Docket File

52-003

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 4, 1996

APPLICANT: Westinghouse Electric Corporation

PROJECT: AP600

SUBJECT: SUMMARY OF MEETING WITH WESTINGHOUSE AND ELECTRIC POWER RESEARCH INSTITUTE (EPRI) TO REVIEW DATA IN SUPPORT OF THE USE OF PASSIVE AUTOCATALYTIC RECOMBINERS (PARS) FOR THE AP600

The Nuclear Regulatory Commission (NRC) staff and representatives of Westinghouse Electric Corporation and EPRI held a meeting in Westinghouse's Rockville, Maryland, office on February 27, 1996. The purpose of the meeting was to review the data in support of PARS for the AP600. Attachment 1 is the list of the meeting attendees. Attachment 2 and 3 are the Westinghouse and EPRI handouts presented during the meeting.

Highlights of the discussion are summarized as follows:

The meeting started with an opening statement from Jack Kudrick of the NRC on what the staff's concerns were for PARs. Mr Kudrick stated that among other things, the staff wanted to understand the PARs design for the AP600, the database that this design is based on, and the division of responsibility for PARs between Westinghouse and a future Combined License (COL) applicant. Westinghouse addressed the former concerns during the meeting. Westinghouse responded to the latter concern by stating that they wanted to qualify the PARs technology for use in the AP600 for design basis accidents (DBA) and that Westinghouse will establish the functional specifications for the PARs. Westinghouse stated that it will be left to the COL applicant to demonstrate that a particular PARs design meets the Westinghouse functional specifications.

The staff wanted Westinghouse to identify the subset of tests that were conducted by Battelle Frankfurt (Germany) that support qualifications of PARs for DBAs for the AP600. Westinghouse committed to supplying this information to the NRC. In addition to the baseline tests (N, O, and P) that Westinghouse identified in their January 11, 1996, submittal to the NRC, the staff said they would also be interested in tests that show the effects of the following on the operation of the PARs: hydrophobic coatings, contaminants and catalytic poisons, low concentrations of hydrogen, and long term operation.

The staff was also concerned with the environmental qualification of the PARs. For example, although the staff had seen data on the effects of temperature and pressure on the PARs it did not see any data indicating the effects of radiation. The staff felt that there needed to be agreement on the environment in which the PARs would be expected to function. The staff recommended that a good starting point might be something similar to the requirements

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found in 10 CFR 50.49 for the environmental qualification of electrical equipment. While Westinghouse did not agree with this approach, it did agree that this issue needs to be resolved through further meetings with the NRC.

The staff had questions on the version and the use of the computer code GOTHIC in the Battelle Frankfurt tests. EPRI was not sure of the version and the detailed use of this computer code. The staff also indicated that it would like Westinghouse to identify the basis, and source of conservatism or margins, for the use of PARs for DBAs. The staff indicated that there would be a forthcoming request for additional information on the subject of PARs that would document the staff's questions and concerns.

original signed by:
Joseph M. Sebrosky, Project Manager
Standardization Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Docket No. 52-003

Attachments: As Stated

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DATE	04/ /96	04/ /96	04/4/96	04/4/96	

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WESTINGHOUSE/EPRI/NRC AP600
MEETING ATTENDEES
FEBRUARY 27, 1996

NAME	ORGANIZATION
Donald Lingren	Westinghouse
Mark Willis	Westinghouse
Dan McDermott	Westinghouse
Brian McIntyre (part time)	Westinghouse
John Trotter	Polestar
Charles Thompson	Department of Energy
Dean Shah (part time)	Consolidated Edison
John Hosler	EPRI
George Sliter	EPRI
Michael Snodderly	NRC/DSSA/SCSB
Jack Kudrick	NRC/DSSA/SCSB
Asismios Malliakos	NRC/RES/DST/AEB
Joe Sebrosky	NRC/DRPM/PDST

Attachment 1

AP600 PASSIVE HYDROGEN CONTROL

AP600

PASSIVE AUTOCATALYTIC RECOMBINER PERFORMANCE
NRC - EPRI - WESTINGHOUSE
FEBRUARY 27, 1996 MEETING

Attachment 2

D. J. McDermott
Westinghouse

AP600 PASSIVE HYDROGEN CONTROL

DESIGN BASIS HYDROGEN CONTROL STATUS:

AP600 Design utilizes two passive autocatalytic recombiners for design basis hydrogen control

SAFETY ANALYSIS REPORT:

Section 6.2.4 draft submitted to the NRC via NTD/NRC-96-4621 on January 11, 1996. Submittal included:

- Safety analysis report section 6.2.4
- EPRI Report "NIS Par Depletion Rate Equation for Evaluation of Hydrogen Recombination During an AP600 Design Basis Accident
- NIS Quality Assurance Manual (German)
- Battelle Frankfurt Quality Assurance Manual (German and Translation)
- Comparison of Battelle QA Manual to NQA-1

Section 6.2.4 Safety Analysis Section scheduled to be submitted March 1996

AP600 PASSIVE HYDROGEN CONTROL

DESIGN BASIS:

Following a LOCA hydrogen generation based on:

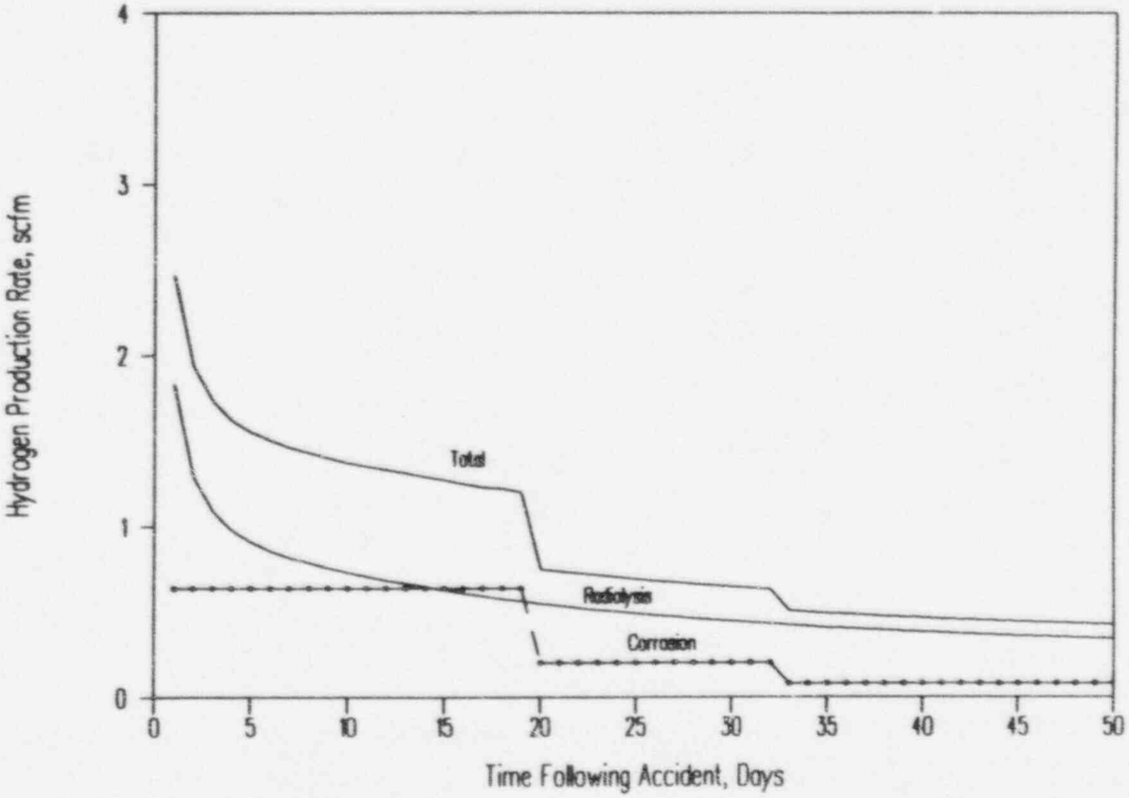
- zirconium fuel cladding reaction with water
- radiolysis of water within RCS and the sump
- Corrosion of materials of construction
- Hydrogen dissolved in reactor coolant

AP600 hydrogen generation rate assumptions are detailed in the safety analysis report

Generation rates are consistent with the guidance of Regulatory Guide 1.7

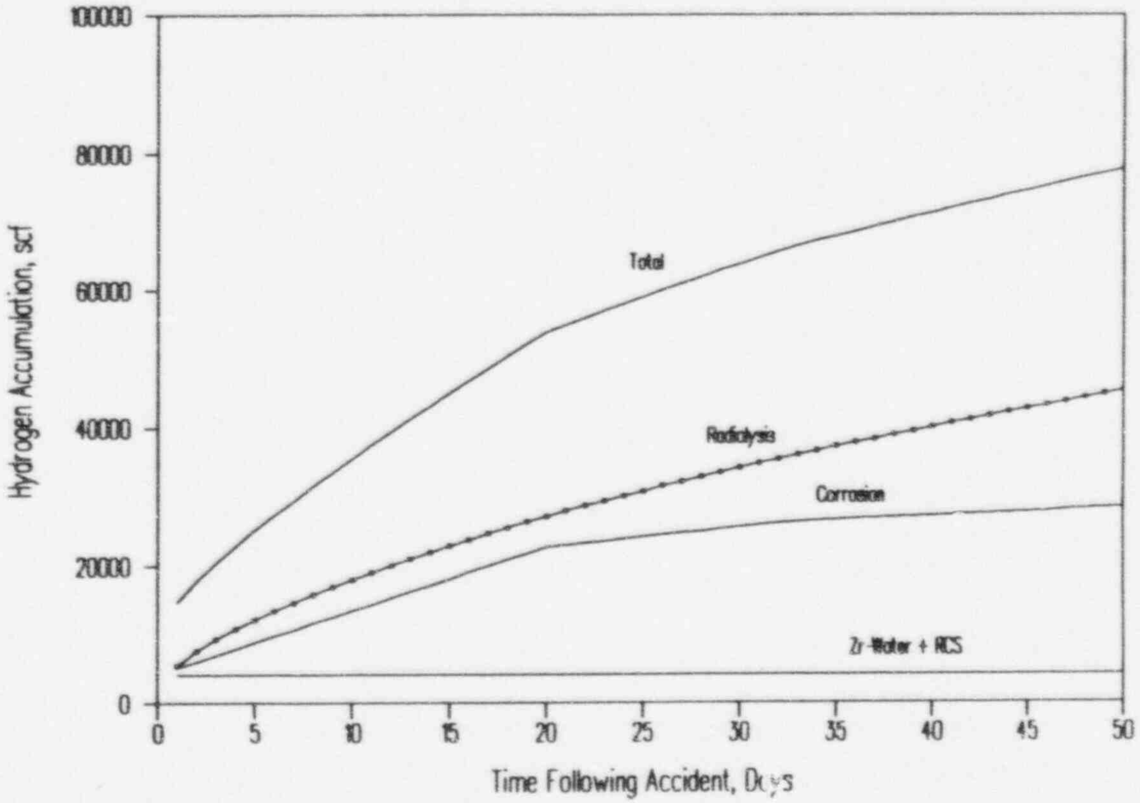
AP600 PASSIVE HYDROGEN CONTROL

HYDROGEN PRODUCTION RATES



AP600 PASSIVE HYDROGEN CONTROL

HYDROGEN ACCUMULATION IN CONTAINMENT - NO RECOMBINER



AP600 PASSIVE HYDROGEN CONTROL

HYDROGEN RECOMBINATION SUBSYSTEM

Two passive autocatalytic recombiners are utilized in AP600 Hydrogen Control System to control the relatively slow releases post LOCA. PAR's are defined as safety-related and seismically designed. Operation is independent of any moving parts, electrical power or any other support system. Therefor, the system is available following any event resulting in the release of hydrogen.

