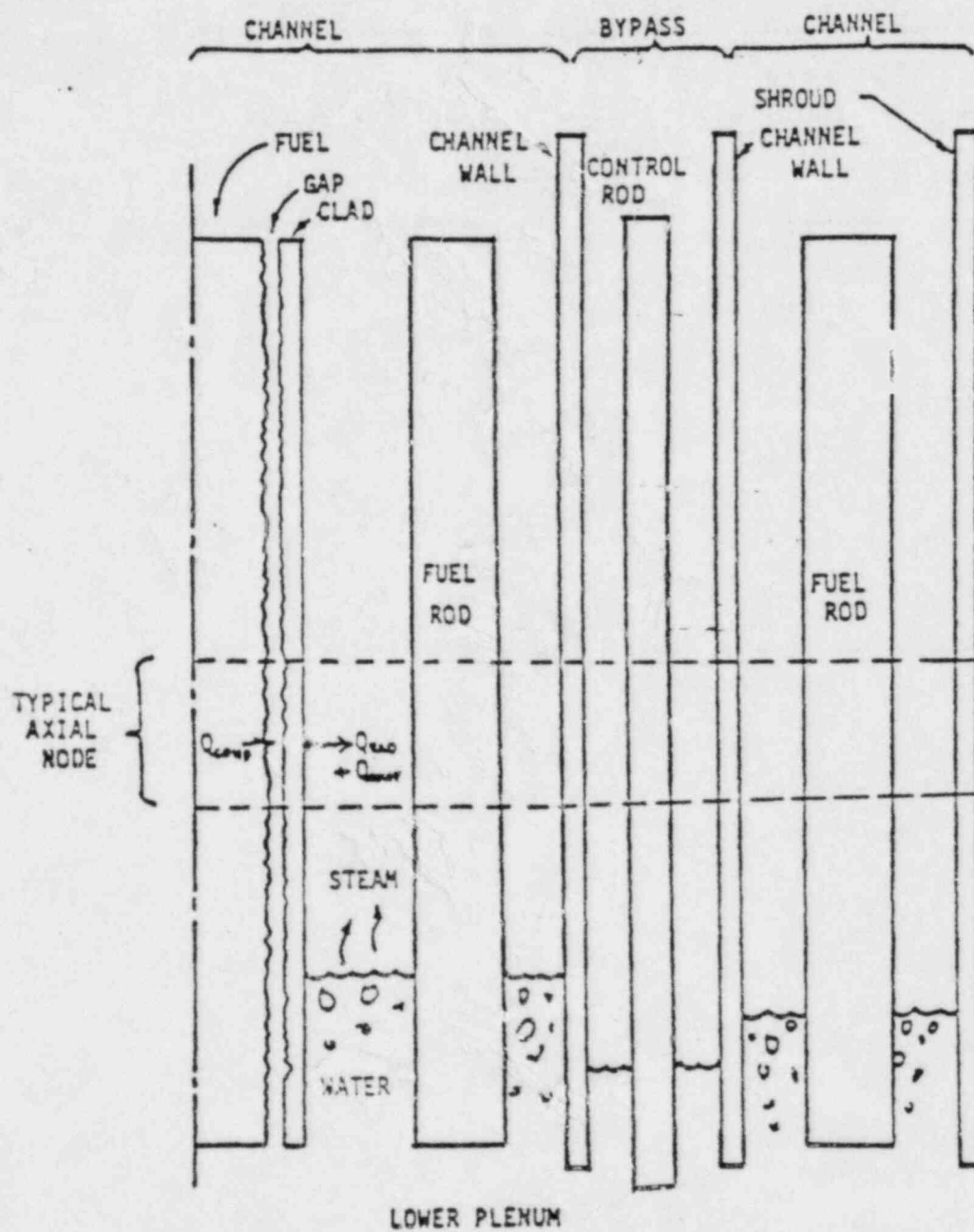
B. R. Thomas
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BWR CORE HEATUP CODE

