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Chemical Technology Division

PLAN FOR RADIONUCLIDE TRACER STUDIES OF THE RESIDENCE TIME DISTRIBUTION IN THE WILSONVILLE DISSOLVER AND PREHEATER

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EXECUTIVE SUMMARY

Stimulus-response measurements using radiotracers have been used to measure residence time distribution (RTD) and hydrodynamic parameters for the preheaters and dissolvers at the Ft. Lewis Solvent Refined Coal (SRC) and the Exxon Donor Solvent (EDS) coal conversion pilot plants. These previous RTD studies are reviewed.

We present here a plan for a series of radioactive tracer studies proposed for the Advanced Coal Liquefaction Facility at Wilsonville, Alabama. The objective is to measure the slurry- and gas-phase residence time distributions for the preheater and dissolvers in the SRC-I mode. Xenon-133 and gold-198 (on carbonized resin or as an aqueous colloidal suspension) will be used as tracers for the gas and slurry, respectively. Four experimental phases are recommended for the RTD tracer studies: (1) preheater; (2) dissolver with 100% takeoff; (3) dissolver with 100% takeoff and solids withdrawal; and (4) dissolver with 50% takeoff. Eighteen gas-tracer and 22 liquid-tracer injections are projected to accomplish the four experimental phases; details are presented in Table S.1. Two to four tracer injections are projected for preliminary tests to ensure the capability of safe injection of the radiotracers and the collection of statistically significant data. The projected time schedule for all aspects of the study is shown in Table S.2.

The total costs of the proposed plan are $233,500. An itemized summary of expenses is presented in Table S.3.

Recommendations are also made for other radiotracer investigations that should be undertaken if these proposed studies produce quality data.

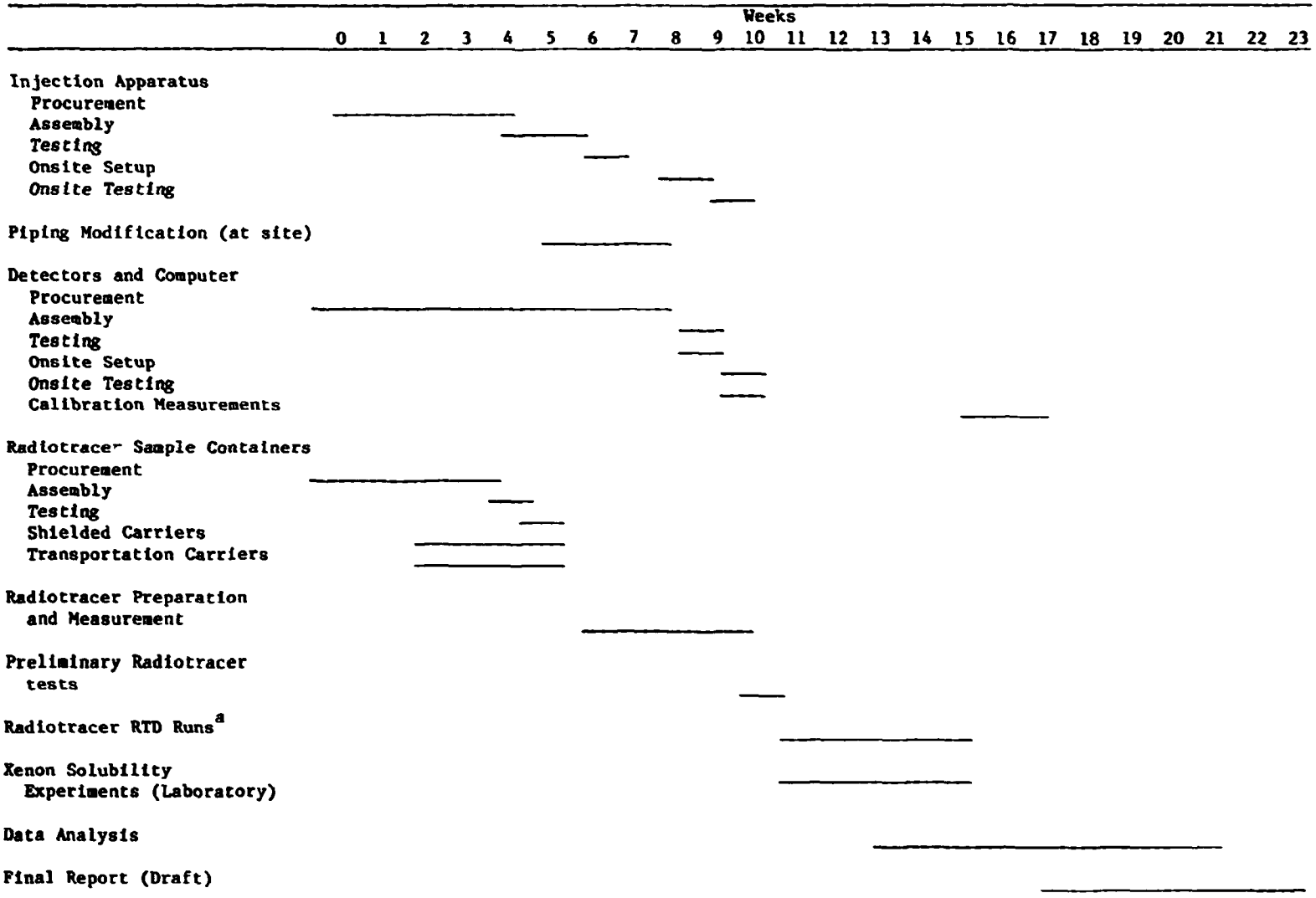
Table S.1. Experimental design for RTD radiotracer studies

Run phase	Vessel	Dissolver operating condition	Slurry rate	Gas velocity	Injections ^{133}Xe	Injections ^{198}Au	Run days
1[a]	Preheater (B102)	-	Optimum design	High	2	2	3
	Preheater (B102)	-	Optimum design	Intermediate	2	2	
	Preheater (B102)	-	Optimum design	Low	2	2	
2	Dissolver (R101)	100% Takeoff	Optimum design	High	2	2	3
	Dissolver (R101)	100% Takeoff	Optimum design	Intermediate	?	2	
	Dissolver (R101)	100% Takeoff	Optimum design	Low	2	2	
3	Dissolver (R101)	100% Takeoff (solids withdrawal)	Optimum design	High or Intermediate	2	2	2
	Dissolver (R101)	100% Takeoff (solids withdrawal)	Optimum design	Low	2	2	
4[b]	Dissolver (R101)	50% Takeoff	Optimum design	High		2	2
	Dissolver (R101)	50% Takeoff	Optimum design	Intermediate	2	2	
	Dissolver (R101)	50% Takeoff	Optimum design	Low	—	2	—
	Total				18	22	10

[a]When preheater tests are made, the tracers will be monitored at the dissolver sites also, providing additional information.

[b]When takeoff is at the 50% point, the large void volume may reduce the information obtained from the gas tracer injections.

Table S.2. Projected time schedule for RTD radiotracer studies



[a]If experimental problems should occur after this sequence has started, this could possibly require termination of the experiment and starting again with radiotracer preparation and procurement. A time shift would then result for all subsequent tasks.

Table S.3. Summary of total costs for RTD radiotracer studies

Expense items	Total costs (1983 dollars)
Manpower	$99,800
Ancillary onsite costs	7,900
Tracer injection system apparatus	5,500
Onsite installation	300
Detector mounts and installation	2,050
Wilsonville piping modifications (cost to Catalytic, Inc.)	3,000
Tracer containers, lead containers, and shipping containers	4,600
Tracer preparation	7,000
Detector system (hardware, assembly, programming)	63,200
Detector system installation	500
Van rental	3,000
Calibration measurements	200
Xenon solubility study costs	1,000
Radiation monitoring	1,000
Computer charges	1,000
Final report (editing and materials)	3,000
Contingency (15%)	30,450
Total	$233,500

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ABSTRACT

Stimulus-response measurements using radiotracers to measure residence time distribution (RTD) and hydrodynamic parameters for the preheaters and dissolvers at the Ft. Lewis Solvent Refined Coal (SRC) and the Exxon Donor Solvent (EDS) coal conversion pilot plants are reviewed.

A plan is also presented for a series of radioactive tracer studies proposed for the Advanced Coal Liquefaction Facility at Wilsonville, Alabama, to measure the RTD for the preheater and dissolvers in the SRC-I mode. The tracer for the gas phase will be ^{133}Xe, and ^{198}Au (on carbonized resin or as an aqueous colloidal suspension) will be used as the slurry tracer. Four experimental phases are recommended for the RTD tracer studies: (1) preheater; (2) dissolver with 100% takeoff; (3) dissolver with 100% takeoff and solids withdrawal; and (4) dissolver with 50% takeoff. Eighteen gas-tracer and 22 liquid-tracer injections are projected to accomplish the four experimental phases. Two to four tracer injections are projected for preliminary tests to ensure the capability of safe injection of the radiotracers and the collection of statistically significant data. A complete projected cost and time schedule is provided, including procurement of necessary components, preparation of the radiotracers, assembly and testing of tracer injection apparatus and detection systems, onsite work and tracer injections, laboratory experimentation, data analysis, and report writing.

