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Air Products

AIR PRODUCTS POST LOCA RECOMBINER TEST SUMMARY

Prepared for

Washington Public Power Supply System

July 1978

Report No. APCI-78-8

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Air Products

1. Introduction and Background

Historically, Air Products and Chemicals, Inc. (APCI) has used catalysts to produce certain high purity gases by removal of excess oxygen or hydrogen by "deoxo" catalysis. Deoxo catalysis is most appropriate for applications requiring the complete removal of one of the reactants while a slight excess of the second reactant is tolerable because it is either beneficial, neutral, or can be removed easily in subsequent processing.

There are many practical applications of deoxo catalysis in use daily in the chemical processing industry. The preparation of oxygen-free argon with one percent or higher hydrogen content is required for heat treatment processes. Due to the small (5°F) difference in the boiling points of argon and oxygen, the use of cryogenic fractionation to produce ppm levels of oxygen in argon is difficult and costly. An alternative is to produce 97% argon and inject hydrogen to react catalytically with the oxygen present. This results in a product with less than one ppm(v) of oxygen content.

Another example of deoxo catalysis followed by removal of the excess reactant is the removal of hydrogen from helium. Helium present in certain natural gas streams is first produced as 70% helium, 29+% nitrogen with 500 to 1,000 ppm(v) of hydrogen. The hydrogen is removed by injecting sufficient air to provide oxygen at 200 to 300 ppm(v) in

excess of that which is stoichiometrically required. Following catalysis, the hydrogen concentration is 1 ppm(v) and the excess oxygen, water of reaction and nitrogen contaminants may now be readily removed by adsorption and drying techniques.

Deoxo catalyst can be made from salts of several noble or other metals deposited on various substrates including ceramic pellets, metal wire, and ribbons. The most common have been the noble metals platinum and palladium on alumina and kaolin respectively.

Deposition of palladium salts on durable kaolin produced a very suitable catalyst of high activity, such that the hydrogen-oxygen reaction could be initiated at ambient temperature. This catalyst, NIXOX®, was produced by the Houdry Division of APCI and is in service in over fifty recombiners designed to treat PWR waste gas as well as sixteen reactors in service at APCI chemical plant sites. The range of parameters for all APCI operated reactors and reactors supplied to the nuclear industry are compared to the WNP-2 reactor parameters in Table 1-1.

The Houdry Division continued work to improve both NIXOX and a 0.5% platinum on alumina catalyst. Figure 1-1 shows a picture of the Houdry 0.5% platinum on alumina catalyst and lists the characteristics of the catalyst. This work culminated in the automotive emission control catalytic muffler which required particular attention to durability and resistance to poisoning.

TABLE 1-1

WNP-2 OPERATING PARAMETERS VS. RANGE OF ALL

APCI CATALYTIC REACTOR PARAMETERS

Parameter	Range Of All Other APCI Reactors	WNP-2 Data
Gas Service (Principal diluent)	10 Ea. argon, 5 Ea. nitrogen, 1 Ea. Helium, 6 Ea. steam (BWR) 6 Ea. Nitrogen (PWR)	Air plus steam
Bed Diameters, (inches)	8 to 78	15.5
L/D Ratios	0.14 to 2.8	1.10
Inlet Temperatures, (°F)	80 to 350	490 to 550[2]
Inlet Pressures, (psia)	49 to 1220	18 to 44[3]
Temperature Rise, (°F)	1 to 900	580
Mass Velocity[1] $\frac{lbm}{hr\text{-}ft.^2}$	287 to 2454	501 to 1060
Space Velocity[1] min. -1	27 to 675	111 to 124

(1) Terms defined in Section 3.1.2.

(2) Higher WNP-2 inlet temperature is designed to prevent halogen interaction with the catalyst. This higher temperature actually enhances the highly efficient catalytic H_2-O_2 reaction.

(3) This recombiner pressure range corresponds to a pressure range in the containment of 0-18 psig or a range of 14 to 32 psia at the skid inlet.

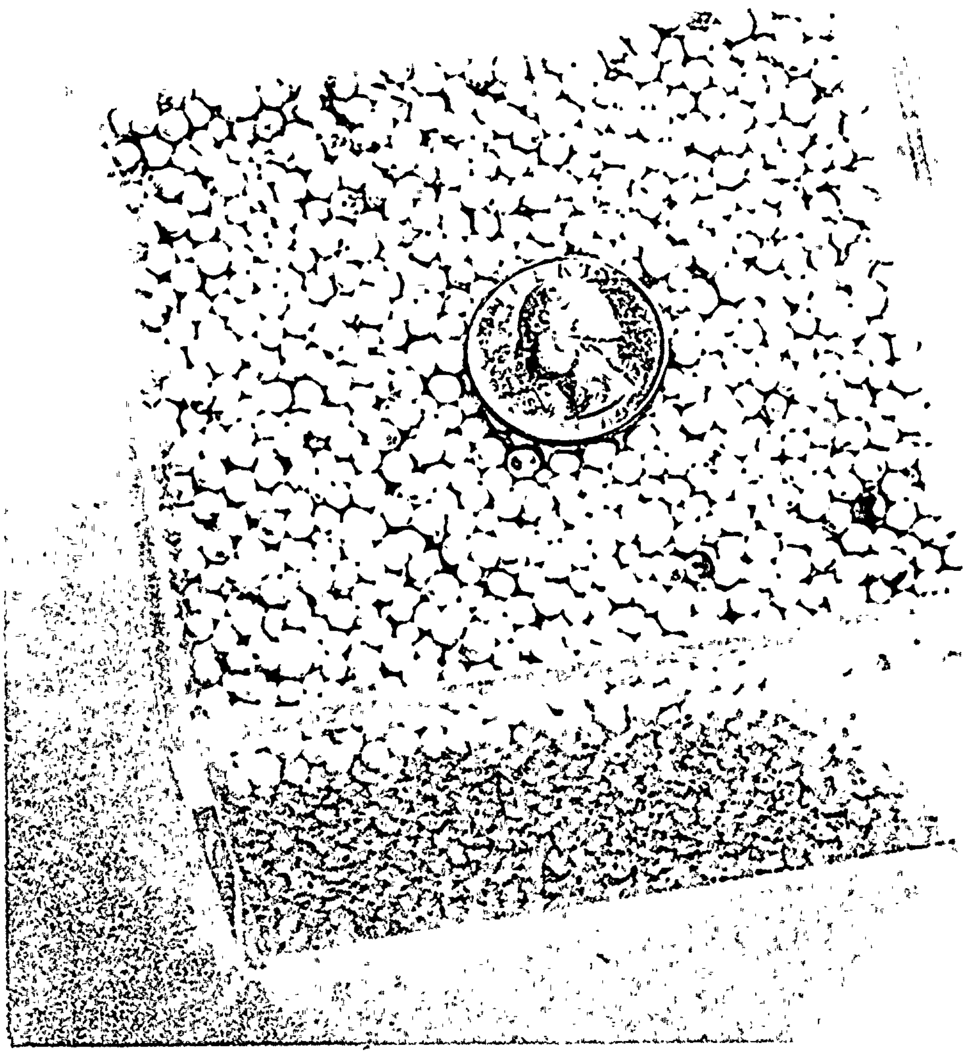

FIGURE 1-1

PLATINUM ON ALUMINA CATALYST

(POST LOCA APPLICATION)

PLATINUM CONTENT:	0.5%
FORM:	PLATINUM IMPREGNATED BEADS
SIZE:	SPHERICAL BEADS 3.3 mm. AVE. (2.4 to 4 mm)
BULK DENSITY:	44 lbs/ft^3 (0.7 kg/l)
SURFACE AREA:	85 m^2/gm
CRUSHING STRENGTH:	18 lbs/pellet

APCI's entry into catalytic recombination for the nuclear power industry was in 1969. Since that time PWR waste gas systems, large recombiners for BWR off-gas, and the current Washington Public Power Supply System, Nuclear Project No. 2, (WNP-2) recombiner for post LOCA service have been produced.

This report is directed at summarizing the catalyst test data generated by APCI since 1969 and the full-scale testing of the WNP-2 recombiner system. The data emphasizes the acceptability of catalytic recombination for post LOCA service.

Section 2 discusses the successful full-scale testing of the WNP-2 post LOCA systems. This Section also contains a description of the total recombiner system as well as detailed equipment data for individual components.

The third Section treats the wide spectrum of catalyst test work completed to date. It begins with a discussion of scaling factors and their application to catalytic recombiner design. Also included is the test work conducted by Southern Nuclear Engineering (SNE) in 1970-71 (Reference 1) which proved the resistance of platinum on alumina catalysts to all the chemicals postulated to be present in a post LOCA containment environment. This testing included exposure to radiation and laid an important foundation for later APCI testing.

The proprietary APCI catalyst test work covered in Section 3.3 centers on providing a substantial amount of data which proves that catalytic recombiners do operate at high efficiency in the presence of halides.

The testing exposed the catalyst bed to long-term runs with both iodine and methyl iodide at concentrations equal to or exceeding those postulated to be present in PWR and BWR containments after a loss of coolant accident.

Section 4 summarizes the methods which were used to verify that the WNP-2 recombiner system will maintain structural integrity during a seismic disturbance. This includes a general analysis of the seismic design review and the qualification criteria utilized.

The IEEE qualification report is covered in Section 5. This Section discusses the methods and test data utilized to verify that the WNP-2 recombiner system meets the requirements of IEEE 279-1971 for safety related systems.

Section 6 consists of a mechanical design report. The purpose of this Section is to demonstrate that the WNP-2 equipment meets the specified design requirements. It includes a description of the major items of equipment, an outline of the design approach, and a discussion of the seismic qualification technique.

The final section summarizes the completed test and design work and lists conclusions which demonstrate the acceptability of the catalytic recombiner for the WNP-2 application.

[illegible]

2. Full-Scale Performance Testing

2.1 Introduction

In order to verify the predicted design performance of the APCI post LOCA recombiner system, full-scale catalyst performance tests were undertaken at the APCI test facility in Trexlertown, Pennsylvania. The tests were carried out on two systems, each consisting of a control panel and skid-mounted process component package which will be ultimately installed for service at the Washington Public Power Supply System (WPPSS) Nuclear Project No. 2 site. This report addresses the results of the tests conducted during the period of July and August 1977.

2.2 System Description and Equipment Data

The hydrogen recombiner system is described in Section 6.2.5 of the WNP-2 FSAR and in the proprietary supplement to this report (APCI-78-6P), Section 2.2. A non-proprietary discussion of the system follows.

Air Products

2.2.1 System Description

The flowsheet for the WNP-2 Post LOCA recombiner system is shown in Figure 2-12. Photographs of the recombiner system and control panel are shown in Figures 2-3 through 2-5 and an equipment layout drawing is shown in Figure 2-6.

A detailed process description is contained in the WNP-2 FSAR, Section 6.2.5.

2.2.2 Equipment Details

2.2.2.1 Feed Gas Scrubber

The purpose of the feed gas scrubber is to remove entrained particles and droplets from the contaminant feed gas.

FIGURE 2-3

WNP-2 POST LOCA HYDROGEN RECOMBINER
(ENGINEERING MODEL)

FIGURE 2-4

WNP-2 POST LOCA HYDROGEN RECOMBINER
(ENGINEERING MODEL)

FIGURE 2-5

WNP-2 POST LOCA HYDROGEN RECOMBINER
(INSTRUMENT PANEL)

SKID LAYOUT

FIGURE 2-6

The moisture laden gas, above the bed and spray zone, passes out of the scrubber through a demister where water droplets are removed. The water drains to the bottom of the scrubber and is removed through a liquid seal. The scrubber characteristics and specifications are given in Table 2-4 and Figure 2-7.

NRC Regulatory Guide 1.7 postulates the release of one percent of the solid core material to the coolant, and under LOCA conditions, this coolant is then released to the containment. Since the containment is saturated with moisture after a LOCA, it is reasonable to assume that if any particulate material resulting from the LOCA is dispersed in this atmosphere, it is in the form of a liquid phase aerosol, mist, or larger drops, and not as a solid dry dust or fume. Any non-volatile material is either in solution or occluded as a solid phase in liquid. This assumption of saturation is even more valid as one considers that the gas-water vapor mixture from the drywell will cool somewhat as it leaves the containment and moves through the reactor building piping to the recombiner skid. This mixture is further cooled by contact with colder water on the scrubber, so the gas mixture in the scrubber is definitely saturated.

TABLE 2-4

FEED GAS SCRUBBER SPECIFICATIONS

Air Products and Chemicals

	BY	DATE	MISCELLANEOUS VESSEL VERTICAL		
MADE	J. DALY	22 SEPT 76		ENG. PROJ.	00-4-1371
CH'K'D				ITEM NO.	07.01
APPR'D				DESCRIPTION	SCRUBBER

DESIGN DATA

FIGURE 2-7

The postulated solid fission products that are released (uranium, zirconium, etc.) and their oxides are, in general, of high specific gravity. Calculations, based on typical BWR containment solid fission product inventories and NRC Regulatory Guide 1.7 indicate a specific gravity in excess of 6 for these released fission products, whereas "normal" dust has a specific gravity of approximately 3. On the other hand, the liquid aerosol present in the containment is assumed to have a specific gravity only a little above water, 1.05 to 1.10.

This assumption of liquid aerosol composition, therefore, is conservative, since the separation mechanisms such as

are enhanced by high specific gravities. In other words, the more dense the particulate, the easier is its separation from the gas phase.

Even more important than particulate density is the size distribution of aerosols, since particle size determines such properties as settling rate and coagulation rate.

Particle size data is usually presented as

frequency (or cumulative) distribution using one of three weightings (number, area, or mass).

Air Products has assumed that the aerosol particulates reaching the recombiner skid are characterized by a log-probability size distribution with a median diameter of 15.8 microns and a standard geometric deviation of 3.15. The latter assumption is based on the knowledge that most aerosols and particulates have a unimodal distribution of 2 to 4 with 3 being the most probable. Therefore, 15.9 percent by weight of all particles will have an effective diameter less than 5 microns, 34.1 percent from 5 to 15.8, 34.1 percent from 15.8 to 50 and 15.9 percent greater than 50.

As a point of reference, the common atmospheric dispersoids have the following size ranges:

rain	500 to 5000 μ
drizzle	200 to 500 μ
mist	70 to 200 μ
fog	2 to 70 μ
smog	.01 to 2 μ

However, no aerosol is completely stable, since once formed, mechanisms such as coagulation settling, electrostatic repulsion, and condensation cause continuous changes in concentration and size with time. In general, large particles, for instance, larger than 50 μ, are removed rapidly by settling, and small

particles less than 0.5 μ grow rapidly in size due to coagulation. Thus a two standard deviation size range of 5 to 50 microns is a very reasonable assumption, (References 5 and 6 apply to this discussion of particulates.)

There are several mechanisms for separation of particles from the process gas stream in the scrubber such as:

1.

2.

3.

4.

This mechanism would occur for both wet mists and dry dust type aerosols, and is enhanced when specific gravity of the solids is greater than 1.0 and

Another aspect of particulate removal is the degree of removal efficiency, which is very particle size dependent. For example, the efficiency of a particulate filter may be 20% for 1 micron diameter particles and greater than 99% for 5 micron diameter particles. The integrated removal efficiency for the postulated 1.05 specific gravity aerosol

is 88.5 percent.

Beyond the removal in the packed section of the scrubber, the ultimate particle removal is the 4 inch thick York Demister, style 421. York has tested this type at the following conditions:

1. Water entrained in saturated air at atmospheric pressure, ambient temperature,
2. Air velocity of 10 ft.per second,
3. Removal efficiency is applicable over 30% to 110% of tested design velocity,
4. Entrainment load of 4.2 weight percent in air or 110 lbs./hr.-ft.^{2}, and
5. Entrained particle size distribution from less than 5 microns to 80 microns.

The residual entrainment during the test was found to be 0.58 parts of liquid remaining in air per million parts of air by weight.

The removal efficiency is therefore equal to:

$$\frac{42{,}000 - .58}{42{,}000} \times 100 = 99.99862\% \text{ efficiency}$$

York defines the optimum design velocity in feet per second as $U = K\frac{\rho_L - \rho_g}{\rho_g}$, where ρ_L and ρ_g are the liquid and gas densities in pounds per cubic foot and K = 0.35 for all usual process vessels. For the York test conditions above, K is calculated to be 0.322, which meets this criterion. Air Products has established conservative corporate design standards for demisters where any entrainment is critical at a K =

York recommends K values lower than 0.35 for:

1. Operation at very high vacuum or high pressure,
2. Operation with high viscosity liquids,
3. Operation with aqueous solutions having low surface tension, and
4. Operation with systems which have very bad fouling tendencies.

Conditions 1 and 2 above for lower K values are not applicable to the WNP-2 scrubber. Condition 4 usually refers to coking conditions with a high degree of fouling, which in this case is highly improbable as the vapor will have already contacted the Condition 3 is possible, if unlikely, so the initial design value for K was taken as rather than 0.35, as recommended by York.

For K value comparison, the WNP-2 scrubber operates in the pressure range of 32 to 14 psia and temperature range of 220 to 100°F. The calculated WNP-2 velocity averages about 3.0 feet per second which meets York's 30% to 110% applicable range criterion and the range of K's are calculated to be 0.112 at the start of the accident to 0.082 at the end, which is well below the 0.35 recommended value or This shows the conservatism of the Air Products design, even allowing for possible surface tension effects.