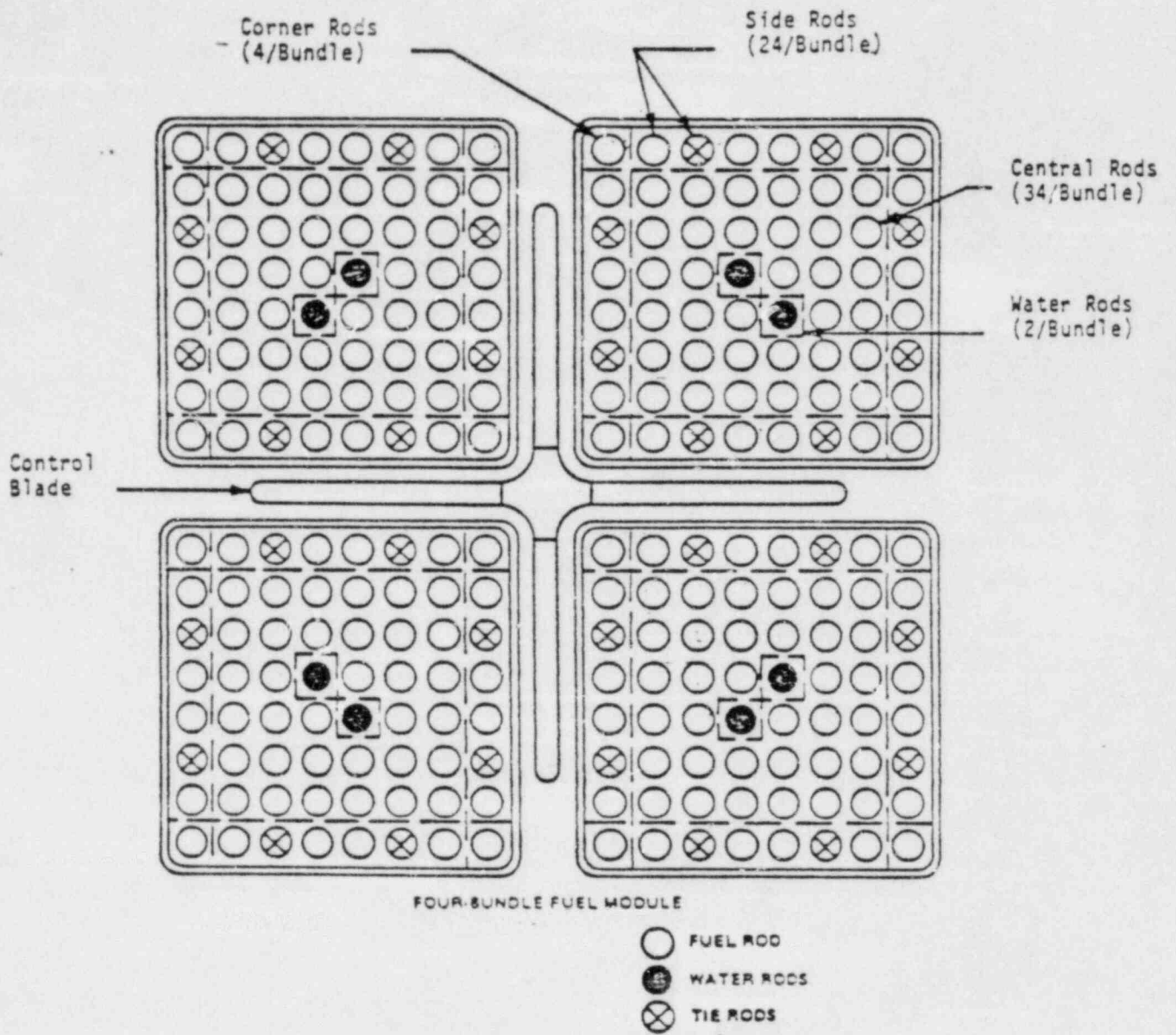
MODELING BASIS



BWR CORE HEATUP MODEL

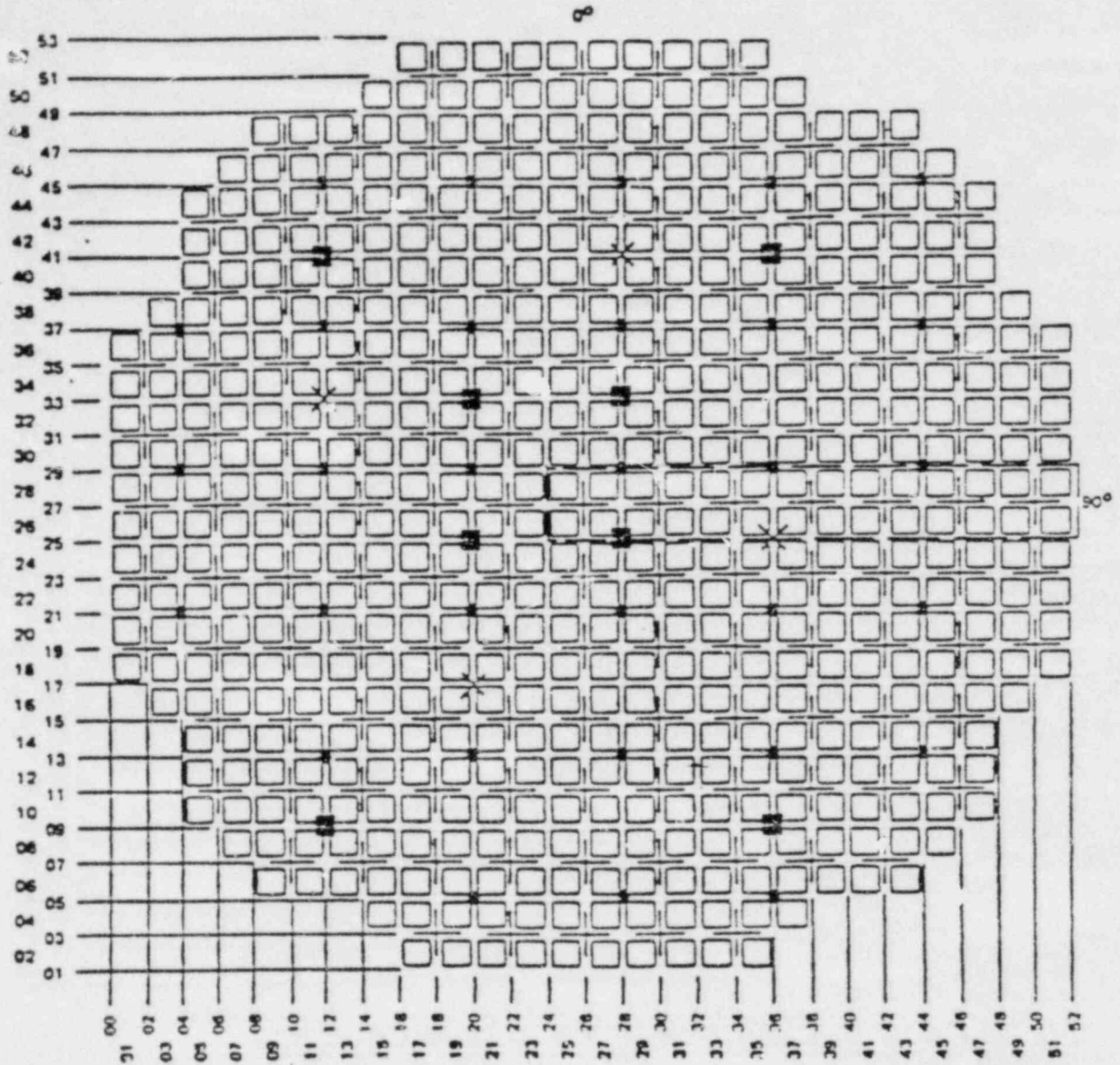


BWR CORE HEATUP CODE CORE MODELING



BWR CORE HEATUP CODE UNIT CELL CONTAINING 4 FUEL BUNDLES
AND 1 CONTROL ROD BLADE

TOP VIEW

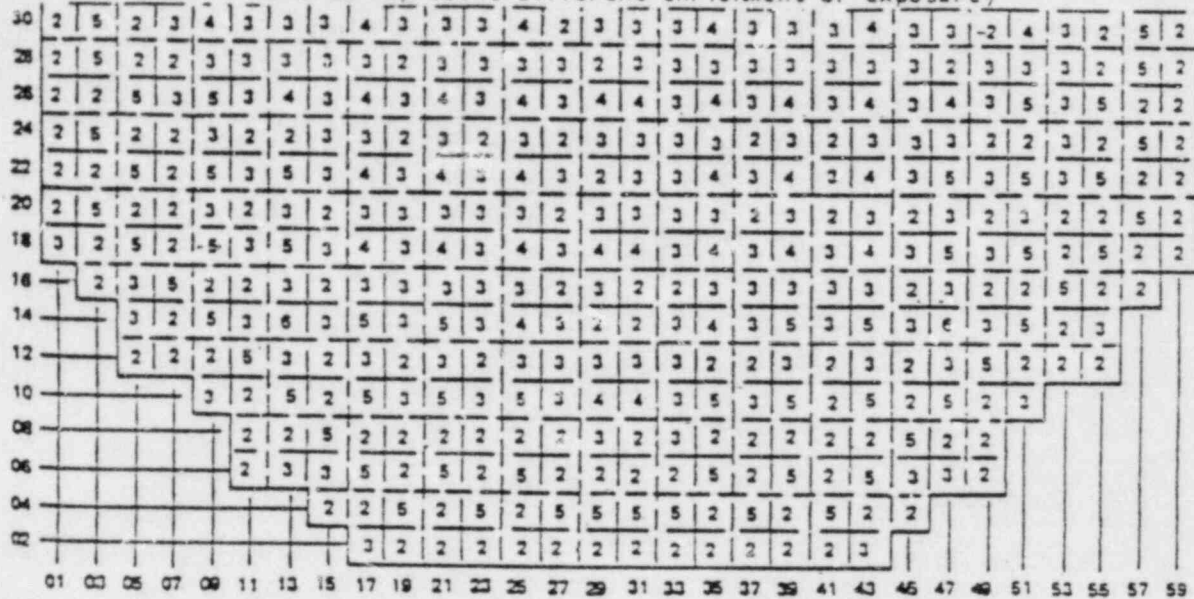


- LOCAL POWER RANGE MONITORING SYSTEM (LPRM) 31
- X SOURCE RANGE MONITORING SYSTEM (SRM) 4
- INTERMEDIATE RANGE MONITORING SYSTEM (IRM) 8
- TOTAL PENETRATIONS FOR NUCLEAR INSTRUMENTS 43

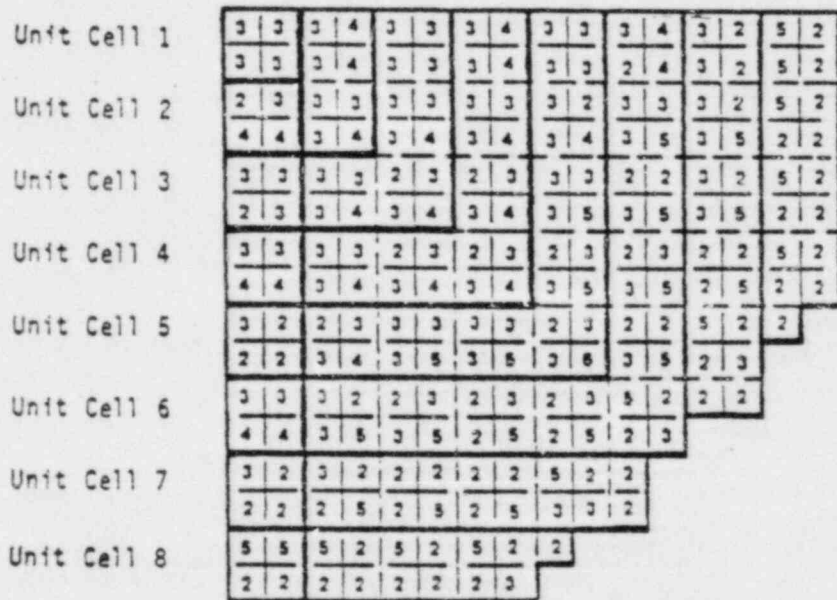
BWR/6 CORE MAP SHOWING RADIAL ARRANGEMENT OF BWR
CORE HEATUP CODE UNIT CELLS

764 Bundle Core Half Core Map - Typical for 2nd Fuel Cycle

(numbers in bundles represent different enrichment or exposure)