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1. INTRODUCTION

The Wilsonville Pilot Plant, operated by Catalytic, Inc. for Southern Company Services, Inc. and sponsored by both Electric Power

Research Institute (EPRI) and the Department of Energy (DOE), provides a unique opportunity to obtain much-needed information concerning the dynamics of the dissolver and the kinetics of the chemical reactions occurring therein. The DOE has expressed interest in maximizing the information obtained from the only currently operating major pilot plant for coal liquefaction study in the United States and has requested Oak Ridge National Laboratory (ORNL) to examine the possibility of residence time distribution (RTD) studies in the dissolver. As part of this evaluation, ORNL has prepared a comprehensive plan for a series of radionuclide RTD studies at Wilsonville. The RTD of the slurry in the dissolver will be measured by determining the exit age-distribution curve of tracers flowing through the equipment. The plan that forms the basis of this report includes identification of tracer materials to be used, equipment and instruments required to carry out the program, and the scope of the test program effects to be evaluated.

A coal liquefaction research and development program was initiated by The Southern Company and Edison Electric Institute in 1972, when a 5.4×10^3 kg/d (6 t/d) thermal coal liquefaction pilot plant was designed and constructed at Wilsonville, Alabama, by Catalytic, Inc. The facility is currently managed and operated by Southern Company Services, Inc., a unit of The Southern Company. In 1973, EPRI assumed the role originated by the Edison Electric Institute as representative of the electric utility industry. Since 1976, the DOE has been a cosponsor of the program.[1]

The original pilot plant consisted of a single-stage thermal process (SRC-I process) and has evolved in the last several years into an advanced two-stage coal liquefaction facility. A critical solvent deashing (CSD) unit (Kerr-McGee) was added in 1978, and a second-stage catalytic hydrogenation unit was installed in 1981. The facility is capable of operation either in the nonintegrated, two-stage liquefaction (NITSL) mode, in which the CSD unit and hydrotreater are combined sequentially without recycle of any stream from the hydrotreater to the SRC or CSD units, or in the integrated, two-stage liquefaction (ITSL) mode, in which a stream or streams from the hydrotreater are recycled.[1] Figure 1 shows a flow schematic of the system.[2]

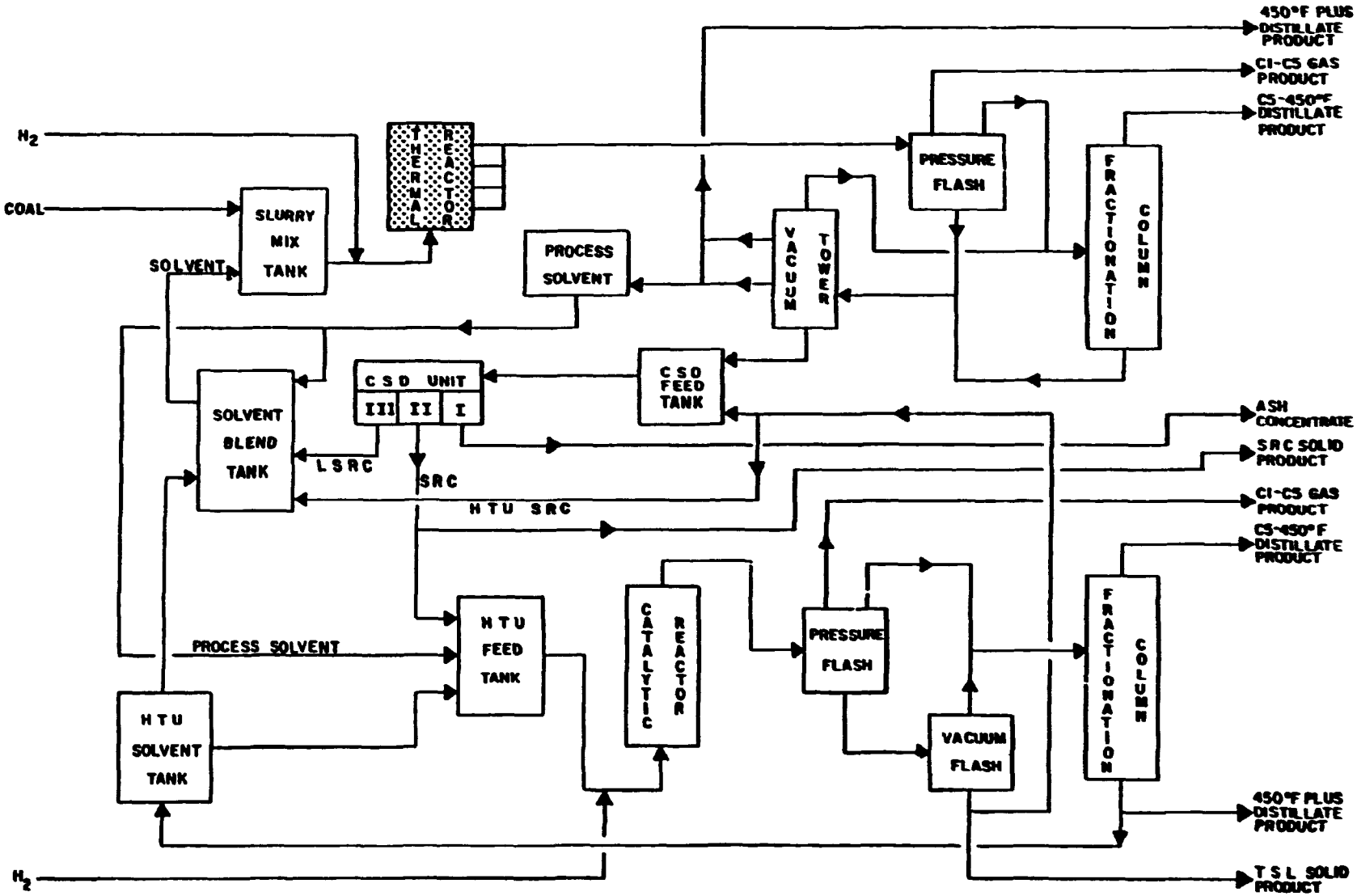


Fig. 1. Wilsonville Advanced Coal Liquefaction R&D Facility
Process Flow Schematic. Source: Catalytic, Inc., Wilsonville, Alabama.

The goal of every industrial chemical process is to produce the desired product economically from the starting materials through a succession of treatment steps. The design and characteristics of the chemical reactors in such processes are critically important for this economic optimization. Two important questions to be considered in the design of chemical reactors are: What changes can be expected to occur? How fast will the changes occur? The first question involves chemical thermodynamics; and the second concerns the various rate processes (e.g., kinetics, heat transfer). Implicit in these rate processes are the flow patterns and characteristics of the chemical reactors under varying operating conditions. If precise information is available about the velocity distribution of the fluids and other phases in the reactor, then the behavior of the vessel can be predicted more accurately. This information permits economic optimization of the process and is important in the scale-up of reactors from pilot plant to industrial scale. This is particularly important under conditions of nonideal flow in the reactor.[3]

In lieu of complete knowledge about the flow in chemical reactors, often knowledge about how long the individual molecules stay in the reactor (i.e., the distribution of residence times in the flowing process stream) is satisfactory for design and optimiz ion purposes. The stimulus-response experimental method is widely used for determining the residence time distribution (RTD) of materials in a reactor under conditions of nonideal flow.[3]

Elements of fluid following different paths through the chemical reactor may require different lengths of time to pass through the reactor. The distribution of these times for the stream of fluid leaving the reactor is called the exit age distribution, E, or the residence time distribution (RTD) of the fluid. If the area under the RTD curve is defined as:

$$\int_0^\infty E \, dt = 1 \, ,$$

then the fraction of the exit stream of age t to t + dt is

$$E\,dt\ ,$$

and the fraction of the exit stream younger than age t_1 is

$$\int_0^{t_1} E\,dt\ .$$

The fraction of the exit stream older than t_1 (Fig. 2) is

$$\int_{t_1}^{\infty} E\,dt = 1 - \int_0^{t_1} E\,dt$$

The RTD, or E, curve is the distribution needed to account for nonideal flow.[3] For any flow, E can be evaluated by using a stimulus-response method in which the stimulus is a tracer added to the fluid entering the reactor and the response is a time record of the tracer leaving the reactor. When no tracer is initially present in the system and an instantaneous pulse of tracer is imposed on the stream entering the reactor, the input is called a δ-function (or impulse) and the normalized response is called the C curve (Fig. 3).