If the WNP-2 hot air flow were assumed very conservatively to be 18.1 lb./min. (the high pressure condition at 7 hours after the LOCA) and constant at this flow for 180 days, the entrained water leaving the scrubber to the blower container would be calculated as follows:

$$0.58 \times 10^{-6} \times 18.1 \text{ lb./min.} \times 1440 \text{ min./day} \times 180 \text{ day} = 2.721 \text{ lbs.} = 1234 \text{ grams}$$

If this quantity of entrained water is assumed to be as high as 10 percent by weight solids, the weight of solids reaching the blower can is 123.4 grams. The water is vaporized in the preheater and the solids are then assumed conservatively to be completely removed by inertial impaction in the catalyst bed.

Air Products

Plugging of the recombiner catalyst bed is highly unlikely even after 180 days of operation since the conservatively calculated solids loading of 123.4 grams has a net volume of only approximately 21 cubic centimeters. Even as a fluffy powder with 80% porosity, the volume of these solids would be only 100 cubic centimeters as compared to the catalyst interstitial void volume of 17,800 cubic centimeters and the cross-sectional area of 1200 square centimeters. It is difficult to postulate how this quantity of material could plug the bed. SNE did not experience plugging at 100 times this volumetric loading.

Even the resulting modest increases in the bed pressure drop would present no serious problem, as the effect is cumulative and builds up slowly at the same time containment pressure and blower motor horsepower are decreasing due to reduced gas density. The blower motor can tolerate a 3 to 4 fold increase in the bed pressure drop with the flow dropping only a few percent and the motor horsepower within operating limits.

2.2.2.2 Rotary Lobe Blower and Motor Assembly

The blower is a rotary lobe, positive displacement gas pump designed to deliver constant gas volume against varying pressures. The blower provides a pressure boost to the incoming containment gas to pass it through the system and to recycle dilution gas in

the system. The blower is directly driven by a TEFC a-c motor suitable for high ambient temperature service. Both blower and motor are supported on a common base and housed in a sealed cylindrical pressure vessel. The container is designed for Sealed gas and power penetrations and the support base are connected to a common flanged head. This allows the entire blower/motor head assembly to be moved in and out on the support rails in the container for installation, inspection, or maintenance.

The sealed container minimizes the problem of radioactive gas leakage because the static flange seals of the container (rather than a rotating shaft seal on the blower) constitute the pressure boundary. The container also provides an ASME Section III, Class 2 pressure retaining envelope around the blower.

The specifications and characteristics of the motor/blower are given in Table 2-5 and Figure 2-8.

2.2.2.3 Preheater and Recombiner Assembly

The preheater consists of sheathed immersion heater elements mounted inside the top of the recombiner vessel. The process gas is heated in this unit to approximately before it enters the catalyst bed. Gas flows across the heater elements from top to bottom and the outlet gas temperature is thermostatically controlled. The heater elements used are standard

Air Products

TABLE 2-5

BLOWER AND MOTOR ASSEMBLY SPECIFICATIONS

Air Products and Chemicals

	BY	DATE	MISCELLANEOUS VESSEL HORIZONTAL	ENG. PROJ.	00-4-1371
MADE	U.DALY	22SEPT76		ITEM NO.	01.14
CH'K'D				DESCRIPTION	BLOWER AND MOTOR
APPR'D					CONTAINER

DESIGN DATA

FIGURE 2-8

industrial elements of low watt density to prevent burnout. Sufficient excess heater capacity allows continued operation even with failure of 30% of the elements.

The heater elements are made of nichrome wire surrounded by magnesium oxide insulation with an outer stainless steel sheath. Elements of this type have been proven to give several years of service and longer in continuous duty so long as adequate temperature control is maintained.

In addition to the exit gas RTD and heater thermostat control, a high temperature heater control is provided to protect against element burnout. This control signal is developed by an RTD placed in proximity to heater element sheaths. Overheating due to loss of gas flow across the heater elements is prevented with a flow measurement element and low flow switch in the separator outlet line. This switch shuts off heater power unless gas flow is maintained. A manual override switch is also provided should the automatic control fail.

The feed gas then enters the catalyst bed itself where the hydrogen/oxygen reaction to form water vapor occurs. The bed temperatures are monitored by a rake of RTD's connected to a multi-point temperature indicator.

Detailed specifications on the preheater/recombiner assembly are given in Table 2-6 and Figure 2-9.

2.2.2.4 Aftercooler/Condenser

The aftercooler reduces the temperature in the recombiner exit gas before it is recycled or returned to the containment. This is a shell and tube exchanger with gas on the tube side and standby service water in the shell.

Detailed specifications on the aftercooler are given in Table 2-7 and Figure 2-10.

2.2.2.5 Phase Separator

The phase separator removes the condensed water of reaction from the process gas prior to its return to the containment.

Detailed specifications on the phase separator are given in Table 2-8 and Figure 2-11.

TABLE 2-6

PREHEATER AND RECOMBINER SPECIFICATIONS

Air Products and Chemicals

	BY	DATE	MISCELLANEOUS VESSEL VERTICAL	ENG. PROJ.	00-4-1371
MADE	J. DALY	22 SEPT		ITEM NO.	0210/02.13
CH'K'D				DESCRIPTION	RECOMBINER/HEATER
APPR'D					

DESIGN DATA

FIGURE 2-9

TABLE 2-7

Aftercooler/Condenser Specifications

Air Products and Chemicals

	BY	DATE	MISCELLANEOUS VESSEL HORIZONTAL	ENG. PROJ.	00-4-1371
MADE	J. DALY	22 SEPT 76		ITEM NO.	02.12
CH'K'D				DESCRIPTION	COOLER CONDENSER
APPR'D					

FIGURE 2-10

TABLE 2-8

Phase Separator Specifications

Air Products and Chemicals

	BY	DATE	MISCELLANEOUS VESSEL VERTICAL	ENG. PROJ.	00-4-1371
MADE	J. DALY	22 SEPT 76		ITEM NO.	02.14
CH'K'D				DESCRIPTION	Phase Separator
APP'D					

DESIGN DATA

FIGURE 2-11

2.2.2.6 Catalyst Description

The catalyst used in the WNP-2 Post LOCA recombiner system is a noble metal (platinum) deposited on a spherical alumina ceramic base. It is manufactured by the Houdry Division of Air Products. Tests performed on this catalyst are described in Section 3 of this report, and a picture of the catalyst along with its physical data is given in Figure 1-1.

The platinum on ceramic base catalyst used for post LOCA applications is a very stable and durable material. Neither the noble metal nor the substrate is reactive with moisture, atmospheric air, normal contaminants in the air, or the stainless steel vessel and piping that contain the catalyst while on standby prior to a LOCA. During standby, the system is isolated from the containment atmosphere and maintained at a positive gas pressure to ensure a positive seal. Shelf life of this catalyst is essentially unlimited.

The mechanical properties of the pellets are resistant to attrition while in the recombiner bed. The crushing strength is well in excess of that experienced by the bottom zone pellets in the packed bed. The rigid structure and shape of the pellets are not subject to physical deterioration under the conditions for its storage and use, and therefore, bed "packing" or densification is not experienced to any measurable extent.

In-place testing on a periodic basis can be used to check recombiner activity and bed pressure drop to prove that bed deterioration or "packing" has not occurred. In the highly unlikely event that replacement of the catalyst is indicated, removal of catalyst and addition of fresh material is a short and simple operation.

2.2.3 Flowsheet and Heat/Material Balance

The engineering flowsheet for the WNP-2 system is given in Figure 2-12. Detailed heat and material analysis is presented in Table 2-9, corresponding to the various balance points indicated on the flowsheet. This particular balance analysis case represents very stringent high temperature and pressure inlet conditions to the recombiner, considering the postulated range of containment parameters.

2.3 Test Scope

2.3.1 Objectives

The systems were tested in accordance with the APCI Performance Test Specification (Reference 2), with the specific test objectives as follows:

2.3.1.1 Demonstration of the adequacy of the recombiner design by verifying recombiner efficiency of 99.0% or greater,

FIGURE 2-12

WNP-2 Post LOCA Recombiner
Engineering Flowsheet

Air Products and Chemicals INC.

BY J. Klosek A. R. Winters DATE 21 Dec. 1976 - Rev. 2 (New Issue) 22 Dec. 1976 SHEET ____ OF ____

SUBJECT HEAT & MATERIAL BALANCE - POST LOCA H_2 RECOMBINER JOB NO. 00-4-1371

TABLE 2-9

NORMAL FEED RATE, MOLES/HR. ______
DESIGN FEED RATE, MOLES/HR. ______
BASIS ______

POINT NO.	1	2	3	4	5	6	7	8
POINT ID	Cont. Feed	Scrub Ovhd	To Blower	Fm Blower	Rec. Outlet	Cool. Outl	Sepr. Vapor	Sepr. Condens.

Air Products and Chemicals INC.

BY J. Klosek DATE 21 Dec. 1976 - Rev. 2 (New Issue) SHEET ____ OF ____
A. R. Winters 22 Dec. 1976

SUBJECT HEAT & MATL. BALANCE - POST LOCA H_2 RECOMBINER JOB NO. 00-4-1371

CASE I

TABLE 2-9

NORMAL FEED RATE, MOLES/HR. ______

DESIGN FEED RATE, MOLES/HR. ______

BASIS ______

POINT NO.	9	10	11	12	13	14	15	
POINT ID	Cont. Ret.	Scrub. Water	Scrub Con	C.W. In	C.W. Out	Recycle	Bed Inlet	

Air Products

2.3.1.2 Demonstration of the adequacy of the preheater and aftercooler design by verifying the operability of these components within the respective design limits, and

2.3.1.3 Demonstration of the adequacy of the motor/blower design by verifying system flowrates at various design conditions.

2.3.2 Specified Test Conditions

A total of six process conditions for system feed were tested. These conditions are listed in Table 2-1 along with the test duration for each condition. Each feed condition was reached and held in steady-state before the "test duration" began. Conditions I through VI were run independently and each test completed before proceeding to the next. At each test condition, readings were taken regularly to verify recombiner efficiency of at least 99.0% reduction of hydrogen (dry basis); and hourly for the feed gas preheat temperature, aftercooler gas temperature, and pressure drop of cooling water through the aftercooler.

These various test conditions were intended to verify performance in accordance with the test objectives over the wide range of possible feed conditions during a post LOCA situation.

TABLE 2-1

PERFORMANCE TEST SIMULATED CONDITIONS

Test Number	I	II	III	IV	V	VI
Simulated Time from LOCA (days)	0.3 to 0.6	0.6 to 2	2-10	10-30	30-180 Long Term	30-180 High Hydrogen
Feed Pressure (psig)	18.0	12.5	5.0	3.0	1.0	1.0
Temperature (°F)	215	190	150	140	100	100
Water Content	SAT	SAT	SAT	SAT	SAT	SAT
Hydrogen Content (dry/ wet) in vol. %	3.5/ 2.0	4.0/ 2.9	3.0/ 2.7	1.5/ 1.4	0.5/ 0.5	4.0/ 4.0
Oxygen Content (dry/ wet) in vol. %	21.0/ 12.2	21.0/ 15.1	21.0/ 18.9	21.0/ 19.6	21.0/ 21.0	21.0/ 21.0
Containment Withdrawal Rate (SCFM/ACFM)	295/ 175	245/ 165	175/ 155	160/ 155	155/ 155	155/ 155
Test Duration (hours)	4	4	4	8	4	4

2.4 Instrumentation

The performance test was run using instrumentation included as part of the systems and additional instrumentation supplied by APCI to monitor feed and outlet parameters. All instrumentation was calibrated using APCI equipment with up to date calibration verification. Hydrogen and oxygen concentrations were monitored using a chromatograph which was calibrated each day of operation using known gas mixtures. Accuracy of the chromatograph and other APCI supplied equipment is shown on Table 2-2.

2.5 Test Setup and Chronology

2.5.1 The flowsheet for the systems tested is shown in Figure 2-1 and the test equipment arrangement is shown in Figure 2-2. The feed gas composition was obtained by mixing hydrogen, air and saturated steam prior to the mixed feed's entry into the actual production system package. The intent was to duplicate the actual post LOCA feed conditions as exactly as possible (including the steam environment). The mixed feed stream was monitored for flow rate, pressure, temperature, and hydrogen concentration prior to entering the feed gas scrubber unit.

TABLE 2-2
EQUIPMENT LIST

	Position	Manufacturer	Model	Range	Accuracy
Pressure Gauge	Pressure Survey	Heise		0 - 125 psi	± 0.1% F.S.
Pressure Gauge	PI-10	Robertshaw	Acragage	0 - 100 psi	± 1/2% F.S.
Pressure Gauge	PI-6	Robertshaw	Acragage	0 - 60 psi	± 1/2% F.S.
Pressure Gauge	PI-5	U.S. Gauge		0 - 60 psi	± 1/2% F.S.
Pressure Gauge	PI-4	Robertshaw	Acragage	0 - 160 psi	± 1/2% F.S.
Pressure Gauge	PI-12	Robertshaw	Acragage	0 - 30 psi	± 1/2% F.S.
Temperature Gauge	Surface Pyrometer	Alnor Instrument	Type 4000A	0 - 300°F	± 1% F.S.
Temperature Gauge	TI-1	Weston		50 - 500°F	± 1% F.S.
Temperature Gauge	TI-2	Weston		0 - 200°F	± 1% F.S.
Temperature Gauge	TI-3	Weston		0 - 200°F	± 1% F.S.
Pressure Drop Gauge	FI-1	Barton		0 - 100" H_2O	1/2% F.S. ΔP
Rotameter	R-3	Brooks	1110-13H561A	8 - 98 gpm	± 2% F.S.

TABLE 2-2 (Continued)
EQUIPMENT LIST

	Position	Manufacturer	Model	Range	Accuracy
Powermeter	Blower	Westinghouse	P6-192	0 - 25,000 watts (3) 0 - 25 amps 0 - 600 volts	
Hydrogen Analyzer	H_2A-1 H_2A-2	Beckman	6C-2A		
Integrator	H_2A-1 H_2A-2	Hewlett Packard	3370A		O_2 ± 1% F.S. H_2 ± 0.1% of reading
Integrator Visual Display	H_2A-1 H_2A-2	Hewlett Packard	18990A		
Chart Recorder	H_2A-1 H_2A-2	Esterline Angus	Speed Servo II		± 0.25% F.S.
Steam Generator		Clayton	E06-33-3	95 - 130 psi	N/A
Compressor		Gordon Smith & Co., Inc.	Smith 100		N/A
Cooling Water Pump		Walter H. Eagan Co., Inc.	VOC-3x2x6	0 - 100 scfm	N/A