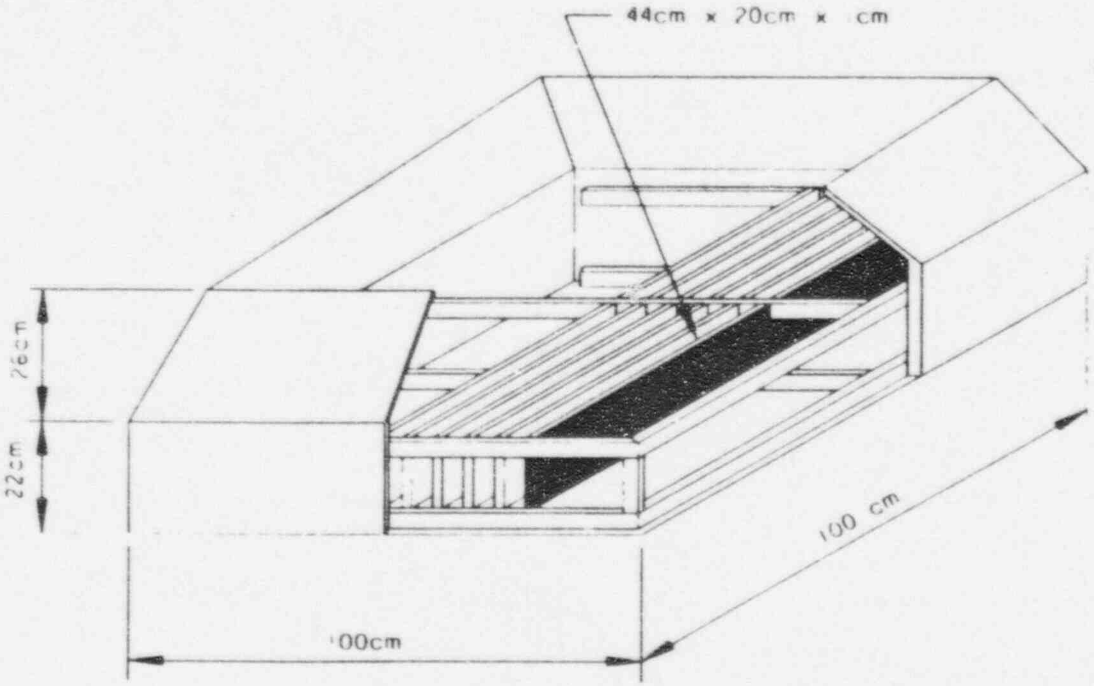
The design is typical of PAR's produced by at least 2 manufacturers

PAR consist of a stainless steel enclosure providing structure for the device and support for the catalyst material. The enclosure is open at the bottom and top extending beyond the catalyst to provide a chimney for additional lift.

AP600 PAR's are located at elevation 162 approximately 13 feet from the containment shell

AP600 PASSIVE HYDROGEN CONTROL

TYPICAL PAR CONFIGURATION



AP600 PASSIVE HYDROGEN CONTROL

PAR LOCATIONS INSIDE CONTAINMENT

AP600 PASSIVE HYDROGEN CONTROL

PAR PERFORMANCE ESTIMATES

PAR's begin recombination upon exposure to hydrogen and oxygen almost immediately provided the catalyst is not wetted. The startup time in a wet condition is dependent on the hydrogen concentration as documented in the EPRI report on NIS PAR depletion rates.

Although AP600 does not include a spray system there some potential for condensation. Consistent with the EPRI report, once hydrogen concentration reaches 1 vol %, a 7 hour delay in recombination is assumed followed by a conservative lower bound depletion rate. The conservative lower bound depletion rate accounts for instrumentation error (during testing), curve fitting and startup delays. This depletion rate is the basis for the analysis provided in the safety analysis report with a comparison to a best estimate performance for a single PAR.

Significant margin is available as demonstrated by the curves of 20% 10% and 1% of the lower bound depletion rate for a single recombiner.

Sensitivity analysis demonstrates tolerance of elevated concentrations.

PASSIVE HYDROGEN CONTROL PERFORMANCE

AP600

PAR SENSITIVITY STUDY · DRY CONDITIONS
IMPACT ON CONTAINMENT H2 CONCENTRATIONS

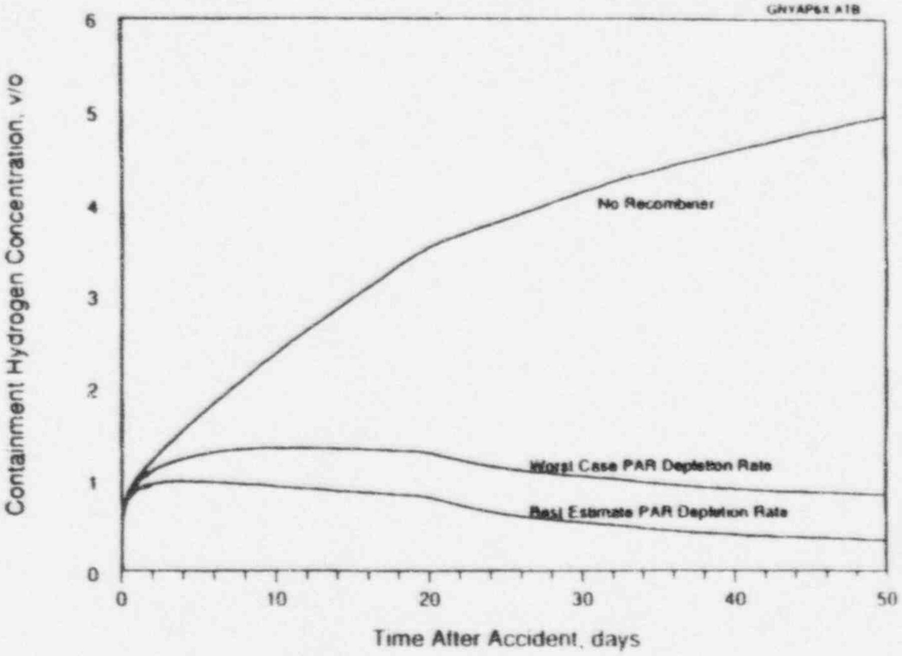


Figure 6 2 4 1

Hydrogen Production Rate

PASSIVE HYDROGEN CONTROL PERFORMANCE

AP600

CONCENTRATION VERSUS VARIOUS DEPLETION RATES

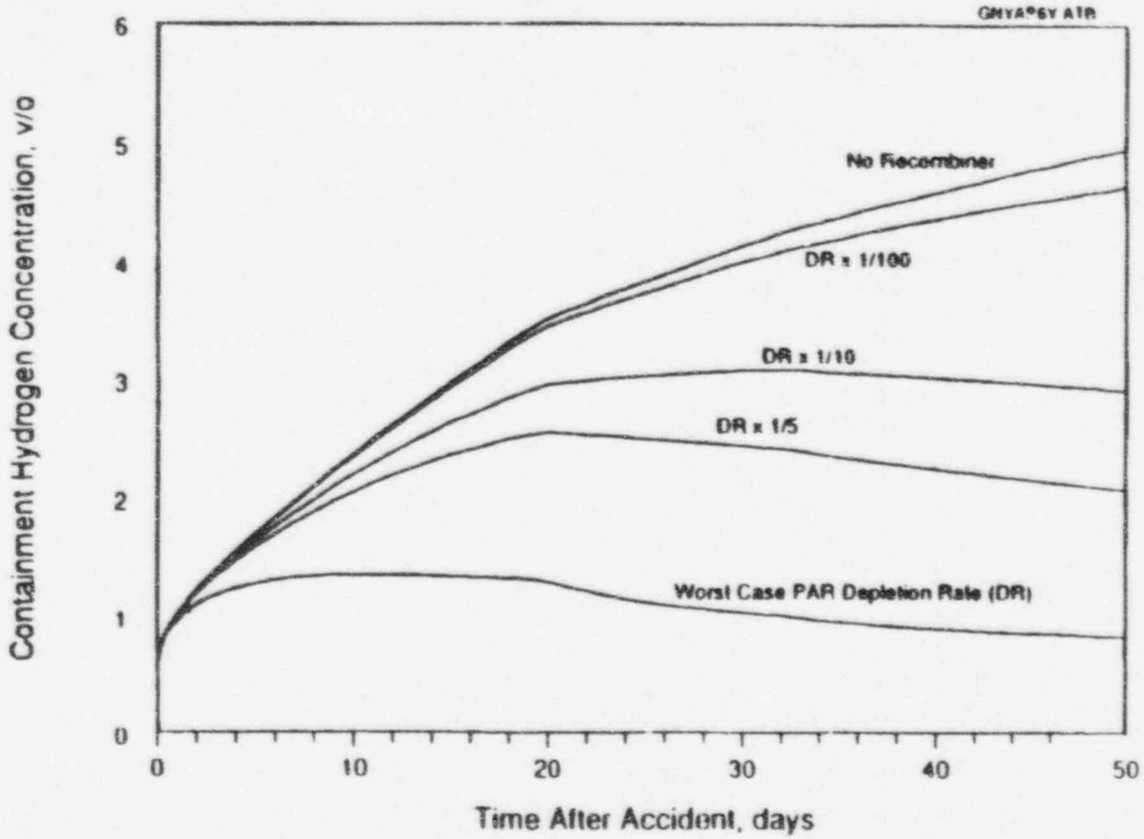
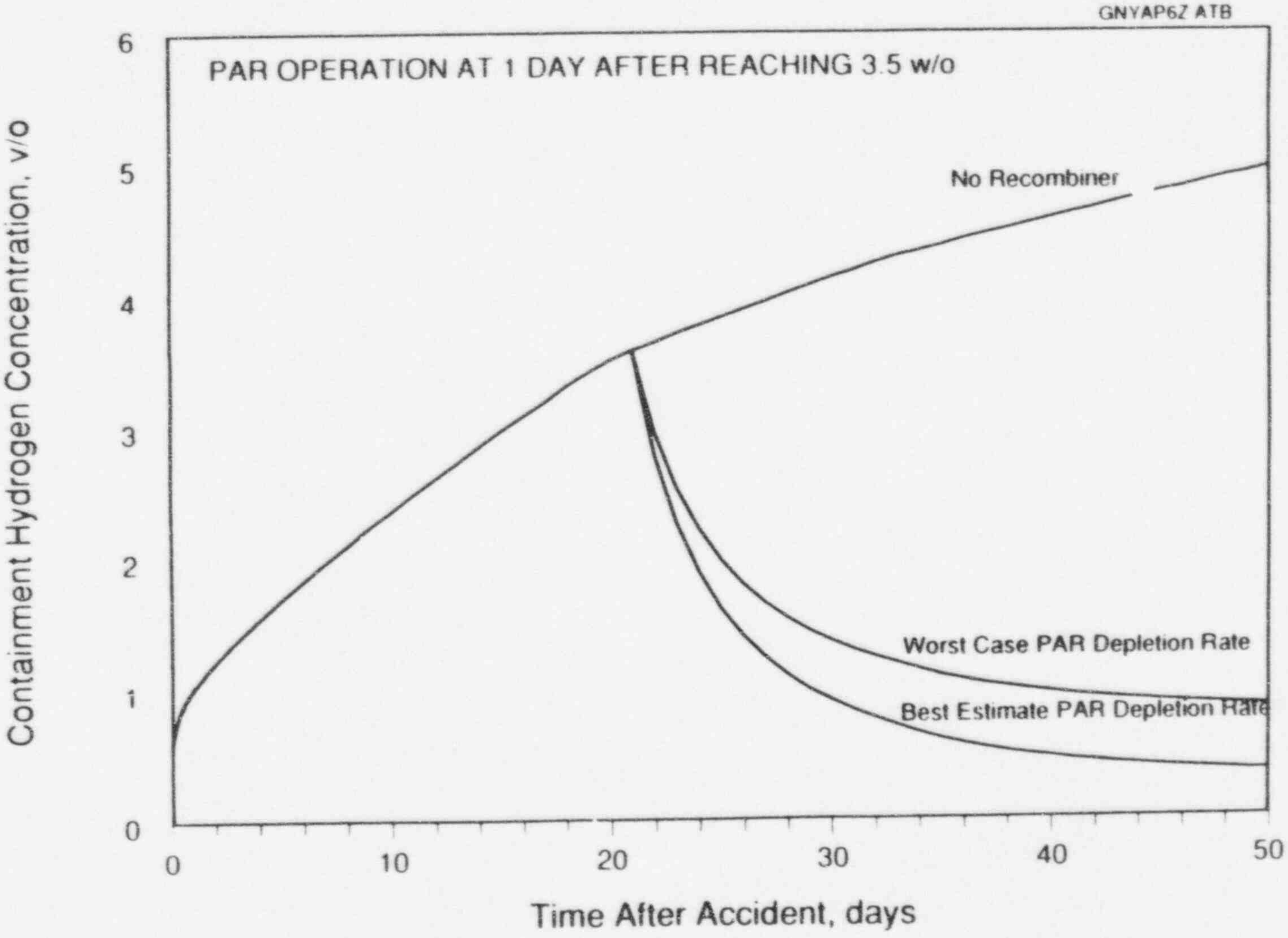


Figure 6.2.4-2

Hydrogen Accumulation in Containment – No Recombiner

AP600 PASSIVE HYDROGEN CONTROL

CONCENTRATION VERSUS STARTUP CONCENTRATION SENSITIVITY



AP600 PASSIVE HYDROGEN CONTROL

PAR DESIGN BASIS ENVIRONMENT

PAR's are designed to withstand the dynamic effects associated with postulated accidents, the environments existing inside containment following the postulated accidents, and a safe shutdown earthquake.