At steady-state flow conditions for a closed vessel,

$$C = E\ ,$$

and the C curve gives the exit age distribution. A closed vessel is defined as one in which fluid enters and leaves only by plug flow (i.e., varying velocities, back diffusion, swirls, and eddies are not allowed at the entrance and exit). This assumption is often satisfied reasonably well in actual vessels.[3]

The term "mean time" of fluid in the reactor with steady state flow of fluid of constant density is defined as

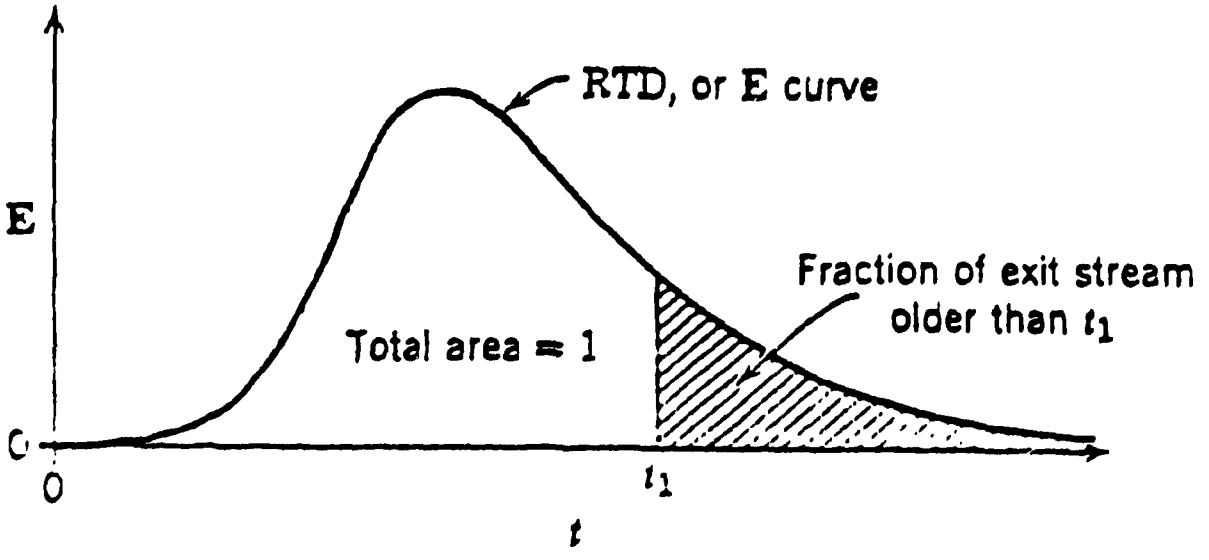


Fig. 2. The exit age distribution (E) curve for fluid flowing through a vessel; also called the residence time distribution (RTD). Source: Chemical Reaction Engineering, Second Ed., ed. by Octave Levenspiel. Permission granted by John Wiley and Sons, Inc., 1972.

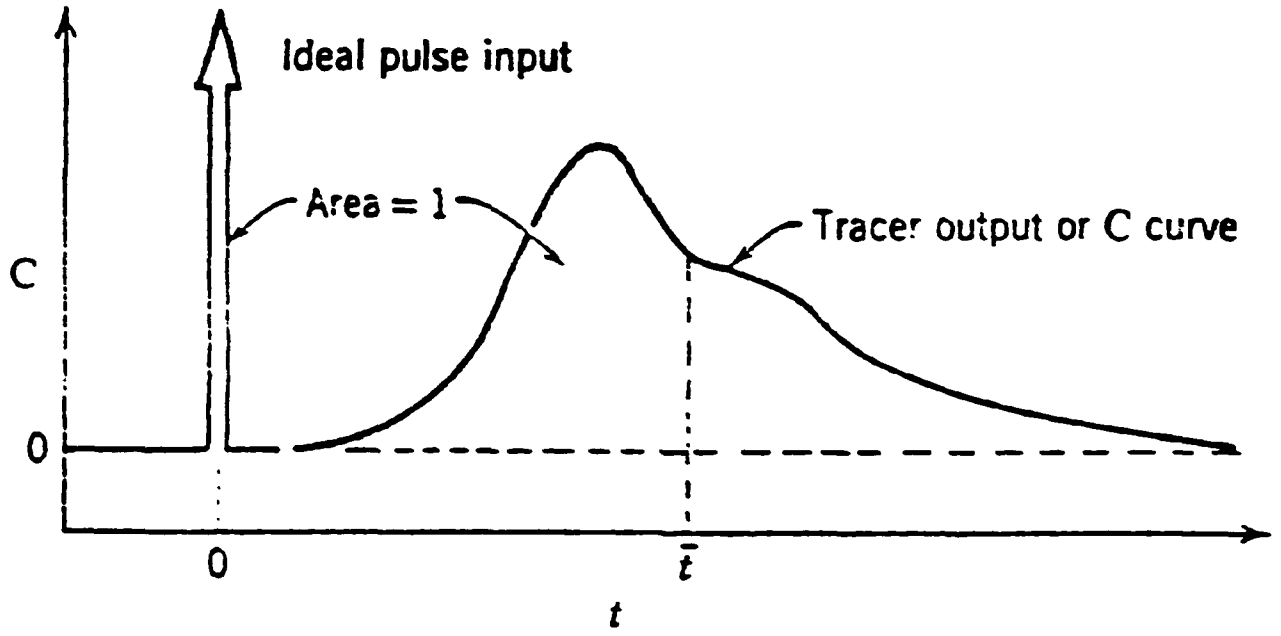


Fig. 3. Typical downstream signal (C curve), in response to an upstream δ-function input signal. Source: Chemical Reaction Engineering, Second Ed., ed by Octave Levenspiel. Permission granted by John Wiley and Sons, Inc., 1972.

$$\bar{t} = \frac{V}{v} = \text{holding time} = \text{mean residence time} = \text{space-time},$$

in which V is the total volume of fluid in the reactor at t = 0, and v is the mean flow rate of the fluid.

$$V = \int_0^\infty (v\, dt) \left(\int_t^\infty E\, dt \right),$$

or

$$\bar{t} = \frac{V}{v} = \int_0^\infty \left[\int_{t'}^\infty E\, dt \right] dt' .$$

Changing the order of integration,

$$\bar{t} = \int_0^\infty \left[\int_0^t dt' \right] E\, dt ,$$

$$= \int_0^\infty t\, E\, dt = \bar{t}_E .$$

Therefore,

$$\bar{t} = \bar{t}_E = \bar{t}_c$$

where $\bar{t}_c$ is the mean residence time for a closed vessel at steady-state flow conditions. These relationships show how stimulus-response experiments using pulse inputs can give the RTD and mean flow rate of fluid in the reactor (i.e., closed vessel). The age distribution information

can be used directly or in conjunction with flow models to predict the performance of flow reactors.[3]

The engineering flow scheme for the Wilsonville Pilot Plant is flexible enough to permit study of the effects of various run conditions.[4] Generally in the single-stage solvent refined coal (SRC) process (Fig. 4), pulverized coal is slurried with a process-derived solvent. The slurry, along with the hydrogen-enriched recycle gas stream, is preheated (in the slurry preheater, Fig. 4) and allowed to react in the thermal reactor (dissolver, Fig. 4) nominally for 30–60 min at 416 to 449 C (780 to 840°F) and 1.38 x 10^7Pa (2000 psig). Effluent from the dissolver is flashed, and the non-condensible gases are separated and scrubbed to remove carbon dioxide and hydrogen sulfide. The scrubbed gas is recycled and mixed with hydrogen to maintain the hydrogen concentration at 85 mol % in the recycle gas stream.[1] The flashed dissolver effluent underflow, containing ash and undissolved coal solids, is then CSD-processed to remove ash. In this treatment, the SRC slurry is distilled to separate the solvent and then extracted with a deashing solvent using conditions near the critical temperature and pressure of that solvent. The SRC, light SRC, deashing solvent, and heavy ash concentrate are separated and collected, and the deashing solvent is recycled. After deashing, the SRC product is solidified or upgraded in the catalytic hydrotreater.[1]