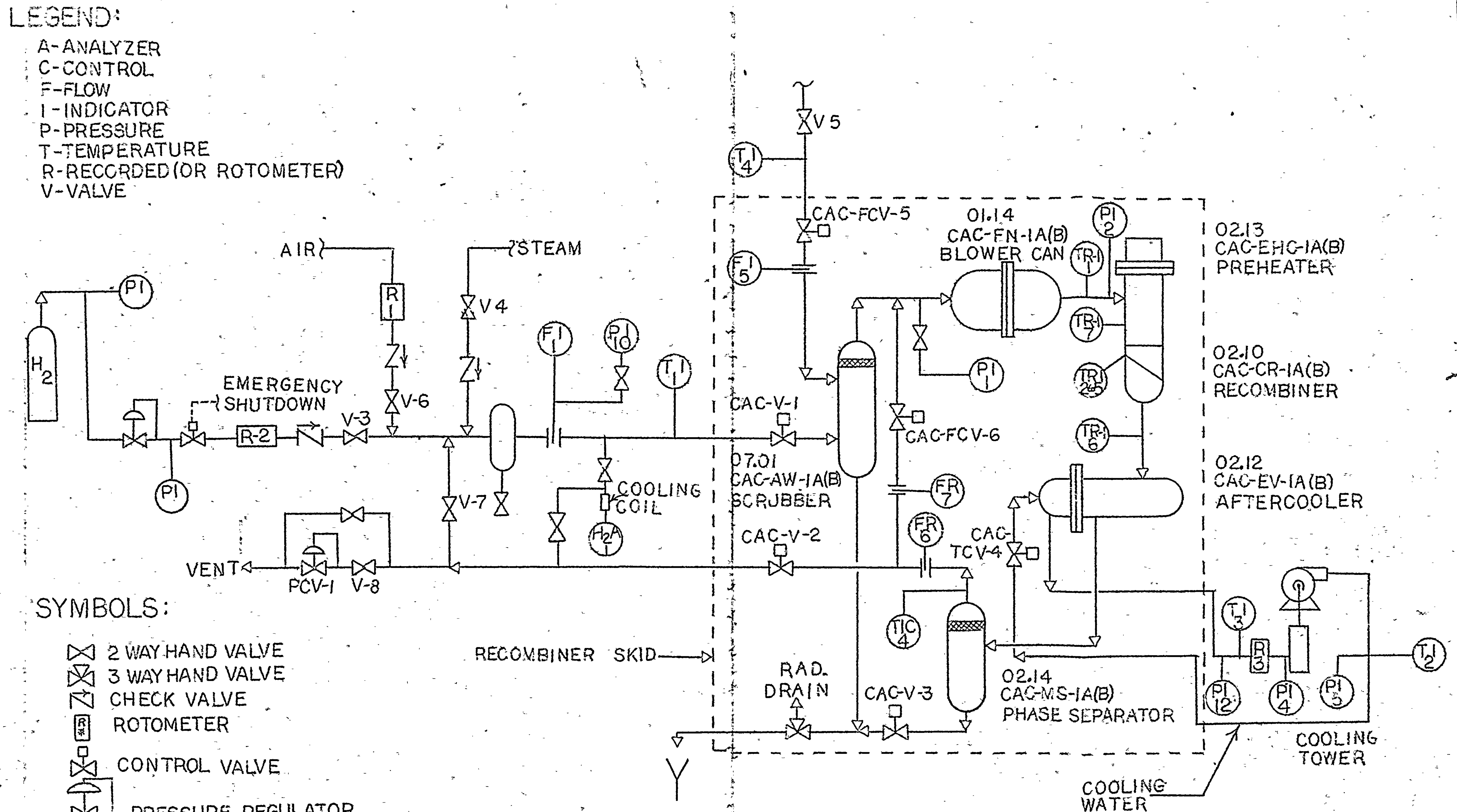

FIGURE 2-1
PERFORMANCE TEST FLOWSHEET

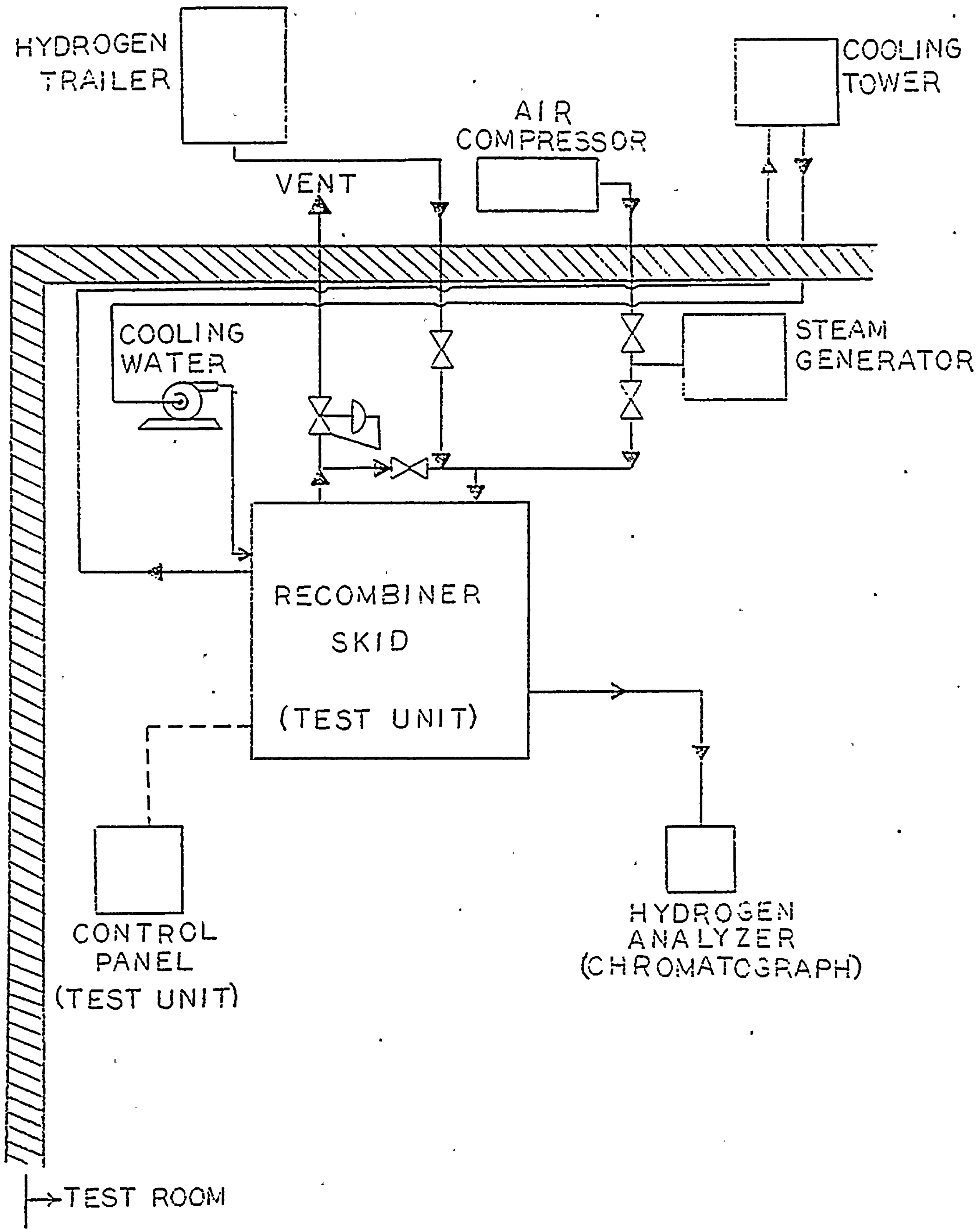

FIGURE 2-2
TEST EQUIPMENT ARRANGEMENT

The gas then passed through the production skid, following the same process flow path as would be used in an actual post LOCA situation, including: motor/blower, preheater, catalyst bed, aftercooler, and phase separator.

Pressures and temperatures were monitored in the process stream and the process cooling water supplies throughout the tests. Outlet flow and hydrogen concentration were also monitored.

2.5.2 System number one, Serial No. P/N 2040 (CAC-HR-1A) was installed within the test room and all test equipment was checked and calibrated for proper operation. The process control valves and all process instrumentation were calibrated and tested. The test support utilities were readied (i.e., hydrogen, steam, cooling water, etc.) and then the system was started up and allowed to stabilize. The various test conditions I through VI were then set up, equilibrium established, and data taken for the test durations specified in Table 2-1. Tests for record were completed on system number one during the period from 18 July 1977 to 22 July 1977.

Upon completion of the tests on system one, it was shutdown and removed from the test room. System number

two, Serial No. P/N 2041 (CAC-HR-1B), was then installed and tests carried out as described above for system number one. Tests for record were successfully completed on system number two during the period of 19 August to 24 August 1977.

2.6 Additional Tests

2.6.1 From 5 August to 8 August pressure drops were measured across skid vessels and found to be within design requirements. In addition, the aftercooler process temperature control loop (TIC-4/TCV-4) was optimized. It was found that this loop could be set at 150°F providing that the recombiner bed outlet temperature was above 600°F. With no hydrogen (minimum bed outlet temperature of 440°F) the control setpoint had to be set at 100°F for good modulating automatic control. Due to the conservative design of the aftercooler, water flow was about 9 gpm for control at 100°F. This is lower than the calculated 10 gpm for control at 150°F. At the elevated bed temperature for recombining 4% hydrogen, 50 gpm was specified on the heat and material balance while only 20-25 gpm was required during test. Temperature rise of the cooling water during all testing was within specification. It is therefore planned that 100°F be the new TIC-4 setpoint for all conditions of the performance test since it requires decreased cooling water and achieves a better system control.

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2.6.2 Scrubber tests were run on 10 August, 1977. Pressure drops measured for various flows through the scrubber were between 11" and 15" of water column, which were within the calculated design limits. Tests included full flow at 18 psig feed pressure and no system recycle. Even though this is twice the design flow of the scrubber, no problems were encountered.

2.6.3 Duplication of a suggested field recombination performance test was demonstrated on 9 August. This test provides a sensitive, simple and safe procedure for checking recombiner catalyst bed condition. It involves operation of the recombiner system while taking a suction through a permanently installed test line and discharging through another permanently installed test line.

Using a 4% H_2 in N_2 mixture, 33-40 SCFM is injected into the H_2/N_2 test connection, while the system is processing a total test flow of 140-150 scfm. This will provide essentially a 1% H_2 mixture at the recombiner catalyst bed. This mixture is run for fifteen to twenty minutes and a bed temperature rise of 120-150° is observed. This temperature rise indicates the catalyst is performing satisfactorily and completes the field test. It was found that three standard cylinders of a mixture of 4% H_2 in N_2 gave approximately 16.5 minutes of test

time which was satisfactory for test completion. It should be noted that this gas mixture has a low enough concentration of hydrogen to prevent a hazardous condition even in the event of operator error.

2.7 Conclusions

2.7.1 Examination of the test results summarized in Tables 2-1 and 2-3 shows that recombiner efficiencies were, under all conditions, greater than 99.0%. In fact, calculated efficiencies were essentially 100% in all cases. This excellent performance was predictable, based on the recombiner efficiencies obtained in the APCI Test Program discussed in Section 3.3 of this report. These full-scale system tests fulfilled the H_2 recombination test objective.

2.7.2 The preheater and aftercooler on both units performed within design limits. The process temperature leaving the aftercooler never exceeded 100°F under any conditions (for test cooling water temperature of about 60°F) and for the most part was close to 85°F. For actual 85°F inlet cooling water, the process outlet temperature is calculated to be about 100°F. The preheater was able to control feed gas temperature adequately as shown in Table 2-3.

TABLE 2-3

SUMMARY OF PERFORMANCE TEST OBJECTIVES

System	Measurement (Avg.)	TEST CONDITIONS I	II	III	IV	V	VI
P/N 2040/P/N 2041	Hydrogen - Inlet (% Dry Basis)	3.48/3.39	3.93/3.85	2.93/2.85	1.54/1.58	0.53/0.51	3.83/3.70
	*Hydrogen - Outlet (% Dry Basis)	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
	**Efficiency (%) $\geqslant$ $\left(\frac{H_2 \text{ in} - H_2 \text{ out}}{H_2 \text{ in}}\right) \times 100$	99.900/ 99.900	99.900/ 99.900	99.900/ 99.900	99.900/ 99.900	99.900/ 99.900	99.900/ 99.900
	Aftercooler (02.12) CAC-EV-1						
	***Cooling Water In Pressure (psig)	16.57/ 18.26	19.02/ 16.97	16.57/ 17.18	18.24/ 18.25	20.16/ 18.22	16.75/ 16.13
	Cooling Water Out Pressure (psig)	12/8.5	11/9.1	12/8.5	8.5/8.5	11/8.5	12/9.9
	Pressure Drop (ΔP) (psi)	4.57/9.76	8.02/7.87	4.57/8.68	9.74/9.75	9.16/9.72	4.75/6.23
	Preheater (02.13) CAC-EHC-1 (°F) Temperature TR-1-7	491/512	522/547	556/537	535/538	533/551	554/562
	Bed Mass Velocity $lbm/hr\text{-}ft^2$	1115	968	681	640	542	536

*Detectable limit of outlet hydrogen is conservatively based on accuracy which was 0.1% of reading by gas chromatography. All runs gave no indication of hydrogen in effluent.

**Efficiency is calculated using 0.1% of reading for detectable limit, e.g.:

$$\text{Efficiency} \geqslant \frac{3.48 - .00348}{3.48} \geqslant 99.900$$

***Corrected for inlet valve and strainer pressure losses.

2.7.3 The motor/blower design was verified by noting the system flowrates listed in Table 2-1.

2.7.4 The system met all test objectives and operated satisfactorily under all simulated post LOCA conditions tested.

3. Catalyst Testing

3.1 Scaling of Catalytic Reactors

3.1.1 Introduction

The chemical engineer often utilizes the ability to scale laboratory and pilot plant data to design processing complexes involving hundreds of millions of dollars in capital investment. This ability is shared in common with the aerodynamic engineer who uses supersonic windtunnel test data and the hydrologist modeling a river basin for a future dam. In point of fact, they are all solving essentially the same fluid dynamic problem, albeit with differing boundary conditions.

The traditional evolution of chemical processing has been test tube experiments, bench scale studies, pilot plant operation, and finally full-scale plants. The availability of sufficient and accurate laboratory data for thermophysical, thermochemical, and transport properties coupled with the calculating power of modern computer modeling has dramatically changed this evolution. Today's chemical engineer has an enviable track record of successfully moving from concept to full production with few and often no intervening steps. Pilot plants still exist, as much for the marketing manager to test the

sale of a new product before recommending his company commit to a multi-million dollar investment, as for the plant designer.

APCI has relied heavily on laboratory and full-scale plant data to provide a basis for computer modeling of catalytic reactors. In essence, this work has involved as much scale-down as scale-up work. The introduction of each new variable, e.g., steam, lower pressures, higher temperatures, halogens, etc. was evaluated correctly, qualitatively, and quantitatively because the prior established factors were understood.

From 1969 through 1977 APCI laboratories conducted several programs to permit the extension of proven gas processing technology to the nuclear industry. To date, APCI has manufactured some fifty nuclear off-gas systems of which approximately 25% are in operation.

Much of this work was performed in nominal three inch diameter reactors in a pilot plant facility. It was here that the durability of catalysts subjected to steam and flooding with liquid water was originally proven, and subsequently verified by successful plant

installations. In addition, the data demonstrates that APCI 0.5% platinum on alumina catalyst will not disintegrate, dissolve or become permanently deactivated by water.

The pilot reactor was used to screen candidate replacement catalysts, such as Houdry 0.5% platinum on alumina, by comparing its performance against comparable NIXOX (Houdry palladium on kaolin catalyst) tests.

Finally, the pilot reactor was used for a series of short and long-term catalyst life tests in the presence of iodine and methyl iodide vapors with a range of post LOCA atmospheres for both inerted and non-inerted containments.

3.1.2 Reactor Concepts

Flow reactors can be characterized as being one of two very specific patterns commonly referred to as plug flow or back-mix reactors. The latter are also referred to as CSTR's - continuous flow stirred tank reactors, while the former are sometimes referred to as slug flow, piston flow, tubular flow, or non-backmix flow reactors. Real reactors can approximate ideal behavior closely, or can exhibit wide deviations through such mechanisms as channeling of flow, recycling of fluid inside the reactor,

and stagnant regions of incomplete mixing.

The catalytic recombiner bed used by APCI is plug flow which is characterized by orderly flow with no elements of flow overtaking any other element. Diffusion along a flow path and differences in velocity of any two elements are minimized. While lateral mixing may occur, longitudinal mixing should not. All fluid elements therefore have the same residence time.

It is from this consideration that reactor designers evolved the space concept, defined as:

$$\text{Space Velocity} = \text{Time}^{-1} = \frac{\text{Volume of feed/unit time}}{\text{Gross catalyst bed volume}}$$

For instance, a space velocity of 100 min.$^{-1}$ means a flow of one hundred catalyst bed volumes of feed per minute, or without considering the effects of temperature, mole changes, and bed and pellet porosities, the time of exposure of any molecule to the catalyst is roughly 1/100 of a minute. Also, doubling the flow rate (doubling the space velocity) will half the time of exposure and lessen the time for reaction of that molecule.

Conversely, doubling the volume of catalyst for the original flow rate (halving the space velocity) will double the time of exposure and increase the time for the reaction to take place. This allows one to use a given mass (or volume) of catalyst in a large diameter, shallow bed, or in a small diameter, long bed, or even in a multiplicity of parallel packed tubes. Practice usually is dictated by cost of vessel, pressure drop or requirement to add or remove heat of reaction.

Another useful design concept is that of mass velocity:

$$G = \frac{\text{Mass per Unit Time}}{\text{Unit Cross-Sectional Area}} = \frac{\text{lbm}}{\text{hr.}} \times \frac{1}{\text{ft.}^2}$$

$$= \frac{\text{lbm}}{\text{hr.} - \text{ft.}^2}$$

This concept is used in fluid flow and heat transfer in the well-known and technically recognized dimensionless Reynolds number and Stanton number respectively. As applied to reactors, two sizes operating at the same mass velocity have the same pressure drop per unit length of bed. Beyond this, criteria are known relating allowable mass velocity to fluid density, originally developed to aid the designer in preventing bed attrition in packed driers and adsorbers, and secondly, to limit fluidization in up-flow beds (unless, of course, one is designing a

fluidized bed reactor, where the minimum allowable flow must be determined).

Air Products has designed and operated recombiner beds with a broad range of cross-sections and flow rates but with essentially the same mass velocities. In other words, the test reactor behaves very similarly to the manner in which an equivalent cylindrical section of the same diameter and length of a larger bed would behave. This allows immediate prediction of full scale operation from tests on units of smaller cross section. For example, data derived from the performance of a three inch diameter test catalyst bed will provide acceptable design criteria for predicting the performance of a full scale catalytic reactor when such parameters as inlet hydrogen concentration, inlet temperature, pressure, and bed depth are the same, and the catalyst bed volume is scaled for the full scale flow rate so that the mass velocity is also the same as the test bed. The mass velocity concept also permits the use of the same distribution plate and support screen geometries for both test and full-scale reactors thereby eliminating these scale-up variables. Air Products has successfully used this concept of scaleup and scaledown in many applications.

3.1.3 Scaling Details

Scaling of catalytic reactors involves several areas of varying complexity. These are covered in the following paragraphs.

3.1.3.1 External Piping and Nozzles

This area involves a rather straightforward application of fluid dynamics to calculate the appropriate cross-sectional area and account for the wall thickness as required by the mechanical design and various Code considerations. The piping entrance and exit pressure drop losses are easily determinable.

In addition, the design should include good judgement in providing entrance nozzle impingement plates and deflectors for cases where the inlet flow might jet directly on the surface of the catalyst. If this is ignored conditions may exist during startup, which would promote bed movement and may result in a non-uniform bed depth. This is potentially a significant problem in a shallow bed reactor with low length/diameter ratios of 0.1 to 0.2.

In the case of the WNP-2 downflow type catalytic recombiner this potential problem has been eliminated by utilizing a full diameter, low velocity, preheating section located above the catalyst bed to dissipate any maldistribution of flow.

3.1.3.2 Flow Distributors and Supports

It is important that a well proportioned flow distributor be provided. This can be placed at either or both ends of the catalyst bed. The most advantageous position to provide the distributive function is in the bed support plate.

