# HYDROGEN SOURCE TERM FOR BWR DEGRADED CORE ACCIDENTS


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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

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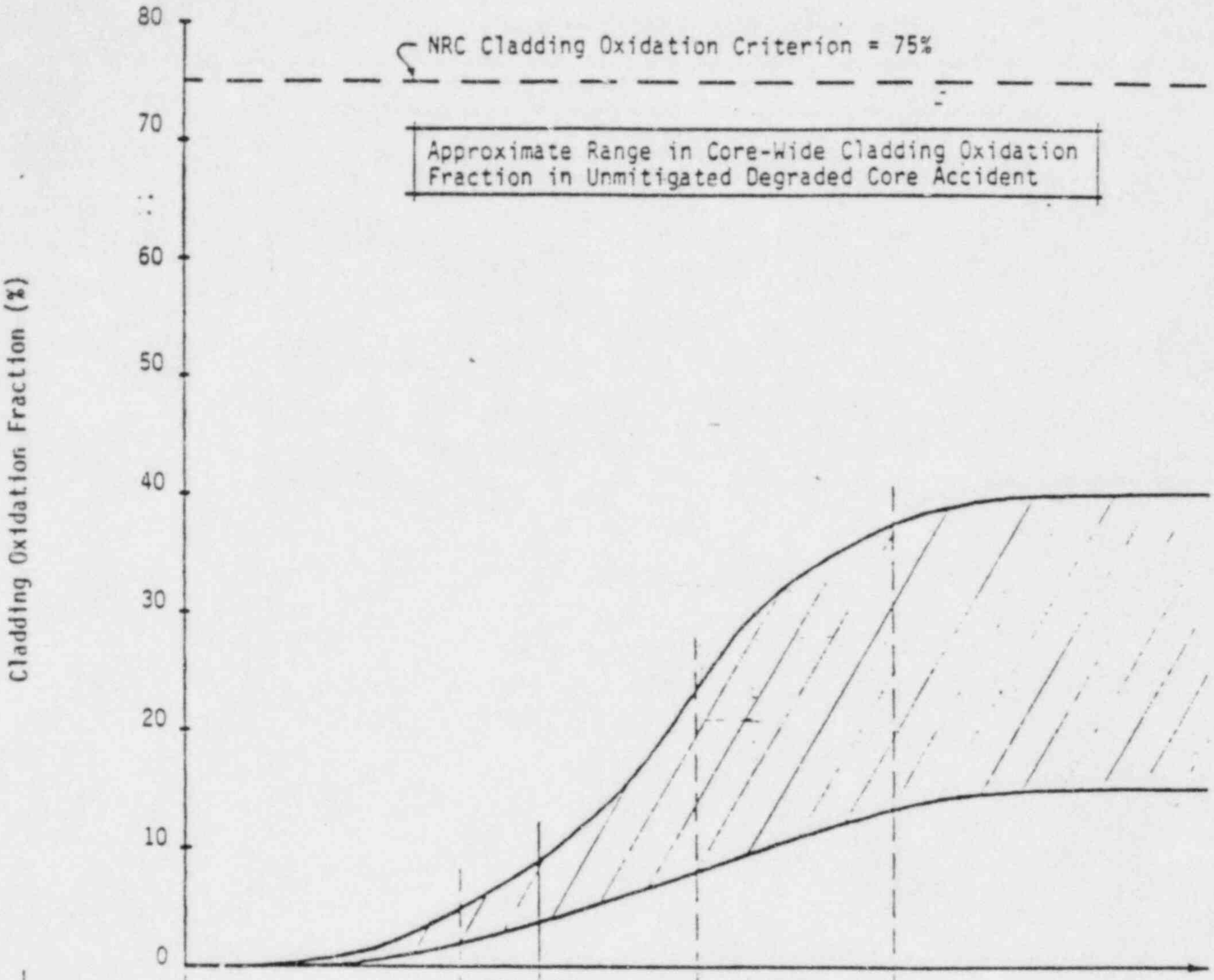
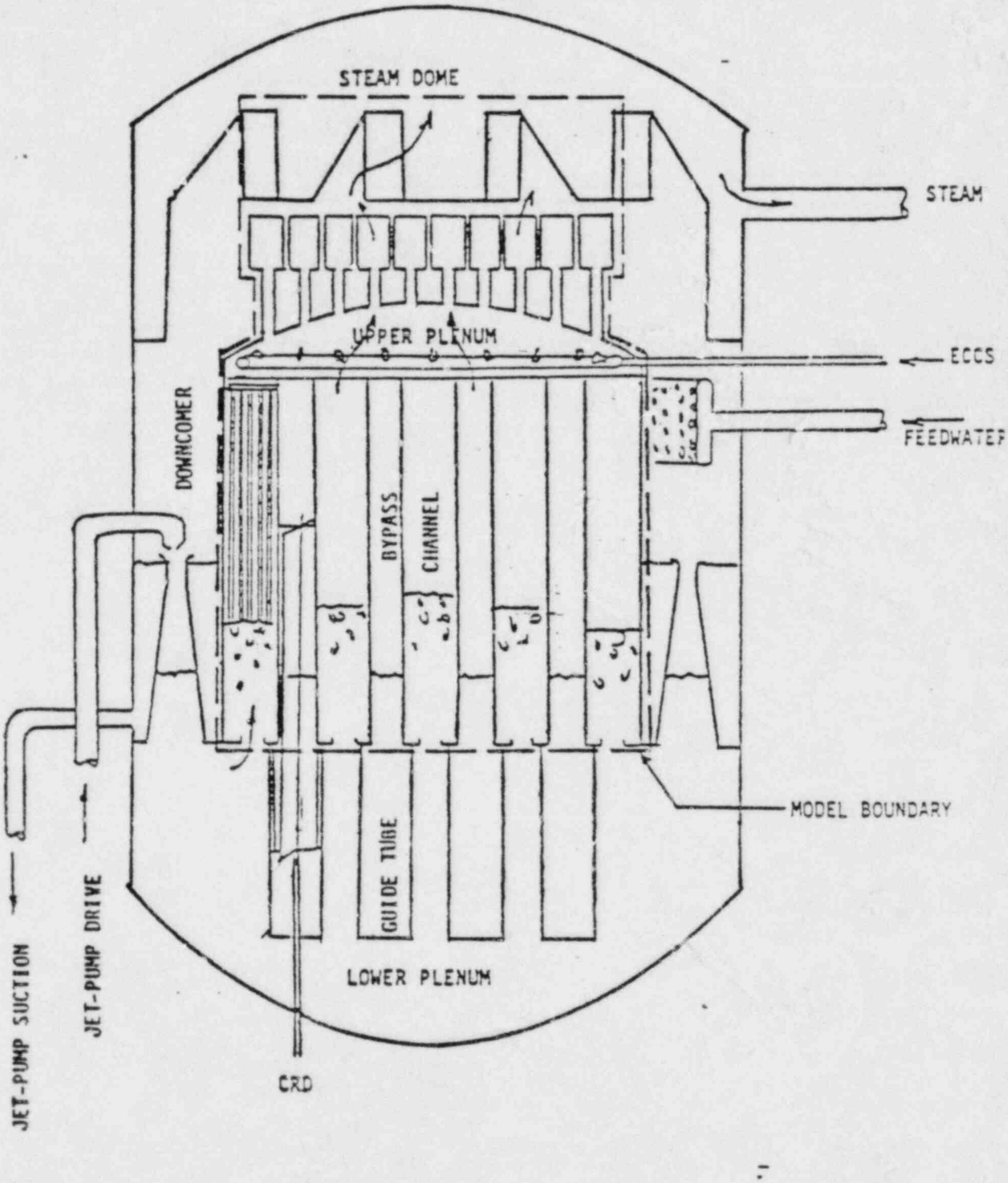



| Core Conditions | | | | |
|---|---|---|---|---|
| Core Max Temp | < 2000 °F | 2000 °F to 3500 °F (Zry Melt) | 3500 °F to 5200 °F ($UO_2$ Melt) | > 5200 °F |
| Water Level | Top of Core | ~ 3/4 Uncovered | ~ 9/10 Uncovered | |
| Geometry | Essentially Intact | Local Distortion and slumping | Generalized Slumping Beginning | Major Slumping/RPV Bottom Head Failure |