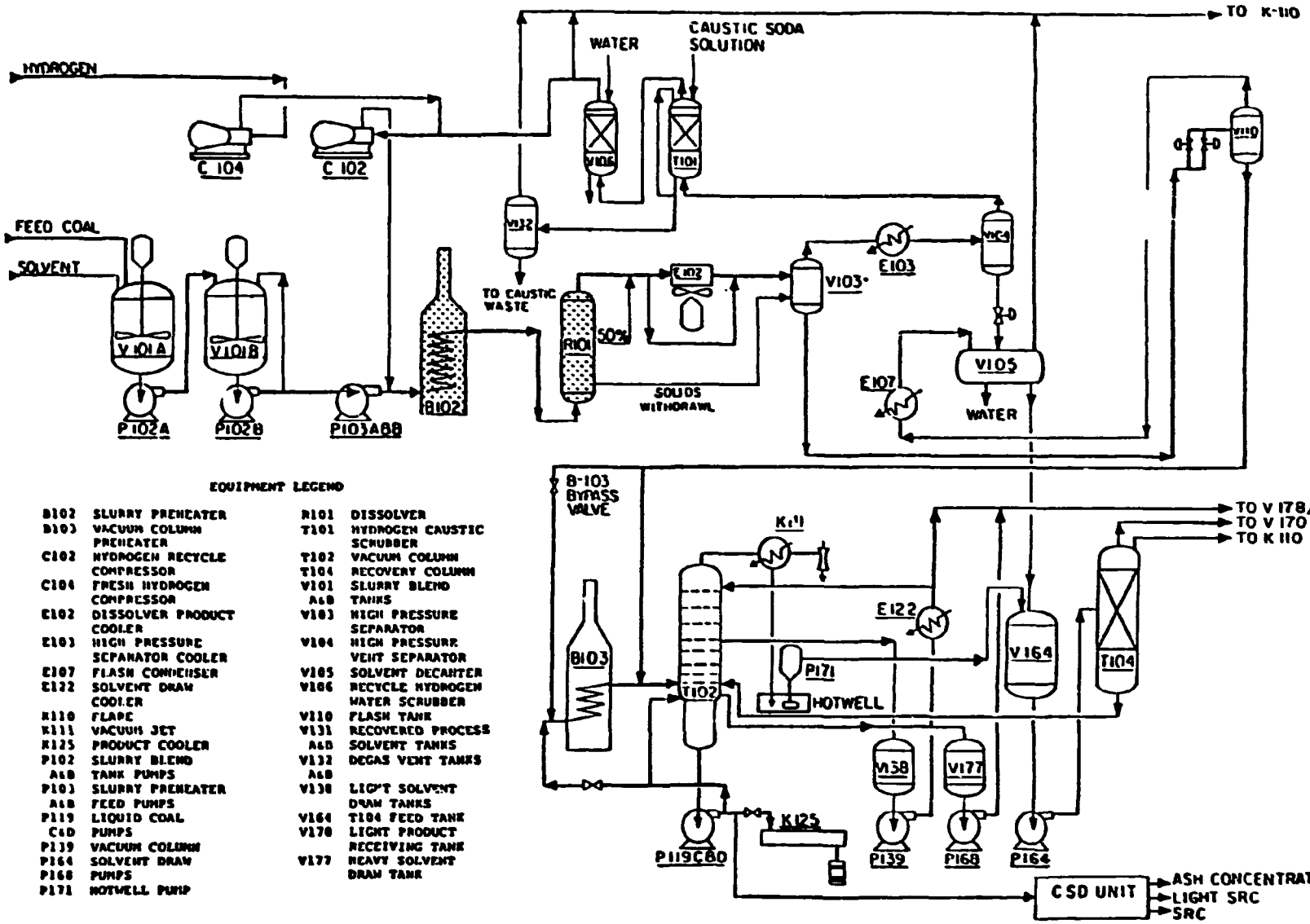
2. BACKGROUND

Residence time distribution studies using radiotracers have been conducted for preheaters and reactors at the Ft. Lewis SRC Pilot Plant[5-9] and the EDS Pilot Plant.[10-14]

2.1 FT. LEWIS SRC PILOT PLANT STUDIES

2.1.1 Experimentation

To verify design assumptions and flow calculations, RTD studies using radiotracers were conducted on the preheater B and dissolver at several operating conditions.[5-7] From preliminary tests conducted with



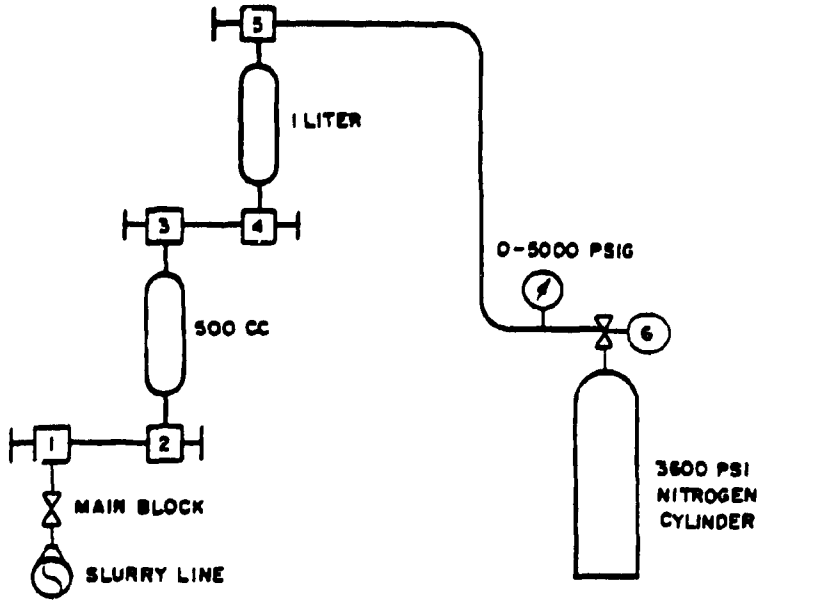
EQUIPMENT LEGEND

B102	SLURRY PREHEATER	R101	DISSOLVER
B103	VACUUM COLUMN PREHEATER	T101	HYDROGEN CAUSTIC SCRUBBER
C102	HYDROGEN RECYCLE COMPRESSOR	T102	VACUUM COLUMN
C104	FRESH HYDROGEN COMPRESSOR	T104	RECOVERY COLUMN
E102	DISSOLVER PRODUCT COOLER	V101 A&B	SLURRY BLEND TANKS
E103	HIGH PRESSURE SEPARATOR COOLER	V103	HIGH PRESSURE SEPARATOR
E107	FLASH CONDENSER	V104	HIGH PRESSURE VENT SEPARATOR
E122	SOLVENT DRAW COOLER	V105	SOLVENT DECANTER
K110	FLARE	V106	RECYCLE HYDROGEN WATER SCRUBBER
K111	VACUUM JET	V110	FLASH TANK
K125	PRODUCT COOLER	V131 A&B	RECOVERED PROCESS SOLVENT TANKS
P102 A&B	SLURRY BLEND TANK PUMPS	V132 A&B	DEGAS VENT TANKS
P103 A&B	SLURRY PREHEATER FEED PUMPS	V138	LIGHT SOLVENT DRAW TANKS
P119 C&D	LIQUID COAL PUMPS	V164	T104 FEED TANK
P139	VACUUM COLUMN	V170	LIGHT PRODUCT RECEIVING TANK
P164	SOLVENT DRAW PUMPS	V177	HEAVY SOLVENT DRAW TANK
P168			
P171	HOTWELL PUMP		

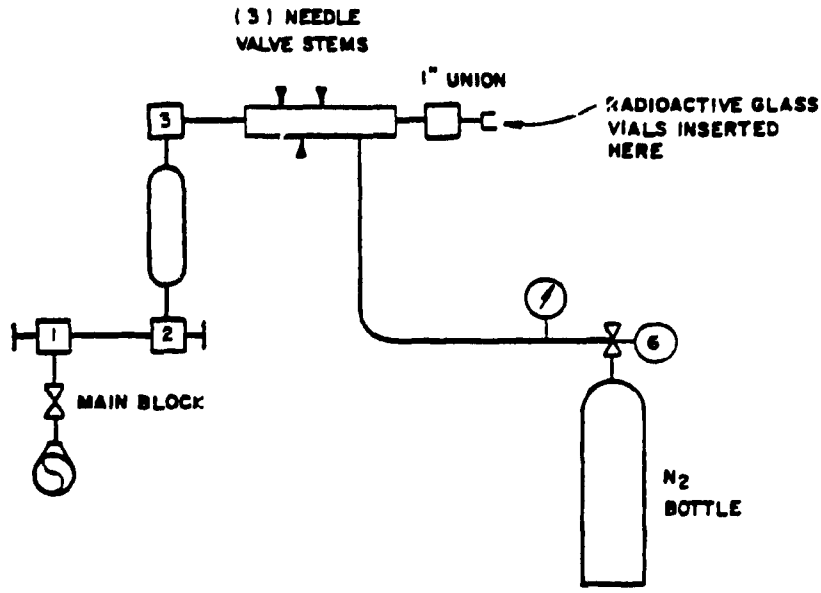
Fig. 4. Solvent refined coal (SRC) unit flowsheet. Source: Technical Progress Report, Runs 238 and 239 with Illinois No. 6 Coal, Doc. No. Fe-10154-117, Catalytic, Inc., Wilsonville, Alabama.