The WNP-2 recombiner is constructed with a support plate at the bottom of the bed which is overlayed with two stainless steel screens. The support plate is #10 gauge stainless steel and contains 5/16" diameter holes on a 1.078" by 1.600" rectangular pitch, thereby providing a 4.45% open area when compared to the total available reactor cross-sectional area. This is calculated as follows:

Air Products

$$\% \text{ Open Area} = \left[\frac{\pi (5/16")^2}{4} \Big/ (1.078" \times 1.600")\right] \times 100$$

$$= \frac{0.0767 \text{ in.}2}{1.7248 \text{ in.}2} \times 100$$

$$= 4.45\%$$

The pilot plant reactor used a distributor plate having a total of 52, 1/16" diameter holes. The reactor inside diameter was 3.26" resulting in an open area to available reactor area of 1.9%:

$$\% \text{ Open Area} = \left[52\left(\frac{\pi\, 1/16^2}{4}\right) \Big/ \left(\frac{\pi (3.26)^2}{4}\right)\right] \times 100$$

$$= \frac{0.1596 \text{ in.}2}{8.3469 \text{ in.}2} \times 100$$

$$= 1.9\%$$

The WNP-2 percent open area compares very favorably with that of the pilot reactor, even though, the test reactor was designed for a wider range of test parameters.

The stainless screens overlaying the support plate assure that no catalyst bead can "blind" a distributor hole. The first screen above the distributor plate is 4 mesh by 0.047" diameter wire.

This acts as a plenum between a second screen and the distributor plate. The second screen is 16 mesh by 0.035" diameter wire. The cross-sectional opening per grid of screen is therefore calculated to be:

$$0.0625" - 0.035" = 0.0275"$$

$$(0.0275")^2 = 0.00076 \text{ in.}^2$$

The catalyst beads are a nominal 0.13" in diameter and rest on this screen, thereby preventing blinding of any distributor plate hole.

3.1.3.3 Bed Size Scaling

In addition to the fluid dynamic conditions discussed above, the principal scaling consideration in heterogeneous catalysis is the sizing of the bed itself. This requires a mathematical model of the reaction mechanism, inherently a differential equation, expressing the rate of change of composition with time. This equation can be integrated to give the composition of H_2 and O_2 incrementally

throughout the reactor once the boundary conditions of inlet and outlet composition, temperature and pressure are imposed.

From an intensive study of test data on platinum/palladium catalysts, APCI has found that the rate of reaction of hydrogen and oxygen is controlled by two resistances - a mass transfer resistance and a temperature dependent resistance. The data came both from pilot reactor operation and from full-scale operation in several reactors over a wide range of diluents, temperatures, pressures, mass velocities, etc. This data checks well against other recombiner investigations made by Southern Nuclear Engineering and Combustion Engineering. (See References 1 and 7).

Hydrogen and oxygen must diffuse from the bulk gas to the catalyst surface. The limiting component is not determined by the stoichiometric ratio of hydrogen and oxygen in the bulk gas, but by

the limiting concentration ratio calculated from the mass transfer coefficients. In some recombiners, BWR vent gas for example, control of the reaction actually changes from oxygen to hydrogen as the reaction progresses through the bed.

The temperature dependent resistance (chemisorption or adsorption on the catalyst surface) further affects the reaction rate.. This resistance has been empirically correlated from a wide range of data by calculating the mass transfer effect and backing out the temperature resistance.

Both the temperature and mass dependent resistances decrease with increasing absolute temperature and the reaction rate therefore increases non-linearly as temperature increases due to the combined effect of both resistance terms.

The data and the model of reaction rate show that given adequate superheat, the composition of the hydrogen/oxygen carrier gas is not really that important, i.e., nitrogen, air, argon, or steam are all

reasonable diluents. In addition, pressure has no real effect on the rate of reaction.

The rate of reaction expression may be written as:

$$r_a = \emptyset \, k_{ga} \, a \, (P_a\text{, bulk} - P_a\text{, surface})$$

$$= \frac{\text{lb moles of component A reacted}}{\text{hr. ft.}^3 \text{ of catalyst}}$$

where:

$\emptyset$ = temperature coefficient ($0 < \emptyset \leq 1$)

k_{ga} = mass transfer coefficient of component A in the bulk mix
$= \frac{\text{lb moles}}{\text{hr. ft.}^2 \text{ atm}}$

a = catalyst external surface area, $\text{ft.}^2/\text{ft.}^3$

P_a, bulk = partial pressure of component A in the bulk gas, atm

P_a, surface = partial pressure of component A at the catalyst surface (≈ 0 for very rapid reactions)

To size a catalyst bed the rate expression above is plugged into the design equation for an adiabatic plug flow reactor. The resultant expression is then solved by numerical integration. The reactor heat balance equation is solved simultaneously.

The computer solution of the equation involves taking 2.5°F or 10.0°F increments of temperature, starting at the bed inlet temperature, solving the material balance for the increment, and determining whether H_2 or O_2 is the controlling component. In addition, the program calculates the incremental length of the bed at the given incremental temperature to accomplish the incremental reaction and the resulting incremental pressure drop. From this solution the designer can select the bed depth for a specified set of conditions.

This reaction model and calculational procedure are presently used with a typical safety factor of 3 to 5 to design all recombiners. The significance of this design approach is that the effects of composition, preheat temperature, and mass flow rate are properly estimated from a sound fundamental framework. A large group

of lab data has been correlated and the model has been tested against the design of over a dozen different recombiners (bed diameters up to 78 inches). The ability to scaleup from lab data to full size units has been clearly demonstrated.

An example of how the reaction model is used is presented in the program print-out, Figure 3-1, which is the computer simulation of actual pilot test run 40-01-1, using Houdry 0.5% platinum on alumina catalyst.

The pilot reactor bed depth was 3.8 inches of 0.5% Pt on alumina, a limit picked to insure enough unreacted H_2 to provide a meaningful conversion calculation. The mass velocity was 341 lbm/hr-ft^2, with inlet concentrations of H_2 and O_2 of 23,972 and 38,048 ppm(v) respectively. The outlet hydrogen concentration analyzed was 14 ppm(v), representing a 99.94% conversion. The computer

M #242.3/76: RUN 40-91,CONDITION 1,DRY,HOUDRY HSC931..5%PT ON ALUMINA

BED DIAMETER= 3.260 IN

FEED: TEMPERATURE= 202.0 F
PRESSURE= 21.0 PSIA

	MOLE %	MOLES/HR	LBS/HR
H2	2.3972	0.0172	0.03
O2	3.8049	0.0273	0.87
H2O	0.0	0.0	0.0
N2	93.7979	0.6730	18.85
AR	0.0	0.0	0.0
HE	0.0	0.0	0.0
TOTAL	100.0000	0.7175	19.76

CATALYST BED DESIGN

MASS VELOCITY G = 340.88 LB/HR-FT2

BED DIAMETER= 3.26 IN
BED VOID FRACTION= 0.352
BED SURFACE AREA= 239.3 FT2/FT3
BED BULK DENSITY= 51.1 LB/FT3

BED INC.	TEMP,F	MOLAR PPM HYDROGEN	MOLAR PPM OXYGEN	CONTROLLING COMPONENT	TEMPERATURE COEFFICIENT	DIFFUSION K,M/HR-FT2-ATM	CUMULATIVE BED LENGTH,IN	CUMULATIVE DP,PSI
0	202.0	23972.1172	38044.7734				0.0	0.0
1	212.0	23309.9984	37726.3994	H2	0.306	2.096	0.019	0.000
2	222.0	22646.9867	37403.6367	H2	0.315	2.106	0.038	0.000
3	232.0	21983.0703	37080.4844	H2	0.324	2.117	0.057	0.000
4	242.0	21319.4297	36758.9297	H2	0.333	2.127	0.075	0.000
5	252.0	20652.9648	36432.9727	H2	0.342	2.137	0.094	0.001
6	262.0	19986.5953	36104.6250	H2	0.351	2.147	0.113	0.001
7	272.0	19319.5977	35783.8750	H2	0.359	2.157	0.132	0.001
8	282.0	18651.6797	35458.7305	H2	0.368	2.167	0.151	0.001
9	292.0	17982.9334	35133.1719	H2	0.376	2.177	0.171	0.001
10	302.0	17313.3711	34807.2266	H2	0.384	2.186	0.190	0.001
11	312.0	16642.9727	34480.8472	H2	0.392	2.196	0.210	0.001
12	322.0	15971.7500	34154.1094	H2	0.400	2.205	0.230	0.001
13	332.0	15299.6914	33824.9414	H2	0.408	2.214	0.251	0.001
14	342.0	14626.7891	33499.3711	H2	0.416	2.224	0.272	0.002
15	352.0	13953.0625	33171.3906	H2	0.424	2.233	0.293	0.002
16	362.0	13279.4922	32843.0078	H2	0.431	2.242	0.315	0.002
17	372.0	12603.0820	32514.2070	H2	0.439	2.251	0.338	0.002
18	382.0	11925.9742	32185.0000	H2	0.446	2.259	0.362	0.002
19	392.0	11249.7227	31855.3789	H2	0.454	2.268	0.385	0.002
20	402.0	10571.7734	31525.3438	H2	0.461	2.277	0.412	0.003
21	412.0	9892.9844	31194.9053	H2	0.469	2.285	0.439	0.003
22	422.0	9213.3320	30864.0469	H2	0.475	2.294	0.467	0.003
23	432.0	8532.9781	30532.7456	H2	0.482	2.302	0.497	0.003
24	442.0	7851.4727	30201.0742	H2	0.489	2.311	0.528	0.003
25	452.0	7169.2500	29868.9609	H2	0.496	2.319	0.562	0.003
26	462.0	6485.1680	29534.4297	H2	0.502	2.327	0.599	0.004
27	472.0	5802.2305	29203.4844	H2	0.509	2.335	0.640	0.004
28	482.0	5117.4258	28870.1133	H2	0.515	2.343	0.684	0.005
29	492.0	4431.7500	28534.1164	H2	0.522	2.351	0.735	0.005
30	502.0	3745.2083	28202.1016	H2	0.528	2.359	0.793	0.005
31	512.0	3057.7920	27867.4609	H2	0.534	2.367	0.862	0.006
32	522.0	2369.6951	27532.3965	H2	0.540	2.374	0.947	0.007
33	532.0	1680.3769	27196.8945	H2	0.547	2.382	1.061	0.009
34	542.0	990.2807	26860.9746	H2	0.553	2.390	1.233	0.009
35	552.0	299.3518	26524.6250	H2	0.558	2.397	1.617	0.013
3501	553.4	199.5780	26474.0547	H2	0.563	2.403	1.745	0.014
3502	554.4	133.0564	26443.6602	H2	0.563	2.403	1.874	0.015
3503	555.0	89.7063	26422.0742	H2	0.563	2.403	2.003	0.016
3504	555.5	59.1384	26407.6797	H2	0.563	2.403	2.132	0.017
3505	555.7	39.4759	26398.0781	H2	0.563	2.403	2.261	0.019
3506	555.9	25.2841	26391.6875	H2	0.563	2.403	2.389	0.020
3507	556.1	17.5724	26387.4219	H2	0.563	2.403	2.518	0.021
3508	556.1	11.6819	26384.5742	H2	0.563	2.403	2.647	0.022
3509	556.2	7.7880	26382.6797	H2	0.563	2.403	2.776	0.023
3510	556.2	5.1929	26381.4180	H2	0.563	2.403	2.905	0.024
3511	556.3	3.4613	26380.5742	H2	0.563	2.403	3.033	0.025
3512	556.3	2.3075	26380.0117	H2	0.563	2.403	3.162	0.026
3513	556.3	1.5384	26379.6406	H2	0.563	2.403	3.291	0.028
3514	556.3	1.0254	26379.3867	H2	0.563	2.403	3.420	0.029
3515	556.3	0.6837	26379.2227	H2	0.563	2.403	3.549	0.030
3516	556.3	0.4558	26379.1094	H2	0.563	2.403	3.678	0.031
3517	556.3	0.3039	26379.0391	H2	0.563	2.403	3.807	0.032
3518	556.3	0.2026	26378.9883	H2	0.563	2.403	3.936	0.033
3519	556.3	0.1351	26378.9570	H2	0.563	2.403	4.064	0.034
3520	556.3	0.0900	26378.9375	H2	0.563	2.403	4.193	0.035
3521	556.3	0.0600	26378.9258	H2	0.563	2.403	4.322	0.037
3522	556.3	0.0400	26378.9141	H2	0.563	2.403	4.451	0.038
3523	556.3	0.0267	26378.9063	H2	0.563	2.403	4.580	0.039
3524	556.3	0.0178	26378.9023	H2	0.563	2.403	4.709	0.040
3525	556.3	0.0119	26378.8984	H2	0.563	2.403	4.838	0.041
3526	556.3	0.0079	26378.8984	H2	0.563	2.403	4.967	0.042
3527	556.3	0.0053	26378.8984	H2	0.563	2.403	5.096	0.044
3528	556.3	0.0035	26378.8984	H2	0.563	2.403	5.225	0.045
3529	556.3	0.0023	26378.8984	H2	0.563	2.403	5.354	0.046

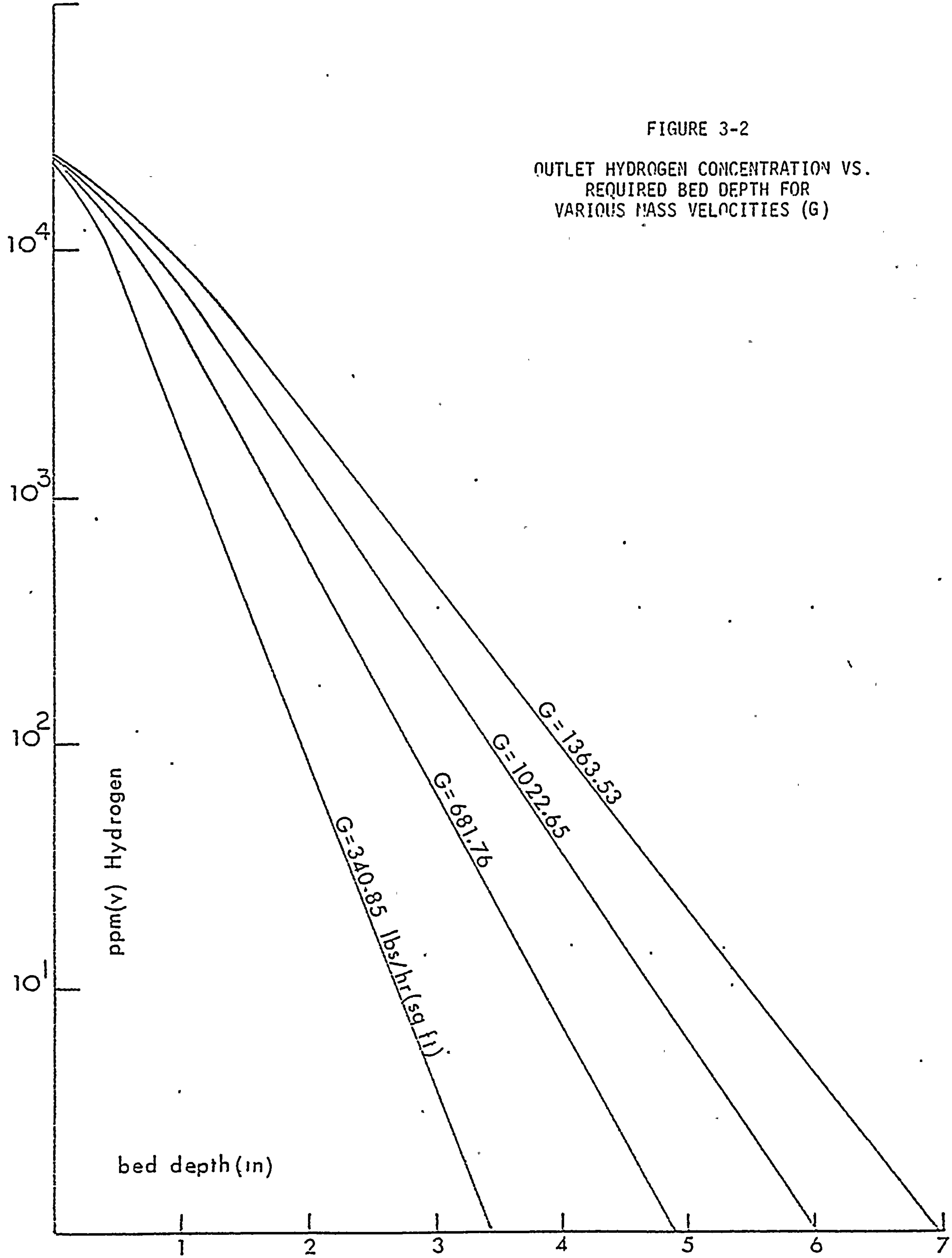
FIGURE 3-1

predicted bed length (based on Nixox catalyst reaction equations) required for the above given inlet boundaries is approximately 2.55 inches. This run in combination with many others, therefore, established an average correction factor for bed length of 1.40 to calculate the required bed depth for 0.5% platinum on alumina catalyst based on Nixox computer results. This accounts for the slight difference in catalyst activity of NIXOX and 0.5% platinum on alumina.

The mass velocity (G) previously mentioned is important in predicting the bed performance. The bed length required varies directly with the square root of the mass velocity as determined by pilot plant and operating plant data and the computer model. In short, given an inlet composition, temperature, and pressure a doubling of the mass flow rates requires $2^{0.5}$ or 1.414 times the bed length. This is graphically displayed in Figure 3-2.