The conditions under which the PAR's are assumed to operate are consistent with the lower bound depletion rates from the EPRI report:

Inlet temperatures from 100 to 330° F
Containment pressure from 1 to 4 bars
Hydrogen concentrations up to 5 vol%
Steam concentrations ranging up to 75%
Condensing steam environment

EPRI Technical Support of Passive Autocatalytic Recombiners (PARs) for DBA Hydrogen Control in AP600

G. Sliter
J. Hosler

Westinghouse/NRC PAR Meeting
Rockville, MD
February 27, 1996

Attachment 3

AGENDA TOPICS

- Original EPRI PAR Information in Support of Design Certification
  - EPRI PAR Report
  - German PAR Test Data
  - NRC Evaluation
- Westinghouse/NRC Request for Additional Information
  - Quality Assurance Applied in PAR Tests
  - Lower Bound Depletion Rate Estimate for AP600 DBA Analysis

EPRI PAR REPORT

- Submitted to NRC by EPRI ALWR Program in April 1993
- Purpose -- technical basis for generic acceptance of PARs-only for accident combustible gas control (in combination with free-volume dilution in all ALWRs and pre-inerting in SBWRs)
- Focuses on NIS PAR as representative of PAR technology
- Final design and procurement specs may call for any PAR design that meets performance and qualification specs (other commercially available PARs include AECL and Siemens)
- Depletion rate curve from EPRI report is nominal NIS design curve and is starting point for estimation of lower bound curve to be discussed later

GERMAN PAR TEST DATA

- Tests performed at Battelle Frankfurt in 1990-91on full-size prototype (1m by 1m by 0.5m) and segment models (10cm by 10cm by 0.5m)
- Test conditions representative of BWR/PWR and DBA/SA
  - Dry and steam tests
  - Mostly oxygen rich (one test oxygen starved)
  - Hydrogen concentrations up to 8 vol.%
  - Wetness (delays catalyst heatup)
  - Potential poisons (iodine, carbon monoxide and oil/cable fire)
  - Variations in ambient temperature and pressure

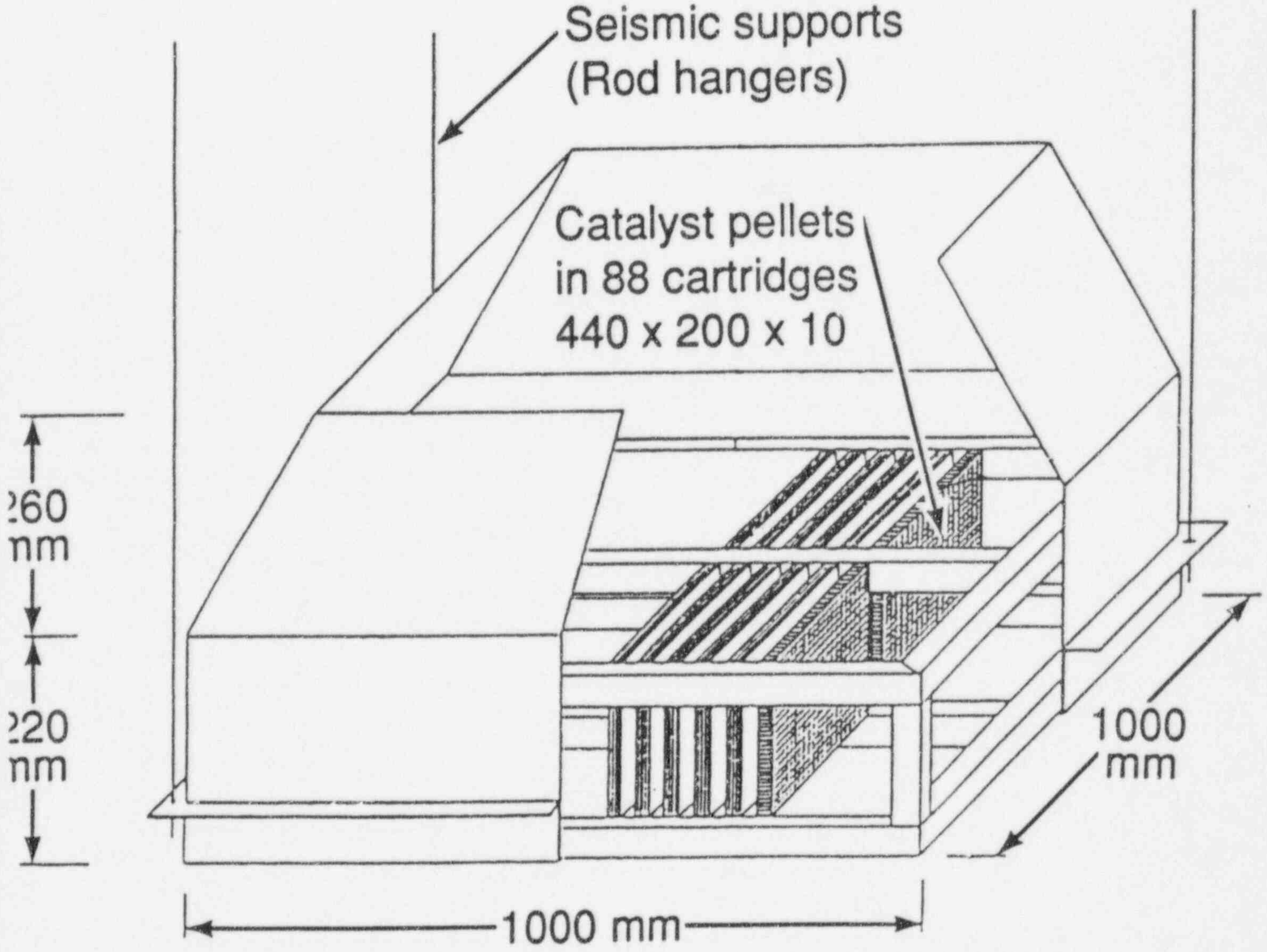
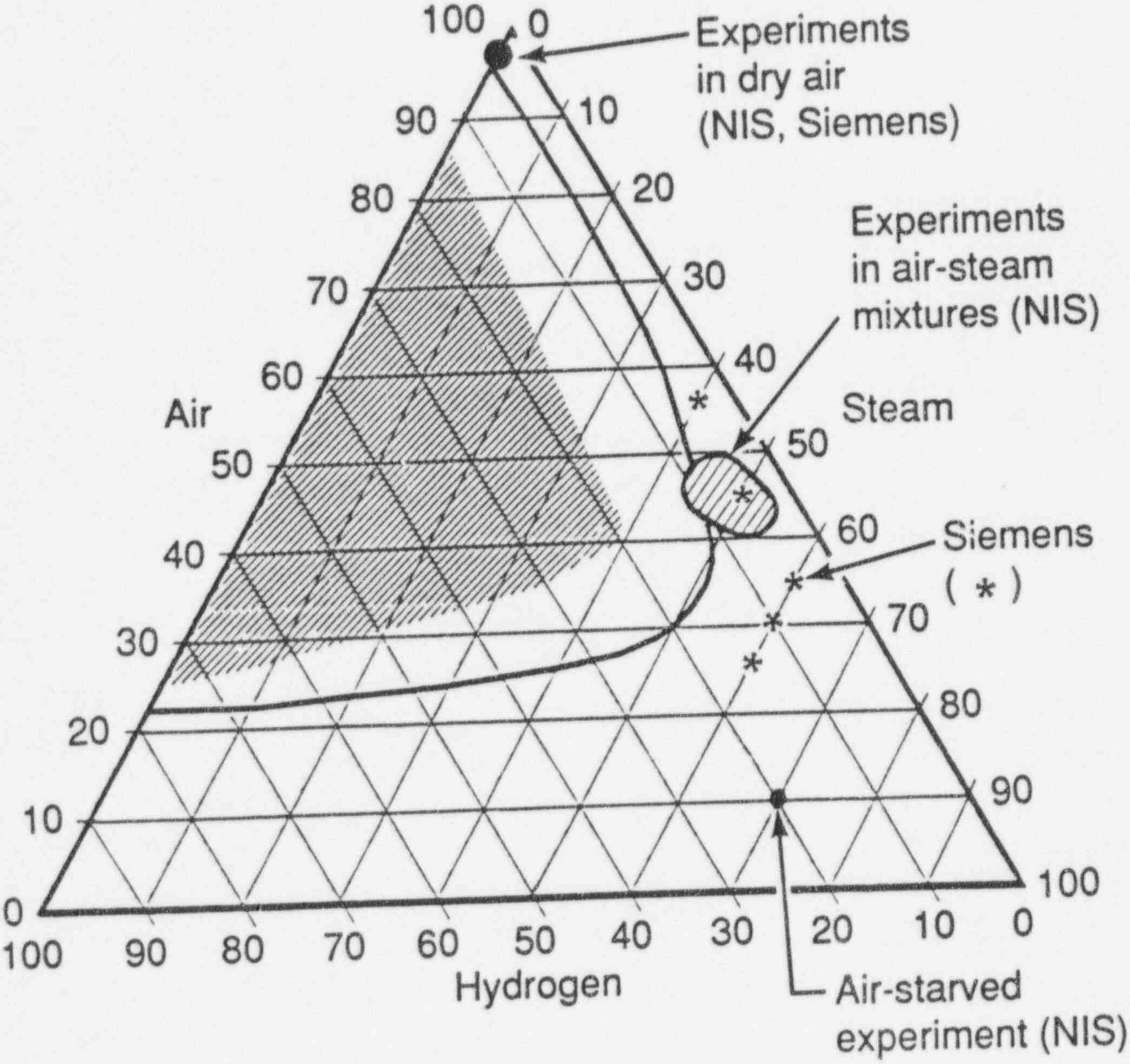

Seismic supports
(Rod hangers)
Catalyst pellets
in 88 cartridges
440 x 200 x 10
260
mm
220
mm
1000
mm
1000 mm

Table 3.1

Overview of PAR Test Program

Test Phase	Test Device	Number of Tests	Test Purpose/Scope	Test Conditions
1A Screening	Forced flow in a laboratory tube apparatus	45	Screening catalyst materials (24 types)	1-2 bar; 0-50 % steam; 0-3% H_2; 20-120°C
		8	PAR - model geometry; 4 types	
1B Model	Natural convection in an airlock chamber with 10 m^3 free volume	11	PAR - model; geometry effects	1-2 bar; 0-50 % steam; 0-6 % H_2 20-125°C
		10	Different materials	1-2 bar; 0-50 % steam 0-3 % H_2; 20-125°C
		20	Adverse influences (wet conditions, 0_2-poverty*, reverse flow, CO, iodine, silicon oil vapor, hydrocarbon oil and cable fire)	1-2 bar; 0-50 % steam; 0-11 % H_2; 20-125°C
2 Prototype	Multicompartment model containment (208 and 640 m^3)	4	PAR prototype function (depletion rate and mixing)	1 bar; 40-50 % steam; 3-5 % H_2; 20-125°C
	One compartment in model containment (41 m^3)	4	PAR prototype strength (deflagration tests)	1 bar; 0-25 % steam; 9-10 % H_2; jet ignited; 0.18-0.42 bar pressure peak
	Total	**102**		

* 2% 0_2; 20% H_2; 70% steam; 10% air


Experiments in dry air (NIS, Siemens)
Experiments in air-steam mixtures (NIS)
Siemens (*)
Air-starved experiment (NIS)
Air
Steam
Hydrogen
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
100
90
80
70
60
50
40
30
20
10
0