radioactive gold flakes and colloid, it was concluded that the slurry traveled as an entity.[5] In subsequent experiments, ^{82}Br-tagged bromophenanthrene was used as the liquid-phase tracer, and ^{41}Ar was used as the gas-phase tracer.[6,7] The radionuclide tracers were prepared by irradiation in a nuclear reactor at the University of Washington, Seattle, located about 48 kM (30 miles) from the pilot plant site. Preheater B was a modified rectangular coil made of 142 m (467 ft) of 5.1 cm (2-in.) schedule 160, stainless steel, 321 seamless tubing. The coil consisted of 14 turns on a 15 cm (6-in.) vertical spacing (i.e., with very small slope from horizontal), and the operating mode was upflow.[5] The dissolver vessel was a 9 x 0.6 m (30 x 2 ft) I.D. stainless steel vessel with 7.6-cm (3-in.) thick walls and 2.7-m^3 (95-ft^3) total internal volume.[7] The equipment used for carrying out the RTD experiments consisted of (1) an apparatus for injecting the tracer impulse into the process stream immediately upstream from the preheater (Fig. 5)[7]; and (2) radiation detectors [5-cm diam x 5-cm thick (2-in. diam x 2-in. thick) sodium iodide (NaI) scintillation detectors] mounted on the pipelines for monitoring the radiotracers, amplifiers, integral discriminators, rate meters, analog recorders (pen chart), and digital readers (multichannel pulse-height analyzer) shown in Fig. 6. The digital data were recorded on magnetic cassette tape and, after the tracer experiment, were put into the memory of a Univac 1100 Computer using an interface specifically constructed for this purpose.[6]

For both the preheater and initial dissolver studies, the tracer injections were made 5 m (16 ft) upstream from the preheater. In subsequent dissolver studies, tracer injections were made near the middle (measured vertically) of the reactor. To obtain more precise data on backmixing, efforts were made during radiotracer injections into the dissolver to minimize introduction of a significant gas bubble that would disturb the normal flow path in the dissolver.[7] Detectors for the preheater tests were mounted on the pipelines 0.6 m (2 ft) from the preheater inlet and ~10 m (32 ft) from the preheater outlet.[6] For the first dissolver tests, detectors were placed at the inlet and 19.5 m (64 ft) downstream on the outlet line. For the later backmixing dissolver tests, four detectors were mounted on the dissolver: one at



LIQUID-SLURRY APPARATUS



GAS INJECTION APPARATUS

Fig. 5. Injection apparatus used in radiotracer tests at the Solvent Refined Coal Plant, Ft. Lewis, Washington. Source: Solvent Refined Coal (SRC) Process, Final Report, Vol. 1. Englewood, Col., May 1982.

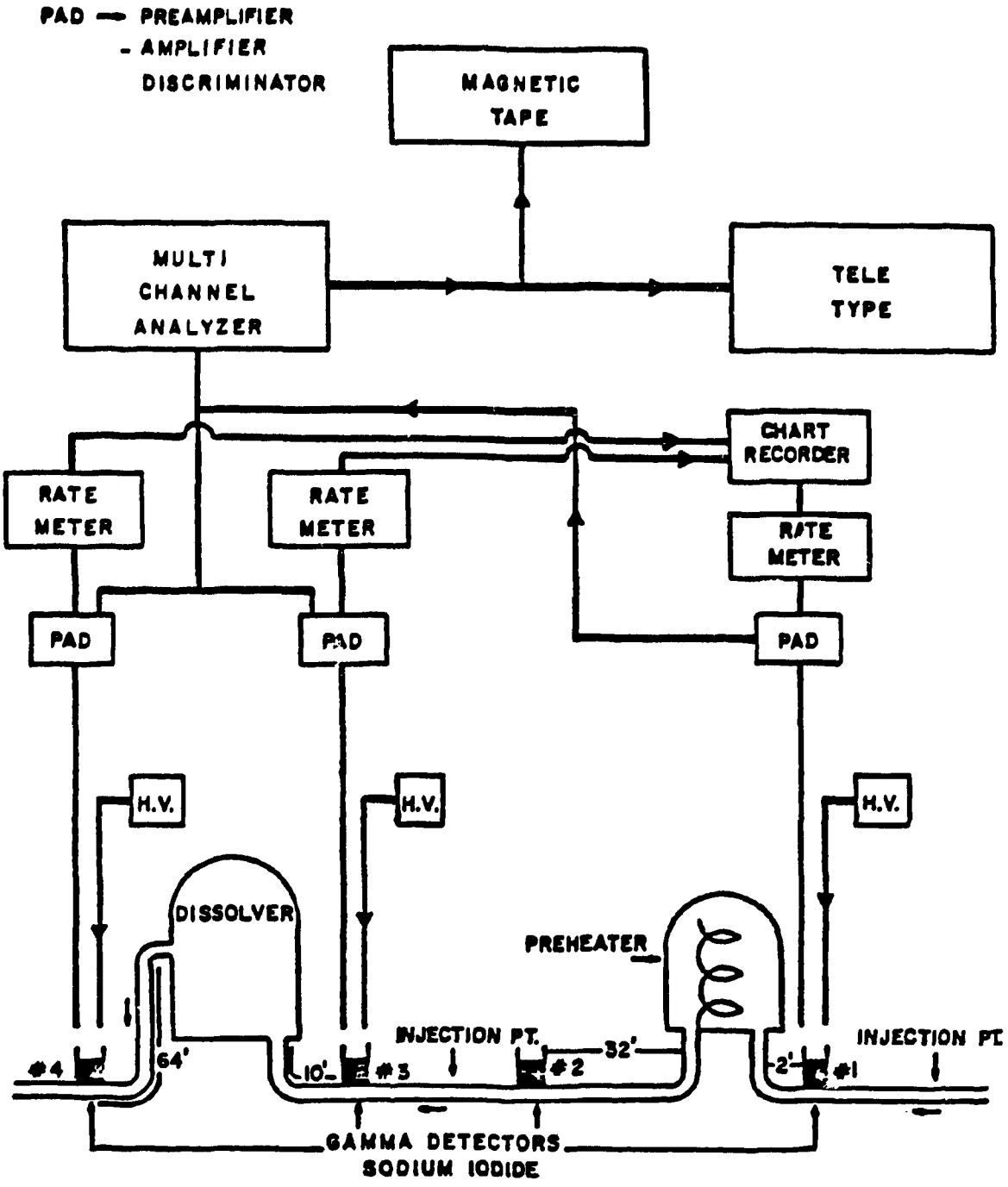


Fig. 6. Electronic equipment and schematic of flow tracer at the Solvent Refined Coal Plant, Ft. Lewis, Washington. Source: D. F. Rhodes, E. G. Miller, and E. L. Thomas. Radiotracer Tests on SRC-I Preheater at Ft. Lewis, Report No. 532TL015, Gulf Science and Technology, Pittsburgh, Penn., November 1980.

the middle injection point, and others at the bottom, middle, and top of the dissolver (Fig. 7). Instrumentation required for the dissolver mixing tests is shown schematically in Fig. 8.

2.1.2 Calculations

Mean residence times and dispersion numbers were calculated from the digital data taken during each run. The mean residence time was determined by subtracting the centroid of the inlet peak from the centroid of the outlet peak. The peak centroid (μ) was determined from the equation

$$\mu = \frac{\sum_{i=a}^{b} A_i t_i}{\sum_{i=a}^{b} A_i} .$$

in which A_i is the counts recorded in channel i of the multichannel analyzer, t_i is the time associated with the ith channel (i.e., dwell time x channel number) and a, b are peak boundaries.[6,7] Peak variance (σ^2) is defined as

$$\sigma^2 = \frac{\sum_{i=a}^{b} A_i \, (t_i - \mu)^2}{\sum_{i=a}^{b} A_i} .$$

The dispersion number (D/uL) is defined by the following equation:[6,7]

$$\frac{D}{uL} = \frac{1}{8} \left\{ \left[\sqrt{\frac{8}{(MRT)^2} \left(\sigma^2_{out} - \sigma^2_{in} \right) + 1} \right] - 1 \right\},$$

where MRT is the mean residence time, σ^2_{out} is the variance of the outlet peak, and σ^2_{in} is the variance of the inlet peak.