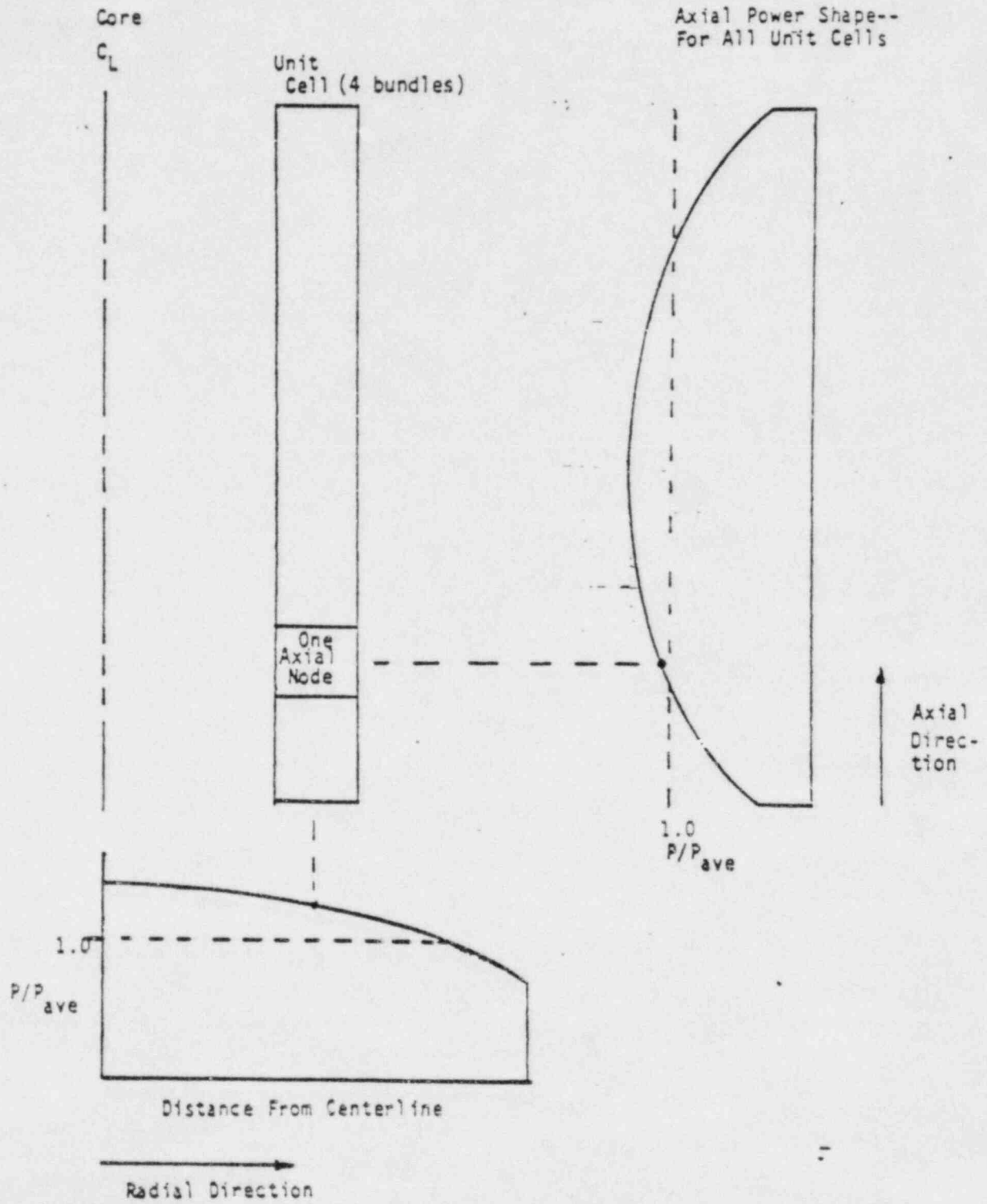


Quarter Core Map Showing Unit Cells and Their Core-Wide Grouping

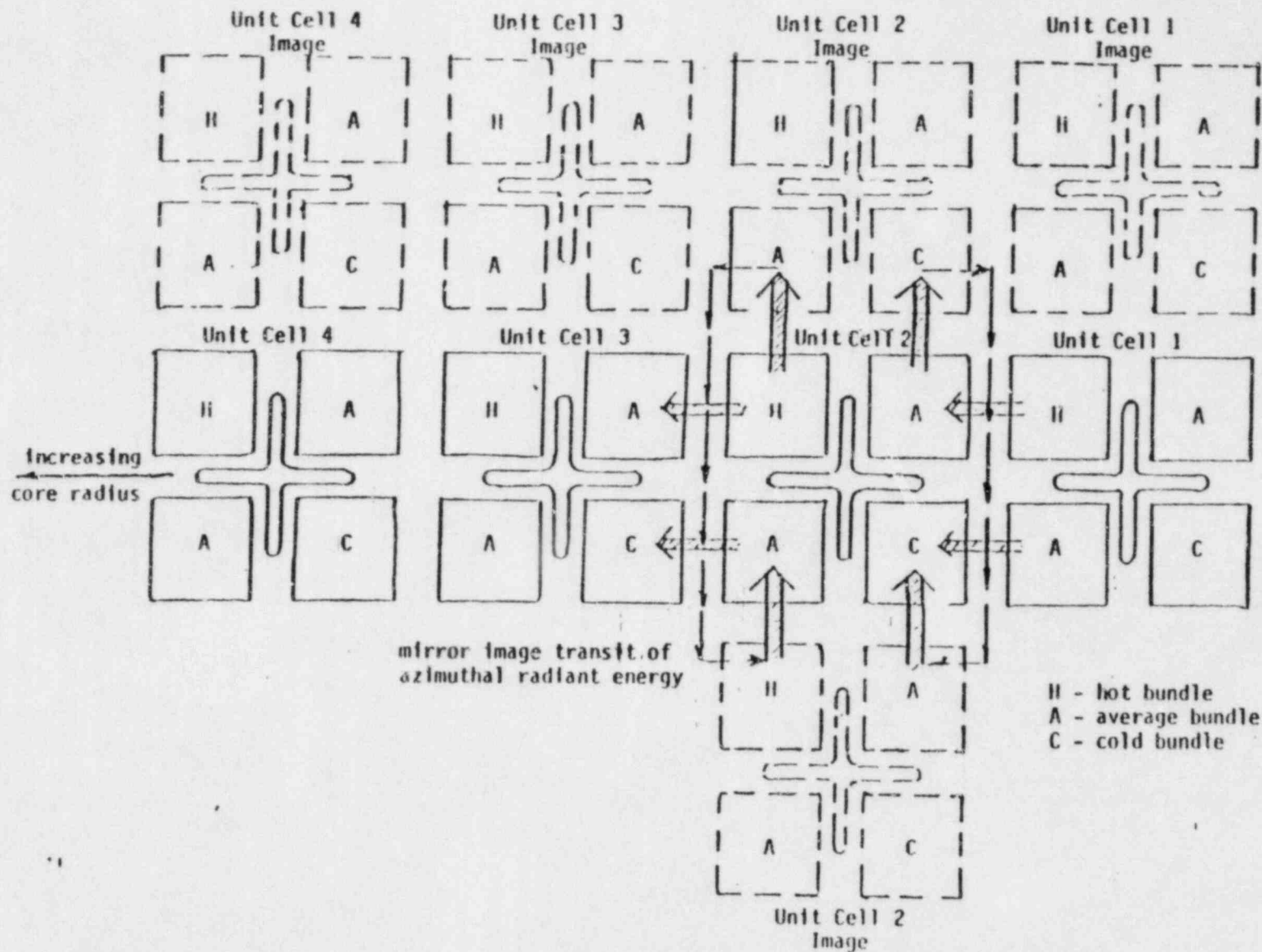


TYPICAL 764 FUEL BUNDLE, 251-INCH RPV BWR/6 CORE MAP
SHOWING RADIAL ARR'G'T OF BWR CORE HEATUP CODE UNIT CELLS

Radial Power Shape--
Function of Position



AXIAL AND RADIAL PEAKING FACTORS



SCHMATIC OF BWR CORE HEATUP CODE UNIT CELL ARRANGEMENT TO ACCOUNT FOR RADIATION BETWEEN ADJOINING BUNDLES AND UNIT CELLS

BWR CORE HEATUP MODEL

- GROSS CORE MODEL
 - UP TO EIGHT FOUR-BUNDLE UNIT CELLS
 - CORE BOTTOM INLET FLOW HYDRAULICALLY SPLIT BETWEEN FUEL BUNDLES AND BYPASS
 - TOTAL LIQUID INVENTORY MASS & ENERGY BOOKKEEPING
 - BUNDLE LEVEL CALCULATIONS BASED ON MANOMETRIC BALANCE WITHIN CHANNELS - ONE BYPASS LEVEL
 - MASS & ENERGY BOOKKEEPING ON VAPOR & HYDROGEN IN DRIED OUT PORTION OF EACH FOUR-BUNDLE UNIT CELL
 - FUEL RODS AND CHANNEL WALLS HEATUP FROM NUCLEAR ENERGY AND OXIDATION (STEAM AND HYDROGEN LIMITED)
 - CONTROL BLADE HEATUP INVOLVES THERMAL RADIATION BETWEEN BUNDLES AND CONTROL BLADES
 - TOP CORE SPRAY INTO UPPER PLENUM
 - CCFL FLOW INTO FUEL BUNDLES
 - BYPASS FILLING WITH ORIFICED FUEL BUNDLE BOTTOM INFLOW

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BWR CORE HEATUP CODE
CODE FEATURES

BWR CORE HEATUP MODEL (CONT'D)

● STRUCTURES OUTSIDE CORE

- SIMPLIFIED ABOVE CORE STRUCTURE (STEAM SEPARATOR/ DRYER) - HEATED BY VAPOR & HYDROGEN FROM CORE
- THERMAL RADIATION MODELING OF SHROUD AND RPV WALL
- DOWNCOMER LEVEL CALCULATION BASED ON RPV MANOMETRIC BALANCE AND CONSISTENT WITH TOTAL RPV INVENTORY

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HYDROGEN SOURCE TERM
CALCULATIONS

- SCOPING STUDY OF H₂ PRODUCTION RATES COMPLETED
- HYDROGEN PRODUCTION DURING HEATUP LIMITED BY STEAM SUPPLY/PRESENCE OF HYDROGEN
- PROGRESSING DEGRADED CORE ACCIDENT (NO ATTEMPT AT CORE RECOVERING) DOES NOT RESULT IN MAXIMUM H₂ RATE PRODUCTION
- PROBABLE MAXIMUM H₂ RATE PRODUCTION OCCURS IN EARLY PHASE OF RECOVERING OF CORE (ECCS INJECTION) STARTING FROM ALREADY ADVANCED HEATUP (PORTIONS OF CORE AT OR ABOUT ZIRCALOY MELT CONDITIONS)
- ABSOLUTE H₂ PRODUCTION RATE PEAKS IN CORE WILL BE SOMEWHAT MUTED WHEN H₂ FLOWS REACH DRYWELL/WETWELL

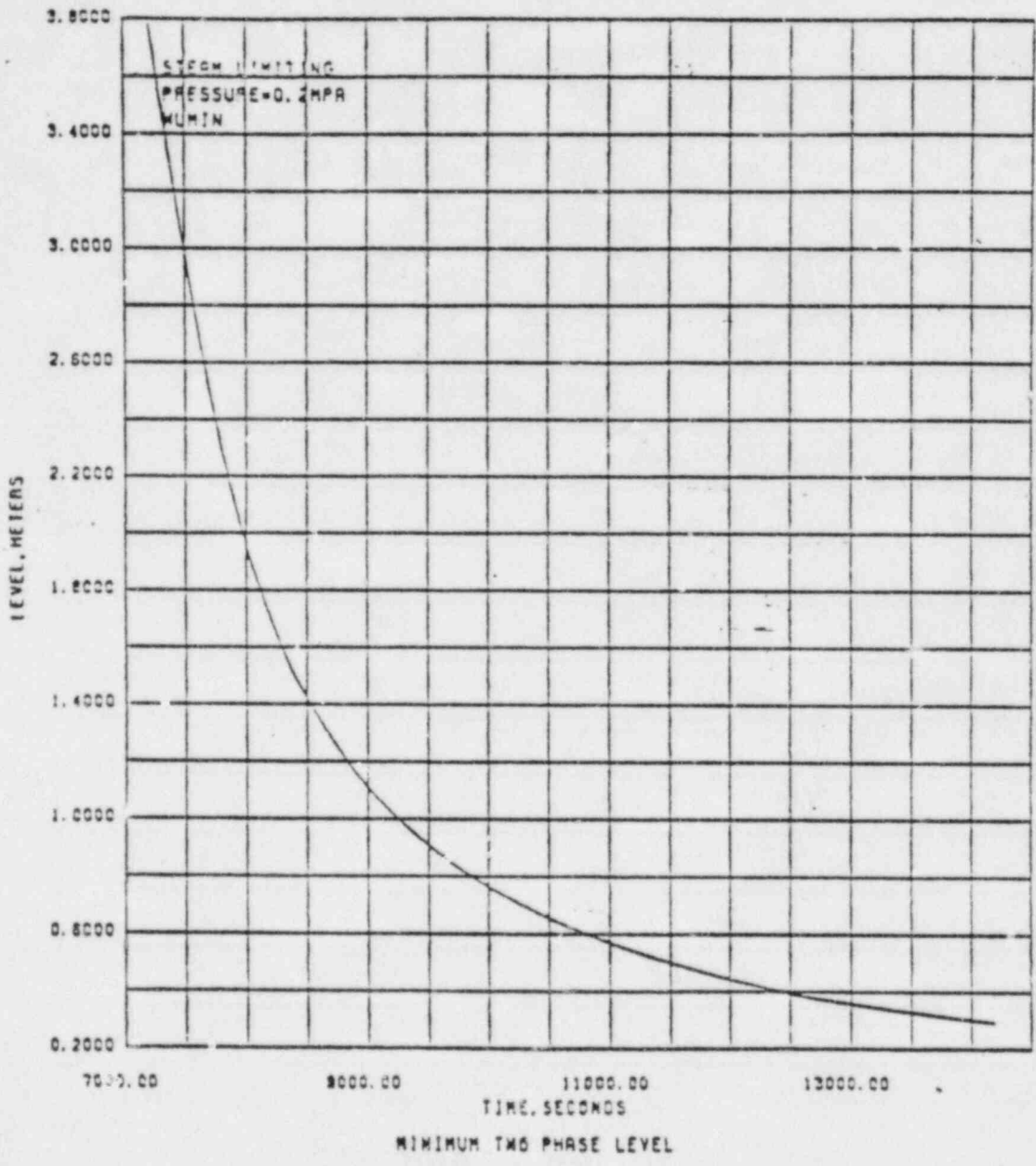
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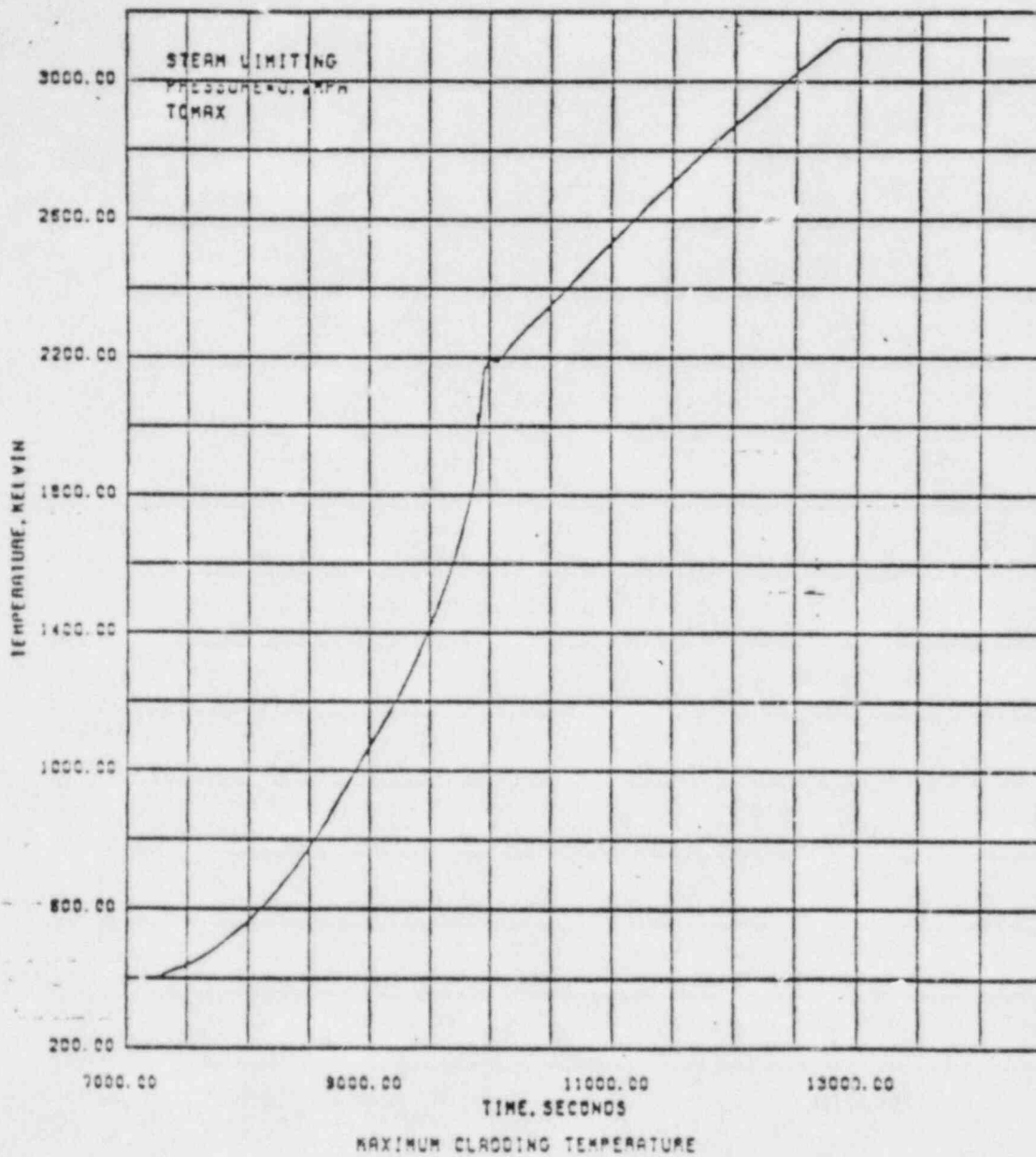
HYDROGEN SOURCE TERM CALCULATIONS