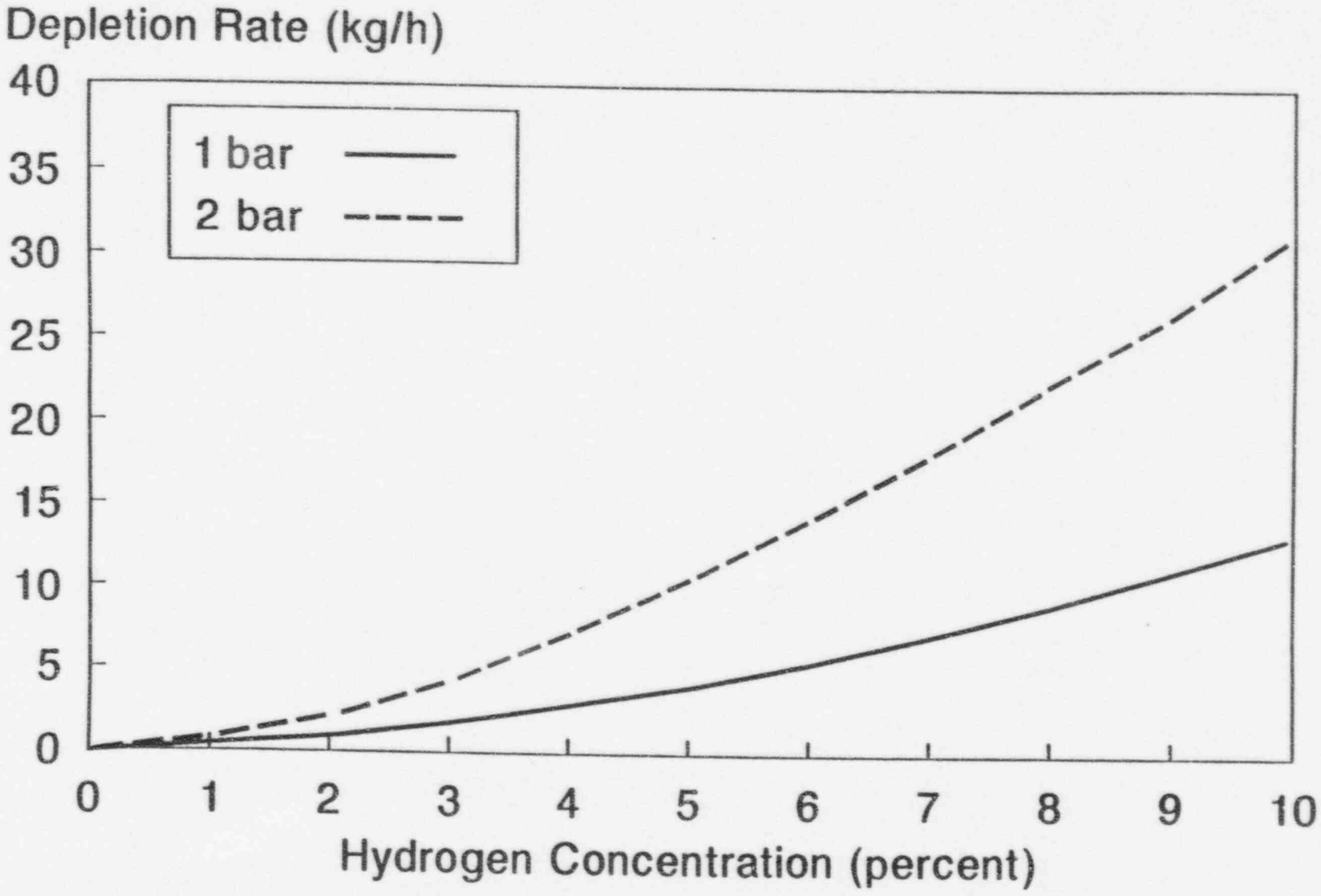


Fig. 4.1 Experimentally Determined PAR Depletion Rate as a Function of Hydrogen Concentration (1 bar = no steam, 2 bar = 50% steam)