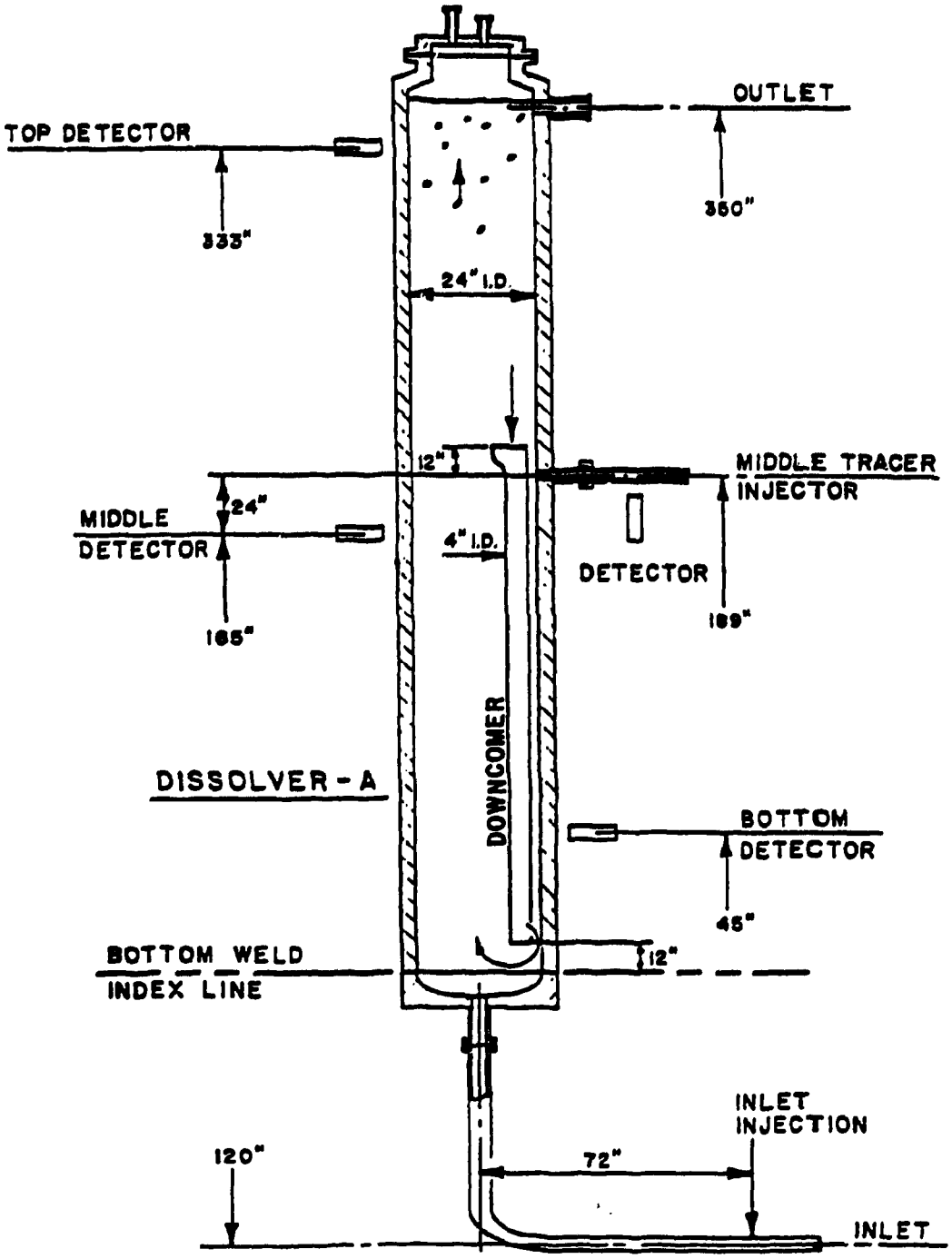


Fig. 7. Radiotracer detector locations for dissolver at the Solvent Refined Coal Plant, Ft. Lewis, Washington. Source: Solvent Refined Coal (SRC) Process, Final Report, Vol. 1. DOE/ET/10104-46 (Vol. 1), Pittsburgh and Midway Coal Mining Co., Englewood, Col., May 1982.

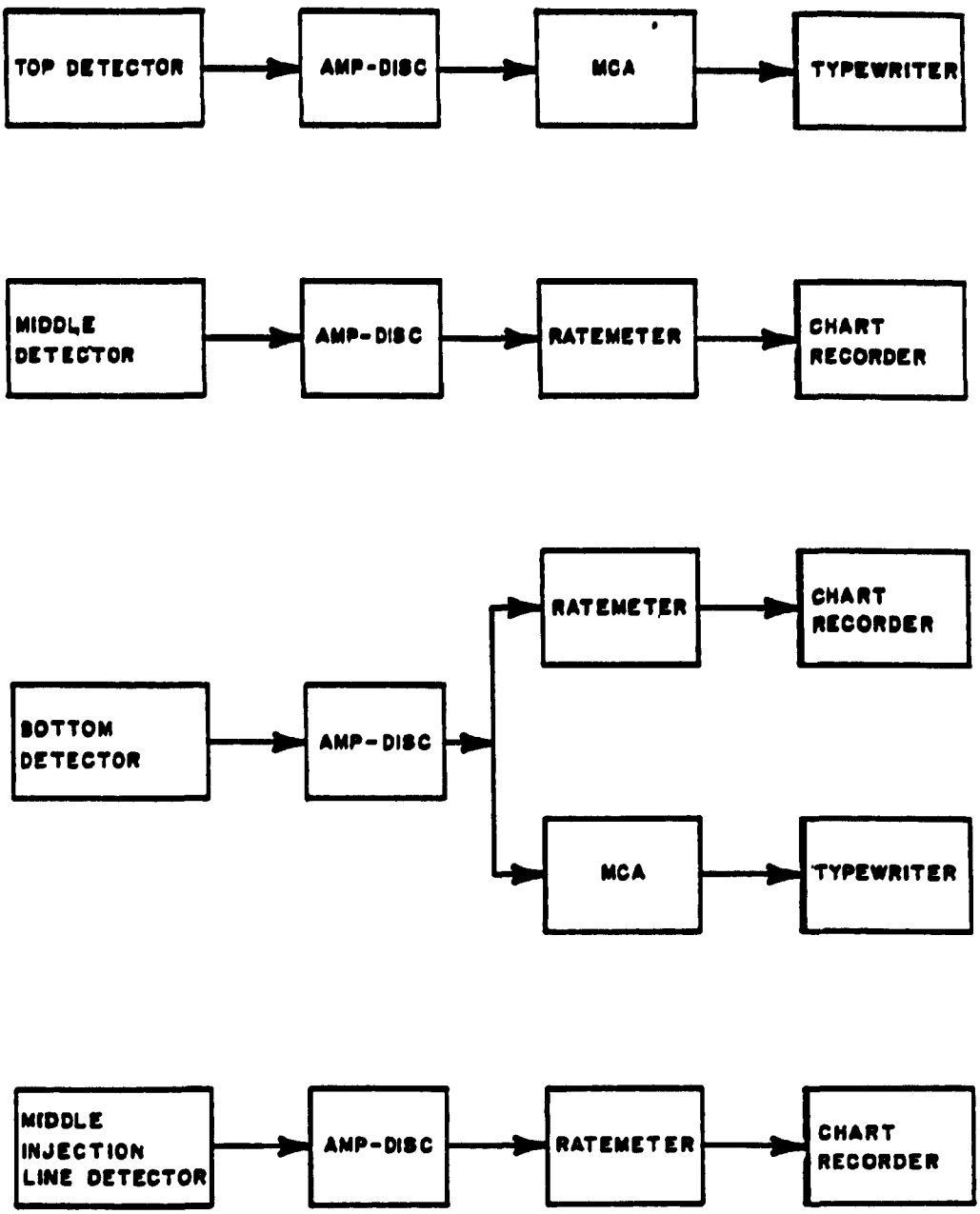


Fig. 8. Diagram of instrumentation system used in dissolver mixing tests at the Solvent Refined Coal Plant, Ft. Lewis, Washington. Source: Solvent Refined Coal (SRC) Process, Final Report, Vol. 1. DOE/ET/10104-46 (Vol. 1), Pittsburgh and Midway Coal Mining Co., Englewood, Col., May 1982.