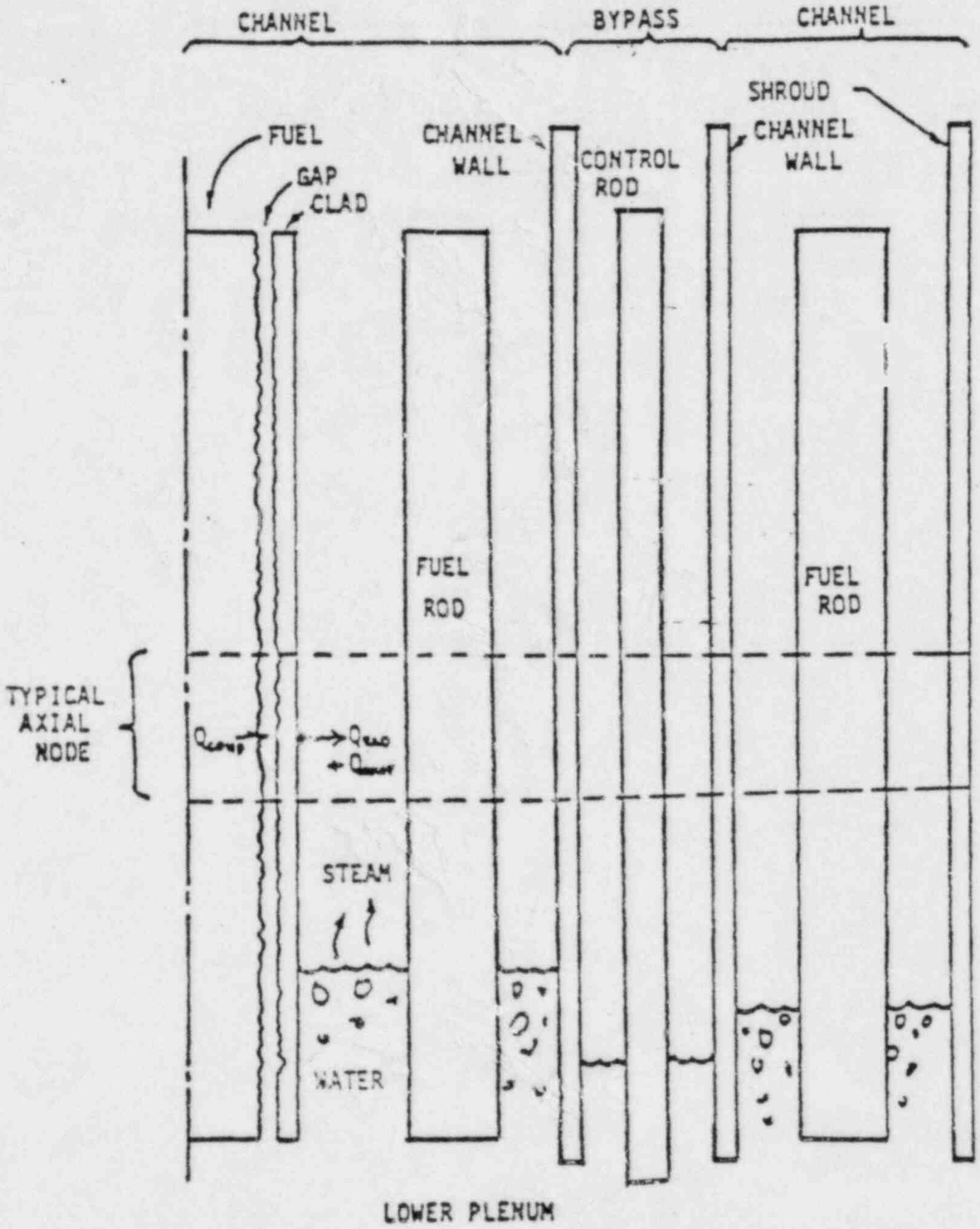
G R Thomas
27 June 1983

# BWR CORE HEATUP CODE

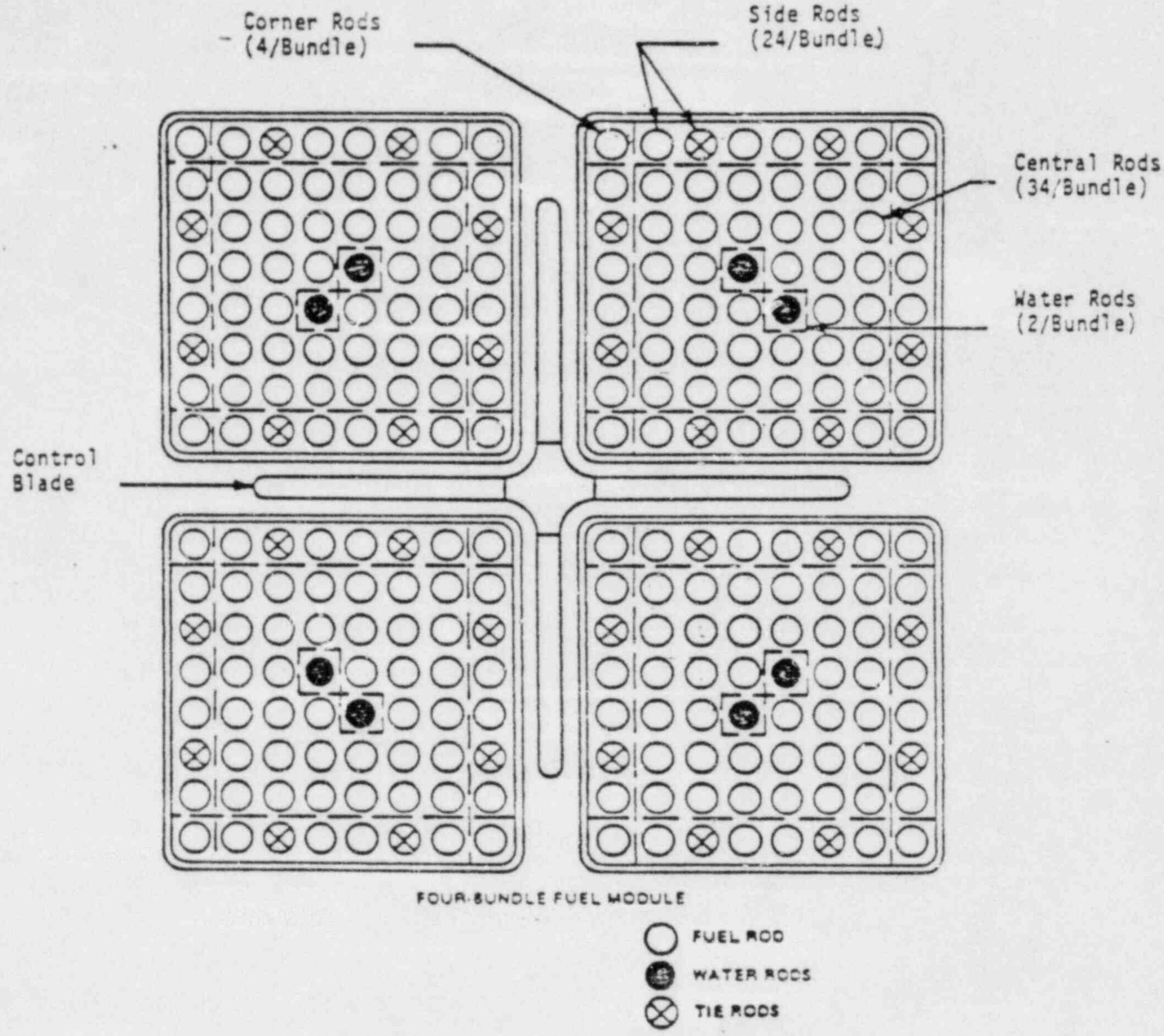
# MODELING BASIS




BWR CORE HEATUP MODEL

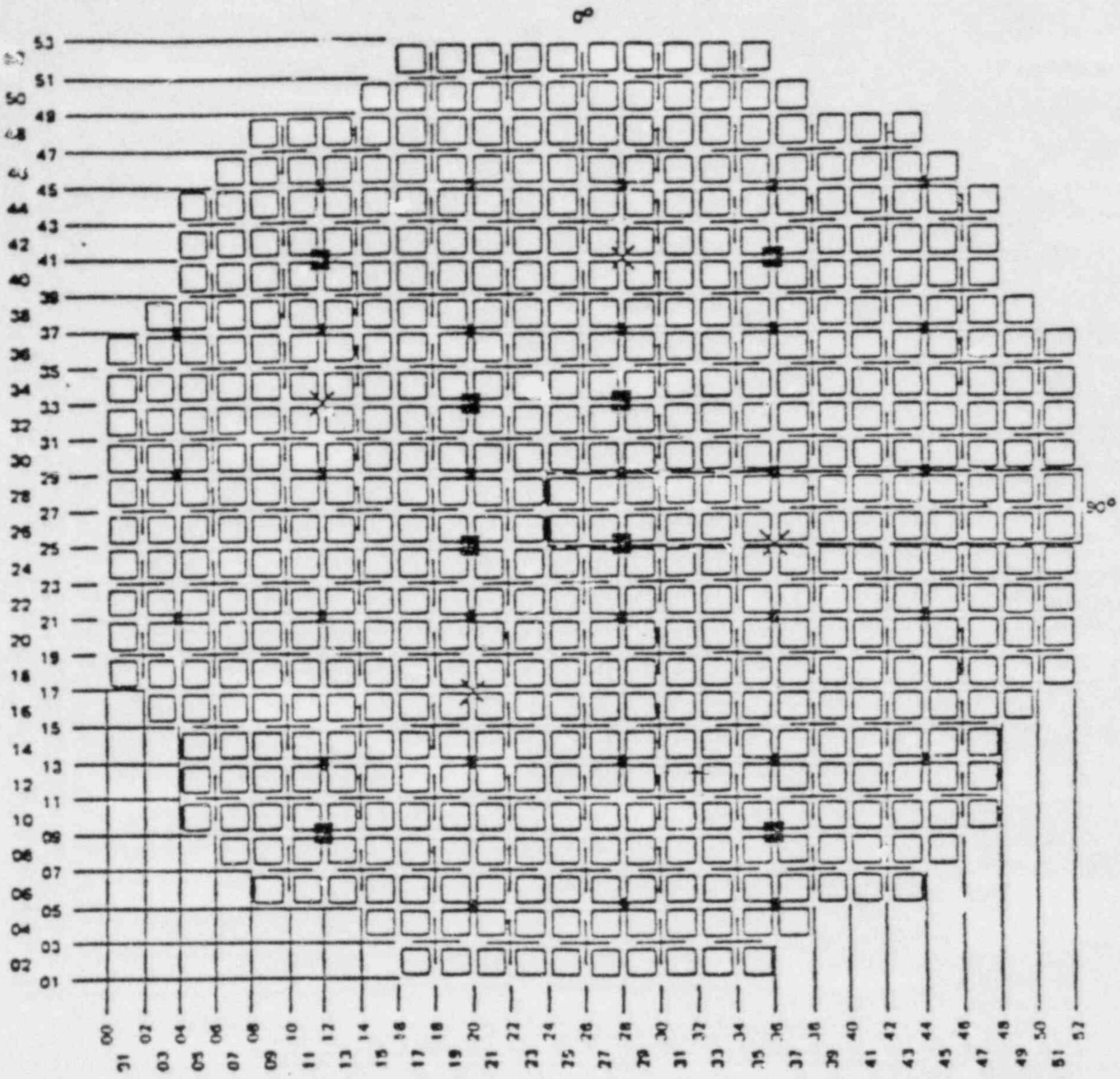



BWR CORE HEATUP CODE CORE MODELING




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

TOP VIEW

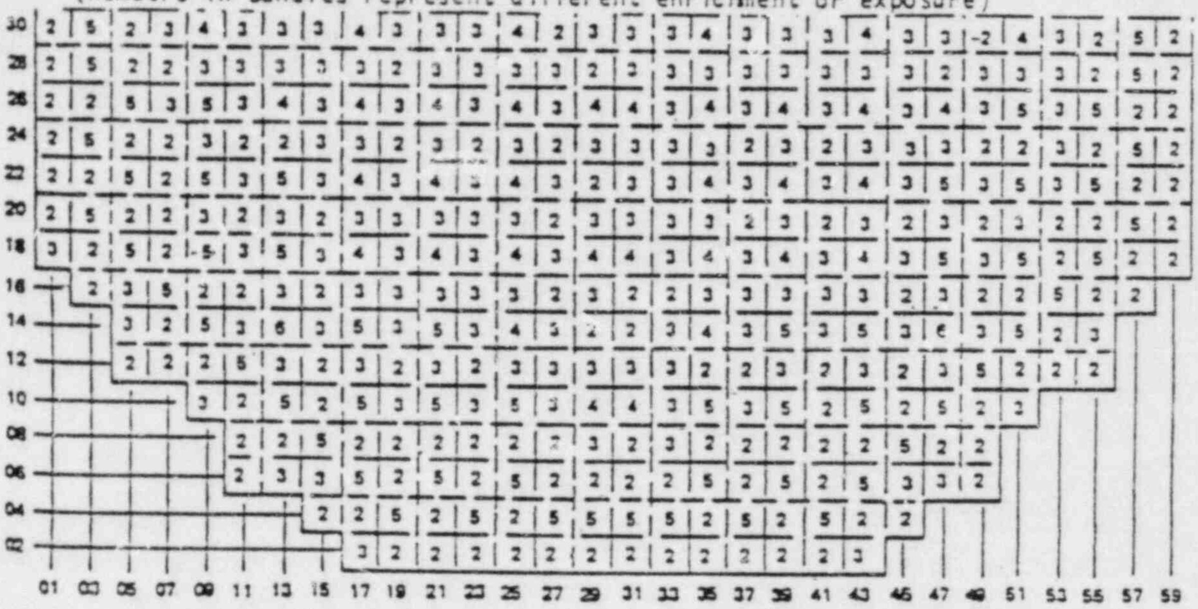


- ● LOCAL POWER RANGE MONITORING SYSTEM (LPRM) 31
- X SOURCE RANGE MONITORING SYSTEM (SRM) 4
- ■ INTERMEDIATE RANGE MONITORING SYSTEM (IRM) 8
- TOTAL PENETRATIONS FOR NUCLEAR INSTRUMENTS 43