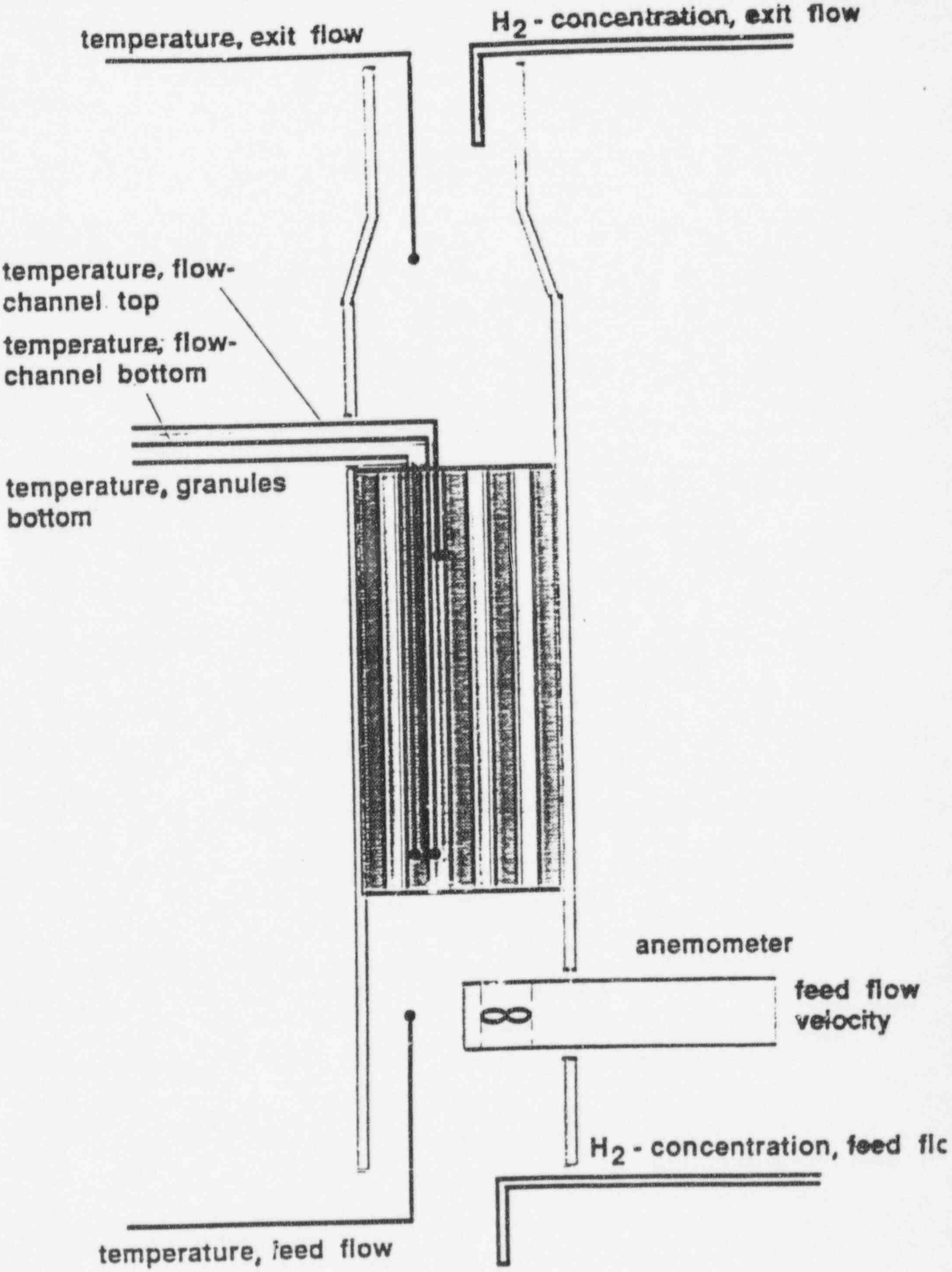


Fig. B.4 Arrangement and Instrumentation for the Model Tests

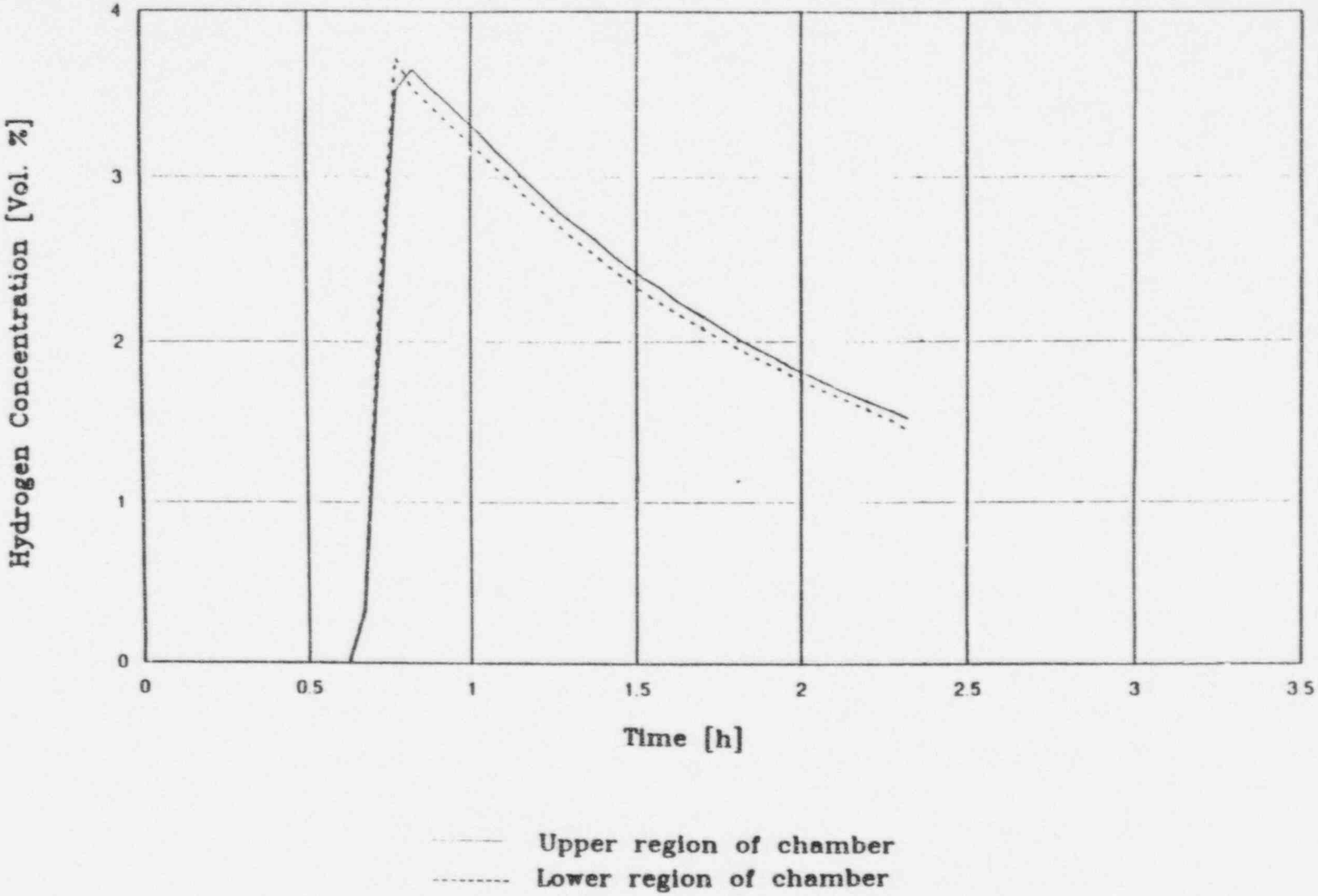


Fig. B.8 Measured Hydrogen Concentration Distant from the PAR Model

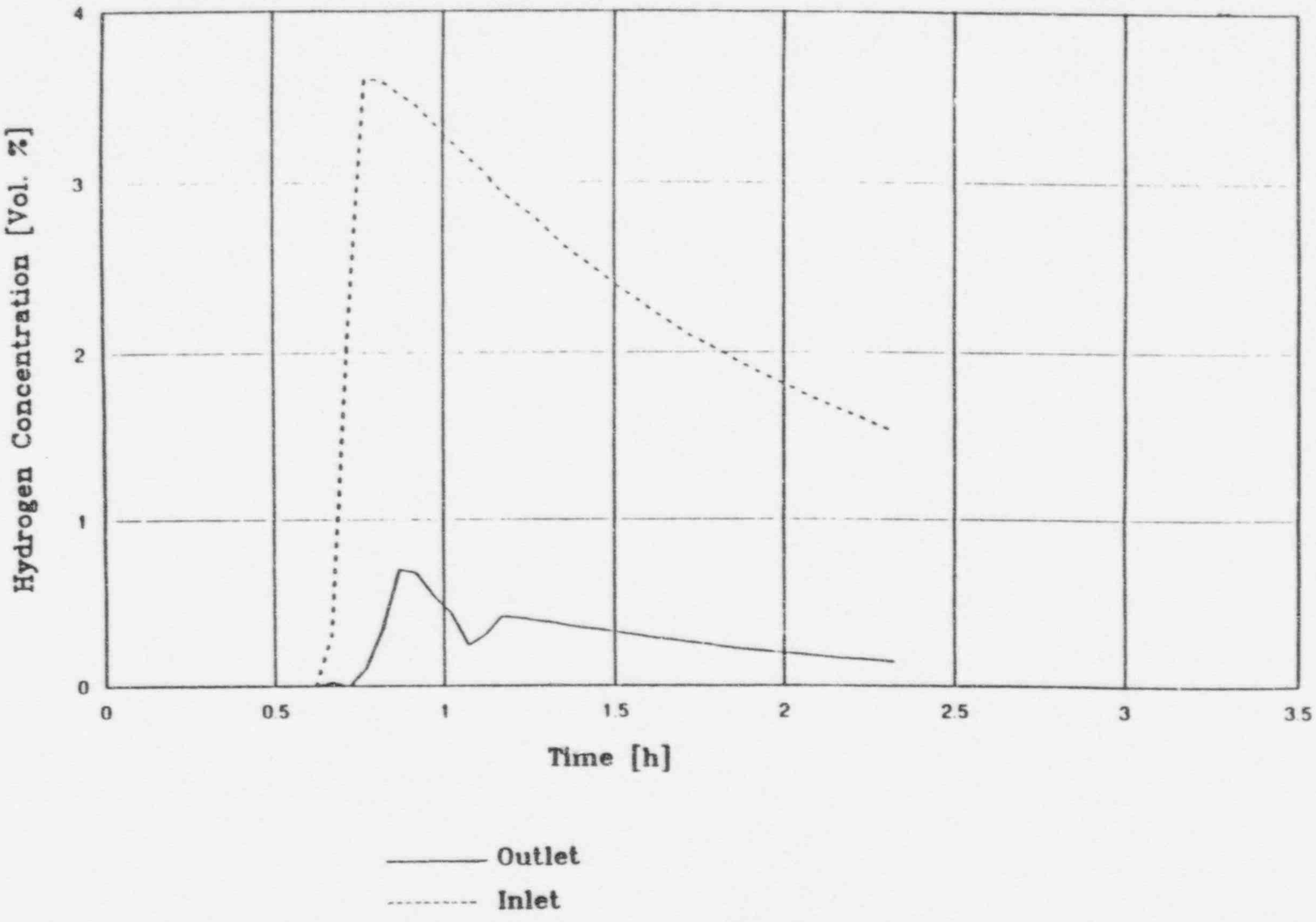


Fig. B.9 Measured Hydrogen Concentration of Outlet and Inlet of PAR Model

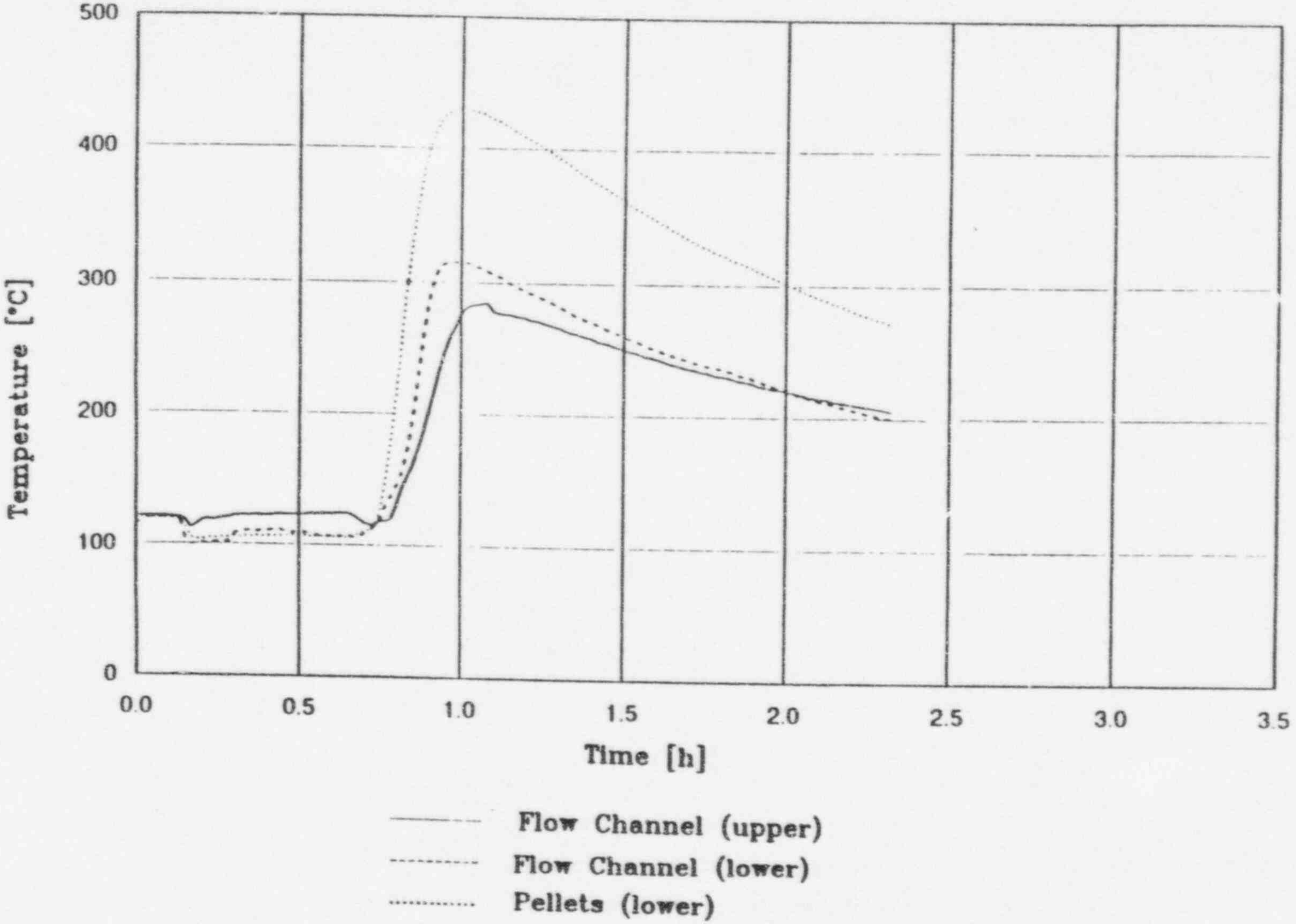
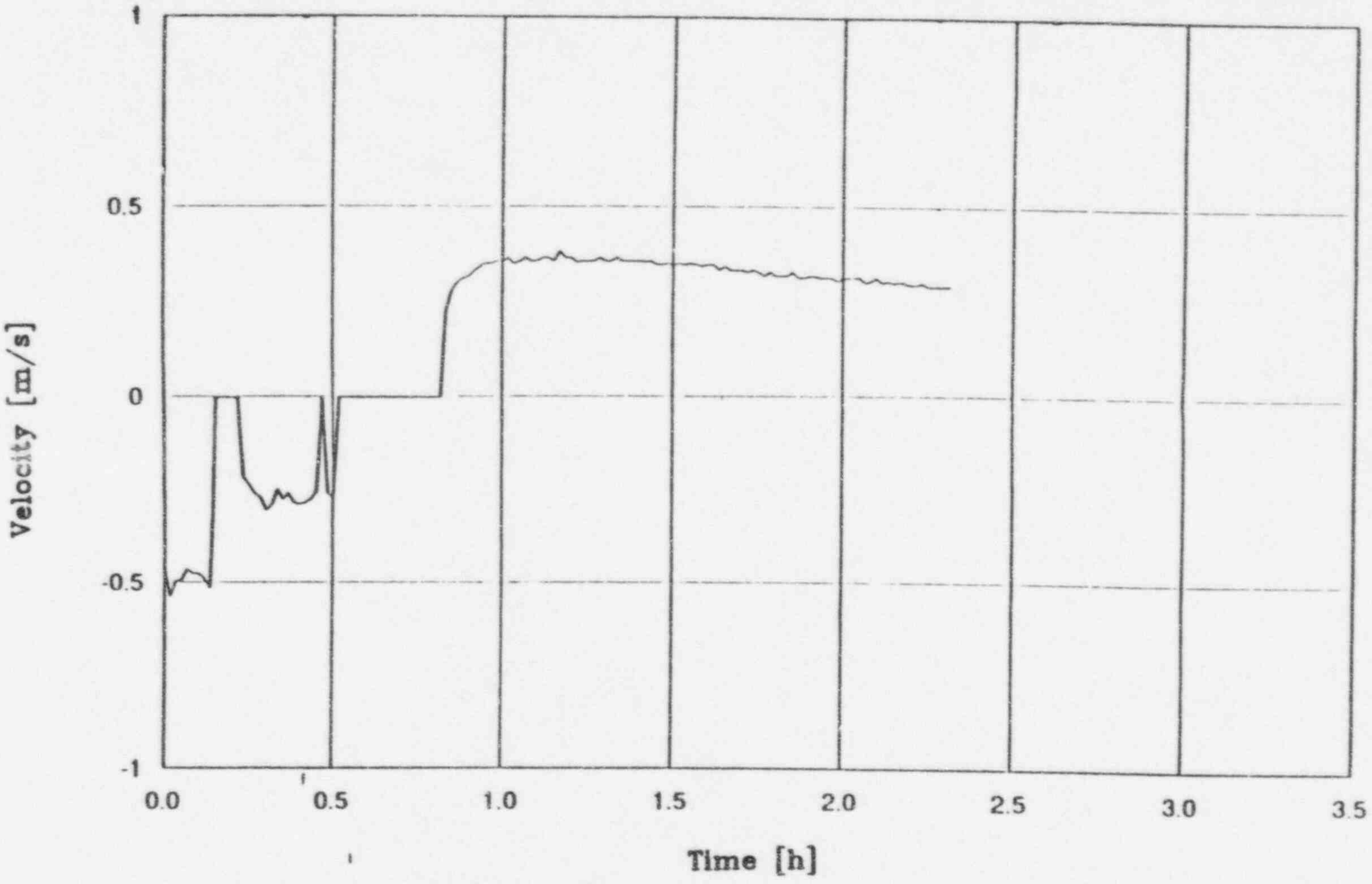


Fig. B. 10 Measured Temperature History along a Flow Channel and in the Pellets



——— Vertical Gas Velocity at Inlet of PAR Model

Fig B.11 Inlet Flow Measured with Anemometer Directly beneath Model

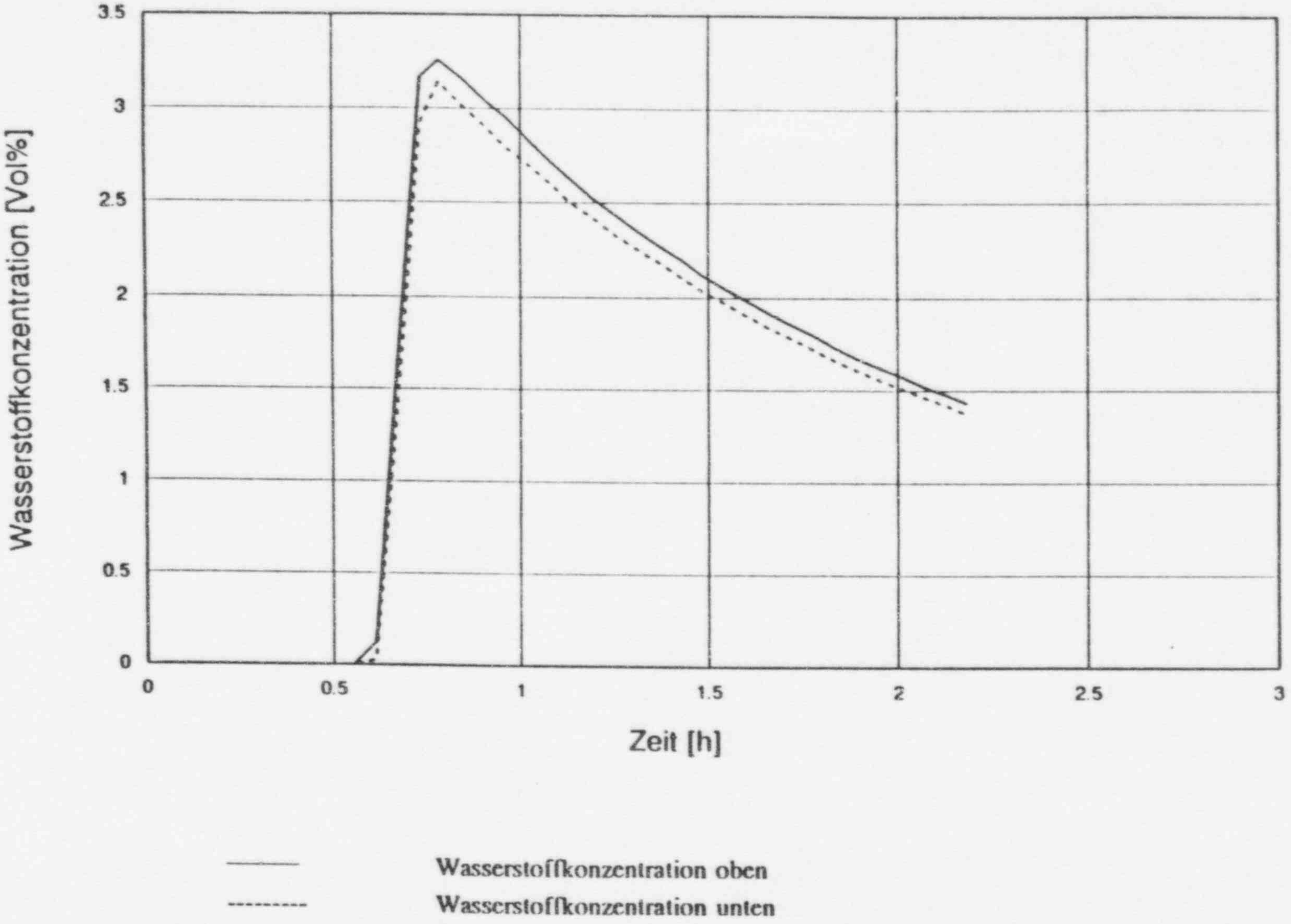


Bild N-01: Wasserstoffkonzentration im Versuchsbehälter (Versuch N: 2.3.a)