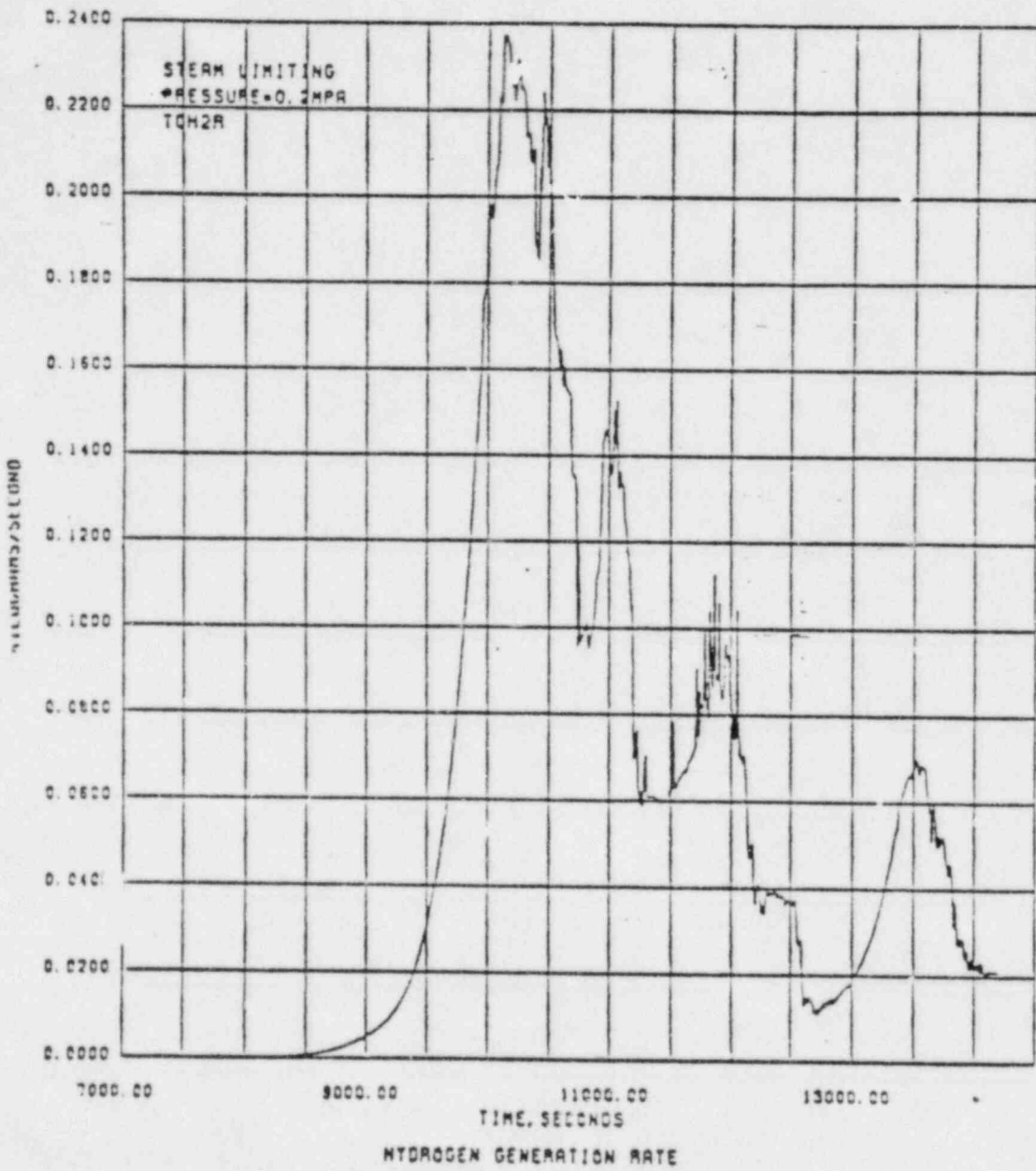
SCOPING STUDY RESULTS

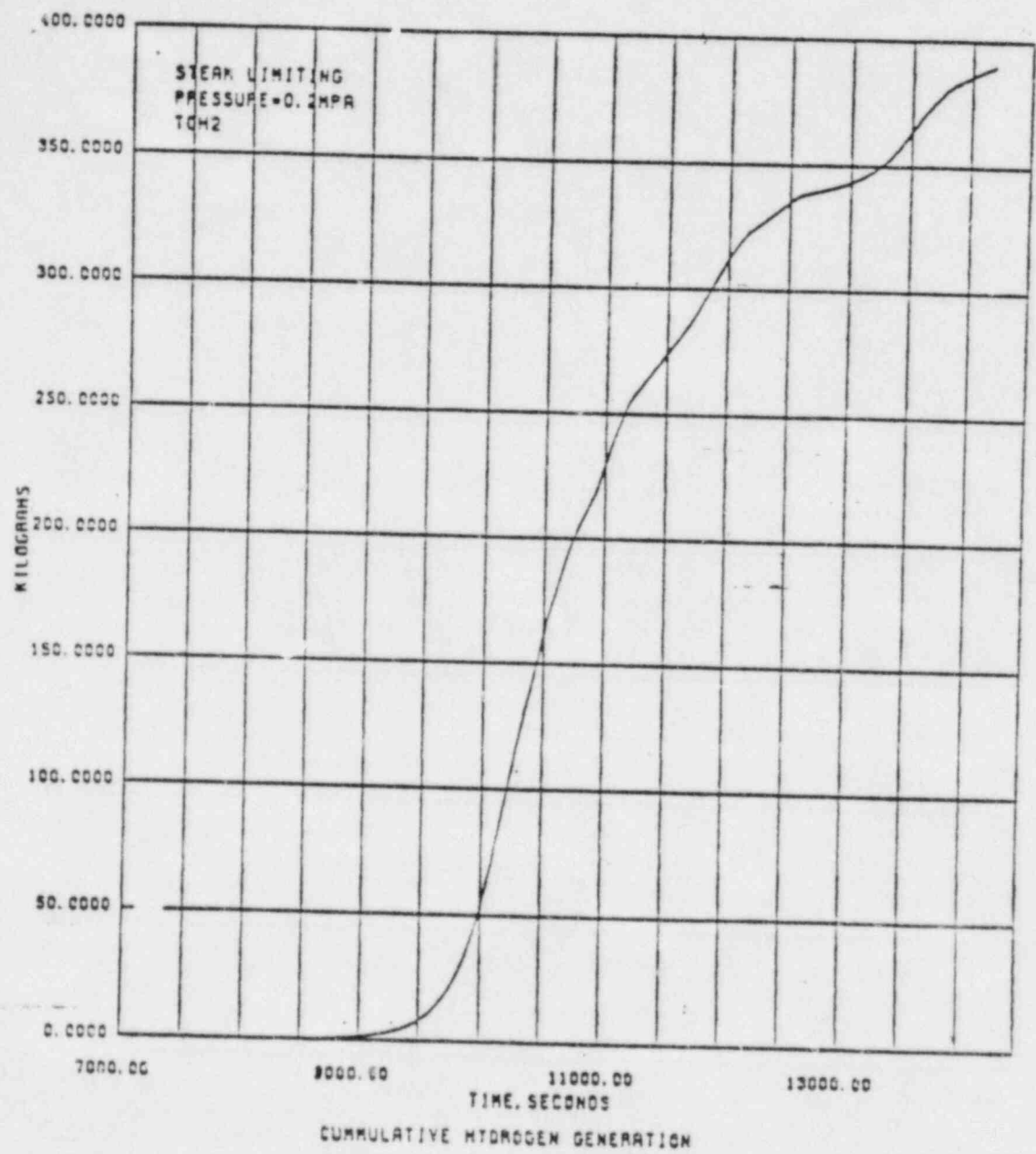
RUN	ACCIDENT CONDITIONS					RESULTS	
	PRESSURE (ATM)	RADIATION MODEL	START OF CORE UNCOVERING (SEC)	START OF CORE RECOVERY (SEC)	CORE FLOW (LBM/SEC)	H ₂ PEAK	PRODUCTION (LBM/SEC) SUSTAINED MAX.
1	~2	FULL	7200	--	0	~0.5	~0.5 (~10 MIN.)
2	~2	UNIT CELL	7200	--	0	~0.5	
3	~40	FULL	7200	--	0	~0.66	~0.5 (~15 MIN.)
4	~40	FULL	7200	10,000	8 (CRD)	~0.8	~0.6 (~10 MIN.)
5	~40	FULL	7200	10,000	90 (RCIC)	~1.5 (<1 MIN)	~0.8 (~10 MIN.)
6	~40	UNIT CELL	7200	10,000	660 (CORE SPRAY)	~1.35	~0.6 (~ 7 MIN.)