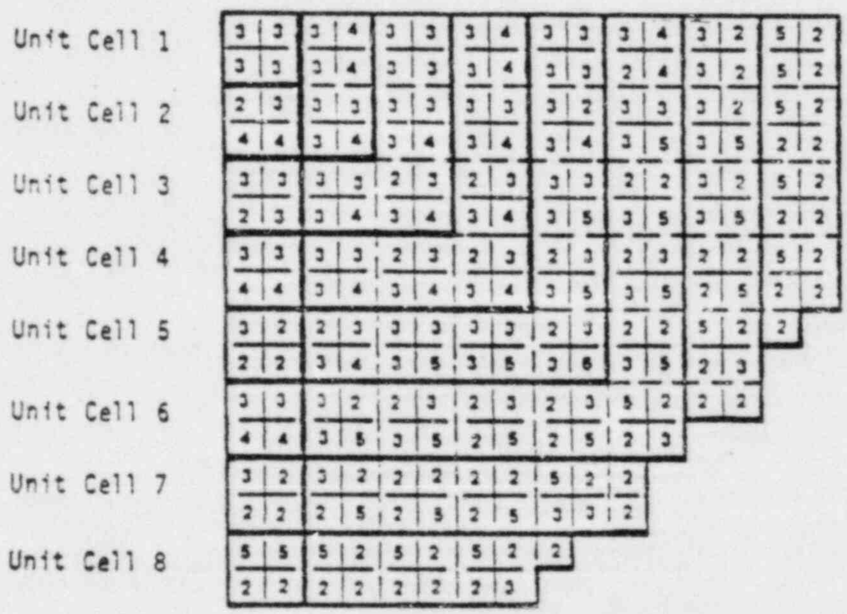
BWR/6 CORE MAP SHOWING RADIAL ARRANGEMENT OF BWR CORE HEATUP CODE UNIT CELLS

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

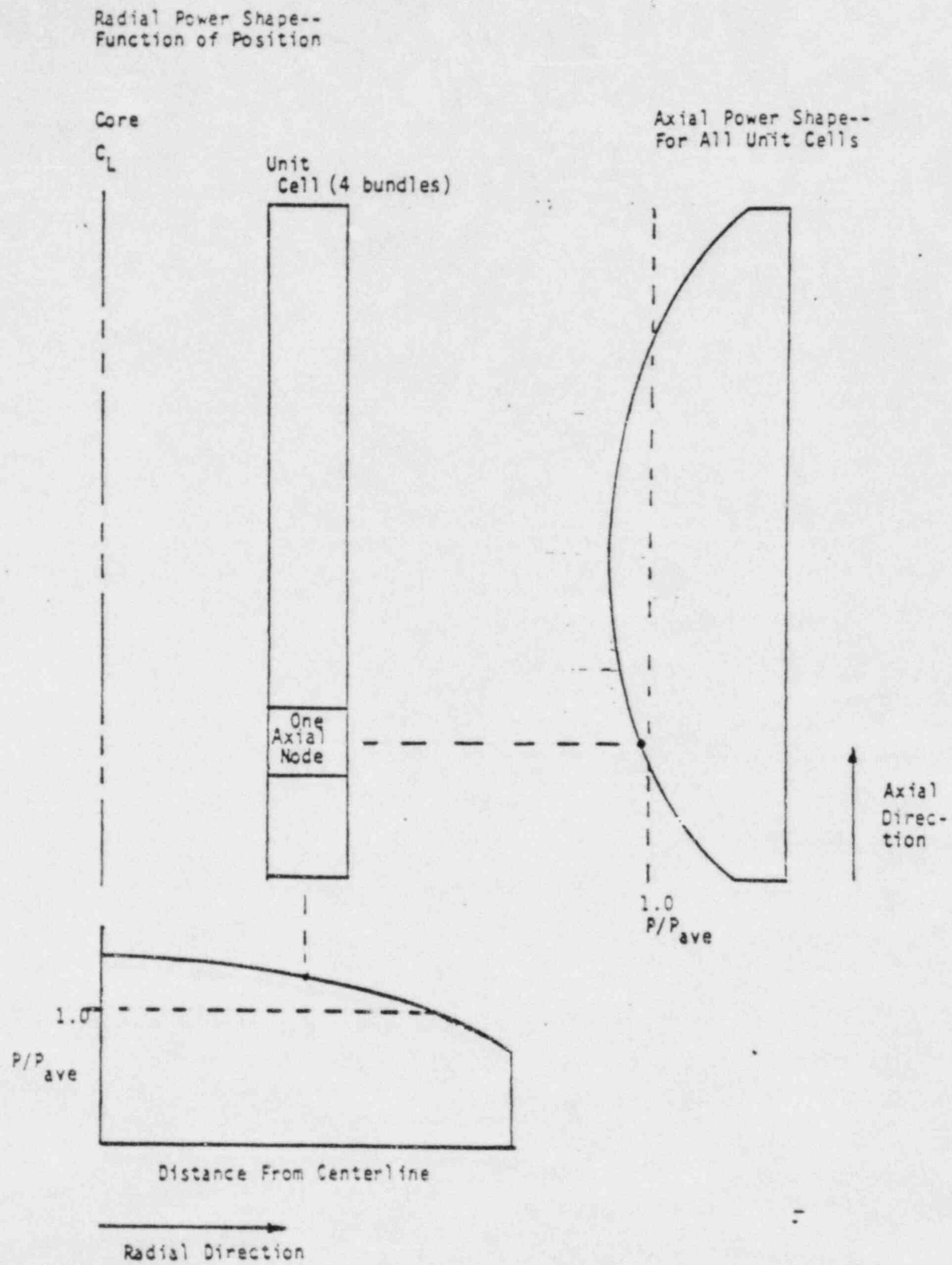
(numbers in bundles represent different enrichment or exposure)



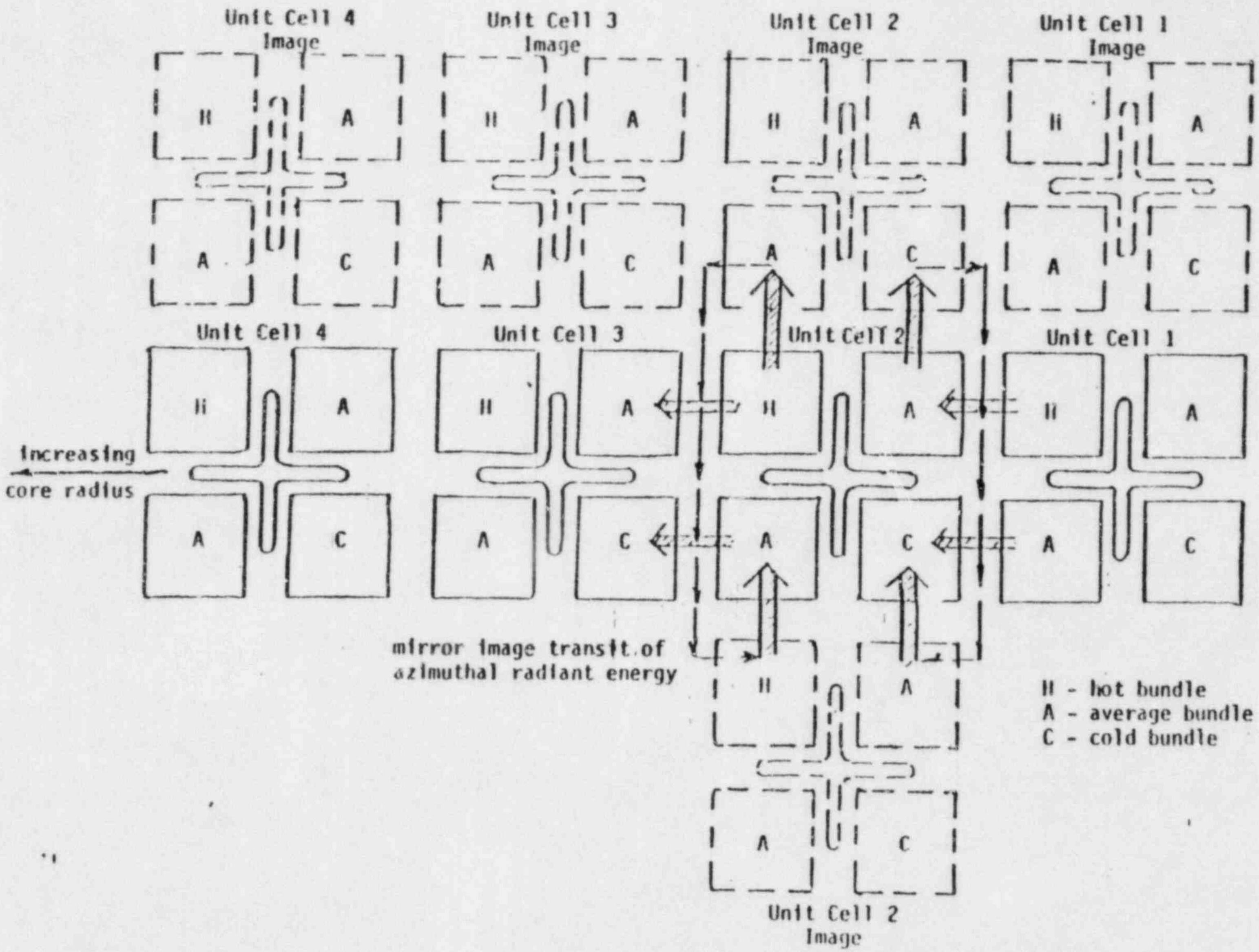
Quarter Core Map Showing Unit Cells and Their Core-Wide Grouping




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




AXIAL AND RADIAL PEAKING FACTORS




SCHEMATIC 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 $H_2$ 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 $H_2$ RATE PRODUCTION
- PROBABLE MAXIMUM $H_2$ 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 $H_2$ PRODUCTION RATE PEAKS IN CORE WILL BE SOMEWHAT MUTED WHEN $H_2$ FLOWS REACH DRYWELL/WETWELL

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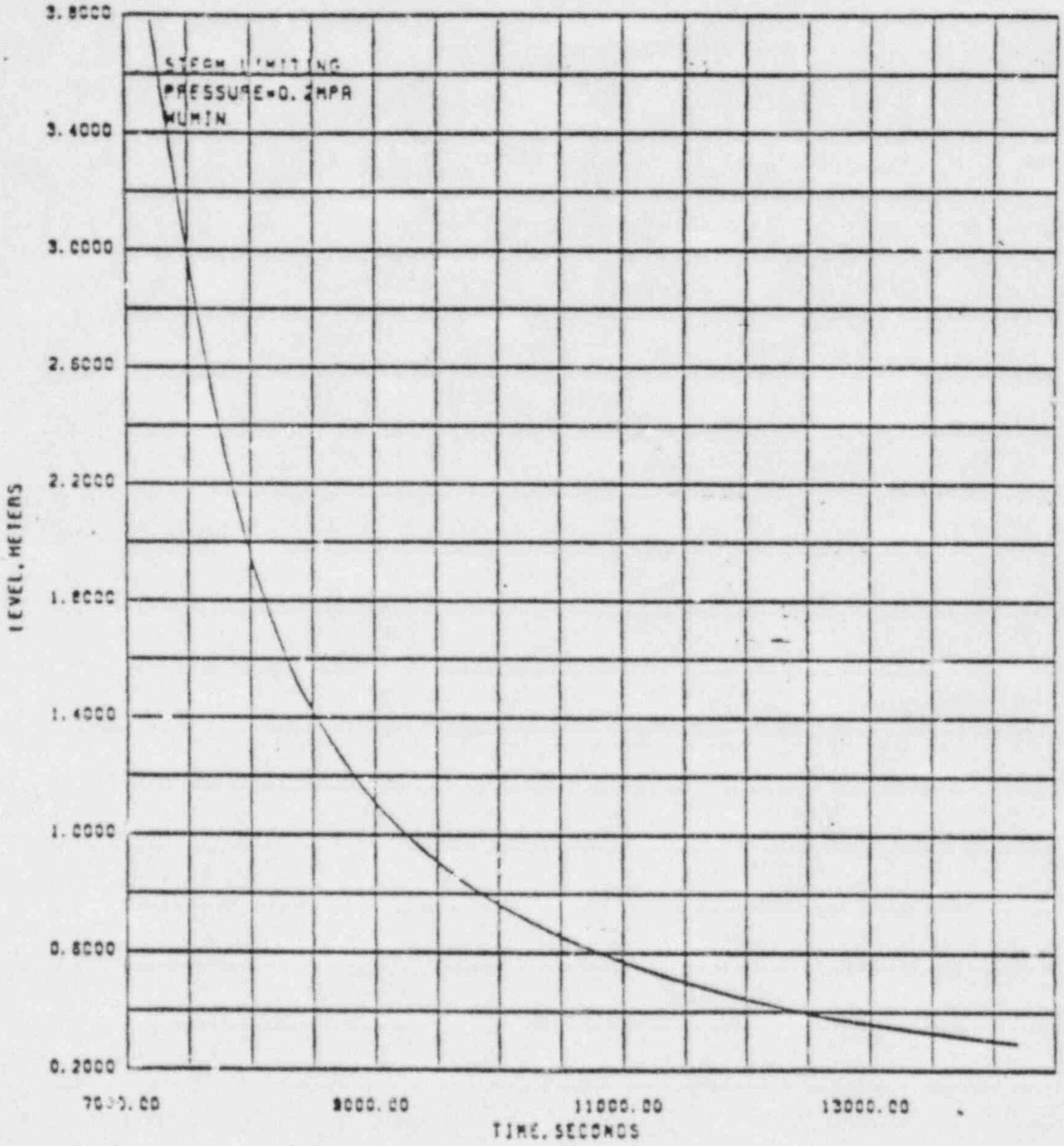
## HYDROGEN SOURCE TERM CALCULATIONS