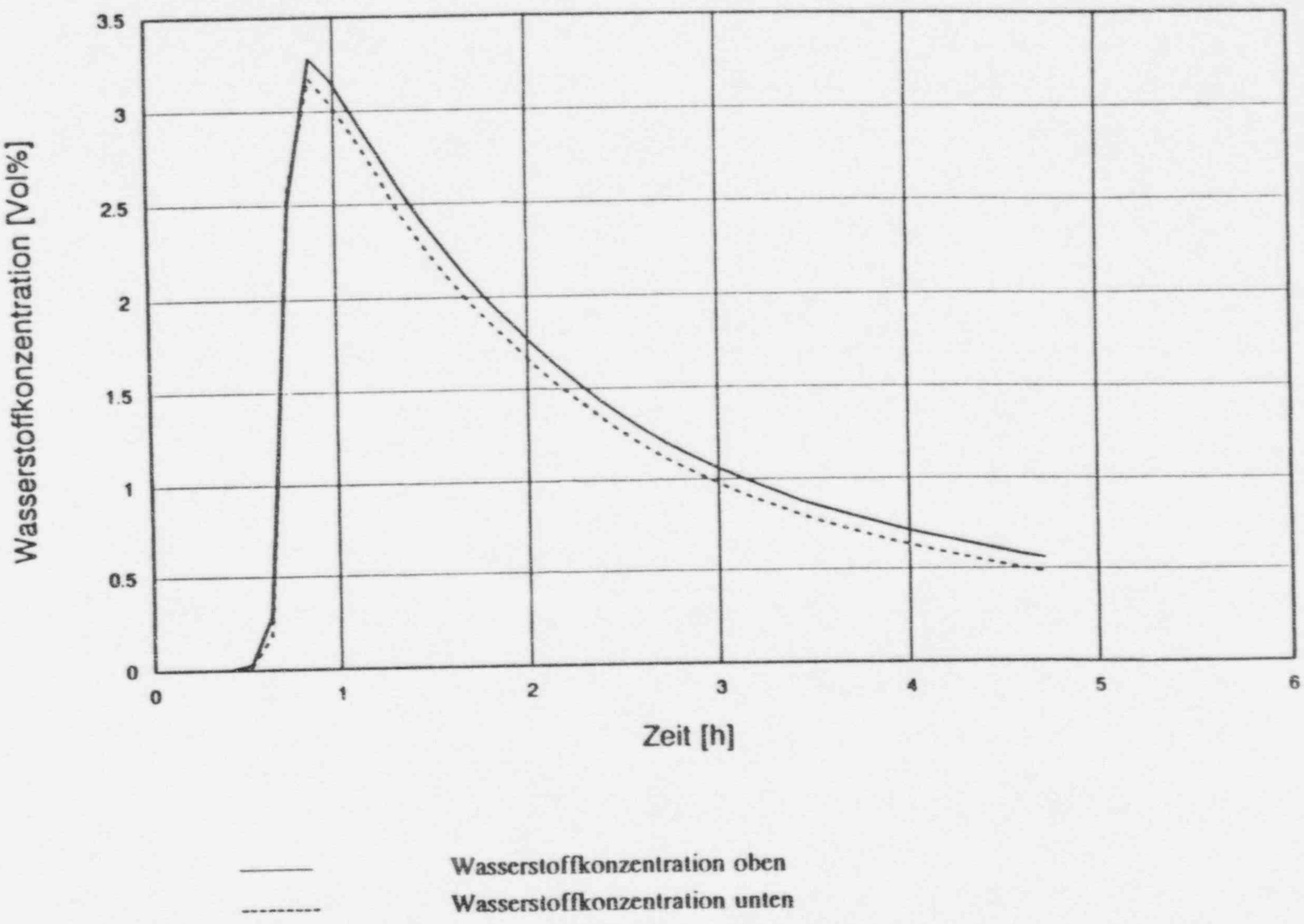


Bild P-01: Wasserstoffkonzentration im Versuchsbehälter (Versuch P: 2.3.c)

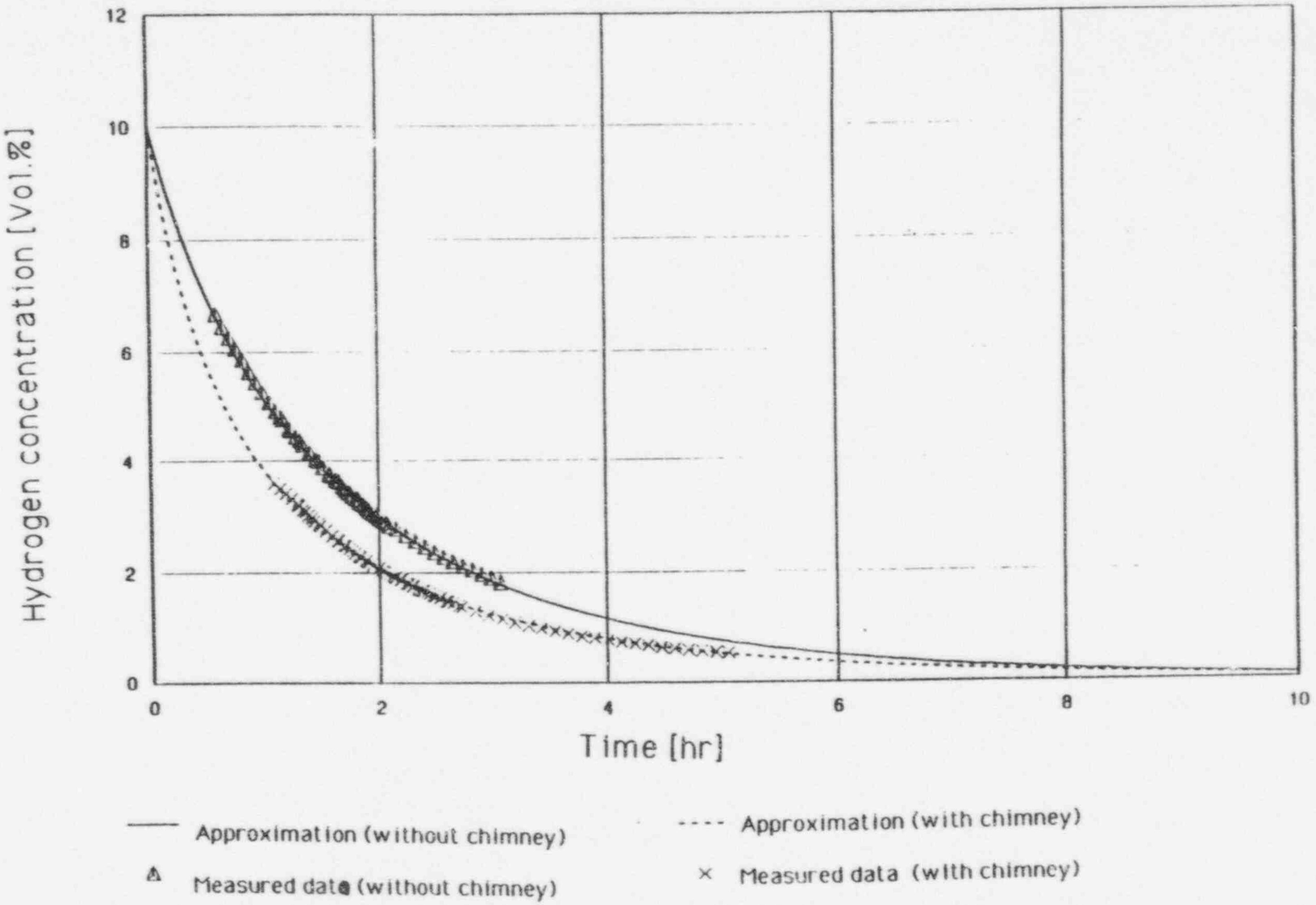


Fig. B. 6 Experimental Data with and without Chimney and Related Approximation Function

Appendix D

THEORETICAL TOOLS

D.1 Empirical Models of Depletion Rate

Since the model and prototype performance tests were conducted over a broad range of parameters, it was necessary to construct a best-fit curve through the data. This curve would not only provide a statistically best value of the results, but also a tool for interpolation, extrapolation, and inclusion of the test results in numerical analyses discussed later in this appendix.

The test measurements give a concentration history $C = C(t)$. The time derivative (slope) of this curve is proportional to the volume flow rate Q through the device. The mass depletion rate M [kg/h] is given by

$$M = QC\eta\rho$$

where η is the recombination efficiency and ρ is the gas density.

Model Test Data To obtain an empirical fit of the data from the model tests, it was assumed that the volume flow was a linear function of the concentration:

$$Q = bC(t) + a$$

This empirical model gave a good fit through the model data and, with the best fit values of the constants a and b, led to the mathematical approximation curves for data with and without chimney shown in Fig. B.6. This analytical approximation of measured performance is convenient for displaying the comparative effects of various influences in figures in Appendix B. With the formula for depletion rate shown above, the best fit curve for flow rate led to the curves of depletion rate versus hydrogen concentration shown in Fig. 4.1.

Prototype Test Data The prototype data added to the set of data points available for a best fit curve. A best fit curve was needed in this phase of the program (1) for having a basis of comparison between the performances of the model and prototype devices and (2) for use as a mathematical model of the PAR in the thermal hydraulic computer code applied for benchmarking against results from the multicompartment tests.

It was found that the assumption of volume flow varying as an exponential function of concentration gave a better fit than the linear assumption with the combined data set. The exponential function is of the form