RUN 1

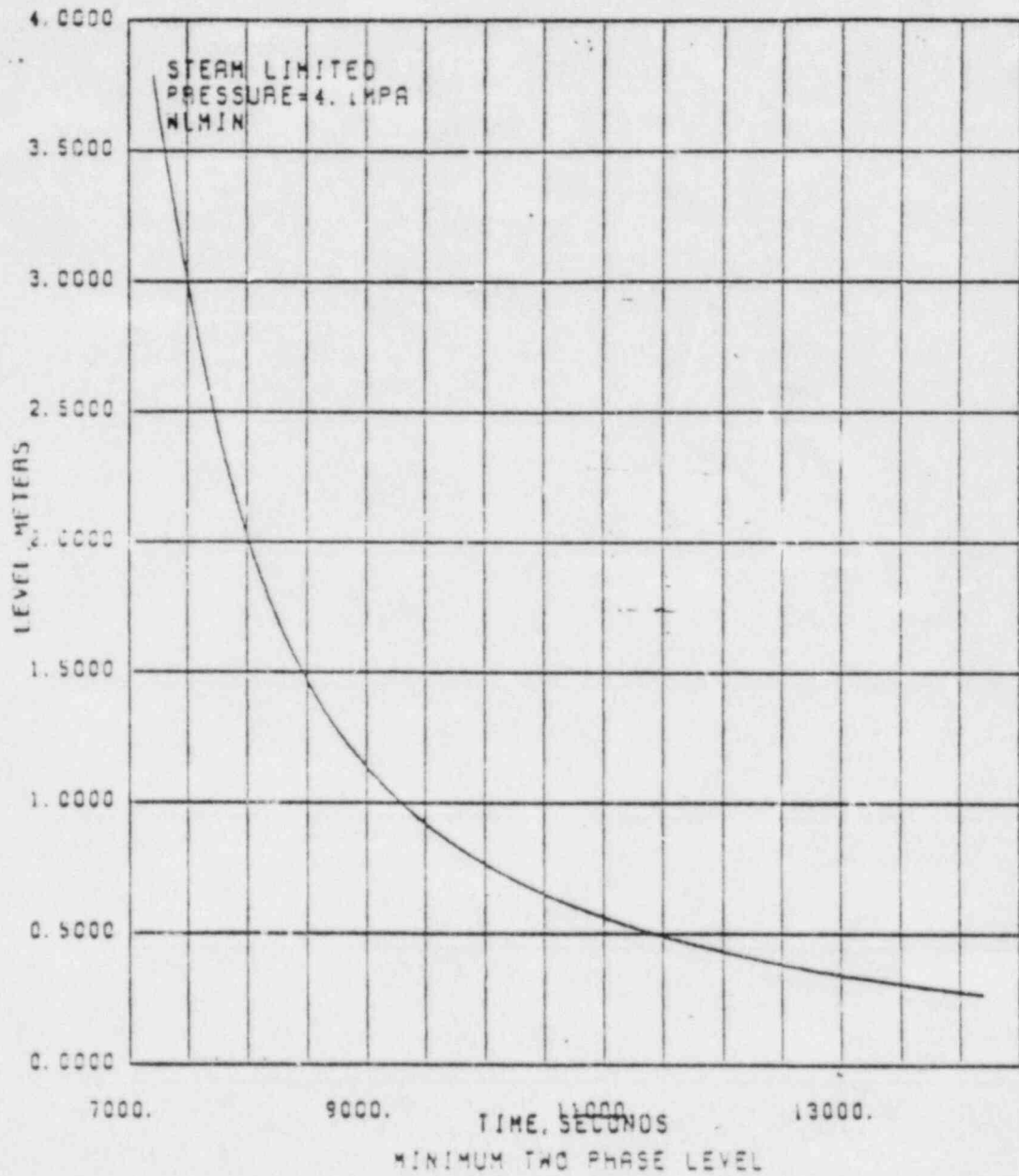


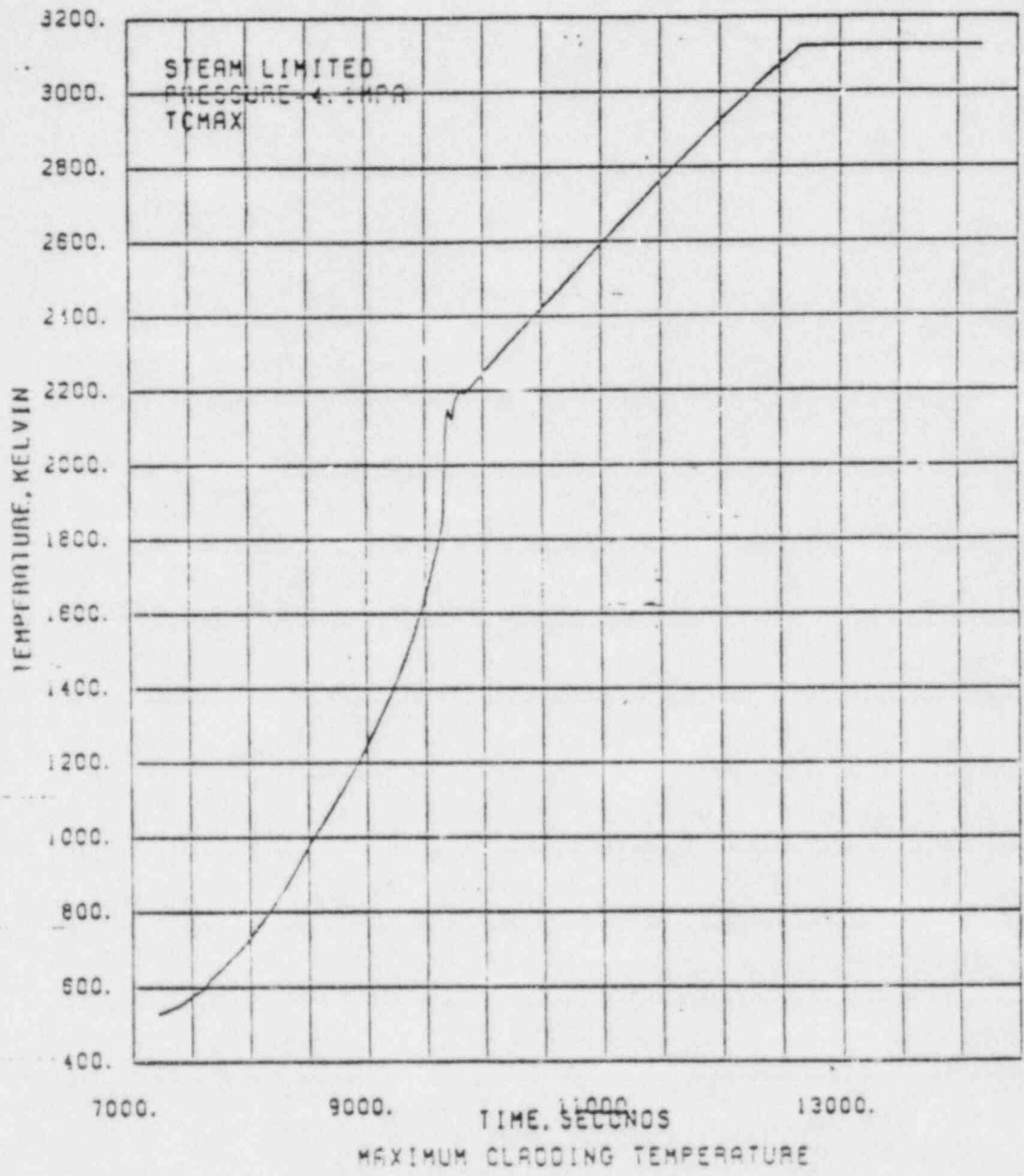


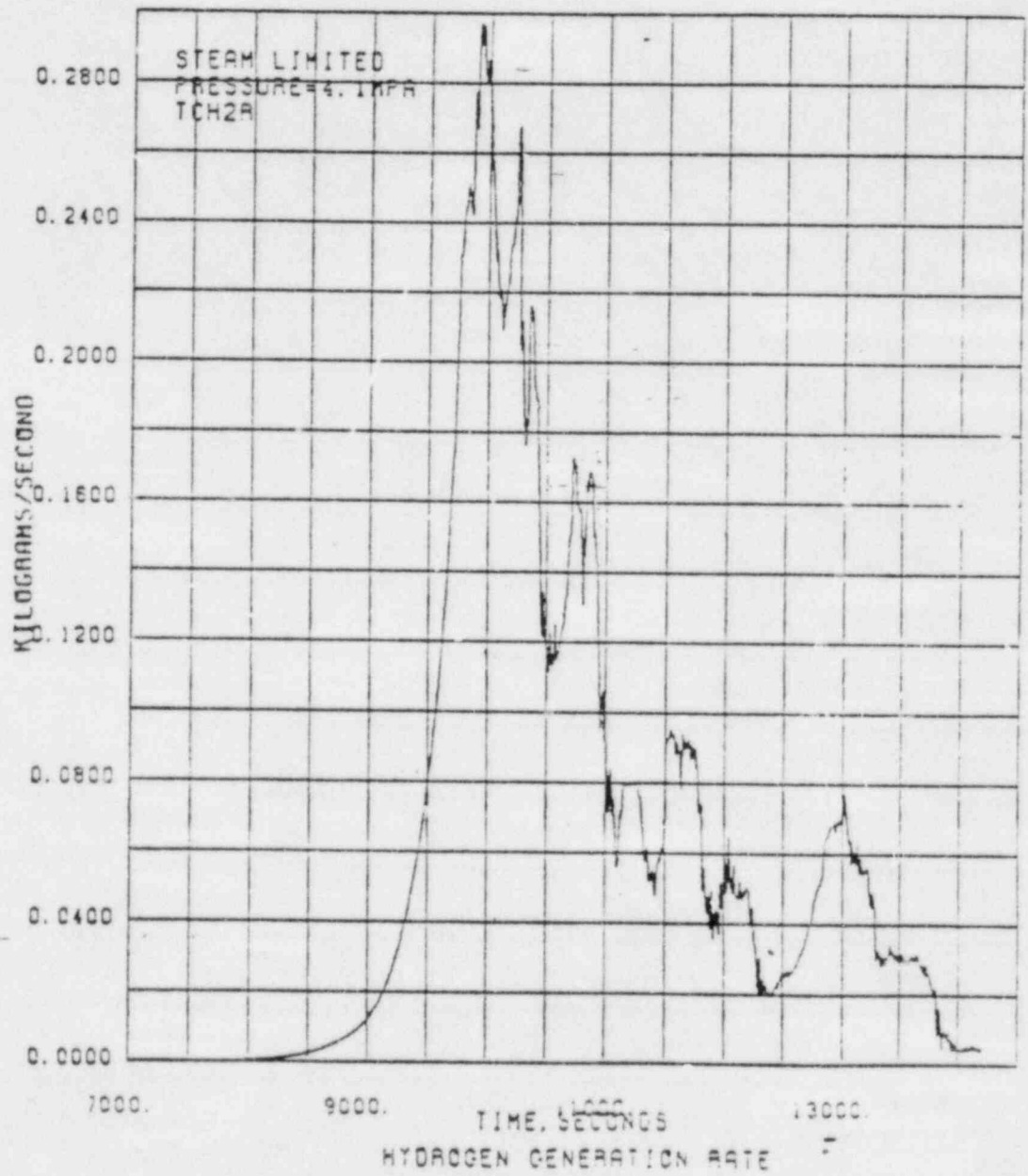


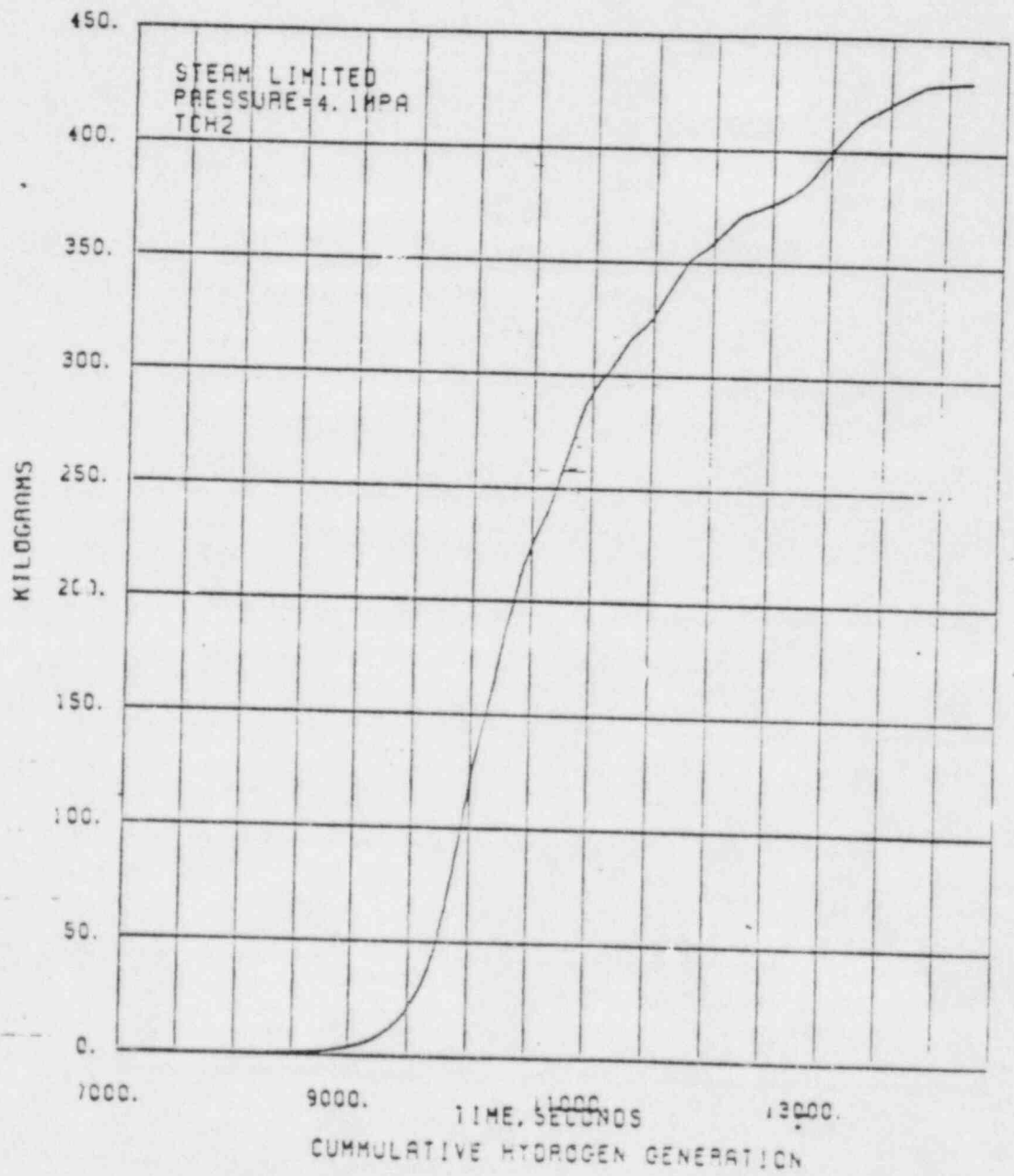


RUN 3

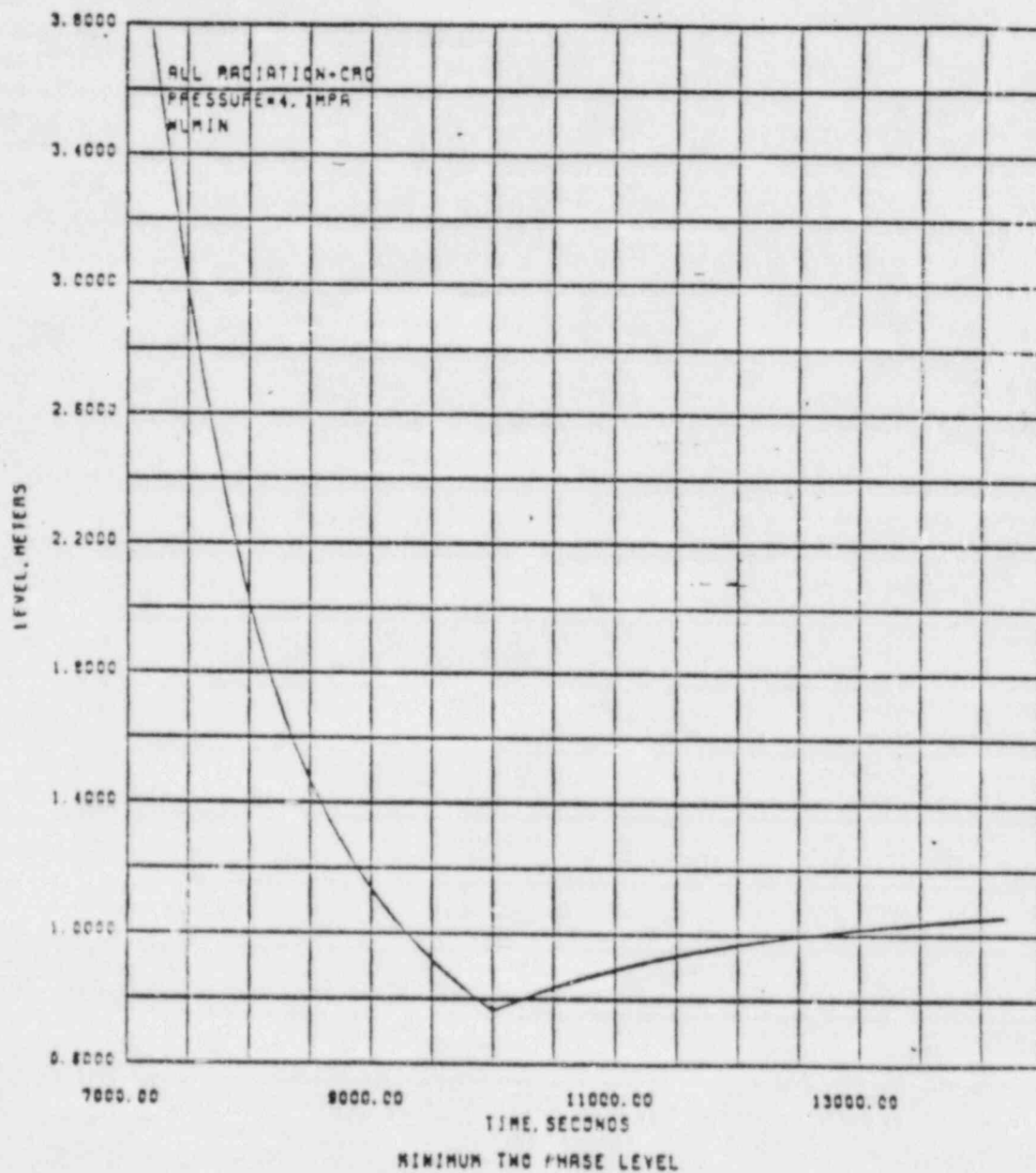


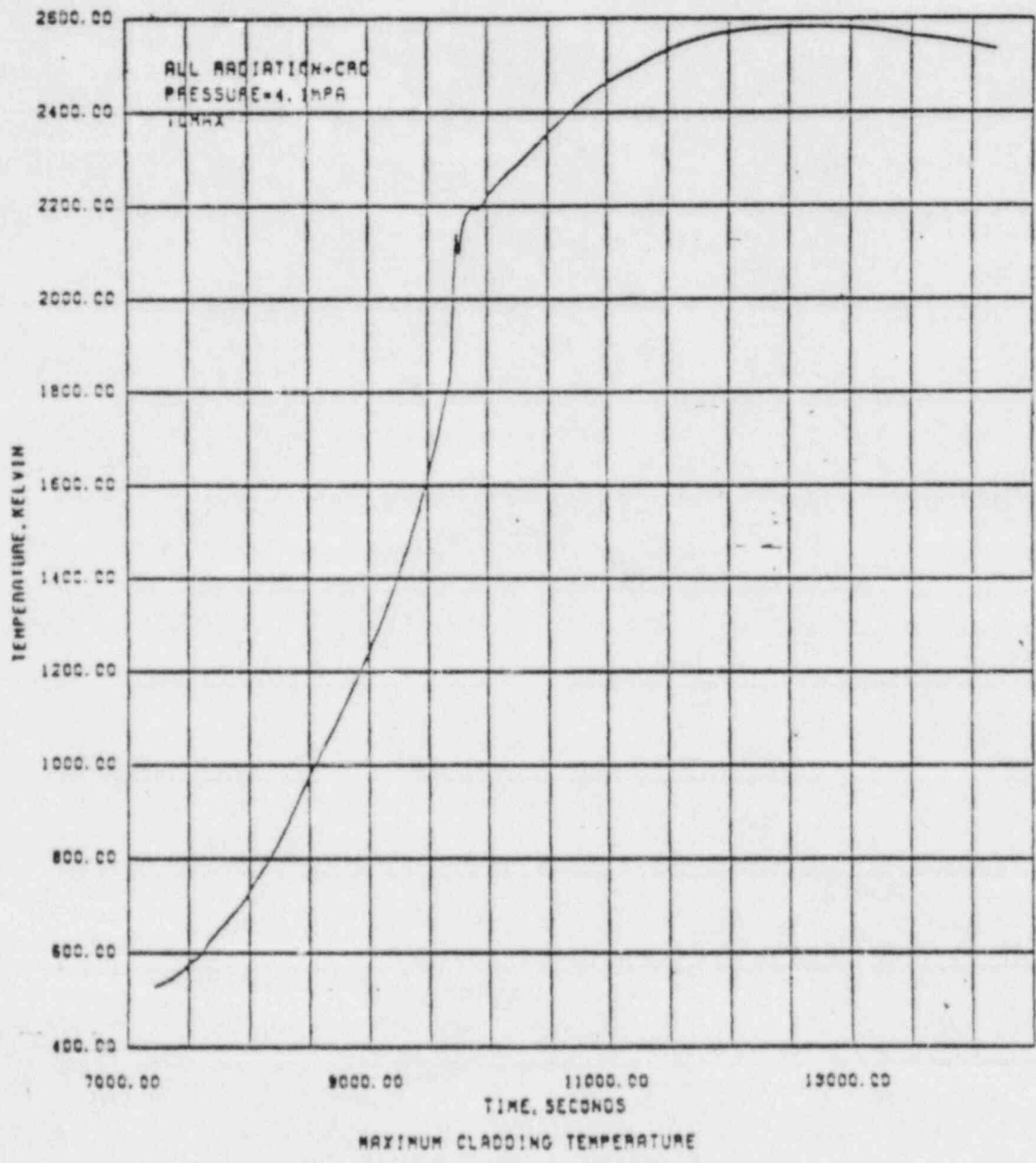


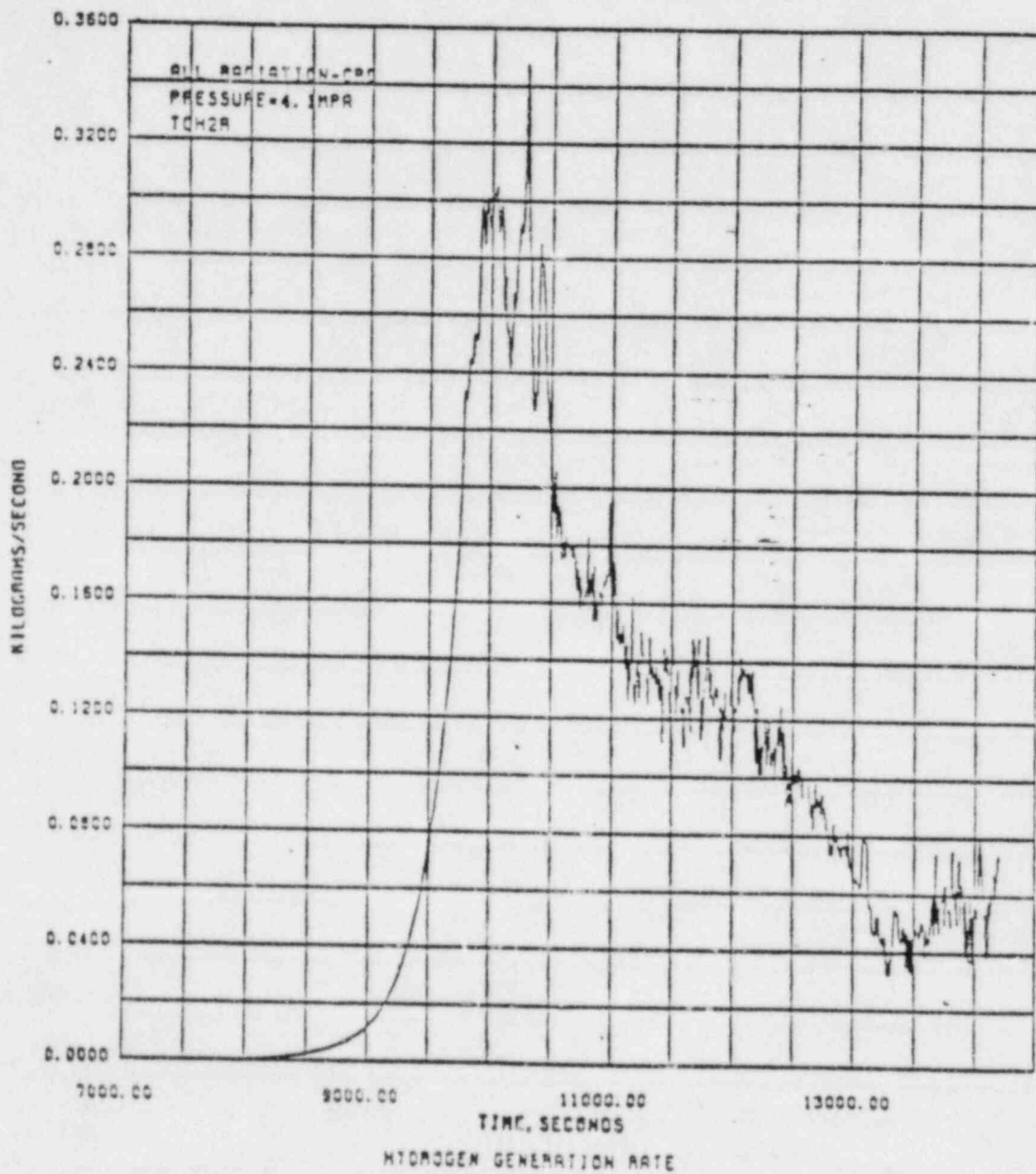