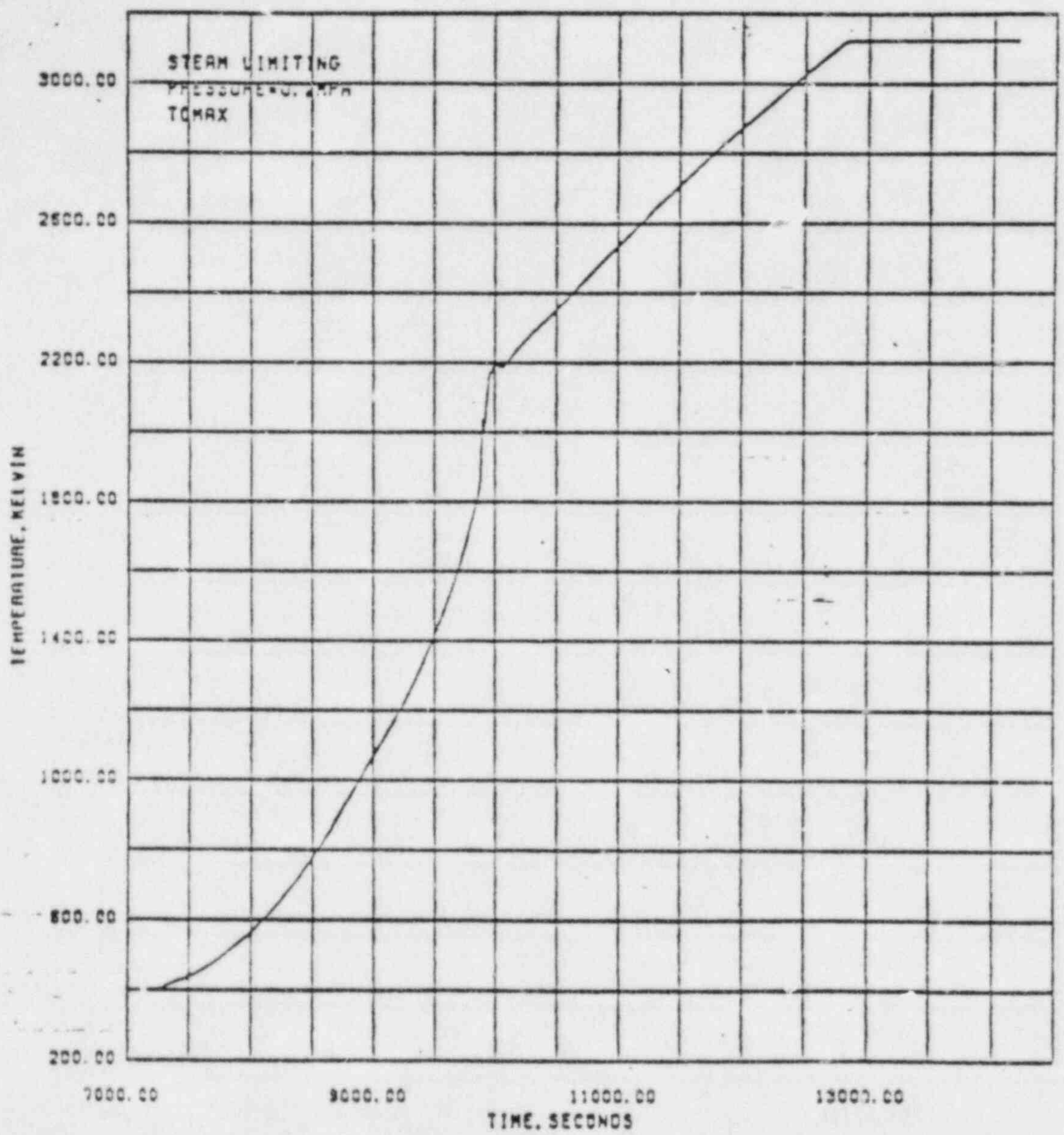
SCOPING STUDY RESULTS

| RUN | ACCIDENT CONDITIONS | | | | | RESULTS | |
|---|---|---|---|---|---|---|---|
| | PRESSURE (ATM) | RADIATION MODEL | START OF CORE UNCOVERING (SEC) | START OF CORE RECOVERY (SEC) | CORE FLOW (LBM/SEC) | $H_2$ PRODUCTION (LBM/SEC) PEAK | 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.) |