$$Q = dC^e$$

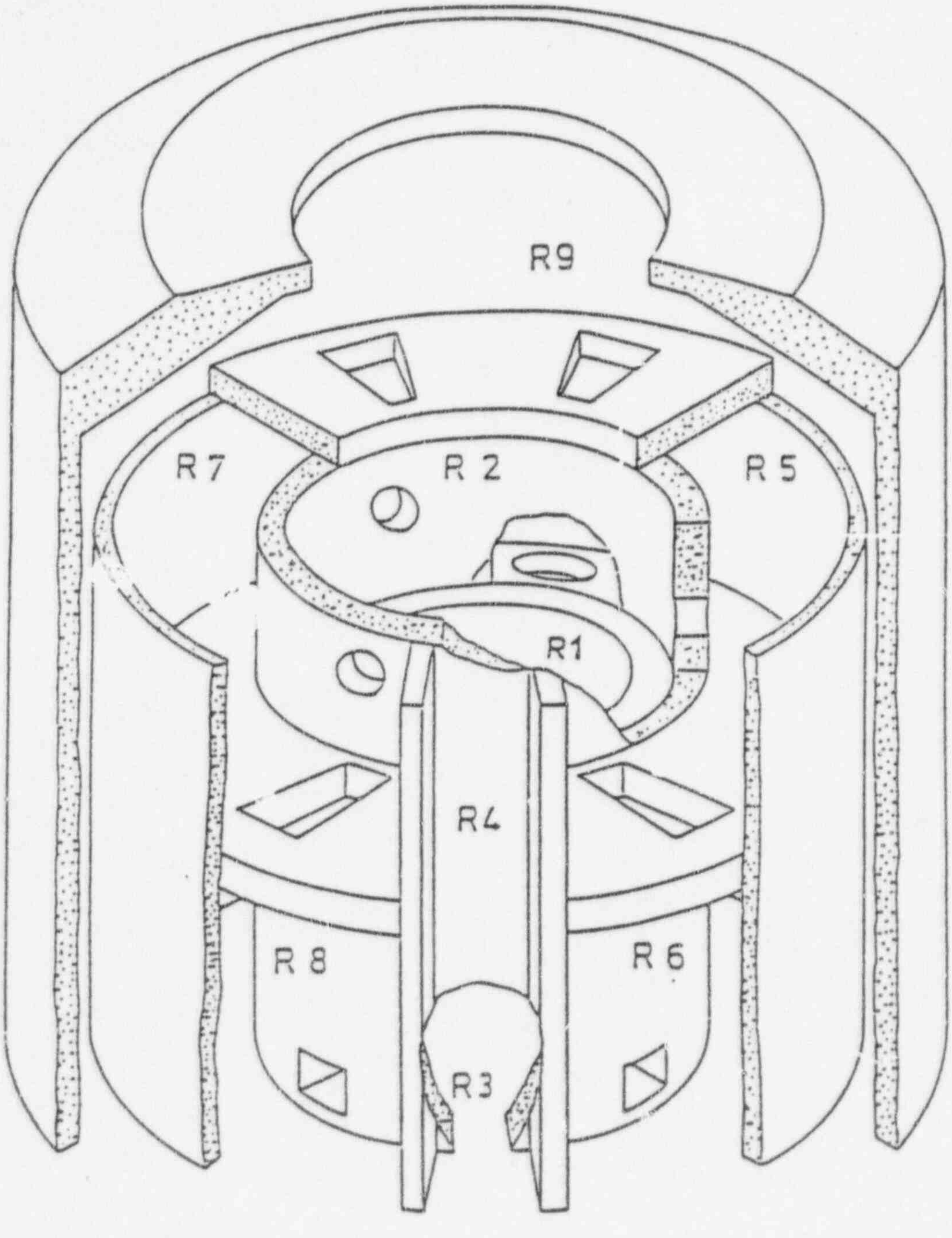
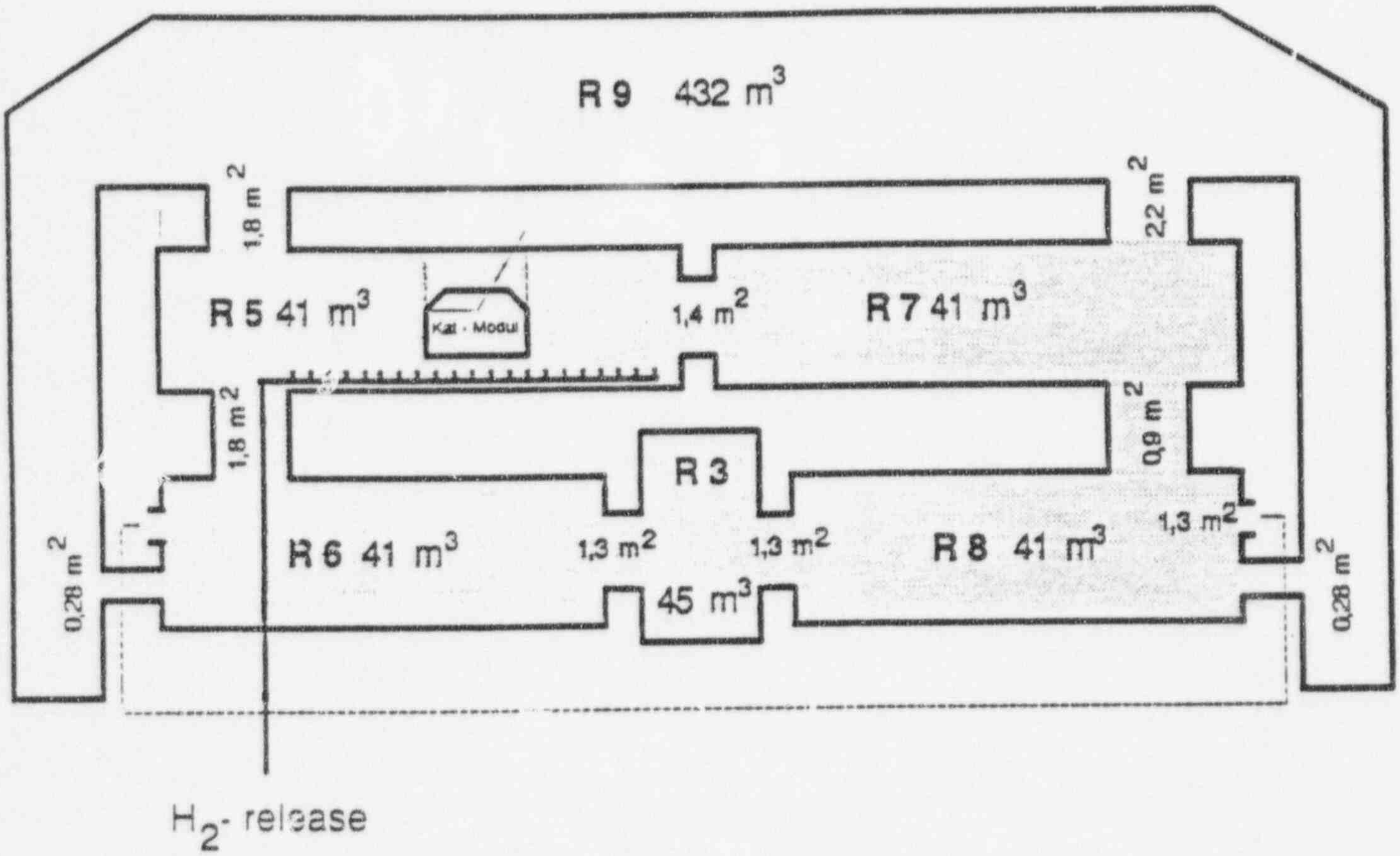


Fig. C.1 Concrete Multicompartment Model Containment (12m diameter) in which Prototype PAR Tests were Performed



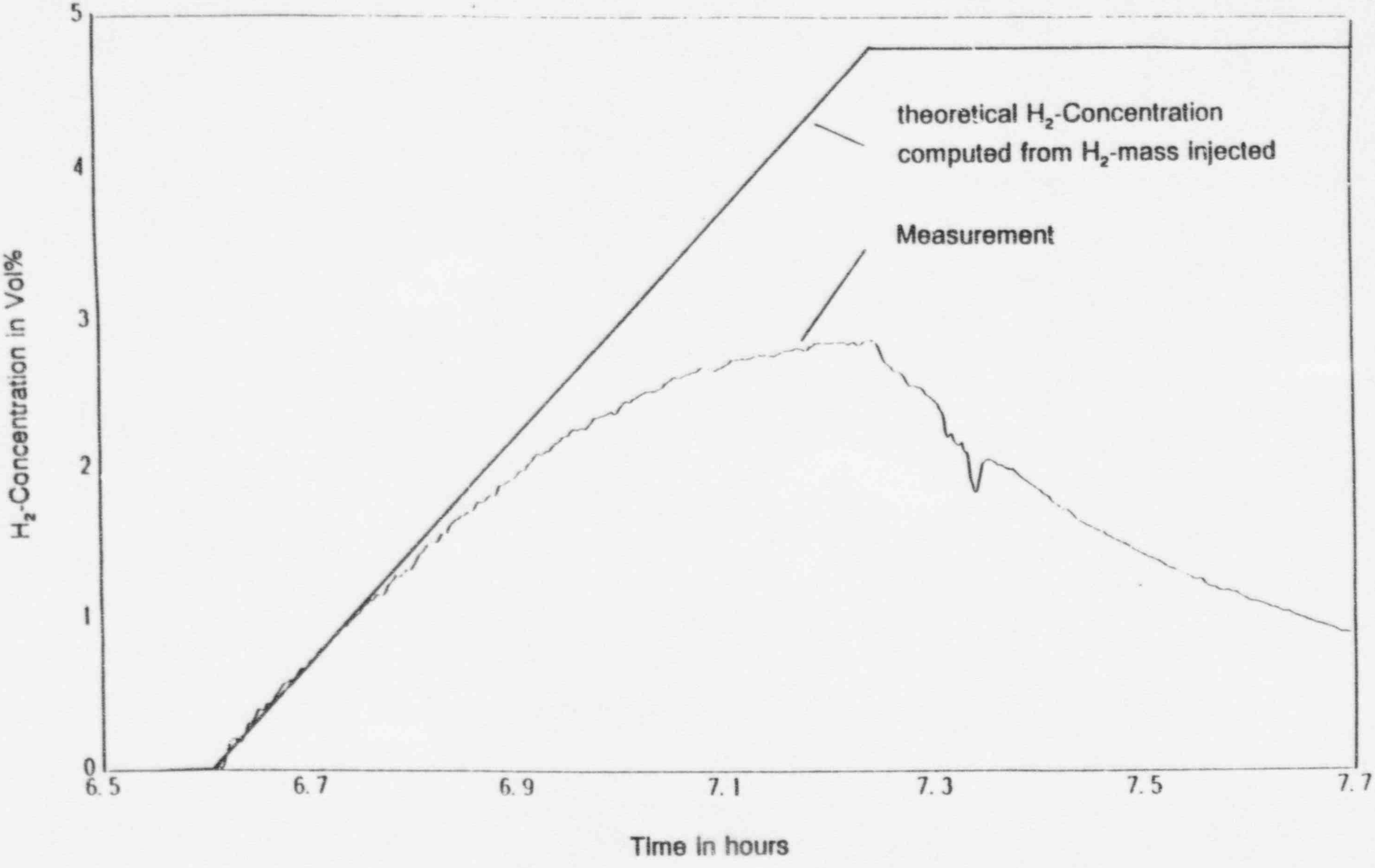
Composition

H_2 : 4.8 Vol.-%
Air: 49.1 Vol.-%
Steam: 46.1 Vol.-%

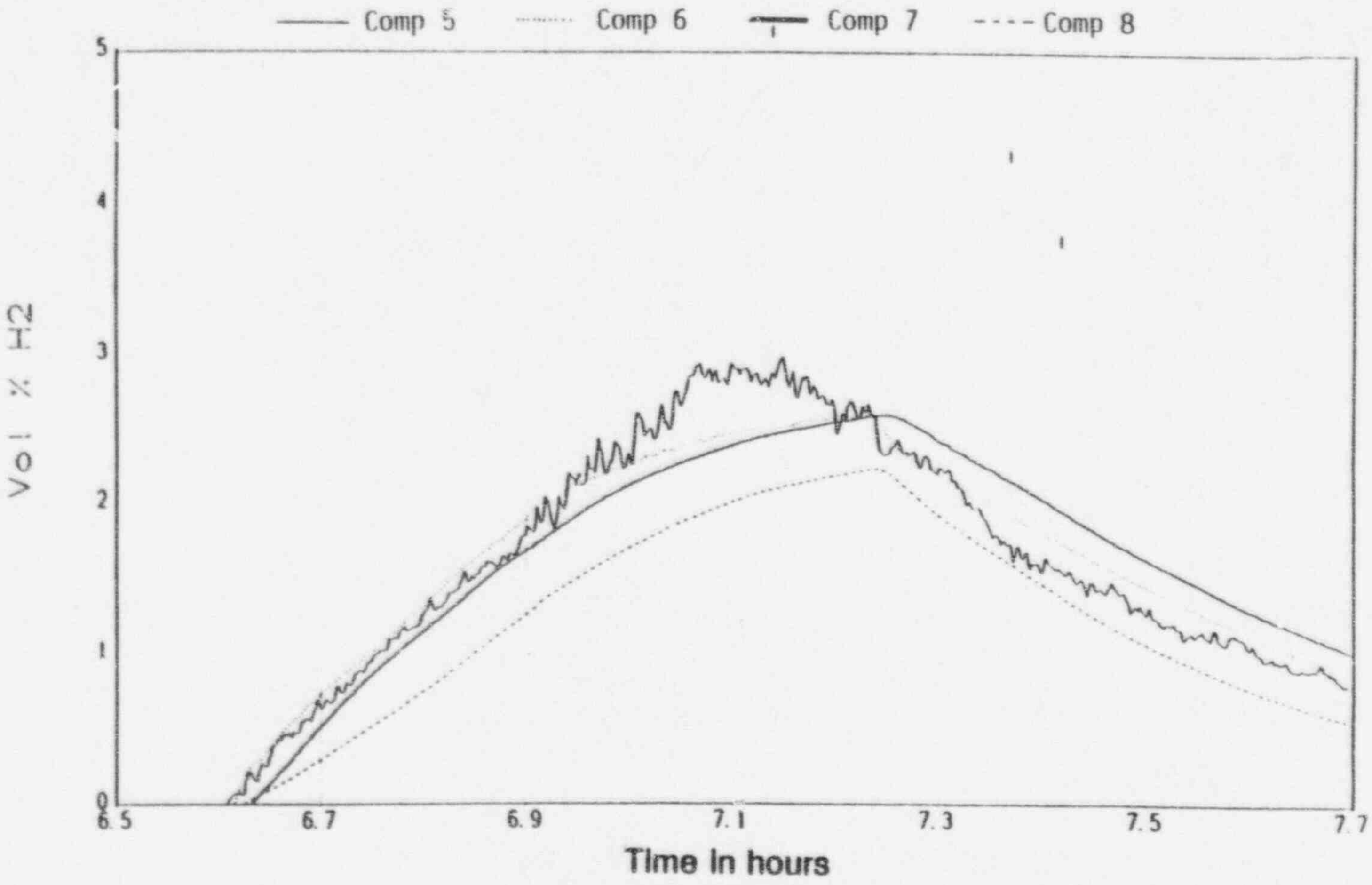
Basic Parameters

Pressure: 1 bar
Temperature: 82 °C

C.2 Experimental Configuration with PAR is same compartment as Hydrogen Injection (Test MC-1a) (unshaded areas closed to test conditions)