Backmixing was calculated from the signals of the "top" versus "bottom" detectors at the side of the dissolver during the middle-point injection. Backmixing is defined as

$$\% \text{ Backmixing} = \frac{\sum_{i=a}^{b} \left(A_{bottom}\right)_i}{\sum_{i=a}^{b} \left(A_{top}\right)_i} (F)(100) ,$$

where $(A_{bottom})_i$ is the number of counts recorded in the ith channel of the multichannel pulse-height analyzer connected to the bottom detector; $(A_{top})_i$ is the number of counts at the top detector; and F is the relative response or efficiency of the bottom detector compared with the top detector. The quantity, F, was measured each day using a 0.3-MBq (8-μCi) sealed source of ^{137}Cs to determine the response of each detector with the source located at the same position from the detector.[7]

Typical gas holdup calculations (from Ref. 7) are presented here:

"Typical gas flow into the dissolver = $V_{in} = 148 \frac{lb/mol}{h}$

Typical vapor flow from the dissolver = $V_{out} = 200 \frac{lb/mol}{h}$

The typical (average) gas residence time is 37 s, and the actual (average) flow rate inside the dissolver is calculated using the gas law:

$$\frac{ACF}{h} = \frac{V}{h} = \frac{nRT}{hP}$$

$$\frac{ACF}{h} = \left(\frac{148 + 200}{2} \frac{lb\text{-}mol}{h}\right)\left(10.73 \frac{ft^3 lb}{in^2 \cdot °R \ lb\text{-}mol}\right)\left(\frac{1320°R}{2015 \ lb/in^2}\right)$$

$$\frac{ACF}{h} = 1223 \frac{ft^3}{h}$$

For a period of 37 s, the actual flow was:

$$\frac{1223\ ft^3/h}{3600\ s/h} \times 37s = 12.55\ cu\ ft.$$

The quantity of gas inside the dissolver at any instant is calculated using the following relation:

$$\frac{\text{Volume of gas}}{\text{Total dissolver volume}} = \frac{12.55\ (100)}{92.67} = 13.5\% .$$

Attempts to correct the gas backmixing measurements for argon solubility in the dissolver slurry failed."[7]

2.1.3 Test Results

Measurements were made of the liquid-phase and gaseous-phase RTD for the preheater at six different plant operating conditions. A typical plot of the digital radiotracer data is shown in Fig. 9. A summary of the results is given in Table 1. (For details of operating conditions, refer to Ref. 7). It was concluded that the gas mixing (dispersion number) was too erratic to correlate with operating variables in the preheater for the SRC-I runs, but that all the gas and slurry dispersion numbers indicated predominately plug flow.[7]

Three series of tracer studies were conducted in the dissolver. In the first series, the tracers were injected into the dissolver inlet, with detectors on the inlet and outlet. In the second and third series, the tracers were injected at the midheight of the dissolvers, with detectors as shown in Fig. 7. Figures 10 and 11 show the liquid and gas mean residence times for the first and second series of tests. Attempted correlations of dispersion number, initial delay times, or backmixing versus gas and slurry rates indicated no significant correlation (possibly because of the narrow range of variables; additional data and plant operating conditions are detailed in Ref. 7). From the dissolver tracer studies, it was concluded that gas flow is essentially

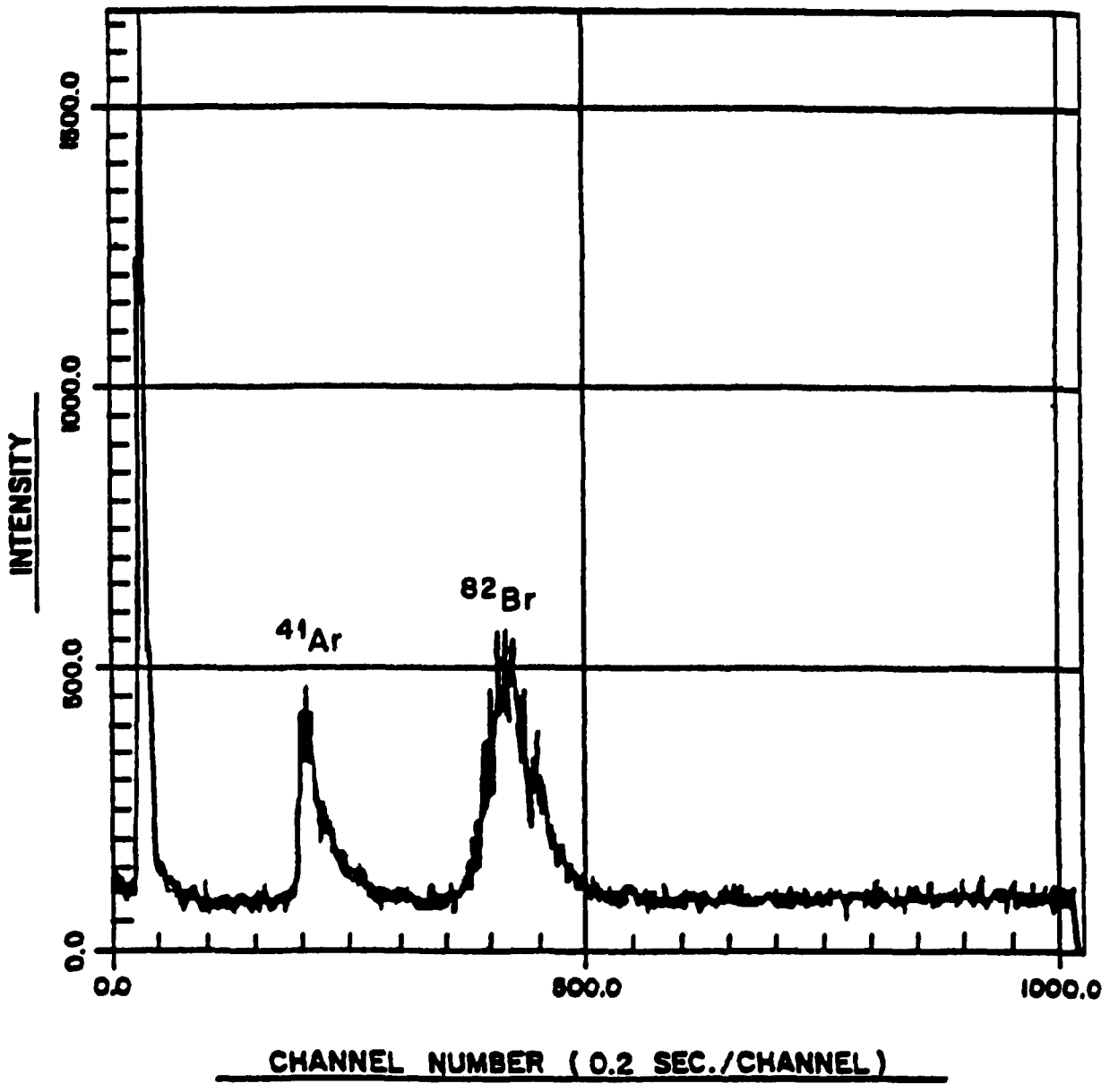


Fig. 9. Response of detectors located at preheater inlet and preheater outlet of Solvent Refined Coal Plant, Ft. Lewis, Washington (0.67 mCi of ^{41}Ar was injected at the preheater inlet on August 12, 1980, 14:45 PDT). The ^{82}Br peak is attributed to contamination in the injection apparatus that resulted in coinjection of ^{82}Br tracer with the ^{41}Ar. Source: Solvent Refined Coal (SRC) Process, Final Report, Vol. 1, Englewood, Col., May 1982.

Table 1. Summary of radiotracer test results from the preheater at the Solvent Refined Coal Plant, Ft. Lewis, Washington
August 12, 1980

Time (PDT)	Phase	Radionuclide	Activity (mCi)	Mean residence time (s)	Dispersion number	Preheater feed rates, lb/h	
						Inlet gas	Feed slurry
12:45	Gas	Ar-41	2.2	52.7	0.00050	570	9070
13:15	Liquid	Br-82	0.59	129.3	0.0022	570	9070
13:55	Gas	Ar-41	0.93	34.1	0.0017	570	9070
14:20	Liquid	Br-82	0.57	82.7	0.0021	570	9070
14:45	Gas	Ar-41	0.67	35.6	0.0015	270	10960
15:00	Liquid	Br-82	0.57	78.8	0.0023	270	10960
15:38	Gas	Ar-41	0.48	52.3	0.0052	270	10960
15:53	Liquid	Br-82	0.57	98.2	0.0016	270	10960
16:50	Liquid	Br-82	Negl.	148.4	0.0029	265	5540
17:05	Gas	Ar-41	0.14	145.5	0.0011	265	5540
17:25	Gas	Ar-41	0.24	34.0	0.0015	265	5540
17:37	Liquid	Br-82	0.55	111.1	0.0067	265	5540

Source of table: Solvent Refined Coal (SRC) Process, Final Report, Vol. 1, DOE/ET/10104-46, Pittsburgh and Midway Coal Mining Company, Englewood, Col. May 1982.