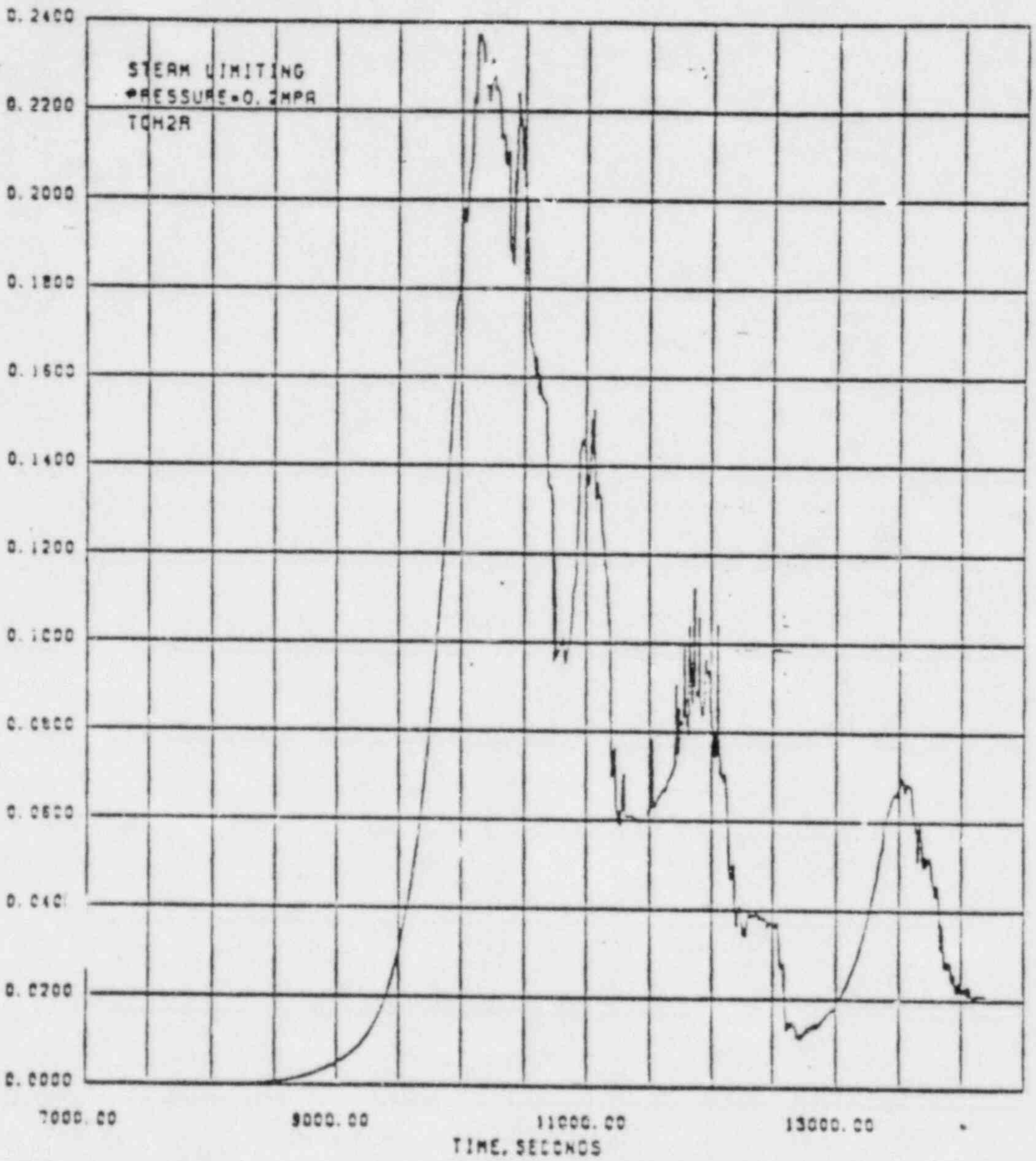
RUN 1



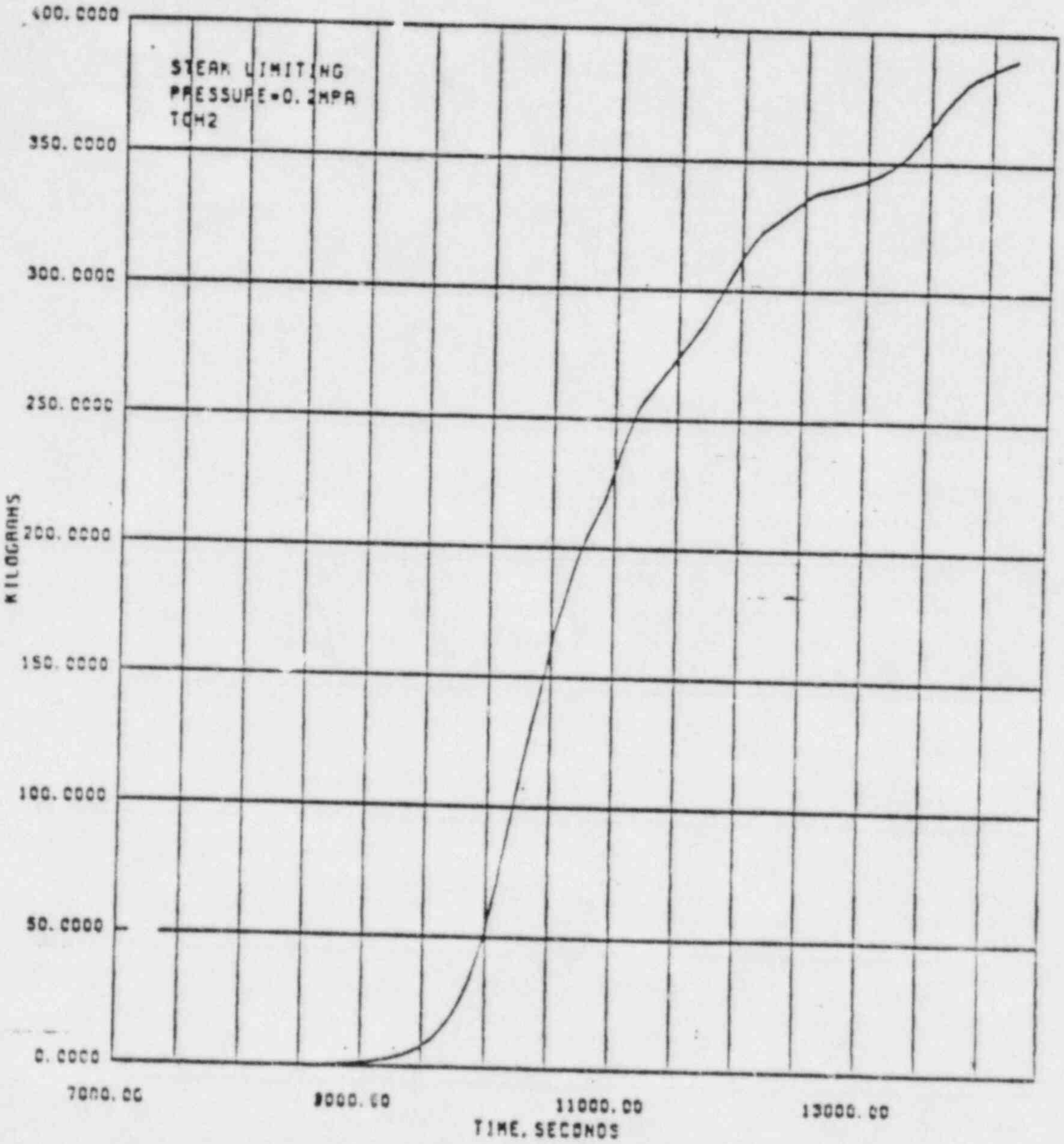

MINIMUM TWO PHASE LEVEL




MAXIMUM CLADDING TEMPERATURE

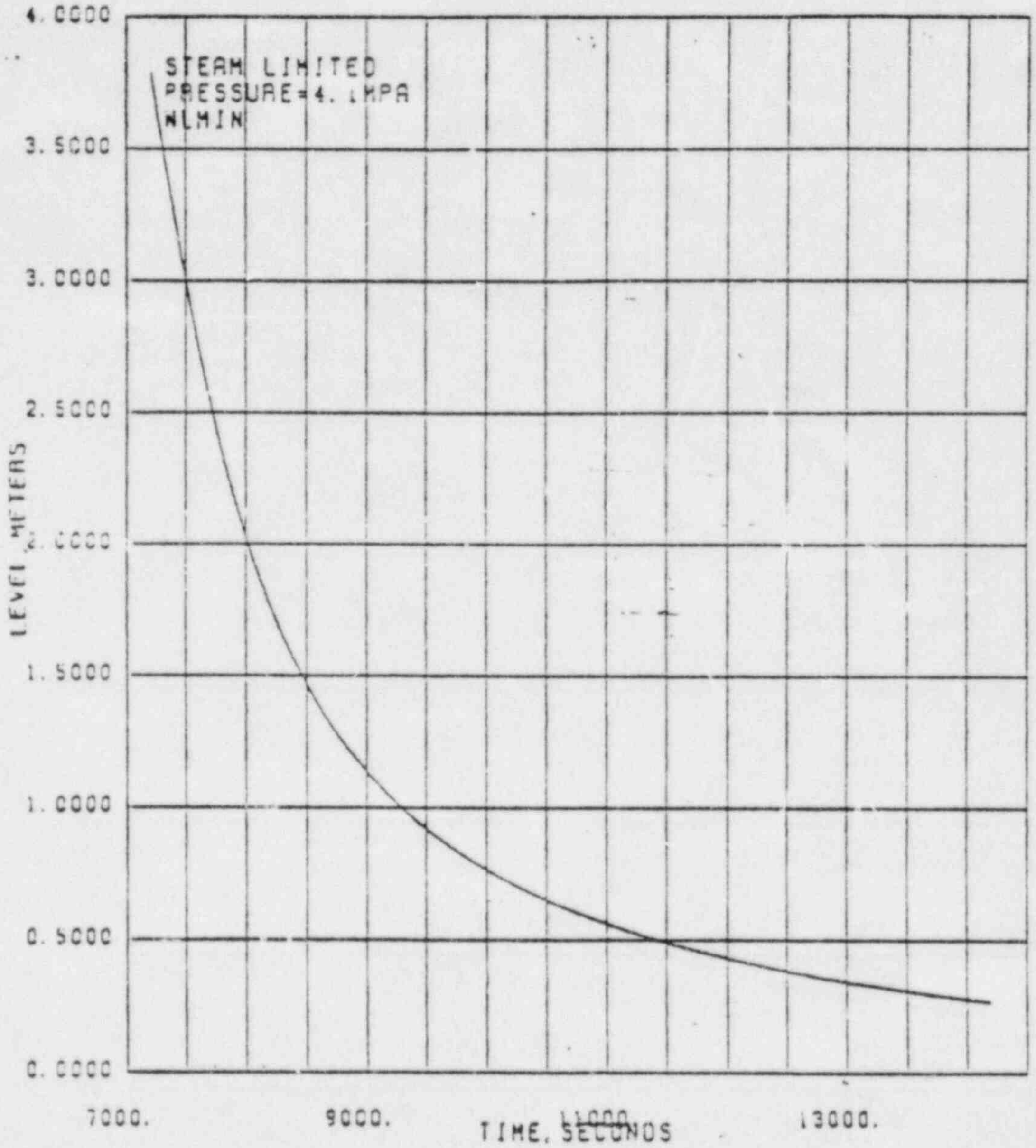



HYDROGEN GENERATION RATE

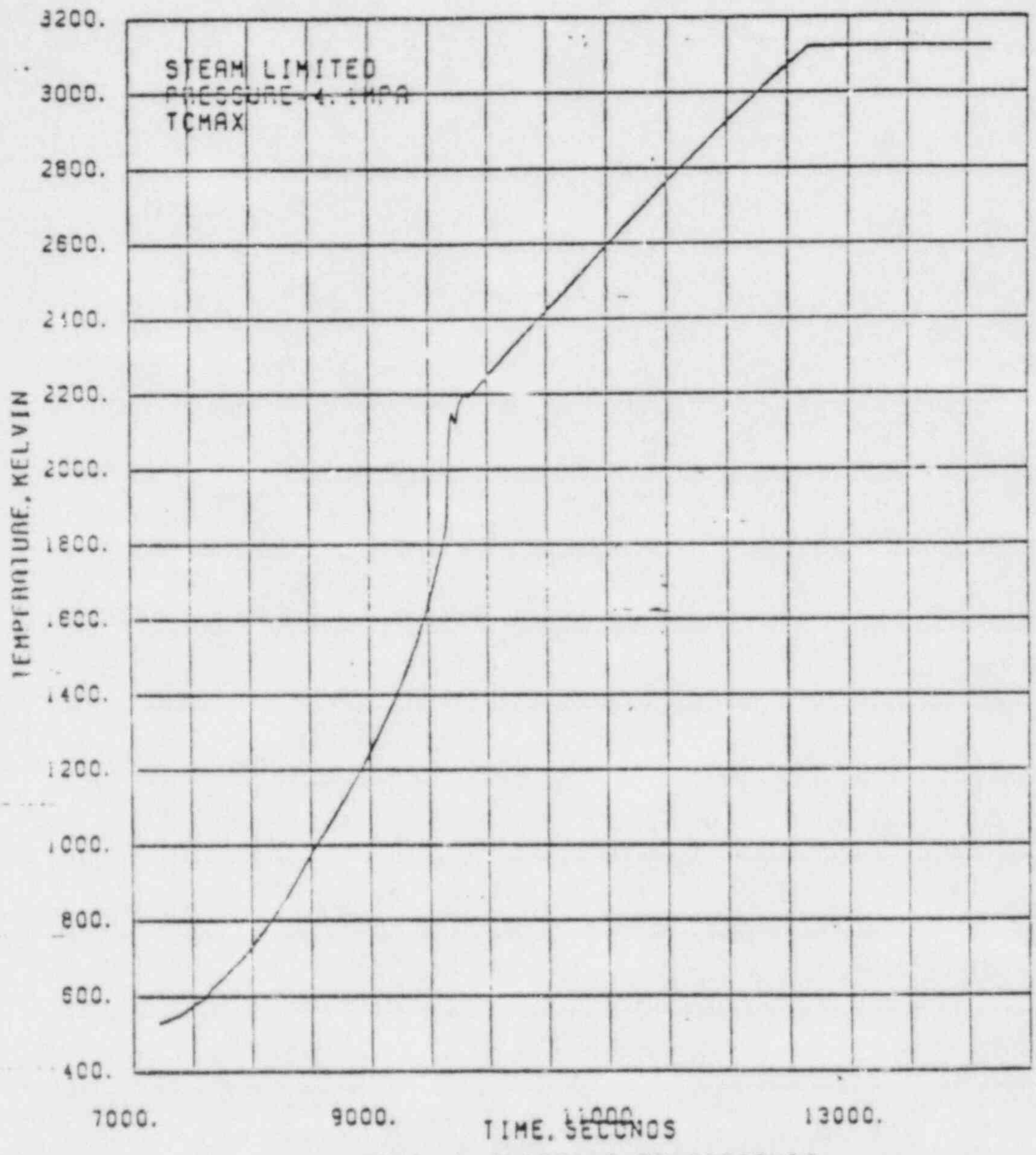



CUMMULATIVE HYDROGEN GENERATION

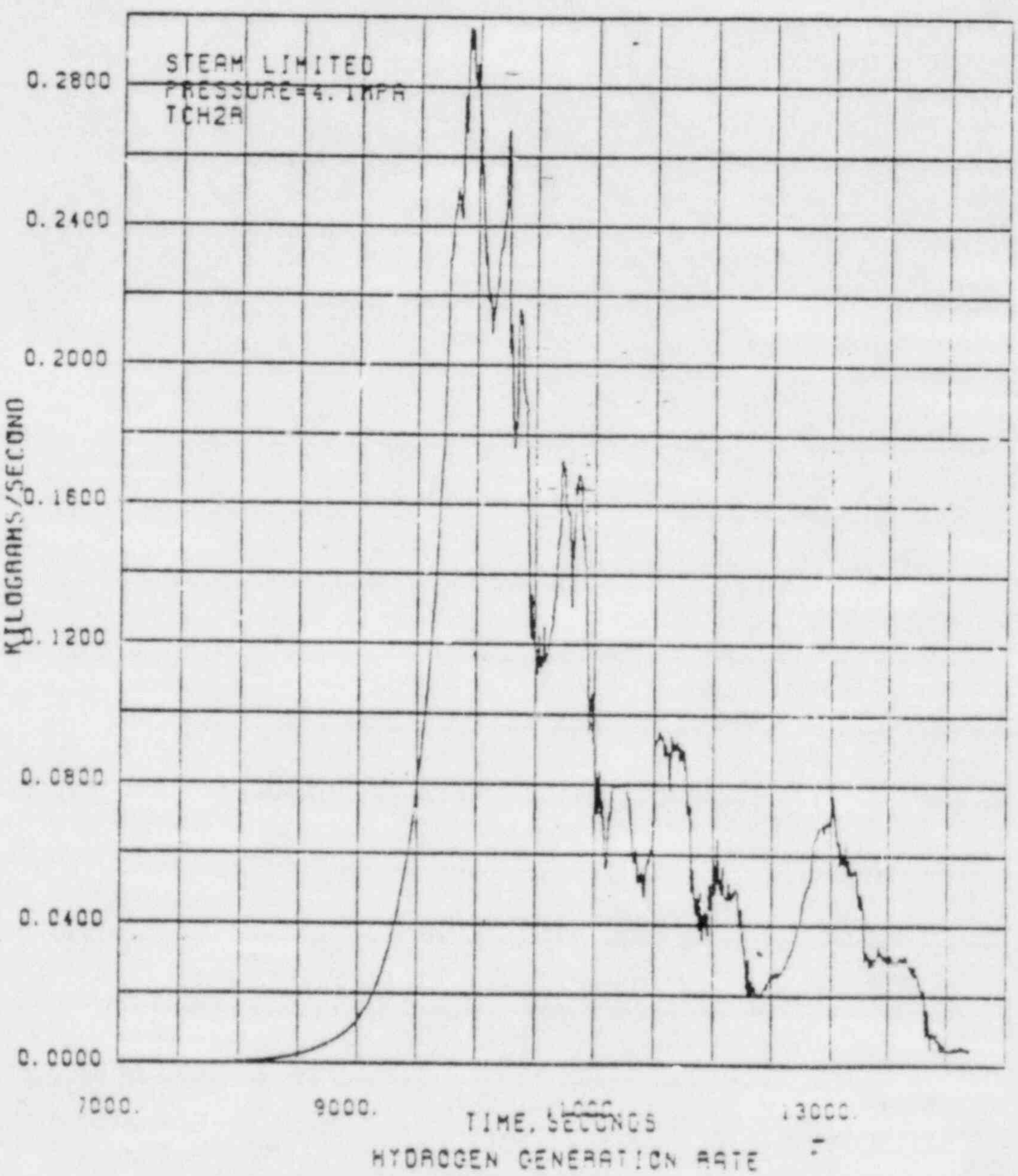