FIGURE 3-2

OUTLET HYDROGEN CONCENTRATION VS. REQUIRED BED DEPTH FOR VARIOUS MASS VELOCITIES (G)



A very significant relationship displayed by the printout (Figure 3-1) is the exponential relation of composition with length, once the reaction is nearly complete and the bed is essentially isothermal. Each decade reduction of the concentration of the limiting reactant requires the <u>same</u> incremental increase in bed depth. Restating, it takes approximately 0.75" of NIXOX (1.06" of Houdry 0.5% platinum on alumina because of the 1.4 bed depth relationship) to reduce H_2 from 5 ppm to 0.5 ppm. This relationship provides a means to employ great conservatism in bed design.

For example, if 3.8" of bed is required to reduce outlet H_2 to 14 ppm, doubling the bed length to 7.6" adds catalytic activity that will reduce the outlet concentration from 14 ppm to 0.00364 ppm as follows:

$$14 \text{ ppm} \times 10^{(-3.8/1.06)} = 14 \times 0.00026 \doteq 0.00364 \text{ ppm}$$

where: 3.8 = amount of added bed depth
1.06 = incremental increase in bed depth required for a decade reduction in outlet H_2 or O_2.

APCI standard design practice is to apply a length factor of at least 3 to 5 which in reality adds several decades in reduction of the limiting component, whether H_2 or O_2. This deep bed design assures high hydrogen conversion efficiencies under all conditions.

3.1.3.4 Secondary Reactions and Reduction in Catalyst Efficiency

Reduction in catalyst efficiency or deactivation of catalysts is a phenomenon where the conversion efficiency of the bed decreases with time. This can occur in a matter of seconds in the case of fluidized beds of petroleum cracking catalysts or in years in the case of some noble metal gauzes used in ammonia synthesis.

APCI initially tested catalyst beds using modest feed temperatures (150 to 200°F as is used in industrial applications) and imposing the halide concentrations expected in a post LOCA containment

atmosphere. The results, anticipated by the Southern Nuclear Report (see Section 3.2), included a reduction in effective catalyst mass of 20 to 25% of its original value in several hours. This reduction in efficiency at these low feed temperatures was considered to be unacceptable for nuclear service.

Based upon the Southern Nuclear work, therefore, APCI focused on the effect of increasing the inlet feed temperatures. As covered in Section 3.3, the increase in feed temperature eliminated reduction in catalyst efficiency due to the presence of the halides. This was not surprising, since the technical literature (and Southern Nuclear test work) predicts that halide compounds of noble metals, platinum in particular, tend to be unstable in the temperature range of 500 to 600°F. This elevated temperature shifts the reaction to the elemental states of platinum and

iodine. All the test data substantiates this and allows a properly operated catalytic recombiner to operate at high recombination efficiency with halides present in the feed gas stream.

Scaling of the recombination reaction has been demonstrated for several types of catalytic recombiners. Section 2 describes the very successful full-scale test results of the WNP-2 recombiner, the design of which was based on the scaling criteria discussed in this section.

Scaling for catalyst efficiency in a contaminated environment is rather straightforward. Consider the 3.26" diameter reactor as a "plug" in a larger diameter reactor of the same bed length. The gases reacting within this "plug" behave in the same manner regardless of the diameter of the total bed if the conditions of plug flow, previously discussed, are

maintained, e.g., good flow distribution, and reasonable mass velocities.

An illustrative corollary of this is that one could scale-up flow rate (while maintaining pressure, temperature, and composition fixed) by providing a multiplicity of smaller reactors arranged for parallel flow.

In summary, if the 0.5% platinum catalyst can tolerate 50 ppm I_2 with feed temperatures of 500-550°F in a 3.26" diameter bed, 3.8" in length, it will perform identically in a 15.5" diameter bed which is 3.8" in length. The 17" length bed used in the WNP-2 reactor simply provides a greater degree of conservatism with even greater tolerance for exposure to higher halide concentrations.

3.2 Catalyst Performance Tests by Southern Nuclear Engineering, Inc.

3.2.1 Summary of Tests and Tested Contaminants

Studies of the effect of various potential poisons from a Post LOCA containment atmosphere on selected catalysts

was made by Southern Nuclear Engineering, Inc. (SNE) under contract with several utilities (Reference 1).

The Houdry platinum catalyst which was also used in the Air Products Test program, was one of the catalysts included in this study and found acceptable by SNE. This catalyst "was exposed to some forty materials, which were considered to be potential poisons. The substances included solutes such as boric acid, sodium thiosulfate and sodium hydroxide, an oil, cleaning agents, the halides I_2, Br_2, CH_3I and HI and several (stable) fission products. Of the many substances used in these tests only the halogens and their compounds gave true significent poisoning." The substances tested are summarized in Tables 3-1 and 3-2 and the SNE report page numbers on which the individual test results appear are referenced.

Among the many tests performed, SNE conducted a plant condition simulation test to determine the long-term capability of selected catalysts (including Houdry platinum on alumina) to operate under the realistic poisoning conditions of a Post LOCA containment atmosphere. The three most severe halogens poisons (I_2,

TABLE 3-1
SOUTHERN NUCLEAR REPORT - SNE-100
POTENTIAL CATALYST CONTAMINANTS* TESTED

High Volatility Liquids	Ref. Pg.	Low Volatility Solids	Ref. Pg.	Gases	Ref. Pg.
Acetone	40	S	46	Acetylene	39
NH_4OH (Ammonia Hydroxide)	40	Te (as TeO_2) (Tellerium Dioxide)	46	SO_2	39
CCl_4 (Carbon Tetrachloride)	40	Mo (as MoO_3)	46	CO	39
Hydrazine	40	Cs (as Cs_2CO_3) (Cesium Carbonate)	46	Freon-12 (CCl_2F_2)	47
H_2O_2 (30% solution) (Hydrogen Peroxide)	40	Rb (as Rb_2CO_3)	46	NH_3	38
Oil (450 gm/cu. ft. increments)	40	RuO_4 (517 gm Ru/ cu. ft.)	46		
$Na_2S_2O_3/H_3BO_3$ (decomposition products)	40-41	Hg (liquid)	46		
		DOP (liquid) (Dioctylphthalate)	48		
		ZrO_2	46		
		Zr	46		

*Poison added in a quantity equivalent to about 700 gm/cu. ft. of catalyst except as noted in parentheses. Standard test conditions were: 1 in. deep, 7/8 in. diameter catalyst bed; 2% H_2-air mixture; 1.2 CFM and 170-180°F inlet temperature.

TABLE 3-2

SOUTHERN NUCLEAR REPORT - SNE-100
POTENTIAL CATALYST CONTAMINANTS* TESTED

SOLUTION POISONS	Ref. Pg.
H_2O (14,000 gm/cu. ft.)	43
$Pb(NO_3)_2$ (Lead Nitrate)	43
Alcohol (8,000 gm/cu. ft.)	43
$CuSO_4$ (Copper Sulfate)	43
CCl_4 (Carbon Tetrachloride) (22,500 gm/cu. ft.)	43
SeO_2 (in NaOH solution)	43
H_2O_2 (Hydrogen Peroxide) (4,000 gm/cu. ft.)	43
Cs_2CO_3 (Cesium Carbonate)	43
RbCl (Rubidium Chloride)	43
H_3BO_3 (Boric Acid)	43
$Na_2S_2O_3$ (Sodium Thiosulfate)	43
$ZnCl_2$ (Zinc Chloride)	43
$SnCl_2$ (Tin Chloride)	43
$NaVO_3$ (Sodium Metavanadate)	48
$FeCl_3$ (Iron Chloride)	43
TeO_2 (Tellerium Dioxide)	43
NaOH	43
NaCl	43
$H_3BO_3/NaOH/Na_2S_2O_3$	43

HALOGENS	Ref. Pg.
Iodine	49-53
Bromine	53-59
Methyl Iodide (CH_3I)	57-60
Hydrogen Iodide (HI)	61-62
Sodium Iodide (NaI)	61-62

*Poison added in a quantity equivalent to about 700 gm/cu. ft. of catalyst except as noted in parentheses. Standard test conditions were: 1 in. deep, 7/8 in. diameter catalyst bed; 2% H_2-air mixture; 1.2 CFM and 170-180°F inlet temperature.

CH_3I, and Br_2) were added to the inlet gas in concentrations chosen as closely representing maximum levels for a 1000 MW(E) PWR with a 2 x 10^6 cu. ft. containment. The feed gas was also bubbled through a water solution of 1.7 wt% H_3BO_3, 0.6 wt% NaOH, and 1.2 wt% $Na_2S_2O_3$. The test was run for 274 hours, with inlet gas (air) containing 2.5% H_2 preheated to 400°F and no catalyst poisoning was noted. Changes in hydrogen and inlet temperature were made, showing no poisoning at 2% and 1% H_2, however, the poisoning effect occurred at a very low inlet temperature of 180°F. Increase of inlet temperature to 400°F allowed the catalyst to return to the efficiency that existed before the poisoning effect. SNE concluded that the catalyst will perform effectively on PWR Post LOCA containment gas without poisoning when inlet temperatures are elevated, and that the catalyst will recover from poisoning due to lower inlet temperatures when temperature is raised again.

Other tests performed by SNE included lifetime testing for 10 weeks without any significant change in the hydrogen removal efficiency. The catalyst was also irradiated for 262.5 hours with a total dose of 1 to 3

x 10^8 rad by a cobalt 60 gamma source at a dose rate of approximately 1 x 10^6 rad/hour. The irradiation of the catalyst had no effect on its hydrogen removal efficiency, as determined by comparison of temperature rise across the bed before and after irradiation.

The effect of temperature and pressure on catalyst performance was found not to be of significant concern in the Post LOCA gas environment. While higher temperatures increase catalytic reaction rate for hydrogen and oxygen, the catalyst efficiency is so high that temperature as a rate controlling mechanism itself has little significance. The catalyst is stable at temperatures well above the expected maximum operating level of 1100°F. With catalyst bed temperatures of 1400°F to 1480°F, the efficiency of a shallow (0.5") catalyst bed declines, but is not significant on a typical full size deep bed recombiner. Pressure also was found to have a limited effect on a shallow (0.25") bed. Higher gas pressure decreases efficiency, but is not significant for a full size bed recombiner.

Other tests performed by SNE, included exposure of the catalyst to large loadings of low volatility materials,

several of which are included in the fission products inventory. The tests demonstrated that high catalyst efficiency was maintained.

This high catalyst efficiency was maintained with massive constituent loadings of 700 gms/ft^3 of catalyst bed. It is further noted that tests were performed consecutively using the same catalyst bed, so that cumulative catalyst exposure was of the order of thousands of grams per cubic foot in some cases.

As discussed in Section 2.2.2.1, the high efficiency of the WNP-2 scrubber guarantees that particulate loadings on the WNP-2 recombiner are close to an order of magnitude less than the loadings which were tested successfully by SNE.

3.2.2 Applicability of the SNE Tests to Air Products' WNP-2 Design

3.2.2.1 Noble Gases and their Decay Products

Recombiner tests performed without the presence of noble gases are valid since the krypton and xenon fission products are chemically inert under the test

conditions and cannot react with the platinum or the catalyst substrate. For a 3200 megawatt thermal reactor operating at 100% capacity for 625 days, the maximum quantity of stable xenon formed is about 4.4 lb-atoms. If this entire inventory is released to the containment atmosphere during a LOCA, the average xenon content in a Mark I or Mark II BWR containment can reach 0.5 mole percent at 120°F and 14.7 psia. These concentration levels will not have any significant physical effects on the overall gas properties of the system. Since krypton levels are almost a factor of ten lower, its effects are even less significant.

The major decay products of the radioactive noble gases are rubidium and cesium daughters. The SNE tests showed these elements in the form of low volatility solids of rubidium

and cesium carbonates had no significant detrimental effect on the working catalyst at bed loadings up to 700 grams of solid per cubic foot of catalyst. In addition, a significant percentage of the daughter products will be formed in the containment following the LOCA before the recombiner system is put into operation. Since the recombiner system includes a scrubber for particulate removal, essentially none of the daughters formed in the containment will reach the recombiner. Therefore, those daughters formed in the recombiner system itself are most significant to the catalyst bed, and that quantity is at least an order of magnitude less than the bed loading tested by SNE. Therefore, solid decay products will not have any poisoning effect derived from physical or chemical interaction with the catalyst.

With respect to radiological effects, the SNE tests showed that a radiation dose in excess of 10^8 rads at a dose rate of about 10^6 rads per hour had no effect on

the hydrogen removal efficiency of the noble metal catalyst. Based upon a 180 day operating period after the LOCA, radiation dose rates on the recombiner would have to exceed 23,000 rads per hour for the entire period to approach this tested level. Since the WNP-2 post LOCA recombiners are not put into operation until at least five hours after the LOCA and only a small volume of the containment atmosphere passes through the recombiner at any instant postulated dose rates on the recombiner from the process stream are at least an order of magnitude lower than the average level needed to reach the accumulated test dosage level. In addition, during the course of operation over a postulated 180 day period, the radiation levels and dose rate will continually decrease. The cumulative radiological effects will not cause any physical damage to the catalyst material.

3.2.2.2 Solvents

Potassium hydroxide and sodium peroxide are not expected to be present in the containment atmosphere. Sodium peroxide is an extremely unstable material and, even if present, would decompose immediately in the presence of water or water vapor to sodium hydroxide and oxygen. Hydrogen peroxide is a possible product from the irradiation of water but only low concentrations can accumulate because of its extreme instability under the conditions of a LOCA. In addition, H_2O_2 is very unstable at elevated temperatures. It decomposes readily to water and oxygen. Therefore, H_2O_2 will not be present in the 500°F feed to the catalytic recombiner.

The SNE report indicates that catalyst bed loadings of up to 700 grams of such materials as NaOH and H_2O_2 produced no

significant reduction in hydrogen removal efficiency. In addition, the Air Products system includes a scrubber system for the removal of entrained particulate material similar to spray solutions discussed above.

3.2.2.3 Differences in Space Velocity

The SNE experiments were designed to screen many materials in a short time by operating one reactor at high space velocity in order to measure finite temperature differences or changes in readings of a thermal conductivity cell which were related to the hydrogen removal efficiency.

The SNE poison addition tests were made in a 7/8" diameter 1" deep bed at a flow rate of 1 cfm (measured at 70°F and 1 atm) at an inlet temperature of 170 to 180°F. The calculated space velocity at 175°F inlet temperature and 14.7 psia is 57.4 $sec.^{-1}$. The corresponding mass velocity is 1078 lbs/ft^2-hr.

The APCI experiments, on the other hand, were designed to simulate full scale system operation at practical mass velocities in a relatively deep bed, measuring hydrogen or oxygen removal efficiency by measuring outlet concentrations in the part per million range using highly accurate gas chromatographic techniques.

The APCI halide addition tests were made in a 3.26" diameter bed over a range of mass velocities of from 124 to 421 lbm/hr.-ft.^{2}. The corresponding space velocities were 1.09 sec^{-1} at 308°F and 4 psig in a 7" bed, and 2.38 sec^{-1} at 516°F and 4 psig in a 12" bed. These parameters meet SNE's recommendation on page 86 of their report that recommends space velocities be approximately 10,000 hr.$^{-1}$ or 2.78 sec^{-1}.

The apparent range of ratios of SNE/APCI space velocities is 24.1 to 52.7. However, when one corrects for the ratio of bed depths to determine residence times per unit length of bed, the ratio range is 2.1 to 4.4. This ratio reflects APCI's desire to simulate full scale conditions as closely as possible and APCI's sensitive effluent gas detection capabilities which allowed the use of lower test space velocities.

Air Products

Actual system beds of the geometry required to equal the SNE mass velocity used in screening experiments would be highly impractical. Such beds would be long and narrow, exhibiting high pressure drops in the inlet, distributors, the bed proper, and the outlet.

However, qualitatively, and to a large extent, quantitatively, the two sets of experiments gave comparable results for the poisoning from I_2 and CH_3I and the significant effect of temperature. The rate of mass transfer and pore diffusion effects of these materials would be expected to be comparable to that of other poisons in the gas phase. It is, therefore, not unreasonable to expect the materials tested by SNE to behave in a similar manner in actual recombiners.

The reader is referred to the SNE conclusions on poisoning of catalysts SN-15 and SN-18 (SNE Report, pages 85 and 86).

3.2.2.4 Time Effect

The basis of the SNE poisoning tests (Section IV of their report) was to subject the catalysts "to relatively greater amounts and concentrations of poisons then could be expected to exist airborne", and at conservatively low H_2 concentrations and low feed temperatures. Per SNE page 36, "the poison material was added in quantities (about 700 grams per cubic foot of catalyst) considerably in excess of that which might be expected to reach the catalyst bed from the containment atmosphere following a LOCA." "Despite the rather massive poison loadings to which the catalysts were exposed, none of the poisons (except the halogens) reduced the efficiencies of the catalysts to values that would be unacceptable for post-accident hydrogen control."

The tests were planned to provide bed loadings in excess of those actually expected. These loadings were accomplished

in a short time period. However, if a considerably longer time were used to effect the same ultimate loading (700 grams per cubic foot of catalyst), the loss of efficiency should not be more than shown in the short term test. Since the results showed no "decrease in efficiency that would be of concern in the operation of a plant size recombiner", long term poison tests were not conducted except for iodine.