C.5 Average Hydrogen Concentration History Measured in Test MC-1a



C.6 Hydrogen Concentration Measured in Different Compartments in Test MC-1a

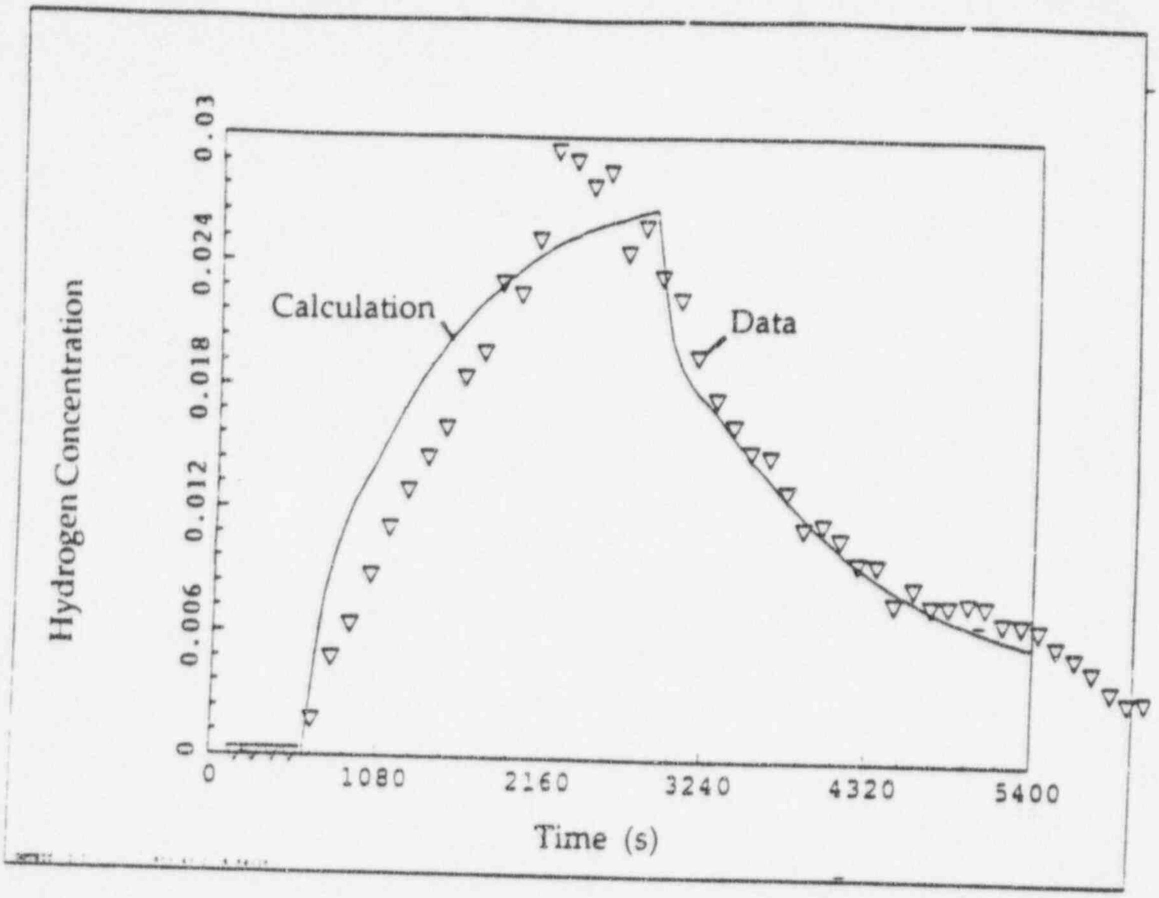


Fig. C.14 Comparison of Calculated and Test Results in Test MC-1a (Compartment R5)

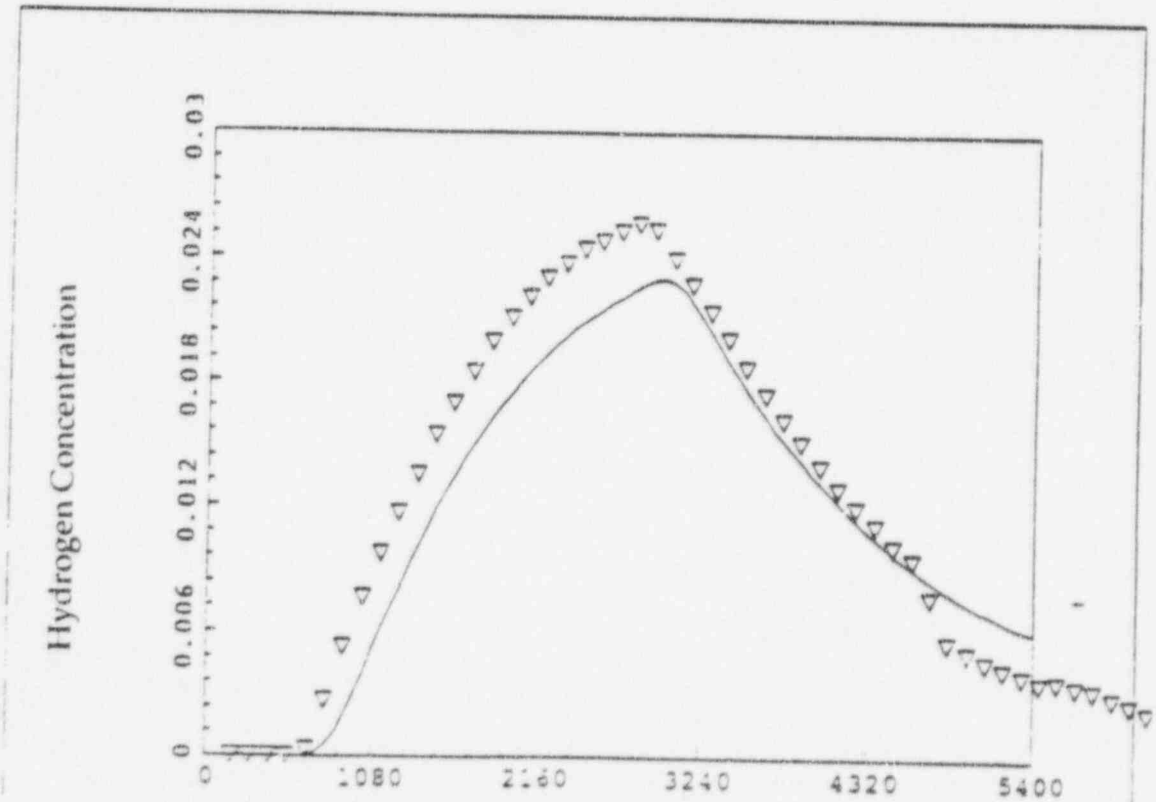


Fig. C.15 Comparison of Calculated and Test Results in Test MC-1a (Compartment R7)

Appendix D

THEORETICAL TOOLS

D.1 Empirical Models of Depletion Rate

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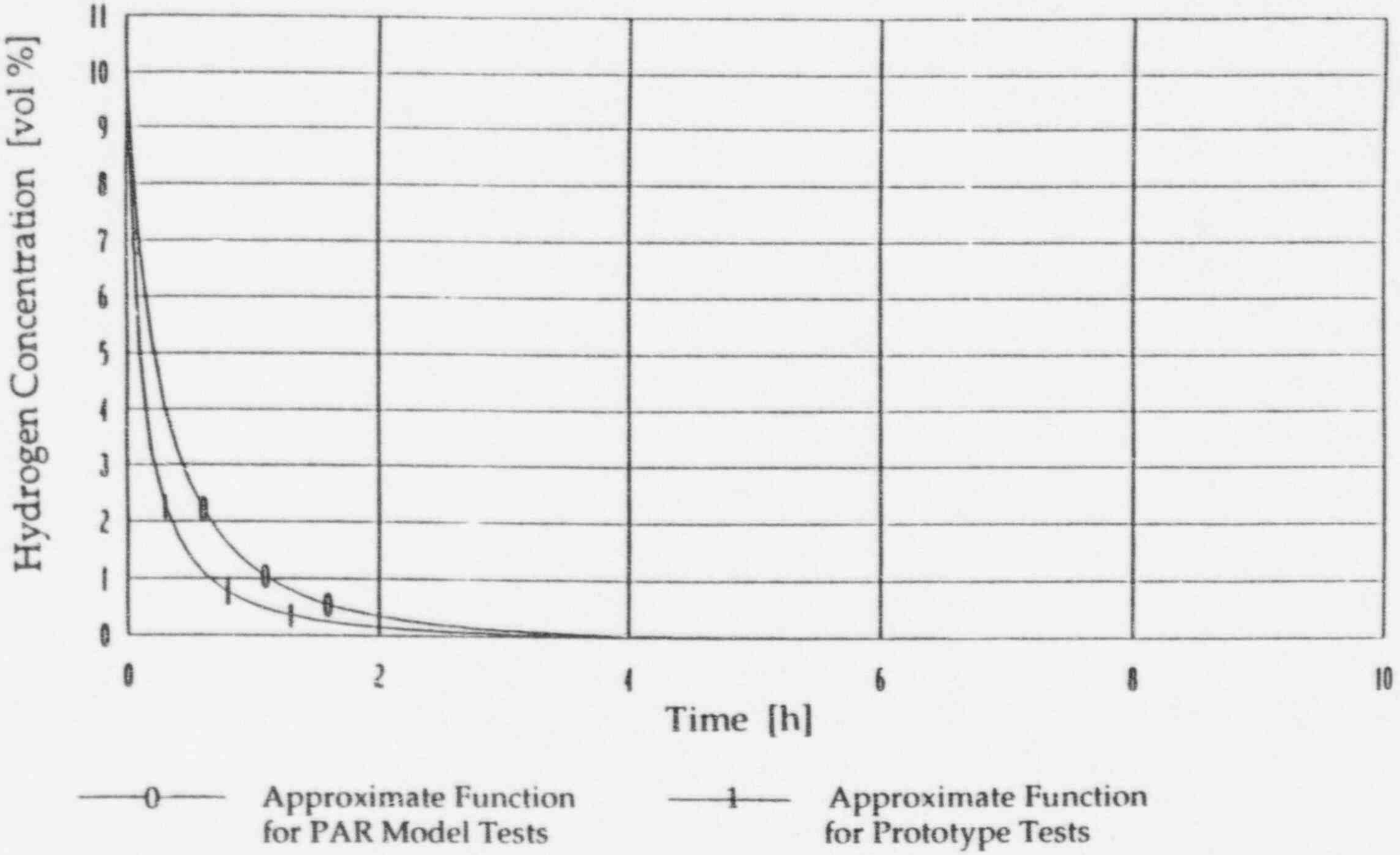
$$Q = dC^e$$



D.1 Comparison of Exponential Approximation Functions for PAR Model and PAR Prototype Tests

WESTINGHOUSE/NRC REQUEST FOR ADDITIONAL INFORMATION

- NRC questions on PAR test data
  - Is quality assurance applied in German tests adequate for design certification?
  - What is uncertainty of measured PAR depletion rates (i.e. provide estimate of lower bound)?
- EPRI information to Westinghouse
  - "Evaluation of Quality Assurance Applied in Battelle Tests of NIS PARs," October 1995
  - "NIS PAR Depletion Rate Equation for Evaluation of Hydrogen Recombination During an AP600 DBA," November 1995

QUALITY ASSURANCE APPLIED IN PAR TESTS

- Tests conducted under NIS and Battelle Frankfurt QA manuals that were in force in 1990-91
- Most important attributes of QA for test program are
  - well controlled and calibrated measurement equipment
  - well controlled test protocol
- EPRI report compares detailed provisions in Battelle QA manual with detailed provisions in
  - NQA-1 Basic Req. 12, Control of Measuring and Test Equipment
  - NQA-1 Basic Req. 11, Test Control
- Conclusion
  - QA is adequate for the data to be used in support of design certification of ALWRs