RUN 3



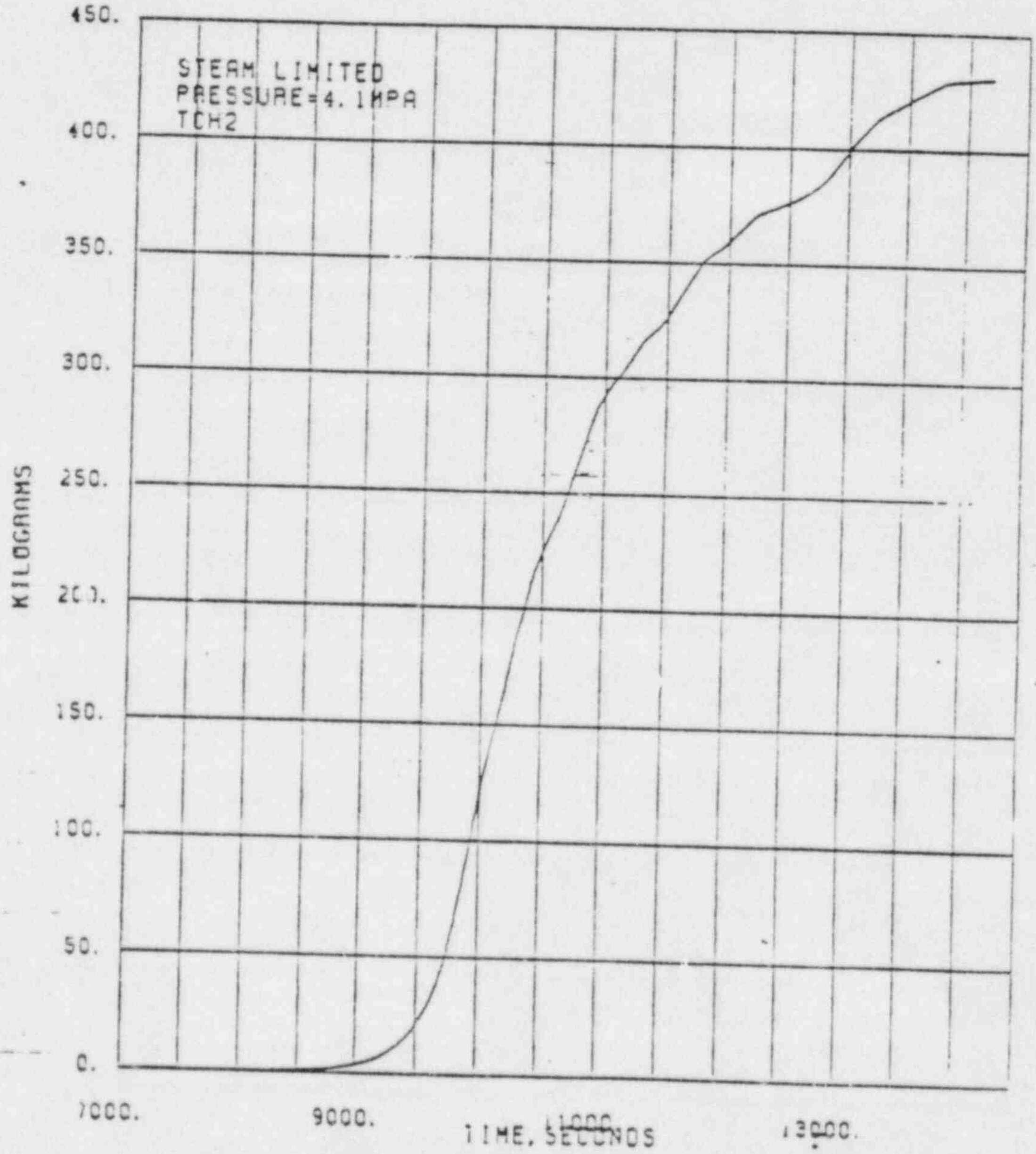

MINIMUM TWO PHASE LEVEL



MAXIMUM CLADDING TEMPERATURE

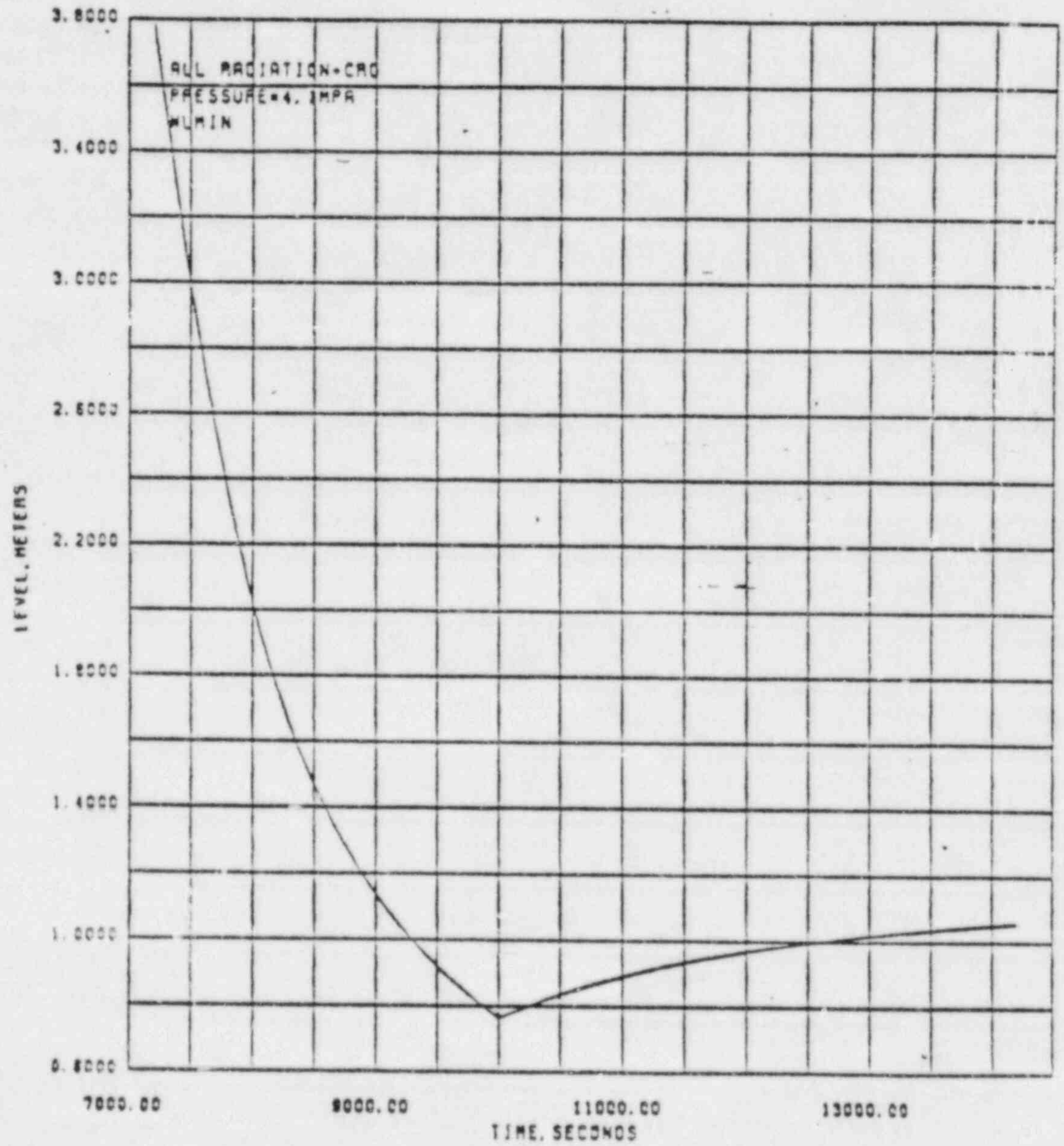


STEAM LIMITED
PRESSURE=4.1MPA
TCH2A
0.2800
0.2400
0.2000
0.1600
0.1200
0.0800
0.0400
0.0000
KILOGRAMS/SECOND
7000.
9000.
13000.
TIME, SECONDS
HYDROGEN GENERATION RATE