3.2.2.5 Additive Effects of Poisons

Referring to SNE Figures 20, 21, and 22, there is no indication that the simultaneous addition of these materials can be any more deleterious than their additions as shown or in any other sequence. The important parameter to control is the total loading of potential poisons that can get to the catalyst. Just as the experimental concentrations of contaminants used by SNE were in excess of those expected to reach the bed from a containment atmosphere following a LOCA with no significant detrimental effect,

a composite of these contaminants at a similar total concentration level will not logically cause any additional effect. In addition, the Air Products system incorporates a scrubber unit which will provide supplemental protection by removing such contaminants that might exist in the feed stream to the recombiner.

3.2.2.6 Methyl Iodide Tests

The argument that the SNE tests were conducted at concentrations well in excess of those predicted in the feed gas from the containment after a LOCA and that only a slight effect on the catalyst efficiency was observed, did not pertain to CH_3I which clearly has a major effect on the catalyst efficiency under the SNE test conditions. Tests with CH_3I were conducted with CH_3I levels equivalent to that expected in the containment atmosphere as illustrated on page 59 of the SNE Report. Tests reported in Figure 29 of the SNE Report used CH_3I concentrations of 1.18×10^{-8} grams per cm^3 and 2.36×10^{-9} grams per cm^3

which are equivalent to 1.8 and 0.4 ppm by volume, respectively. These levels are typical of those expected for a post LOCA containment atmosphere.

Any conclusion that the poison effect did not change as the concentration was reduced is contrary to the results in Figure 29. These data show that at the lower concentration of CH_3I about double the CH_3I loading was required to reduce the hydrogen removal efficiency to a certain level.

For example, at the lower methyl iodide concentration, about 80 grams of CH_3I was added per cubic foot of catalyst to reduce the efficiency to 60% while at the higher level only 40 gram/ft^3 was added to reduce the efficiency to 60%. These results show that the poisoning effect is more severe at the higher concentrations, and correspondingly less severe at lower concentrations. Air Products CH_3I tests summarized in section 3.3 show that at the WNP-2 expected CH_3I levels, with the design APCI systems preheat,

no significant degradation of catalyst performance will occur under post LOCA conditions.

3.2.2.7 SNE Miscellaneous Halide Test

The SNE miscellaneous halide test described on pages 61 and 62 of the SNE Report shows the poisoning effect of HI and NaI in a 2% H_2 - air mixture with a 180°F inlet temperature. Any iodine compound which will react with the platinum of the catalyst will cause reduced efficiency at this low inlet temperature. Air Products tests show that most forms of iodine are converted to HI in a hydrogen containing feed gas and passed through the bed in the effluent gas. HI will not poison the catalyst when the inlet temperature is held above 400°F. The NaI had a detrimental effect in the SNE test for two reasons. The loading was in excess of 700 grams per cubic foot of catalyst (an unrealistic level) and the inlet temperature was too low. In addition, any NaI in the feed gas would be present as a dissolved solid

in entrained water droplets (a non-volatile material); which would be removed in the Air Products system scrubber.

3.2.3 Conclusions

Southern Nuclear Engineering concluded that the Air Products platinum on alumina catalyst exhibited greater hydrogen reaction capabilities than are required for an economically feasible bed size. The catalyst exhibits "more than adequate resistance to potential poisons" when inlet flow to the catalyst is at a temperature of 300°F or higher. The catalyst showed no effect from an extended period of operation or high radiation dose. If inlet air is preheated so that relative humidity is reasonably well below 100%, the Post LOCA steam environment will not have any effect on the catalyst.

SNE also extrapolated the various poisoning test results for different space velocities considered and concluded that as larger full scale beds are used, the allowable specific poisoning loads (gms/cu. ft. catalyst) are even higher than for the test beds. Thus a full scale bed would perform even better than predicted by the SNE data.

3.3 Air Products Catalyst Testing

3.3.1 Introduction and Objectives

The ability of platinum and palladium catalysts to promote the low temperature recombination of hydrogen and oxygen in clean gas service is well established. In contaminated gas service, catalyst activity could be adversely affected by agents in the feed stream which chemisorb on the noble metal surface. Extensive testing by both Air Products and Southern Nuclear Engineering, Inc., has demonstrated that efficient catalytic recombination can be maintained with the trace contaminants postulated in the Post LOCA containment atmosphere.

The results of the Southern Nuclear Engineering tests showed that the halogen/catalyst reaction was the only significant chemisorption process capable of reducing catalyst efficiency in Post LOCA service. Therefore, Air Products focused its testing on the halogens; and more specifically, those halogens found by SNE to have the greatest affect on Pt based catalyst: iodine (I_2) and methyl iodide (CH_3I). These tests were carried out between 1972 and 1976 as part of a complete series of catalyst studies conducted since 1962 at Air Products. The major objectives of this specific test program were to:

Air Products

a. Investigate the effects of iodine and methyl iodide as catalyst poisons which could hinder the performance of a recombiner in Post LOCA applications, and

b. Establish feed gas temperatures that eliminate or reduce the effects of catalyst poisons for a variety of typical feed compositions.

3.3.2 Test Basis

a. Concentrations of Iodine and Methyl Iodide

Calculations based on NRC Regulatory Guide 1.7 and the WNP-2 specified Post LOCA equipment operating constraints show that approximately 5600 grams of non-particulate halogens are dispersed uniformly in the BWR containment of 344,724 $feet^3$. This corresponds to a total halogen (I_2, CH_3I, BR_2, etc.) concentration of approximately 50 ppm by volume (molar ppm). The iodine and methyl iodide concentrations used in the Air Products catalyst test program are all given in ppm by volume, or equivalently, molar ppm. Since the respective molecular weights of I_2 and CH_3I are 253 and 142 in a containment bulk gas of 26-29 molecular weight, the difference between the volume ppm and weight ppm will be significant. For example, the 50 volume ppm of halogens referenced above in the 344,724 $feet^3$ containment is approximately equal to 440 weight ppm.

Examination of the Air Products test results show that Post LOCA simulation runs were made with iodine concentrations ranging from to ppm by volume and methyl iodide concentrations from to ppm by volume.

In summary, halogen concentrations used in the Air Products tests are similar to those expected in the containment following a LOCA based on NRC Regulatory Guides and utility equipment specifications.

b. Catalyst Reaction Theory

Considering the fission product inventory (TID 14844) which may be released to the containment atmosphere, the agents of major concern are the halogens bromine and iodine, particularly iodine since it dominates the halogen inventory. It is known that under certain conditions, iodine can reduce the efficiency of noble metal catalysts.

The reaction of platinum with iodine to form platinum iodides is indicative of reduction in catalyst efficiency. At low temperatures, this reaction proceeds favorably. Literature data and thermodynamic calculations show, however, that platinum iodides are not stable at higher temperatures. With increasing temperature, the stability of platinum iodides decreases as follows:

$$PtI_4 \rightarrow PtI_3 \rightarrow PtI_2 \rightarrow Pt$$

It would be expected, therefore, that certain noble metal catalysts would maintain high constant activity given sufficient temperature. This, in fact, has been confirmed experimentally. With sufficient temperature, an equilibrium condition is achieved where a small fraction of the catalyst bed is partially deactivated but the remaining catalyst is quite active and stable. A more complete description of this equilibrium considers the reactions between hydrogen, oxygen, iodine, and platinum:

$$H_2 + 1/2\ O_2 \rightarrow H_2O$$

$$H_2 + I_2 \rightleftarrows 2HI$$

$$Pt + nI \rightleftarrows PtI_n$$

At the inlet of a catalyst bed, where the catalyst is coldest, there exists the greater tendency of iodine to react with platinum. This reduces the amount of reaction between hydrogen and oxygen; and hence, decreases the catalyst temperature and promotes further reaction between iodine and platinum. Indeed, this has been observed as a cold temperature wave progression through the bed from inlet to outlet. If, however, the preheat temperature is higher or if there is sufficient reaction to maintain a high enough bed temperature, then a stable condition is reached in which fresh iodine entering the

bed passes through or reacts with hydrogen and passes through with the feed gas. Under this condition, some loss of activity in the bed inlet occurs until the maximum amount of iodine is taken up. This loss in activity is relatively small and is readily made up by the remaining catalyst, especially in a deep catalyst bed design. In fact, the WNP-2 bed is designed with a bed depth safety factor of .

3.3.3 Test Setup

The Post LOCA tests were run in the Air Products' laboratory recombiner test facility. The flowsheet for this test unit is shown in Figure 3-3. The test recombiner shown in Figure 3-4 is a vessel of inner diameter, and catalyst bed depths to are possible. Flowrates of to scfm of process gas are used with this system. (The mass flowrates in the unit are equivalent to those for full-size recombiners.)

The test unit includes facilities for metered input flows of hydrogen, oxygen, nitrogen, and steam, along with additions of minor components such as iodine, methyl iodide, etc.

FIGURE 3-3
SCHEMATIC FLOWSHEET
FOR THE
RECOMBINER TEST FACILITY

FIGURE 3-4

TEST RECOMBINER

The feed gas is preheated electrically in a resistance heater with flanged immersion elements. A thermostatic control maintains the desired inlet temperature to the recombiner.

Upon entering the recombiner vessel, the feed flows through a bed of pelletized platinum on alumina catalyst. The hydrogen and oxygen react to form water producing a gas temperature rise of about 145°F for each one percent of hydrogen reacted. Provisions were made to sample and analyze the feed gas immediately prior to reaching the catalyst bed.

The hot recombiner effluent is cooled by water in a shell and tube heat exchanger. The process gas can be sampled for analysis immediately after the condenser.

The recombiner vessel (Figure 3-4) contains thermocouples to monitor the feed and bed temperatures. of the thermocouples are located in the catalyst bed, beginning inch into the bed and spaced inch thereafter. It is the bed temperature measurements that provide a sensitive monitor of any loss of catalyst efficiency. Any platinum-halide reaction reduces the amount

of reaction between hydrogen and oxygen and thereby reduces the catalyst temperature. Progressive loss of efficiency is readily followed as a low temperature front moving through the catalyst bed from inlet to outlet.

Efficiency and the activity of the catalyst are also monitored by analyzing the composition of the recombiner effluent. Gas chromatography is used to measure the hydrogen and oxygen concentrations of the vent gas from the cooler-condenser. An electrolytic trace oxygen analyzer is also used to measure oxygen concentrations below 1000 ppm. The form of halogens leaving the catalyst is checked with a gas sample from the recombiner at a point above the top of the catalyst bed. In some cases, the effluent condensate was collected and titrated with sodium hydroxide solution to determine the acid concentration and with silver nitrate solution to determine the total iodide content.

3.3.4 Post LOCA Simulations

a. Preliminary Tests

In order to initially study the overall effect of iodine and methyl iodide on the catalyst performance, an operating catalyst bed was exposed to iodine and/or methyl iodide

contaminants with the preheat temperature significantly lower than . Figure 3-5 shows the bed temperature profiles at three time intervals for an inerted BWR post LOCA simulation, using a preheat temperature. A deep bed was used in the diameter test chamber with a flowrate of scfh, which is equivalent to a mass velocity of lbm/hr.-ft^2. The feed composition was % N_2, % H_2, % O_2, % H_2O vapor, and ppm I_2 vapor. The unpoisoned bed profile is shown by the curve labeled zero minutes from the start of the I_2 flow.

This is approximately equivalent to a decrease in efficiency from 99.99% to 99.90%.

FIGURE 3-5

BED TEMPERATURE PROFILES FOR RUN 14-01

At the end of this run, the oxygen concentration in the feed was increased from % to %.

This experiment indicates that the reduction in catalyst efficiency due to iodine at a fixed feed gas preheat temperature is clearly influenced by the bed temperature, which is determined by the feed gas composition. The iodine contamination decreases as the bed temperature increases. We can conclude from this that greater reduction in efficiency effects occur when low concentrations of hydrogen or oxygen are reacted at a given preheat temperature. However, this effect produces a negligible reduction in recombiner efficiency as shown in subsequent tests.

In another series of two runs (16-08, 09) simulating inerted BWR Post LOCA conditions and using a deep bed, an attempt was made to determine the effects of hydrogen concentration.

This result, together with the leveling off of the bed temperature, suggests that an equilibrium condition was reached and that no further deactivation was occurring. The oxygen concentration in the effluent at the end of the run was measured as less than

Since a feed of essentially . or ppm was used, this is equivalent to a steady-state oxygen removal efficiency of better than 99.99% with no further deactivation.

This equilibrium characteristic is further illustrated in Figure 3-6 which presents the data from Run 16-09. The conditions for this run were exactly as those for the previous run but the hydrogen concentration was reduced

These results indicate that an equilibrium was again set up but that the reduction in efficiency had been a bit more severe.

FIGURE 3-6

FEED AND BED TEMPERATURE vs TIME FOR RUN 16—09

A series of runs was made to investigate the affect of having an excess of oxygen over hydrogen. In a representative test, run 16-10, the hydrogen was reduced to % and the oxygen to %. The feed temperature was again maintained at °F, with iodine at ppm and CH_3I at ppm.

FIGURE 3-7

FEED AND BED TEMPERATURE vs TIME FOR RUN 16-10

At the end of seven hours, the bed temperatures appeared to have stabilized and the effluent hydrogen concentration was ppm compared with ppm in the feed. This is equivalent to a hydrogen removal efficiency of 99.55%. This decrease in efficiency as compared to run 16-09 (Figure 3-6) results from two conditions. First, the amount of recombination was decreased, so therefore, the maximum bed temperature was reduced, allowing the iodine effect to be more severe.

b. <u>Affect of Preheat on Catalyst Performance</u>
Several test runs were made to determine the effect of influent gas preheat on catalyst performance.

Figure 3-8 shows the bed temperature profiles for run 15-01A. In this run using % hydrogen and

% oxygen in the feed and a preheat temperature of , no deactivation was detected in a deep bed over a period of 200 minutes. The effluent hydrogen concentration was less than ppm, which is equivalent to a hydrogen removal efficiency greater than 99.99%. These conditions represent those that might be experienced near the beginning of a Post LOCA recombiner operation where hydrogen levels are high and the resulting bed operating temperatures will be high.

Figure 3-9 shows more stringent conditions in run 15-02 where the feed hydrogen is reduced to % and the feed preheat temperature is set at °F. In this case, considerable reduction in efficiency took place over the six-hour run period and an equilibrium condition was not reached. This suggests that the preheat temperature was not high enough for these conditions. The effluent hydrogen concentration was measured at ppm at the end of the run which means that at that time the hydrogen removal efficiency of the system was still 98.3%.

FIGURE 3-8

BED TEMPERATURE PROFILES FOR RUN 15-01A

FIGURE 3-9

FEED AND BED TEMPERATURES FOR RUN 15-02

In run 15-03 as shown in Figure 3-10, all conditions were the same except that the feed preheat temperature was increased to °F. As can be seen the temperature profiles, compared to the previous runs, were improved and the bed temperatures were more nearly leveled even after three hours. The hydrogen effluent concentration was measured at ppm at the end of this run which is equivalent to a removal efficiency of 99.6%.

In run 15-04, the feed temperature was increased to °F as shown in Figure 3-11. During the first hour of this run, there was a rise in bed temperature which suggested that some regeneration of the bed is occurring as a result of the higher feed gas temperature. However, within two hours a new steady-state condition was reached that remained for the remainder of the six-hour run. The hydrogen effluent concentration was measured at less than ppm which is equivalent to a hydrogen removal efficiency of 99.97% for these conditions.

The results of this series of the runs are summarized in Table 3-3.

FIGURE 3-10

FEED AND BED TEMPERATURE vs TIME FOR RUN 15-03

FIGURE 3-11

FEED AND BED TEMPERATURES VERSUS TIME FOR RUN 15-04

TABLE 3-3

EFFECT OF PREHEAT TEMPERATURE ON BED PERFORMANCE

IN THE PRESENCE OF IODINE

It is clearly observed that higher preheat temperatures and hence higher bed temperatures reduce the effect of both iodine and methyl iodide on the catalyst. Also, after steady-state conditions are reached, the bed will perform at high efficiency with no further deterioration in performance.

c. <u>Long Duration Tests</u>

Several tests of duration up to 268 hours (greater than 11 days) were conducted with various feed gas conditions to determine the long-term catalyst performance.

A 124-hour simulation of extremely stringent operating conditions was performed. In this run, the feed gas was composed of % nitrogen, % hydrogen, % oxygen, and % water with ppm of iodine and ppm of methyl iodide. The low oxygen concentration controls the recombination reaction and limits the catalytic reaction to only hydrogen. This low reaction rate reduces catalyst bed temperatures and exposes the bed to the full effect of the high iodine content for this long run.

The bed depth was inches and the flowrate scfh for a mass velocity of lbm/hr-ft^2. The average preheat temperature was held at °F.

During the 124-hour run effluent oxygen from the recombiner remained extremely low, to ppm for an oxygen removal efficiency of 99.8%. At 100 hours, the hydrogen flow was deliberately stopped and replaced with nitrogen in the feed gas for two hours leaving halogen and oxygen flow alone with no temperature rise due to H_2-O_2 reaction. The hydrogen flow was then restarted and the bed resumed its same efficiency with but ppm oxygen in the effluent. The recombiner bed temperatures in the first part (inches) of the bed dropped slightly but halogen deactivation was not complete in this zone nor did it progress further into the bed. Figure 3-12 shows the temperature data for this run, 27-01, with the stable performance demonstrated by the constant temperature levels in the catalyst bed.