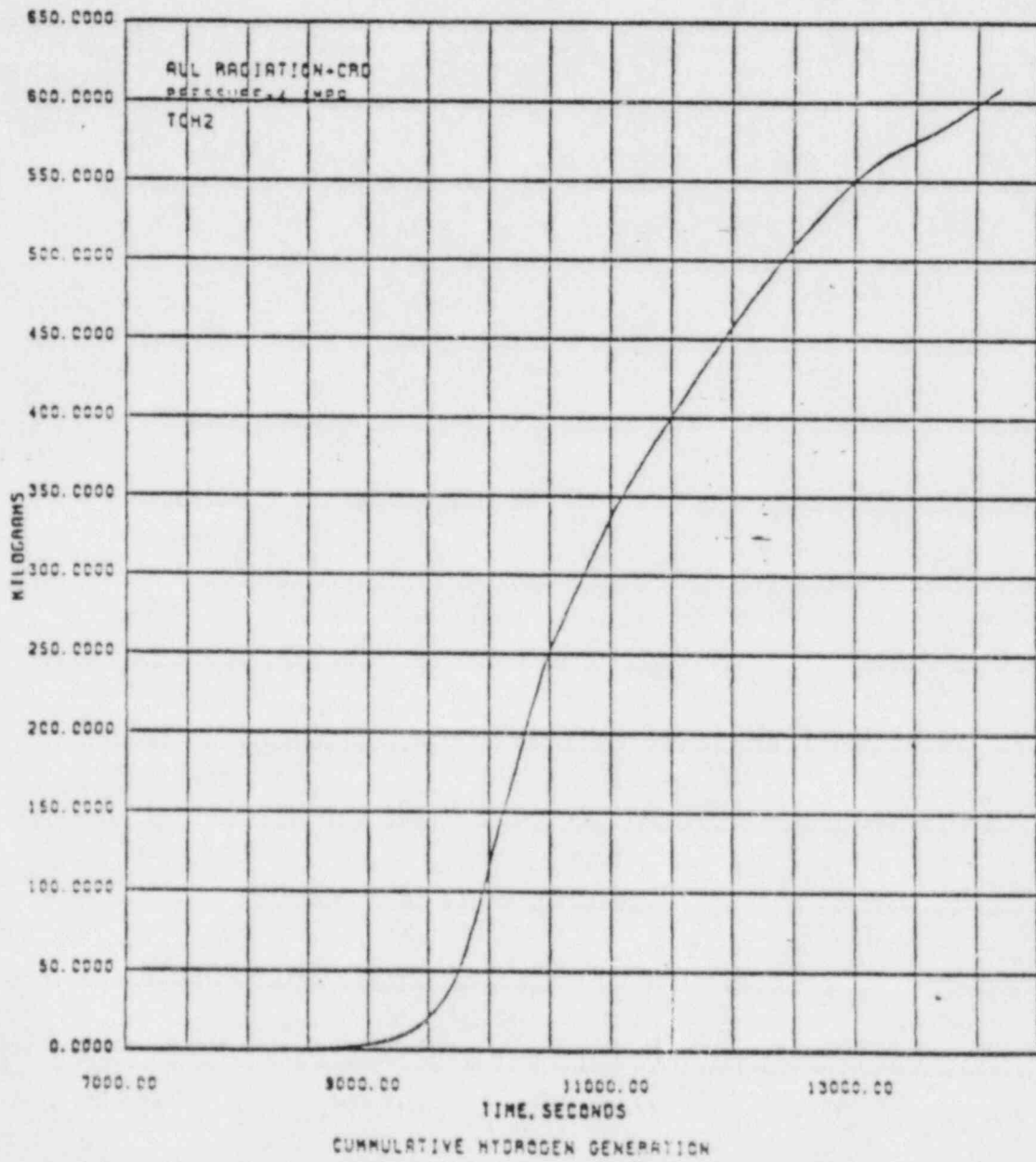


RUN 4

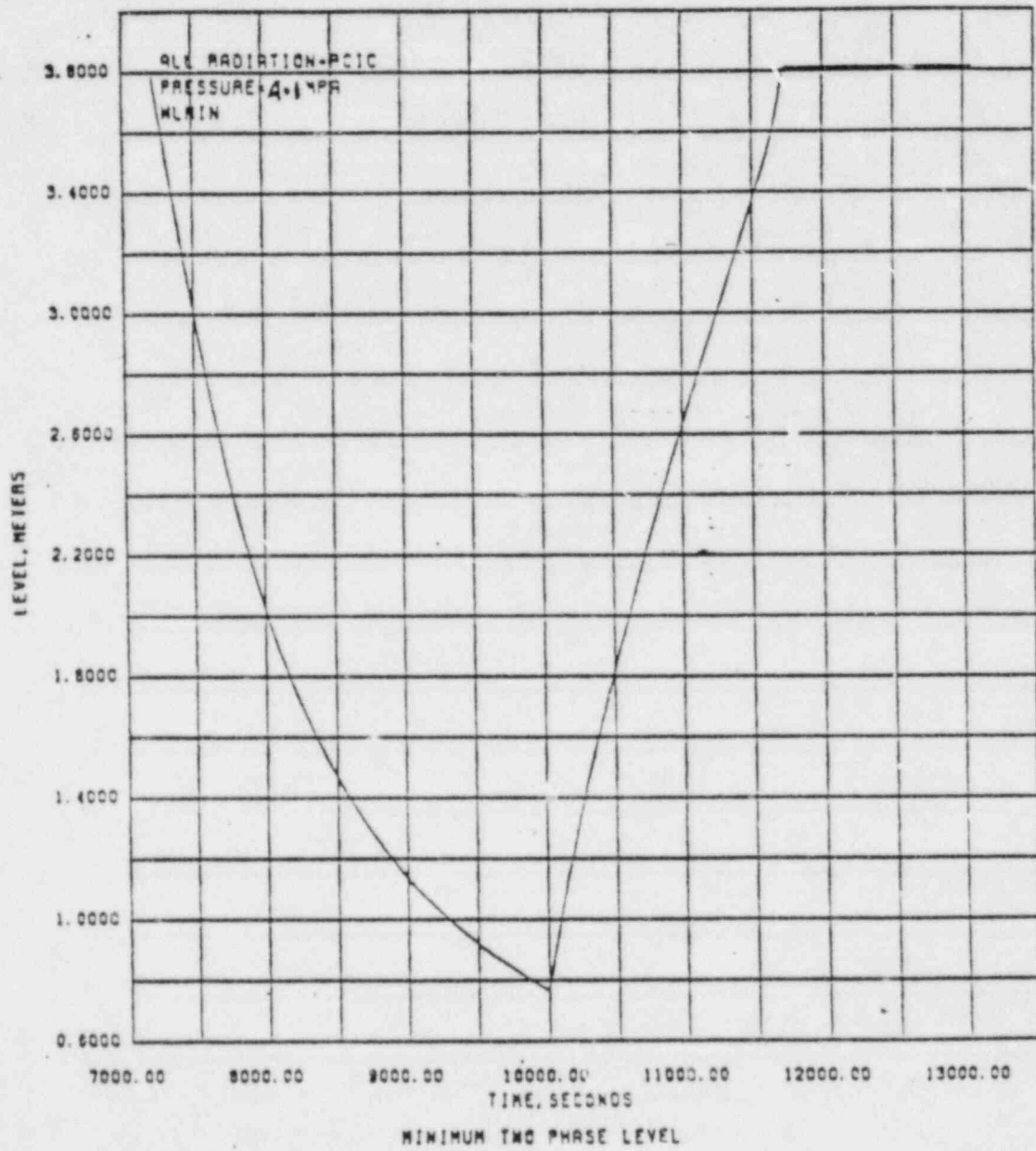


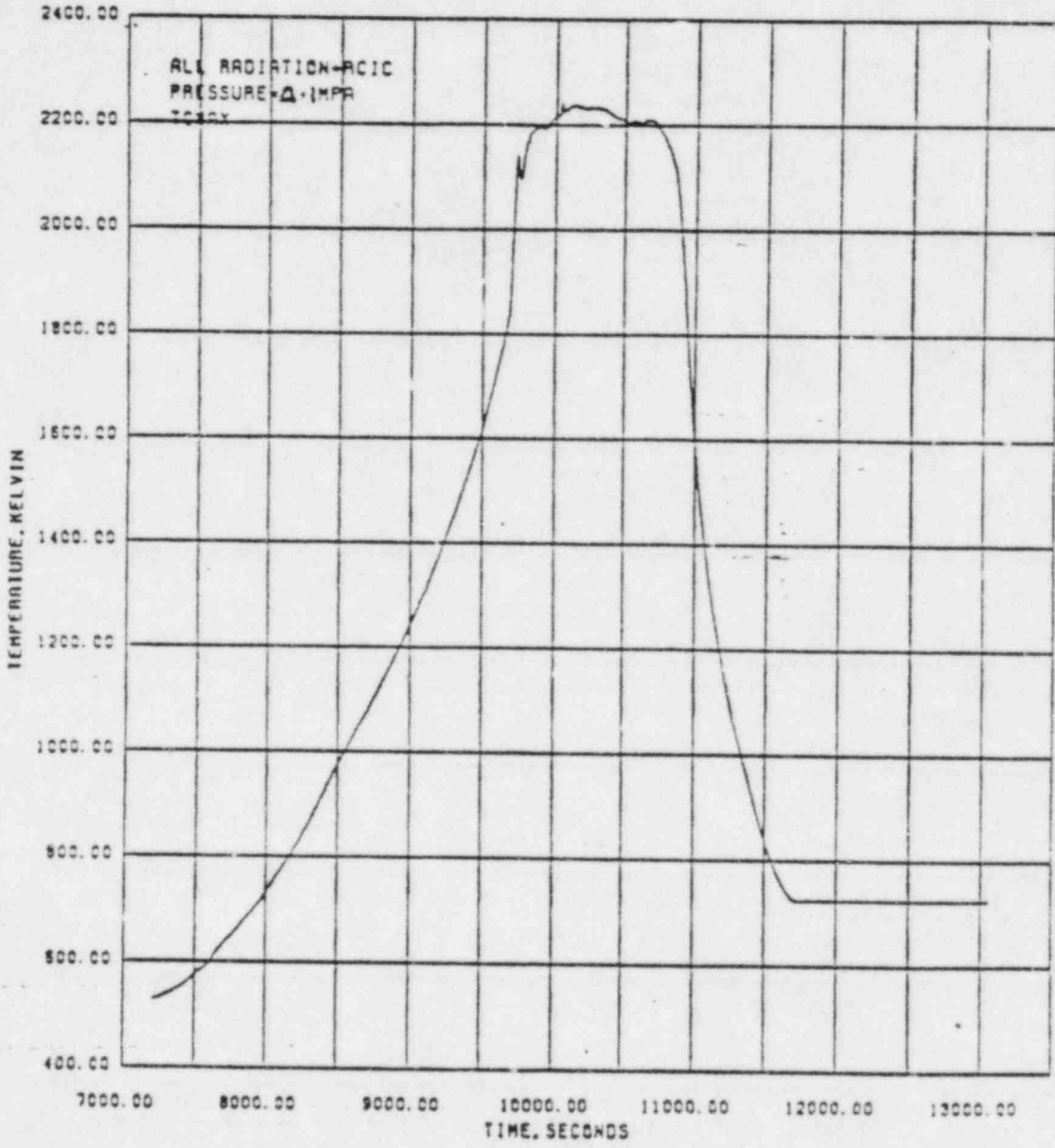




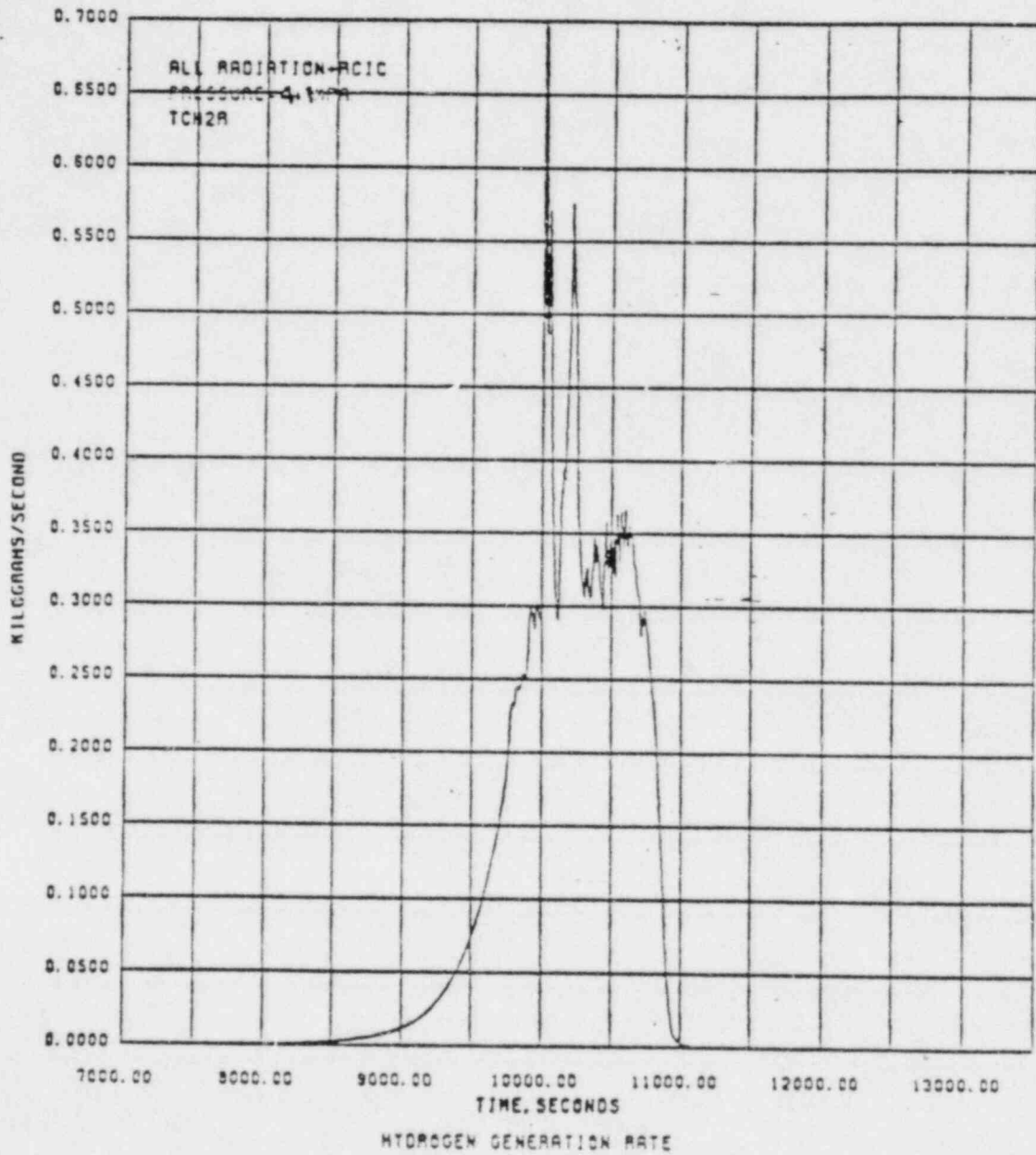


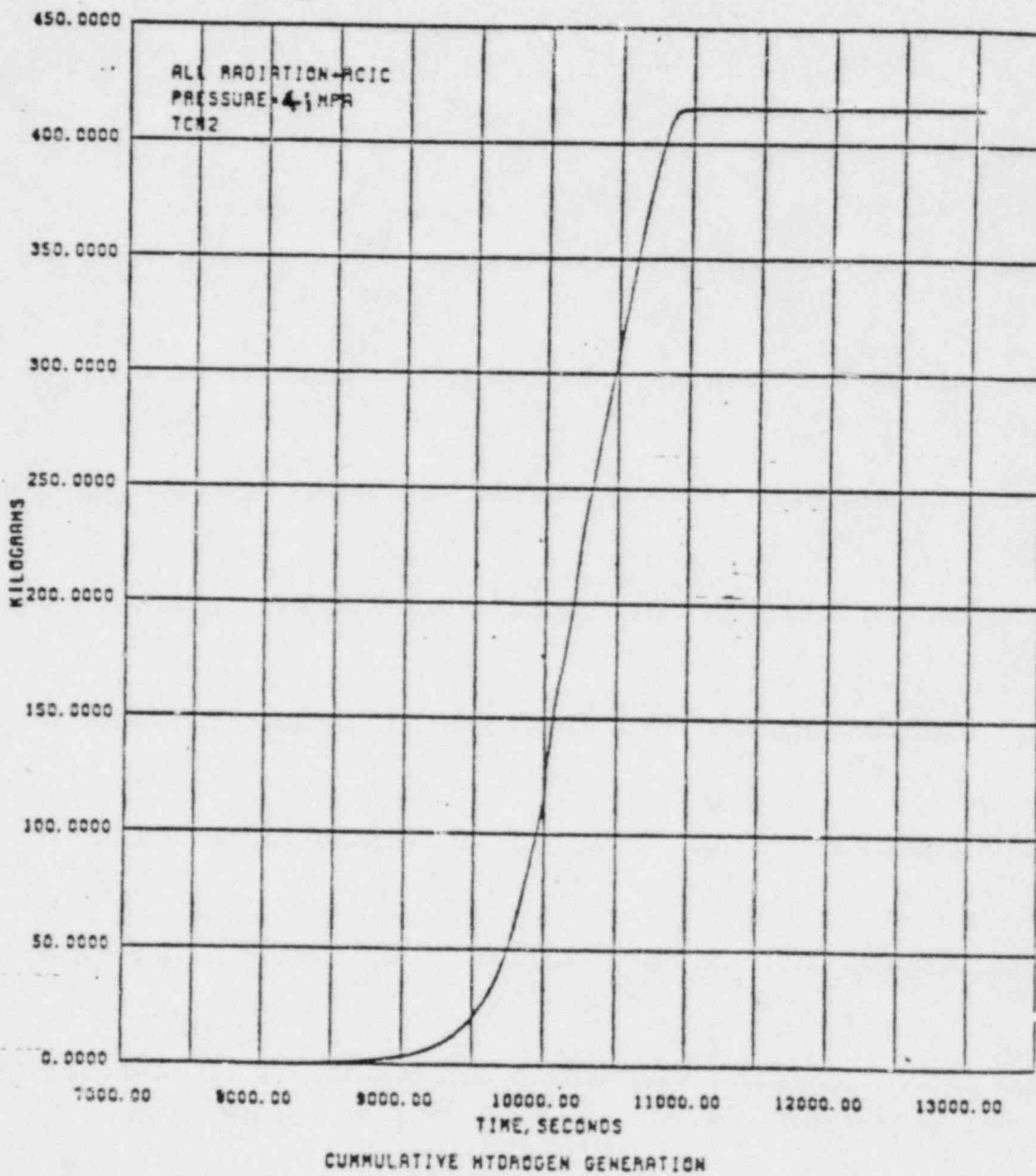
RUN 5





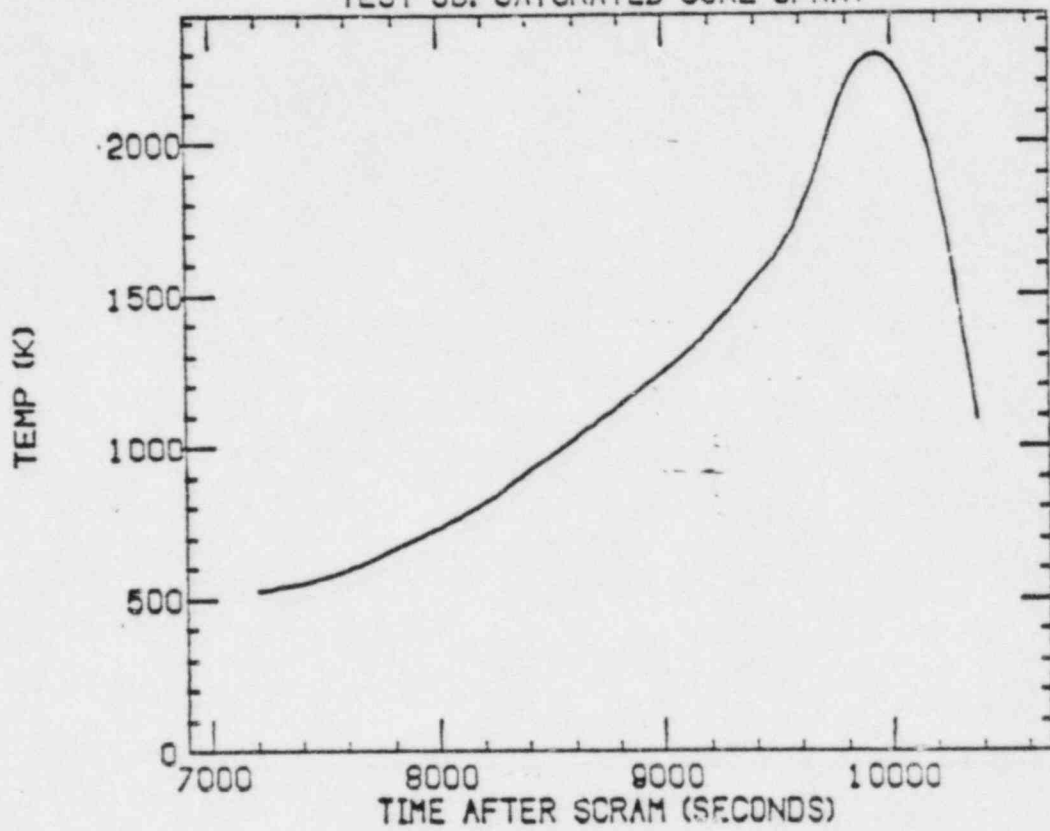
MAXIMUM CLADDING TEMPERATURE





RUN 6

TIME VERSUS MAX. CLAD TEMPERATURE
TEST 5B: SATURATED CORE SPRAY



SUMMARY

- DETAILED BWR CORE HEATUP CODE DEVELOPED
- SCOPING STUDY OF H₂ PRODUCTION RATES COMPLETED
 - PEAK CORE PRODUCTION RATES (≈ 1.5 LBM/SEC) OCCUR FOR SHORT PERIODS (≈ 1 MIN) AT INITIATION OF ECCS OPERATION
 - SUSTAINED CORE PRODUCTION RATES (≈ 10 MINUTES) FOR ALL CASES RANGE OVER 0.5-0.8 LBM/SEC
 - THESE RATES ARE AT CORE - ACTUAL PEAK RATES TO TO DRYWELL/WETWELL WILL BE LOWER (MUTED) AS A RESULT OF PRIMARY SYSTEM THERMAL HYDRAULICS

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TIME VERSUS TOTAL MASS OF HYDROGEN AND GENERATION RATE
TEST 5B: SATURATED CORE SPRAY