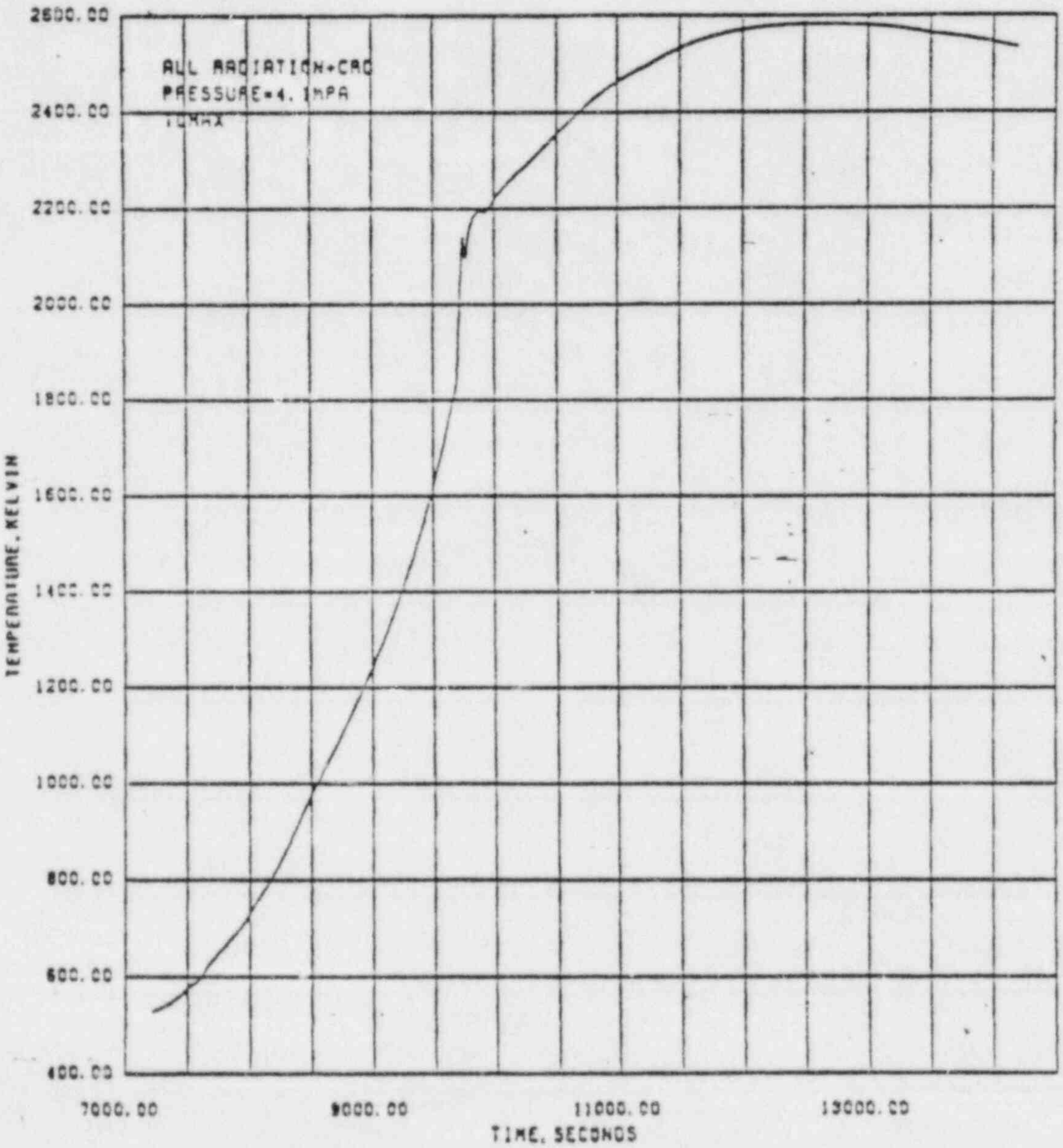



CUMMULATIVE HYDROGEN GENERATION

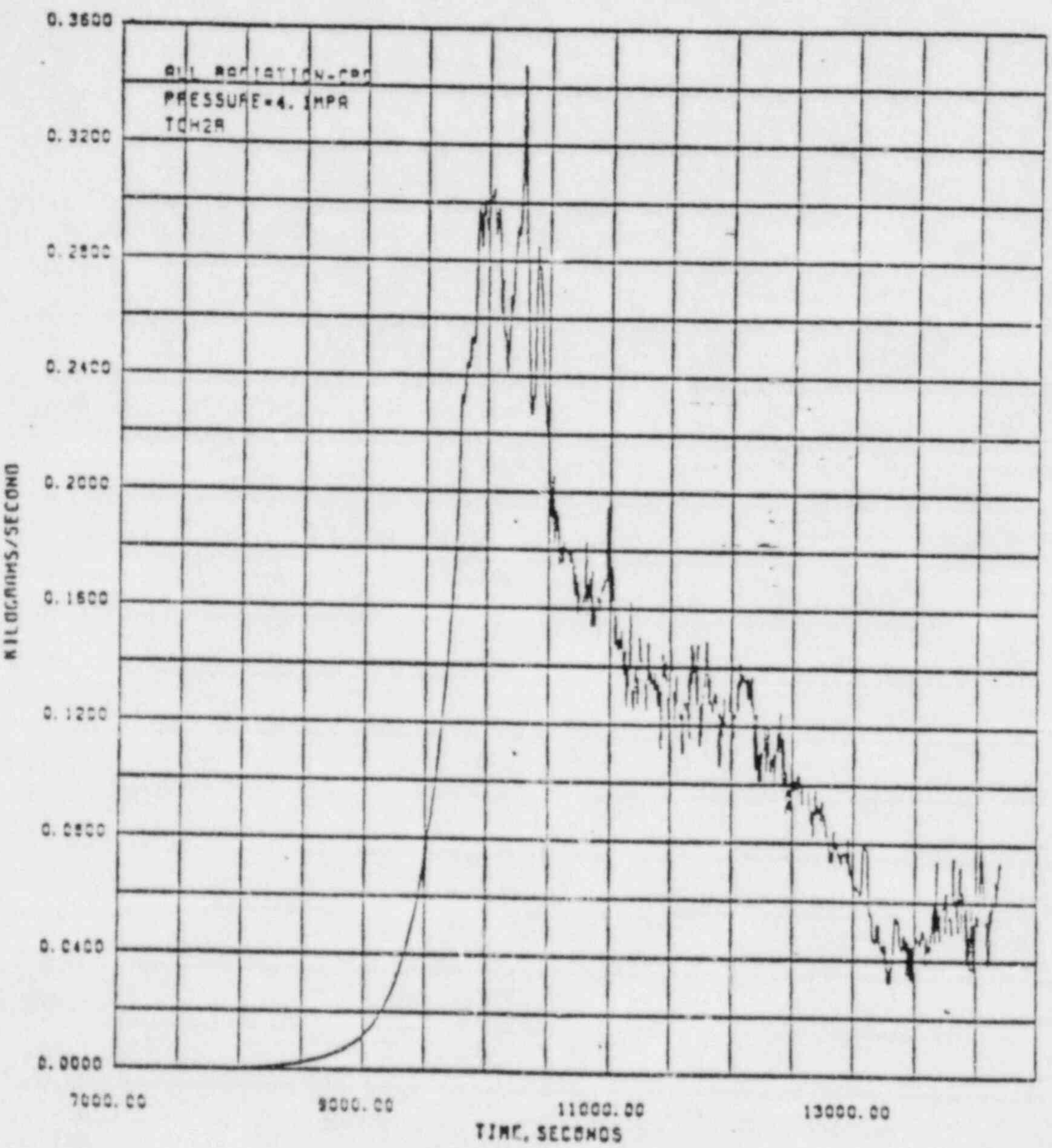
RUN 4



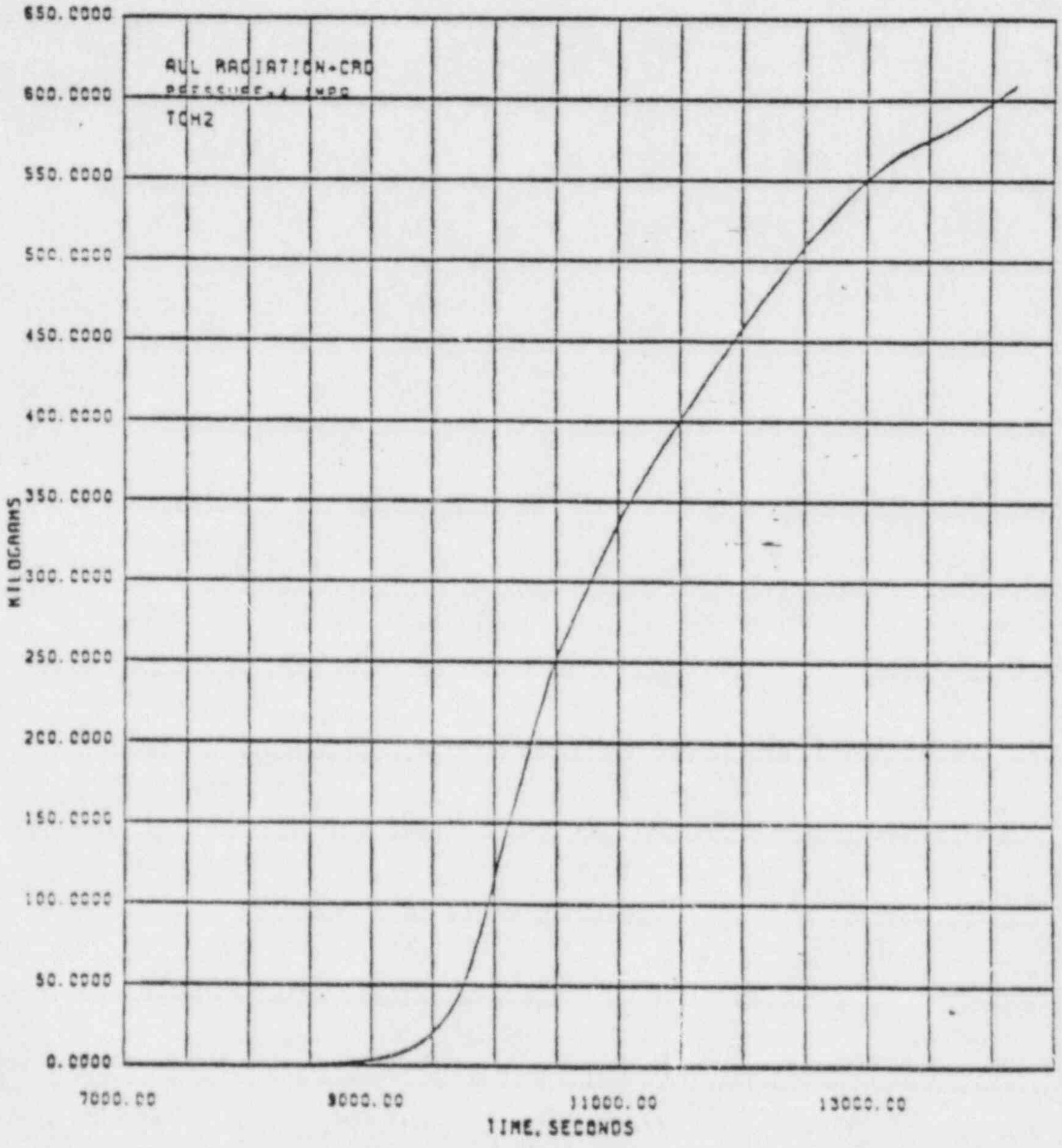
MINIMUM TWO PHASE LEVEL




MAXIMUM CLADDING TEMPERATURE

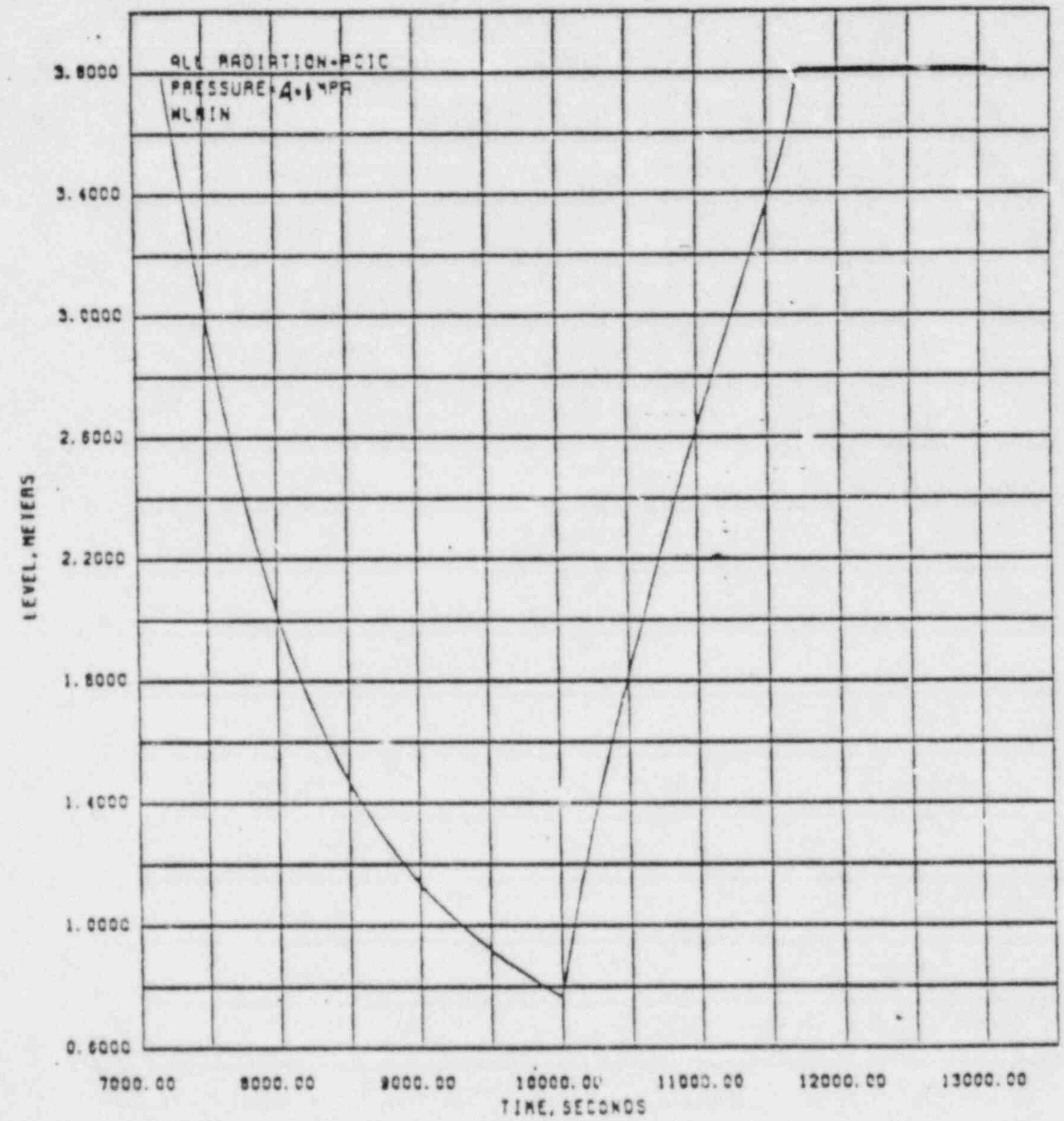



HYDROGEN GENERATION RATE

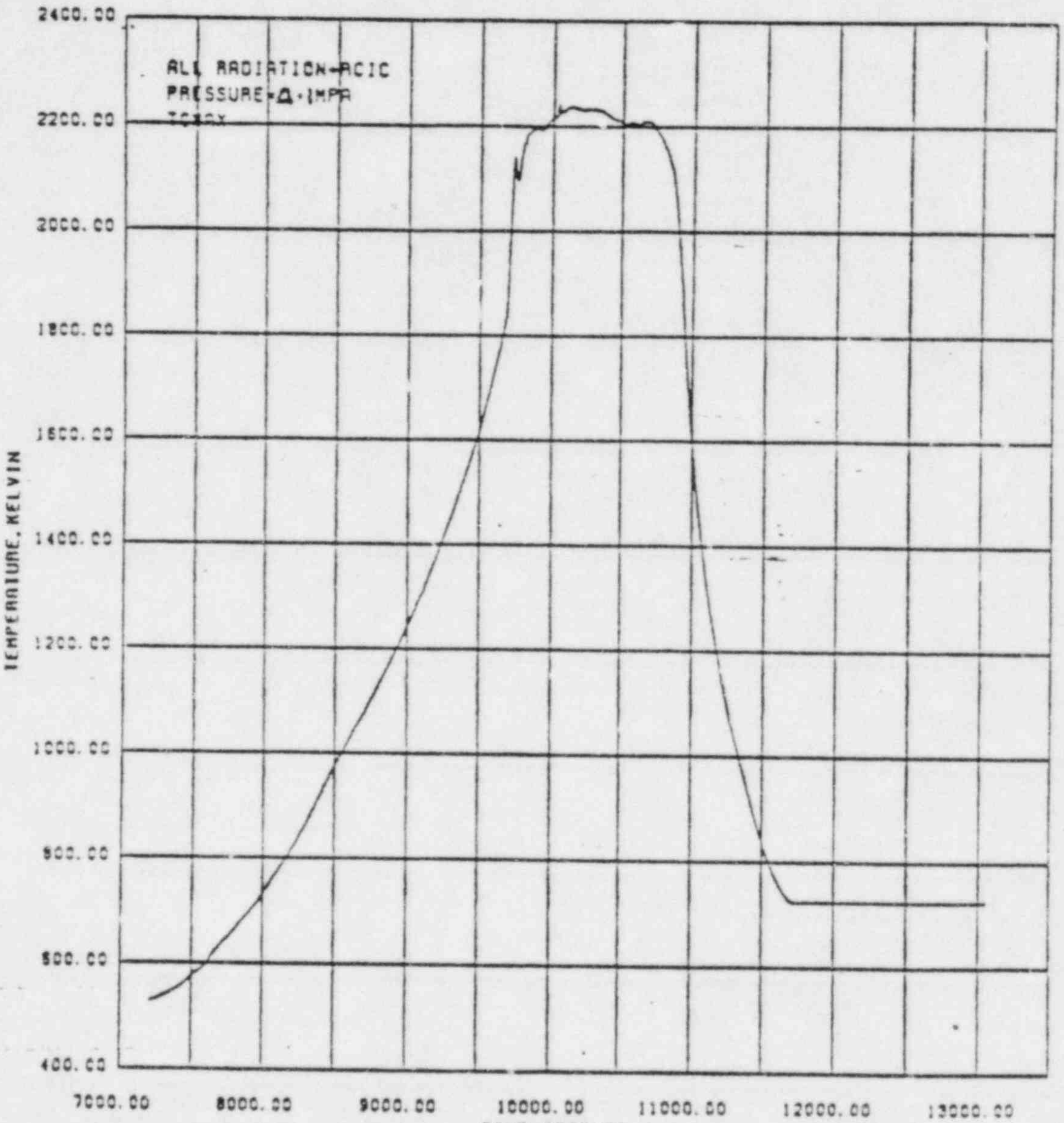



CUMMULATIVE HYDROGEN GENERATION

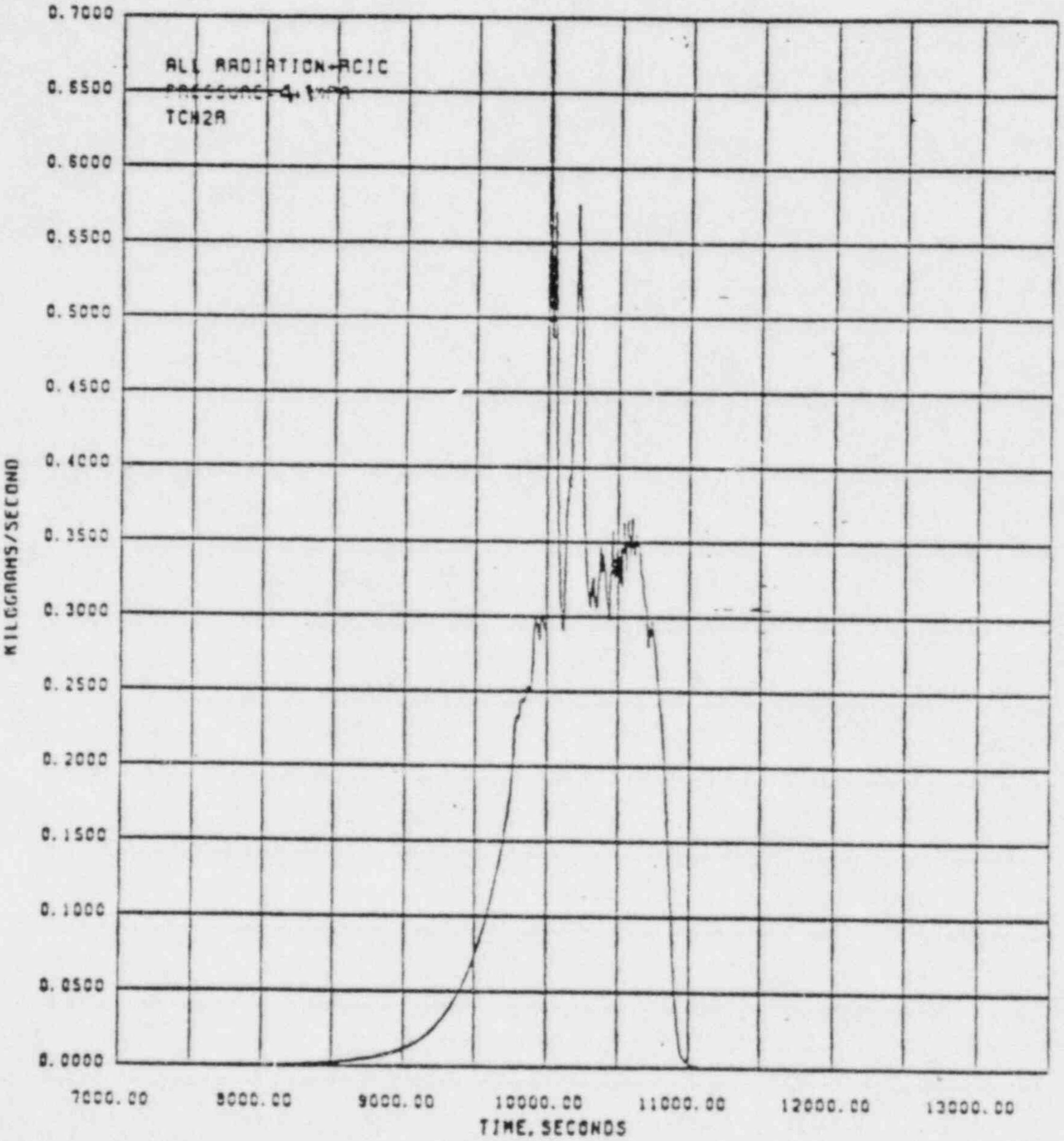
RUN 5



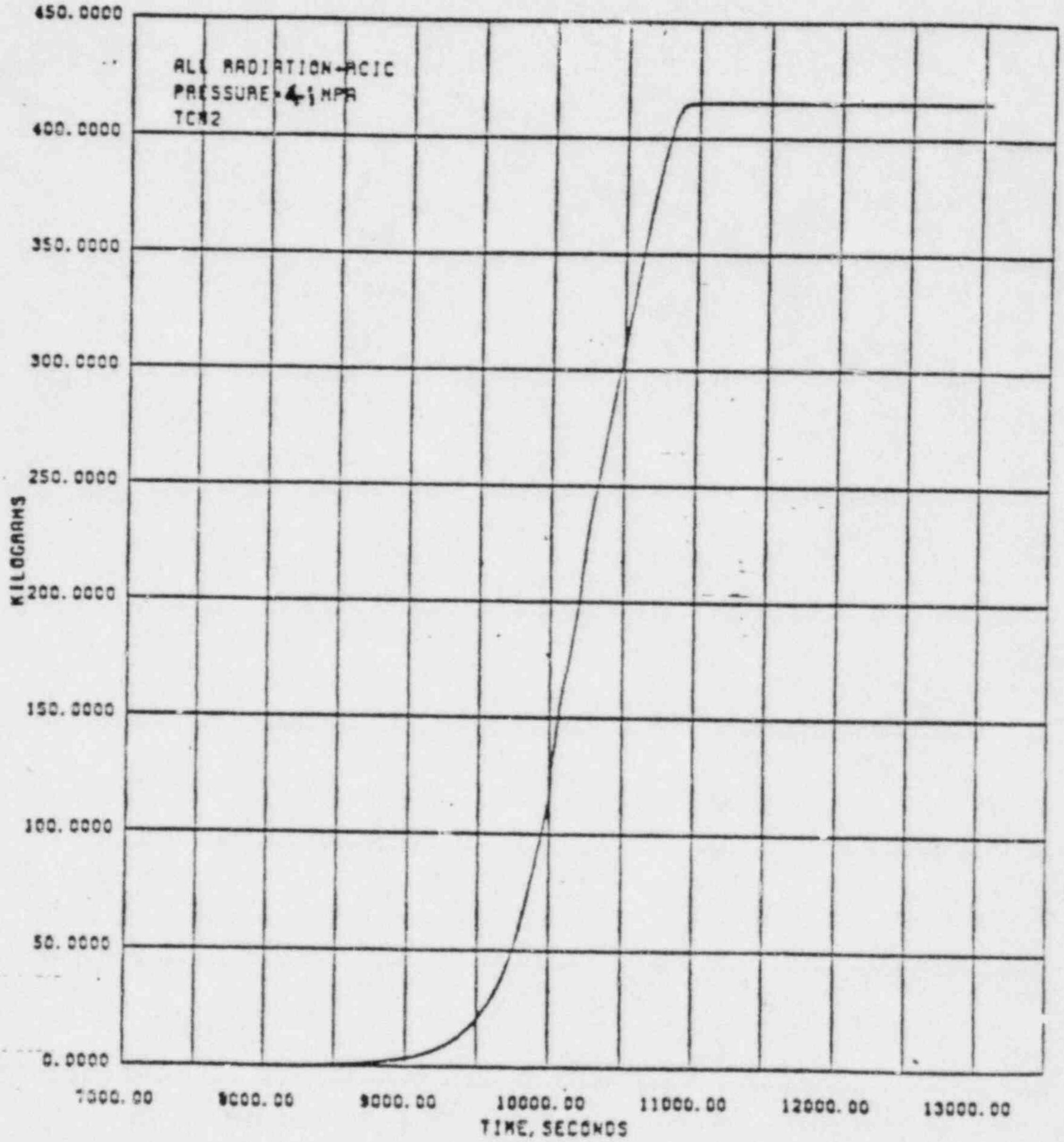

MINIMUM TWO PHASE LEVEL