In this 124-hour test, the catalyst was exposed to a cumulative iodine load of grams per cubic foot of catalyst bed and grams per cubic foot methyl iodide load. For a typical cubic foot full-scale recombiner bed, this test exposure is equivalent to

FIGURE 3-12

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FEED AND BED TEMPERATURES.
RUN 27-01 BWR POST LOCA SIMULATION

at least three times the maximum iodine and five times the maximum methyl iodide loadings predicted to be present in the Post LOCA containment atmosphere. The test results showed that the catalyst activity remained stable and unaffected by this large cumulative load.

In two other long duration Post LOCA simulations, feed gas compositions were selected to provide only about °F bed temperature rise above preheat temperature This represents one of the most stringent operating conditions for the catalyst and yields low operating bed temperatures where catalyst deactivation can be most severe. The length of the runs,100 and 268 hours, were selected to provide performance data over enough operating time to show that equilibrium conditions in the catalyst bed are reached despite continuous exposure to iodine.

Feed conditions for these two runs were:

Feed Condition	100 Hr. Run (19-01)	268 Hr. Run (26-01)
Inlet H_2 (%)		
O_2 (%)		
N_2 (%)		

Feed Condition	100 Hr. Run (19-01)	268 Hr. Run (26-01)
H_2O (%)		
Iodine (ppm)		
Methyl Iodide (ppm)		
Total Gas Feed (scfm)		
Mass Velocity (lb/hr sq.ft.)		
Feed Temperature (average)		
H_2 Removal Efficiency (%)		
Catalyst Bed Depth (in.)		
Catalyst		

The results of these tests are shown in Figures 3-13 and 14 where the feed gas and bed temperatures are recorded as a function of time. As can be seen above, the two runs have essentially the same feed gas conditions including the halogen levels. The 268-hour run (26-01) has a 10% higher gas feed rate and a shallower (58% of the 100-hour run) bed depth. These changes were made to provide a more severe test of the Air Products catalyst in Post LOCA gas conditions.

In addition, a surge of higher iodine concentration feed gas was applied to the catalyst bed after 224 hours of the run to learn if the bed could withstand

FIGURE 3-13

FEED AND BED TEMPERATURES

RUN 19-01 —— POST LOCA SIMULATION

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FIGURE 3-14

FEED AND BED TEMPERATURES
RUN 23-01 —— POST LOCA SIMULATION

and recover from this higher halogen loading. After 60 minutes of exposure to ppm of iodine in the feed (a six-fold increase) the bed temperatures and outlet hydrogen content returned to the same levels as before the halogen surge within an hour from the end of the surge period. This recovery demonstrates the catalytic recombiner's capability if such upset gas feed would occur, even with low hydrogen level in the gas.

The temperatures plotted in Figures 3-13 and 14 show stable performance achieved after initial halogen effect in the top zone of the bed. Hydrogen levels in the effluent remained below the ppm range throughout both test runs indicating the catalyst bed's stability despite continued exposure to high iodine levels. The slight downward trend of the temperatures in the 268-hour run is basically due to the gradual decline in feed temperature over the run.

These Post LOCA simulation tests clearly indicate that the effects of iodine can be avoided by proper selection of feed temperature and operating bed

temperature. The tests also show that highly efficient catalytic recombiner systems can be designed to perform in the presence of iodine.

d. Severe Halogen Concentration Tests

The ability to achieve stable catalytic activity has been demonstrated with feed gas containing extremely high iodine concentrations. The effects of feed preheat temperature and hydrogen content are demonstrated in a unique test described below.

In run 37-01, the feed gas contained % hydrogen, % oxygen, ppm (v) iodine (ppm by weight), and ppm (v) methyl iodide. This iodine level is considerably in excess of that calculated from the Regulatory Guides, being five times greater than the calculated WNP-2 concentration.

In run 37-01, the feed condition was altered sequentially as shown in Figure 3-15. At the start of the run, the feed preheat temperature was set at °F.

POST-LOCA RUN 37-01

FIGURE 3-15

The preheat temperature was then increased to °F. The catalyst began to regenerate immediately and achieved a high equilibrium activity providing 96.3% hydrogen removal efficiency (ppm outlet hydrogen).

The preheat temperature was then increased to about °F (approximately the design preheat temperature). The equilibrium activity of the catalyst increased to provide 99.5% hydrogen removal efficiency (ppm outlet hydrogen).

With the °F preheat, the feed hydrogen concentration was then increased to % a concentration level more representative of a containment atmosphere with hydrogen accumulation. Again, the equilibrium activity of the catalyst increased and stabilized. The outlet hydrogen concentration fell below the detectable limit of ppm. The hydrogen removal efficiency was then in excess of 99.96%.

With the feed hydrogen concentration held constant, the preheat temperature was then reduced first to and then to The reaction temperature maintained a high equilibrium activity and the effluent hydrogen concentration remained below the detectable limit (99.96% removal efficiency).

This test confirms that a design preheat temperature is conservative even with massive influent iodine concentrations.

3.3.5 Conclusions

The Air Products' Post LOCA catalyst performance tests have demonstrated that the APCI 0.5% platinum on alumina catalyst is resistant to loss in efficiency due to halogen contamination and will operate at high efficiencies under the most stringent accident conditions when the inlet feed gas is preheated to approximately 500-550°F.

4. Seismic Summary

4.1 Introduction

This summary covers the methods which were used to assure that the recombiner system would maintain structural integrity during and after a seismic disturbance and functional integrity (See 4.3.1.1) after a seismic disturbance. The following topics are discussed:

a. General analysis.

b. Qualification criteria.

Details for analysis of specific components or frame members and the equipment test data are presented in the IEEE Reliability Qualification Report (Reference 3) and the Mechanical Design Report (Reference 4).

4.2 General Analysis

4.2.1 Definition of Equipment Classifications

4.2.1.1 Group I - Structurally Simple Equipment

Structurally simple equipment is that equipment whose first mode natural frequency is greater than 30 cps. This equipment is treated by simple beam analysis (fixed end, simply supported, etc.) for the purpose of determining frequency.

The seismic load for this equipment consists of a static load corresponding to the equipments' weight times the accelerations specified.

4.2.1.2 <u>Group II - Structurally Complex Equipment (Mathematically Modeled)</u>

Any equipment which had a first mode natural frequency less than 30 cps was idealized by a mathematical model consisting of lumped masses connected by massless springs. This normally required the use of a computer program.

The frequencies and mode shapes were determined for vibrational loads applied in the vertical and two orthogonal horizontal directions (the global directions of the skid were used). Sloshing effects of any contained liquids were included, if significant. The spectral acceleration per mode was obtained from the appropriate response spectrum curve.

4.2.1.3 <u>Group III - Structurally Complex Equipment (Dynamic Test)</u>

Equipment that could not be modeled because of its complexity was dynamically tested.

The dynamic test response spectra enveloped the appropriate required response spectra.

4.2.2 Equipment Classification

4.2.2.1 Structural Skids - Group I

4.2.2.2 Vessels - Group I

4.2.2.3 Piping

The piping system was designed using one of the following analytical techniques:

a. Generally, piping runs were designed to have a first mode natural frequency above 30 cps. This was accomplished by supporting the piping lines at intervals such that each section of pipe between supports met the cps criterion. (Group I)

b. Where operating temperature or piping flexibility prohibited supporting the piping line such that the 30 cps criterion could be met, a dynamic model analysis was employed to evaluate the line. (Group II)

4.2.2.4 Instrumentation

4.2.2.4.1 Control Cabinets - Group II

4.2.2.4.2 Control Components (Instrumentation)

Components mounted in or on the control cabinet were normally considered to be complex components and were purchased with seismic test data or tested as necessary. Prototype testing was acceptable (Group III).

4.2.2.5 Miscellaneous Equipment

4.2.2.5.1 Rotating Equipment - Group III

4.2.2.5.2 Manual Valves (Root, Check, etc.)

Based on their small size, manual valves were normally treated as part of the piping system, and therefore, had to meet the static piping loads. Valves were designed to withstand piping load (Group I).

4.2.2.5.3 Control Valves

The valve bodies were classified by calculations as simple components (Group I). Complex

actuators were dynamically tested (Group III). Valves were designed to withstand piping load.

4.3 Qualification Criteria

4.3.1 Structurally Simple Equipment

The system will maintain structural integrity during and after the prescribed seismic disturbance as defined herein.

4.3.1.1 1/2 SSE Condition

The primary steady-state stresses, when combined with the stresses resulting from seismic accelerations of 0.5g horizontal and 0.32g vertical simultaneously applied to the centers of gravity of the major pieces of equipment on the skid, were limited to those specified in Paragraph 4.3.3 such that there will be no loss of process fluid and no loss of function. No loss of function is defined as having the system components undamaged as a result of the prescribed seismic event, so that the system can be restarted remotely in the unlikely event of an automatic shutdown. Following the seismic event, the system does perform to required design standards.

4.3.1.2 SSE Condition

In addition to the above, the primary steady-state stresses when combined with the stresses resulting from seismic accelerations of 0.8g horizontal and 0.6g vertical simultaneously applied to the centers of gravity of the major pieces of equipment on the skid, shall be limited to those specified in Paragraph 4.3.3, such that there will be no loss of process fluid and no loss of function as defined in Paragraph 4.3.1.1.

4.3.2 Additional Design Loads

The following load conditions are considered to act in conjunction with the seismic loads, and are combined with them in accordance with Paragraph 4.3.3.

4.3.2.1 Normal Plant Operating Condition

This includes normal pressure and dead-weight loads, and any loads imposed by mechanical equipment or external attachments.

4.3.2.2 Upset Condition (Post LOCA Emergency Conditions)

The loads which are associated with abnormal pressure and temperature.

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4.3.3 Allowable Stresses and Load Combinations

4.3.3.1 Vessels

For ASME coded Class 2 and 3 vessels designed to Division I of Section III of the ASME Code:

Design Condition	Membrane Stress Limit (Pm)	Membrane & Bending Stress Limit (Pm + Pb)
1/2 SSE plus normal loads	-	S
SSE plus upset loads	S	Sy

where:

1. S = allowable stress values at the design temperature from Tables I-7, 8, ASME Section III, Appendix I. When design temperature exceeds 800°F, S will be based on Code Case 1481.
2. S_y = Yield stress at design temperature.

4.3.3.2 Structural Components

The AISC Code allowable stress was applied to all structural members for the 1/2 SSE condition. For the SSE condition a 1.5 factor was applied to the AISC allowable stresses.

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4.3.3.3 <u>Piping</u>

The allowable stresses and load combinations for piping designed to Section III, Class 2 or 3 of the ASME Code were in accordance with Section NC-3600. Thermal expansion stress due to startup was not considered sustained load and was treated in accordance with Sub-paragraph NC-3611.1. Earthquake loads were grouped with other sustained loads and the allowable stresses were those called out in Sub-paragraph NC-3611.1(b), (4), (c).

4.3.4 <u>Structurally Complex Equipment</u>

The required response spectrum curves were used to determine the maximum seismic stresses by mathematical modeling. These stresses were combined with primary steady state stresses and were within the allowable stress limits of Paragraph 4.3.3 (Group II). The response spectrum curves may also be used for dynamic tests, in which case the equipment is qualified at or above the acceleration values of the curves (Group III). Design conditions for these groups require no loss of process fluid or function as defined in Paragraph 4.3.1.1.

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5.0 IEEE Reliability Qualification Report

5.1 Introduction

The IEEE Reliability Qualification Report (Reference 3) covers the method and data necessary to assure that equipment meets the intent of IEEE 279-1971 (applicable to WNP-2) for a safety related system. This is accomplished through use of IEEE guides: IEEE 323-1971, IEEE 334-1971, IEEE 344-1971, and IEEE 382-1972. The following topics are discussed:

a) Environmental and process design parameters

b) A reference to applicable guides and standards.

c) A description of the qualification procedure for system conformance to design requirements.

d) Documentation and test reports required for substantiation of system conformance to design standards (Reference 3).

5.2 Environmental Design Conditions

5.2.1 Skid and Skid Mounted Equipment

5.2.1.1 General

All components of the recombiner skid were designed for continuous operation when subjected to the accident environmental conditions described in Paragraphs 5.2.1.3, 5.2.1.4 and 5.2.1.5, following 40 years of periodic cyclic testing under normal environmental conditions.

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5.2.1.2 "Normal" Environmental Conditions

Ambient Temp. Range, °F	70 to 104°
Pressure, in. of water gauge	-1.0 to -0.1
Relative Humidity range, %	20 to 90

5.2.1.3 "Accident" Environmental Conditions

First Six Hours

Ambient Temp., °F	212 (max)
Relative Humidity, %	100 (max)
Pressure, in. of water gauge	-0.25 to +7.0

Next Six Hours

Ambient Temp., °F	150 (max)
Relative Humidity, %	100 (max)
Pressure, in. of water gauge	-0.25 to +7.0

12 Hrs. to 100 Days

Ambient Temp., °F	150 (max)
Relative Humidity, %	90 (max)
Pressure, in. of water gauge	-0.25 to 0.0

5.2.1.4 Radiation Environmental Conditions

Under normal operating conditions, the recombiner skid shall be subjected to gamma radiation at a dose rate of approximately 15 mr/hr. max with a total

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integrated dose, over 40 years, of 5260 rads maximum. Following a LOCA, the total integrated dose, over six months, for the skid and skid mounted equipment, is a maximum 3.1×10^7 rads.

5.2.1.5 Seismic Event

The skidded recombiner system is designed to maintain functional integrity (See 4.3.1.1) after and structural integrity during and after the prescribed 1/2 SSE and SSE conditions. Details of methods utilized and seismic loading for the skidded equipment are given in Section 4, Seismic Qualification and in Section 6, Mechanical Design Report.

5.2.2 Control Panel

5.2.2.1 General

The local control panel, not required for monitoring during post LOCA, is a free-standing, seismically rigid, completely enclosed structure, remote from the skid and supplied with flush mounted instrumentation necessary for system operation. All equipment and instrumentation have been located for front access with no access required on the sides or rear.

Signal and power wiring penetrate through the control panel on top. The control panel and mounted instrumentation have been designed for continuous operation when subjected to the accident environmental conditions described in Paragraphs 5.2.2.3, 5.2.2.4 and 5.2.2.5 following 40 years of periodic cyclic testing under normal environmental conditions.

5.2.2.2 Normal Environmental Conditions

Ambient Temp., °F	70 to 104
Pressure, in. of water gauge	-1.0 to 0.1
Relative Humidity Range, %	20 to 90

5.2.2.3 Accident Environmental Conditions

Same as Normal Environmental Conditions.

5.2.2.4 Radiation Environmental Conditions

A dose rate of 2.5 mr/hr maximum for both normal and accident conditions with a total integrated dose, over 40 years, of 5 x 10^3 rads maximum.

5.2.2.5 Seismic Event

The control panel is designed to maintain functional integrity (See 4.3.1.1) after and structural integrity during and after the prescribed

1/2 SSE and SSE conditions. Details of methods utilized and seismic loading for the control panel and mounted equipment are given in Section 4, Seismic Qualifications and in Section 6, Mechanical Design Report.

5.2.3 Process Requirements

Design Temperature, T	340°F minimum
T max. (operating)	215°F
Design Pressure, P	45 psig minimum
P max. (operating)	18 psig
Flow	155 SCFM minimum
Feed Concentration	Maximum of 4% H_2 by volume on a dry basis in a non-inerted containment atmosphere is processed. Actual feed gas humidity will vary from 0 to 100%.

5.3 Applicable Standards and Guides

5.3.1 IEEE 279-1971 - "Criteria for Protection Systems for Nuclear Power Generating Stations."

5.3.2 IEEE 323-1971 - "General Guide for Qualifying Class 1 Electronic Equipment for Nuclear Power Generating Stations."

5.3.3 IEEE 334-1971 - "Trial Use Guide for Type Tests of Continuous Duty Class 1 Motors Installed Inside the Containment of Nuclear Power Generating Stations."

5.3.4 IEEE 344-1971 - "Trial Use Guide for Seismic Qualification of Class 1 Electric Equipment for Nuclear Power Generating Stations."

5.3.5 IEEE 382-1972 - "IEEE Trial Use Guide for Type Test of Class 1 Electric Valve Operators for Nuclear Power Generating Stations."

5.3.6 IPCEA S-19-81-1974 - "Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy."

5.3.7 IPCEA S-68-516-1973 - "Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy."

5.4 Qualification Procedure

5.4.1 Requirements

The recombiner system must fulfill two requirements in order to be acceptable for safety related operation:

a) Redundancy must be provided to assure operation under a postulated single component failure, and
b) Equipment must be qualified for expected service conditions.

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5.4.2 Redundancy

Redundancy is met by providing two completely isolated, separate systems. Isolation is achieved through physical separation, with one system used as a back-up for the other. Each system, which is composed of a skid and control panel, is designed to independently perform its intended function under the required design conditions.

5.4.3 Qualification

The recombiner system is designed to operate and perform its intended function when subjected to the conditions presented in Paragraph 5.2. The philosophy for qualification which has been followed was to analyze frame members, vessels and piping, and to purchase other components, with assurance that sufficient data was available from the supplier to verify that a component would accomplish its intended service. This meant that equipment purchased had to be tested or analyzed at or above the given service conditions which includes temperature, pressure, humidity, radiation, and seismic criteria. In the event of insufficient support data, additional testing was accomplished. Individual components were then installed in the same configuration as they had been previously qualified, which allowed

correlation of test results to the production units. The seismic analysis done for the skid frame, piping, and control cabinet is covered in detail within the Mechanical Design Report (Section 6). With these frame members structurally "rigid", no amplification of base-load forces had to be considered for component testing and this allowed direct review of component test data to verify enveloping of response spectrum curves. The final step in the qualification procedure was the full-scale performance test (Section 2). This demonstrated the system's ability to perform as a unit and completely integrated all individual components together.

6. Mechanical Design Report

6.1 Introduction

The Mechanical Design Report (Reference 4) covers the design of the following items of equipment being supplied by APCI.

1) Skid frame and structural supports.
2) Vessels - scrubber, preheater/recombiner, cooler condenser, moisture separator, and blower/motor container.
3) All interconnecting piping.
4) Control cabinet.

The purpose of the report is to demonstrate that the equipment meets specified design requirements. The following topics are discussed:

1) A description of the major pieces of equipment.
2) An outline of the overall design approach, including seismic analysis, followed by a description of the design methods applicable to each equipment group.
3) A discussion of the seismic qualification technique and subsequent classification of the equipment for seismic analysis.
4) All analytical and design calculations including applicable computer runs (Reference 4).

6.2 Equipment Description

6.2.1 Skid Support Frame - The frame is used to support all vessels and interconnecting piping as well as some of the process instrumentation. It measures approximately 9' wide by 11' long, and is fabricated from structural steel. Vertical members are used in several locations for structural support of vessels and piping.

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6.2.2 Vessels

6.2.2.1 Scrubber - This vessel, as its name implies, is used to scrub the incoming gas and remove any particulate matter from this stream. It is constructed of stainless steel with an overall height of 7' - 10-5/8" (including legs) and a diameter of 1' - 2-5/8". The internals consist of a packed bed of pall rings, a bed support, and a mesh demister at the top of the vessel.

6.2.2.2 Blower/Motor Container - In order to meet the ASME Section III pressure boundary conditions, the motor and blower were placed within a coded vessel or container. The container is a cylindrical, horizontal vessel fabricated from carbon steel and supported on two steel saddles. Access to the components inside the vessel is attained through a pair of body flanges located roughly in the middle of the vessel. The blower and motor inside the vessel are mounted on a structural frame which is welded to one-half of the container. The overall approximate dimensions of the vessel are height 3' (with supports), length 4'8", diameter of shell 28".

6.2.2.3 Recombiner/Preheater - The recombiner/preheater has a dual function. It is used to raise the temperature of the process gas from approximately 240°F to 525°F before it enters the recombiner section where the hydrogen and oxygen in the feed are combined to form water. The preheater section of the vessel is composed of U-shaped heater elements suspended in the vessel from the top. These elements are nichrome resistance wire sheathed in magnesium oxide and encased in stainless steel tubing.

To accomplish recombination, the gas is fed through a packed bed of pelletized catalyst, supported within the recombiner vessel by a wire meshed bottom support. The catalyst and internal supports are accessible from the top of the vessel by removing the flanged preheater section.

The recombiner/preheater vessel is constructed of type 316 stainless steel. The dimensions of the vessel are approximately 1' - 3-1/2" O.D. by 6' - 3-7/8" high including the leg supports.

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6.2.2.4 Aftercooler - The aftercooler or cooler condenser is a shell and tube heat exchanger used to cool the gas exiting the recombiner from roughly 800°F/1100°F to 100°F while simultaneously condensing the water vapor from the waste gas. The tube bundle is a U-tube type constructed of type 316 stainless steel and welded into the shell. The shell side is also constructed of type 316 stainless steel.

6.2.2.5 Moisture Separator - The moisture separator removes the liquid from the gas stream by passing it through an entrainment mesh. The water exits from a nozzle in the bottom of vessel, while the gas flows out through a top nozzle.

The approximate dimensions of the vessel are 12-5/8" O.D. by approximately 5' long including the support legs. Material of construction is type 304 stainless steel.

6.2.3 Piping - All skid mounted process piping and valves for main flow are 2", 300 series stainless steel. Other piping/valves include:

1) A 3/4" phase separator drain line connecting to a 1-1/2" scrubber drain line,

2) A 1" line for cooling water to the scrubber and 2" lines for cooling water to the aftercooler,

3) A 2" line from the 1" x 2" aftercooler water relief valve into the 3" line from the 1-1/2" x 3" process relief valve, and

4) The hydrogen, nitrogen, and air test lines which are 1/2" and 1".

6.2.4 Control Cabinet - The control cabinet or panel is a structural steel frame cabinet with an overall size of 6' wide x 7' high x 2-1/2' deep. It is covered on the front face with 3/16" thick steel and on all other surfaces with 1/8" thick steel. The surface panels are welded together full length on the outside and stitch welded to the inside frame. Mounting of instrumentation was done according to supplier recommendations for service under seismic conditions.

6.3 Design Approach

6.3.1 General - The recombiner system has been designed in accordance with the requirements of the 1971 ASME Code Section III including Addenda through Summer of 1973. Design loadings consist of dead weight, pressure, and thermal loads, as well as external loads imposed by attachments or machinery. Where significant, the effects of localized stresses have been investigated. Both normal operating and upset conditions were evaluated, with the most severe case governing the selection of the design loads.

6.3.2 Seismic Design - Except for some piping lines, all components of the system have been designed to be rigid, i.e., first mode natural frequency greater than 30 cps. Therefore, a static analysis was used to seismically qualify the equipment for the 1/2 SSE and SSE. The g values used were those specified for the static analysis or rigid equipment. These are as follows:

1/2 SSE	.5g horizontal	.32 vertical
SSE	.8g horizontal	.6 vertical

The dynamic analysis was performed to meet the seismic criteria using specified response spectrum data. Seismic stresses were determined as the resultant of the worst case horizontal (of the two global skid directions) and the vertical. These stresses were then summed with the design loads of Paragraph 6.3.1. The total stress has been limited to the allowable values specified in the following paragraphs, 6.3.3 through 6.3.5.

6.3.3 Structural Skid - The combination of design and seismic stresses has been held to the allowable value 'S' from the AISC code for the 1/2 SSE condition. A 1.5 factor was applied to the AISC allowable stresses for the SSE condition.

6.3.4 Vessels - Design stresses were calculated from very conservative design pressures and temperatures. The combination of seismic and design stresses have been held to the following:

Criteria for ASME coded Class 2 and 3 vessels designed to Division I of Section III of the ASME Code,

Design Condition	Primary Membrane Stress Limit (Pm)	Primary Membrane & Bending Stress Limit (Pm + Pb)
1) 1/2 SSE plus Normal Operating Loads	-	S
2) SSE plus Upset Loads	S	S_y

Where:

a. S - Allowable stress values at the design temperature from Tables I-7, 8, ASME Section III, Apendix I,

b. S_y - Yield stress at design temperature, and

c. Membrane + bending stresses are intended to be maintained to ensure that no gross deformation will occur.

6.3.5 Piping - The allowable stresses and load combinations for piping designed to Section III Class 2 or 3 of the ASME Code was in accordance with Section NC-3600. Thermal expansion stress due to start-up was not considered a sustained load and was treated in accordance with Subparagraph NC-3611.1. Earthquake loads were grouped with other sustained loads and the allowable stresses were

those called out in Subparagraph NC-3611.1 (b) (4) (c).

These allowables are as follows:

Design Condition	Total Longitudinal Stress
1) Design Loads	S
2) 1/2 SSE + Normal Operating Loads	1.2S
3) SSE + Upset Loads	1.8S

Where:

a. S - Allowable stress values at the design temperature from Tables 1-7, 8, ASME Section III, Appendix I, and

b. Membrane + bending stresses are intended to be maintained to ensure that no gross deformation will occur.

6.3.5 Control Cabinet - The design of this unit was handled in the same manner as the structural skid design.

6.4 Qualification Techniques

6.4.1 Definition of Equipment Classifications

6.4.1.1 Group I - Structurally Simple Equipment

Structurally simple equipment is that equipment which can be adequately represented by a one degree of freedom system or equipment whose first mode natural frequency is greater than 30 cps. The equipment is treated by simple beam analysis (fix end, simply supported, etc) for the purpose of determining frequency.

The seismic load for this equipment consists of a static load corresponding to the equipment's weight times the accelerations specified in Paragraph 6.3.2 provided its first mode frequency is greater than 30 cps. If it is not greater than 30 cps, then the appropriate value from the response curve was selected.

6.4.1.2 Group II - Structurally Complex Equipment (Mathematically Modeled)

Any equipment which had more than one degree of freedom and a first mode natural frequency less than 30 cps was idealized by a mathematical model consisting of lumped masses connected by massless springs.

The frequency and mode shapes were determined for vibrational loads applied in the vertical and two orthogonal horizontal directions (the global directions of the skid shall be used). Sloshing effects of any contained liquids were included, if significant. The spectral acceleration per mode was obtained from specified response spectrum curves. The accelerations selected took into account a ±10%

variation in the calculated frequency. The resulting values of inertia forces, shears, moments, stresses and deflections for each mode in each of the global directions were combined by the square root sum of the square method. Modes having frequencies which do not differ by more than 10% had the above mentioned responses combined by the sum of the absolute value method before combining with other modes by the square root of the sum of the squares method.

When considering stress or deflections at any point, the total seismic load consisted of the most severe seismic load produced by one of the horizontal global directions combined with the vertical seismic load by the sum of the absolute value method.

6.4.1.3 Group III - Structurally Complex Equipment (Dynamic Test)

Equipment that cannot be modeled because of its complexity was dynamically tested.

6.4.2 Equipment Classification

6.4.2.1 Structural Skids - The base frame and all columns extending up from the base were designed to have first mode natural frequencies

greater than 30 cps. This reduced the problem to a Group I analysis as defined in Paragraph 6.4.1.1.

6.4.2.2 Vessels - Vessels are of a size and stiffness which allowed them to be treated as single degree of freedom systems. Vessel supports were treated in the same manner as structural members (first mode natural frequency greater than 30 cps). Based on this, vessels were analyzed in accordance with Paragraph 6.4.1.1.

6.4.2.3 Piping - The piping system was designed using one of the following analytical techniques:

6.4.2.3.1 Generally, piping runs were designed to have a first mode natural frequency above 30 cps. This was accomplished by supporting the piping lines at intervals such that each section of pipe between supports met the 30 cps criteria.

This technique was adequate for most ambient lines 4" and smaller, and did not require a frequency check to be made on the overall piping line in question.

Once the supports had been located, the static seismic loads were calculated and applied to the line in accordance with Paragraph 6.4.1.1.

6.4.2.3.2 Where operating temperature or piping flexibility prohibited supporting the piping line such that the 30 cps criterion could be met, a dynamic modal analysis, in accordance with Paragraph 6.4.1.2, was employed to evaluate the line. This normally required the use of a computer program.

6.4.2.4 Control Cabinet - The control cabinet was designed as a free standing structural frame composed of angles and channels covered with a sheet metal shell. Using a dynamic modal analysis, the control cabinet members were sized such that the entire structure had a first mode natural frequency of 30 cps. This analysis was done in accordance with Paragraph 6.4.1.2.

6.4.2.5 Motor, Blower and Heater Elements - Due to the complexity of the equipment, APCI vibration tested the motor and heater elements.

Analysis was in accordance with Paragraph 6.4.1.3.

6.5 Summary of Results

6.5.1 Structural Skid Frame - The structural frame is composed of wide flanged structural beams reinforced between adjacent flanges by 1/4" thick floor plate. The following list of allowable and actual loads on the individual members is offered as a summary and justification of static analysis. The design approach of the skid base frame was to select member sizes and arrangements such that a conservative and rigid structure would result. As can be seen from the list below, the members were selected such that an additional safety factor over and above what the Code requires was applied, and stiffness obtained by adding floor plates (this added strength was not utilized in the calculations) is justification for the rigidity of the base frame.

Calculation Member No.	Size	Actual Max. Load	Allowable Load	Ratio
1 & 2	W6 x 20	1.47 kip-ft	21.6 kip-ft	14.7
3 & 4	STIFFENERS ONLY			
5 & 6	W6 x 8.5	3 kip-ft	10 kip-ft	3.34
7 & 8	W6 x 8.5	4.5 kip-ft	10 kip-ft	2.22
9 & 10	W6 x 8.5	6.79 kip-ft	11.25 kip-ft	1.658
11	W6 x 15.5	18.87 kip-ft	27.3 kip-ft	1.447
12 & 13	W8 x 31	50 kip-ft	75.3 kip-ft	1.5
14 & 15	W8 x 13	4.94 kip-ft	30 kip-ft	6.0

6.5.2 Vessels - All vessels are classified as single degree of freedom systems for analysis purposes. This assumption or modeling technique is an acceptable one for the equipment being considered. In general, the vessel shells are very much stiffer than their supporting members. This results in rigid body motion of the vessel shells about their support or simply a cantilever beam with a lumped mass on the end. This is a conservative model from both a frequency and stress standpoint, because if the piping was considered as restraining the vessel then the frequency would increase and the stress decrease significantly.

Based on the above, the following first mode natural frequencies were calculated and a static analysis performed.

Item Number	Description	Lowest Frequency (CPS)
07.01	Scrubber	36
01.14	Blower & Motor Container	44
02.10/02.13	Recombiner/Heater	32
02.12	Cooler Condenser	37
02.14	Phase Separator	34

6.5.3 Piping - A combination of static and dynamic analytical techniques was used to design the piping system. Table 6-1 summarizes the loading conditions and the resulting calculated first mode natural frequencies for the piping system.

TABLE 6-1

PIPING LOADING CONDITIONS

Group # / Line #'s		Temperature-°F Oper.	Temperature-°F Upset	Pressure-PSIA	Seismic 1st Mode cps	Seismic Type Analysis Static	Seismic Type Analysis Dynamic
1.	2-CFG-100-SS.5NSP	215	250	32.7	31.07	X	
	1-A-109-SS.5NSP	70	70	14.7			
	1/2-H/N-110-SS.5NSP	70	70	14.7			
2.	2-CFG-101-SS.5N-SP	150	250	32.5	53.9	X	
	2-CFG-106-SS.5N-SP	150	180	35.8			
	2-CFG-107-SS.5N-SP	150	180	32.8			
3.	2-CFG-103-SS.5NSP	245	300	44.1	43.01		X
4.	2-CFG-104-SS.5NSP2	1140	1200	44.9	18.69		X
*5.	2-CFG-105-SS.5N-SP	150	180	38.6	28.9	X	
	2-CW-112-CS3N-SP2	96	96	220.			
	1-1/2 2/3-CFG-115-SS.5N-SP						
	SS.5-SP3	70	212	0.			
	1/2-CW-117-CS3N-SP2	70	212	0.			
6.	1-SW-108-CS3N-SP	85	85	165.	35.3	X	
7.	1-1/2-PC-111-SS.5N-SP	158	175	30.8	36.3		X
	3/4-PC-114-SS.5N-SP	158	175	30.8			
	1-PC-116-SS.5N-SP	158	175	30.8			
8.	2-CW-113-CS3N-SP2	85	85	230.	57.5	X	

*Group #5 was analyzed using static seismic approach which had higher g loadings than the response spectrum curve and is, therefore, conservative.

6.5.4 Control Cabinet - Due to the complexity of the cabinet and the mounting of the various components within the cabinet, it was necessary to do a dynamic frequency analysis on the structure to confirm its modes of vibration.

The result of the computer analysis shows that the structural frame and all panel areas where instrumentation is mounted have a first mode natural frequency above 30 cps. This conclusion was reached using a mathematical model in the analysis composed of a beam member structure tied together by finite element plate members.

7. Conclusions

The focal point of a product type test is the demonstration that the product will perform when subjected to the expected environmental conditions. This method of testing is carried out routinely on equipment manufactured for commercial, military, and nuclear power plant services. In cases where a significant number of identical items are produced, the test work is done on a statistical basis employing random sampling techniques.

In the case of the data contained in this report, the full-scale test was performed on both WNP-2 post LOCA systems, resulting in a 100% test rate as opposed to a type test.

In an attempt to answer the question as to the acceptability of the WNP-2 system for its intended use, we have considered catalyst recombiner testing, seismic requirements, IEEE qualification, and the mechanical design qualification. As a result of this work the following can be concluded:

7.1 The WNP-2 full-scale hydrogen-oxygen recombination tests prove the functional ability of the system to reduce containment hydrogen levels to the acceptable limits required by regulations.

It is important to note that the system was operated with steam injection to provide the saturated inlet flow stream expected when the system is subjected to the design environment. This has not been done, to our knowledge, in the type testing of any other type of recombiner. The importance of this point is that injection of liquid water downstream of compression equipment does not prove that a system will operate properly when subjected to the expected environment. For example, the possibility exists of moisture knockout in compression equipment, interconnecting piping, and aftercoolers which must be taken into account since the ambient temperature surrounding the equipment is much cooler than the saturated incoming gas stream.

7.2 The myriad of data reported on catalyst testing clearly supports the engineering conclusion that highly efficient recombination will continue while the catalyst is subjected to the expected environment of various chemicals. The results of the extensive testing with iodine and methyl iodide present credible testimony in support of this statement.

7.3 The WNP-2 recombiner system meets the criteria of maintaining functional integrity after and structural integrity during and after the prescribed 1/2 SSE and SSE conditions. Clearly the

system also meets the requirements of IEEE 279-1971 for safety related equipment.

Upon consideration of all the test and design data included in this report, it is concluded that the technical evidence presented confirms that the WNP-2 recombiner system will perform as specified when subjected to the postulated post LOCA environment.

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8.0 References

1. "Joint Utility Catalytic Recombiner Development Program, Post LOCA Conditions Investigation, July, 1971"; Southern Nuclear Engineering, Inc., Report No. SNE-100.
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