MAXIMUM CLADDING TEMPERATURE



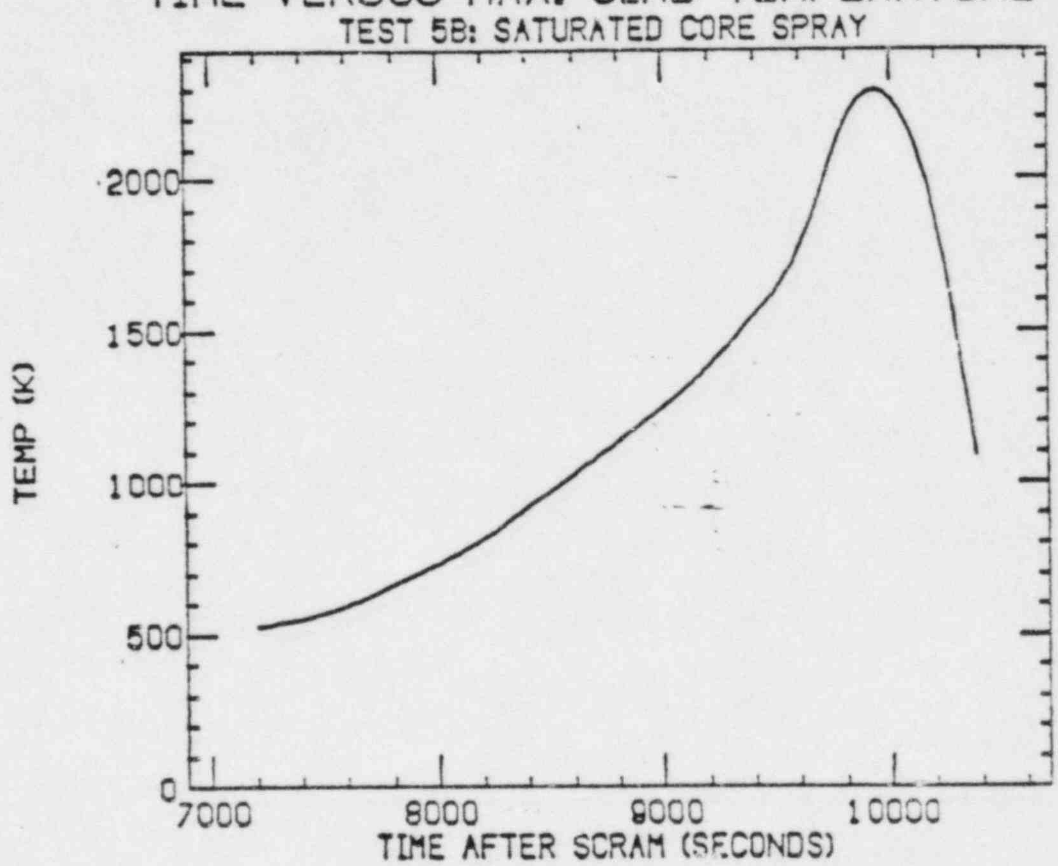

HYDROGEN GENERATION RATE




CUMMULATIVE HYDROGEN GENERATION

RUN 6

# TIME VERSUS MAX. CLAD TEMPERATURE



## SUMMARY

- DETAILED BWR CORE HEATUP CODE DEVELOPED
- SCOPING STUDY OF $H_2$ PRODUCTION RATES COMPLETED
    - PEAK CORE PRODUCTION RATES ($\lesssim$ 1.5 LBM/SEC) OCCUR FOR SHORT PERIODS ($\lesssim$ 1 MIN) AT INITIATION OF ECCS OPERATION
    - SUSTAINED CORE PRODUCTION RATES ($\lesssim$ 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