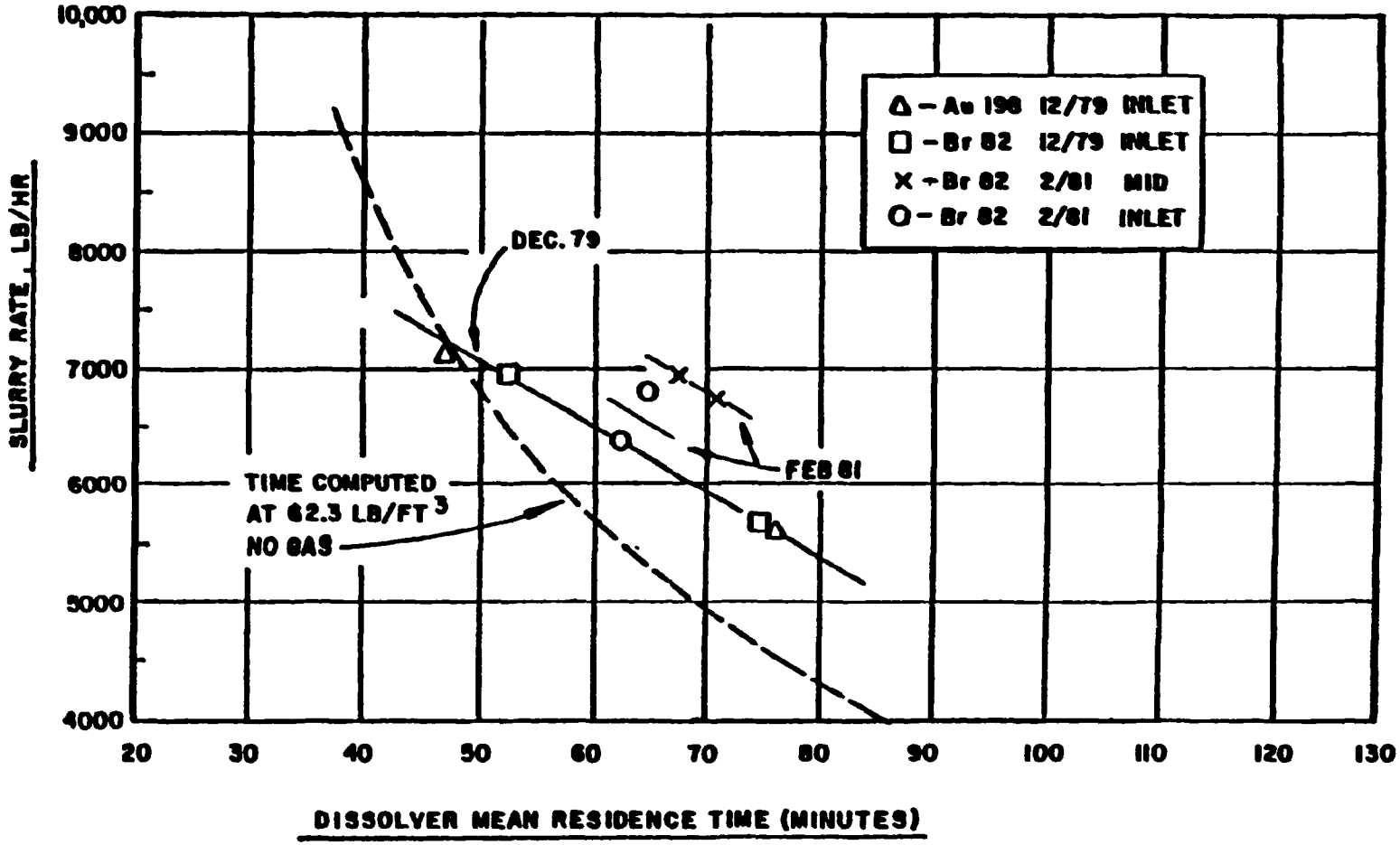


Fig. 10. Dissolver mean residence times measured by radiotracers (liquid) at the Solvent Refined Coal Plant, Ft. Lewis, Washington. Source: Solvent Refined Coal (SRC) Process, Final Report, Vol. 1, DOE/ET/10104-46, Pittsburgh and Midway Coal Mining Co., Englewood, Col., May 1982.

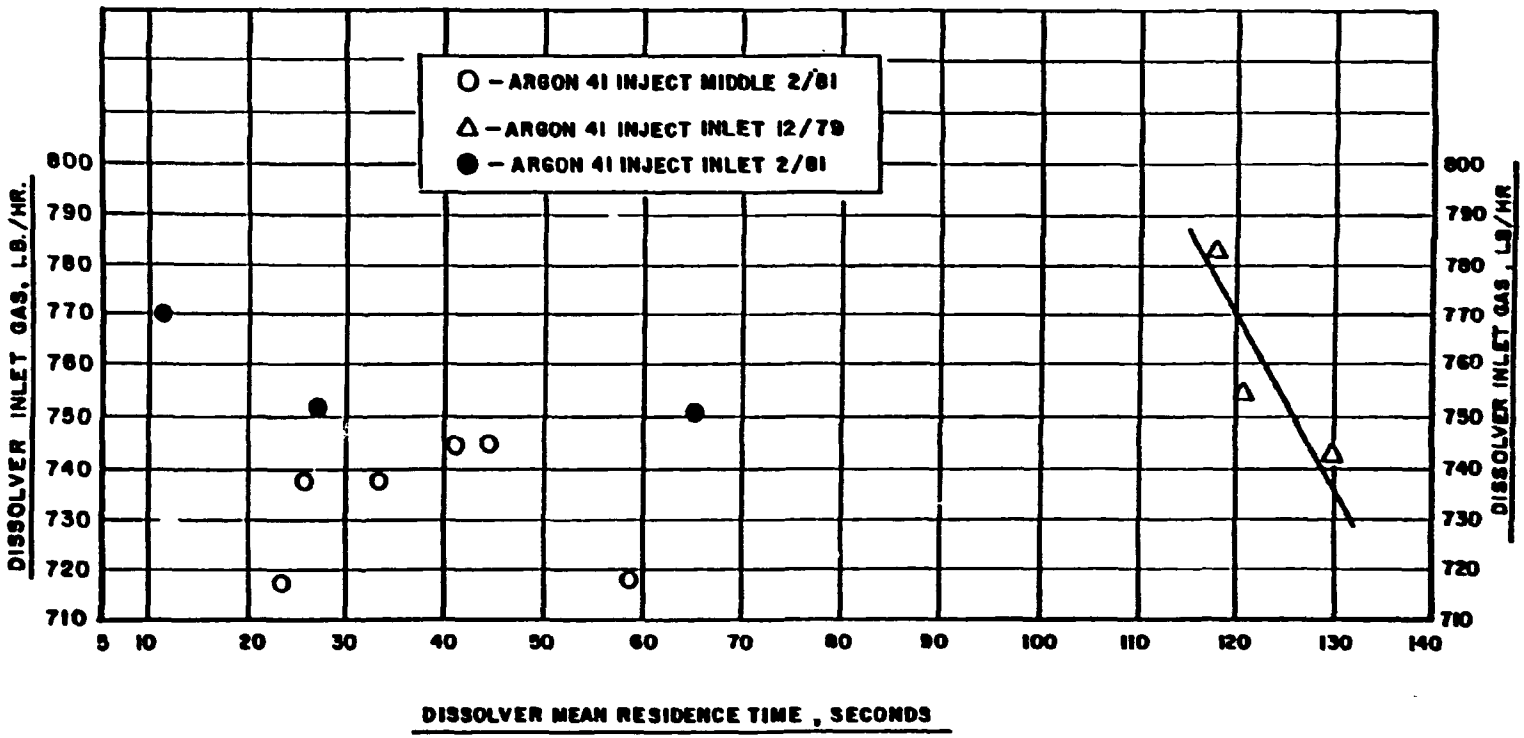


Fig. 11. Dissolver mean residence times measured by radiotracers (gas) at the Solvent Refined Coal Plant, Ft. Lewis, Washington. Source: Solvent Refined Coal (SRC) Process, Final Report, Vol. 1, DOE/ET/10104-46, Pittsburgh and Midway Coal Mining co., Englewood, Col., May 1982.

plug flow, while the slurry was backmixed at all test conditions. Tracer studies were best performed with the detectors mounted on the sides of the dissolver, and injection into the middle of the dissolver between detectors gave good measurement of backmixing. The amounts of radioactive tracer injected in the dissolver tests were not reported.[7] At a gas velocity of 0.03 m/s (0.1 fps), the gas void fraction was ~0.14 of the volume, and the liquid-phase dispersion coefficient was ~0.01 m^2/s (0.04 ft^2/s). The dispersion coefficient seems low, considering the apparently constant temperature throughout the dissolver.[8]

The principal experimental difficulty was reported to be the high radiation background (from the injection apparatus) at the inlet detector.[6] A secondary problem was in assuring complete injection of the radiotracer, particularly when the tracer was the liquid, ^{82}Br-tagged bromophenanthrene. With each injection, efforts were made to place the tracer in the flow-pattern as quickly as possible with minimum disruption of the normal flow. During the series of injections at the middle of the dissolver, some difficulty was experienced in rapidly injecting all of the tracer (particularly with the bromophenanthrene solution) without using excess gas purge and disrupting the normal flow pattern. Two 500-mL cylinders were added as surge capacity in the pressurizing line,[9] but the efficacy of this change was not subsequently reported.

2.2 EXXON DONOR SOLVENT (EDS) PILOT PLANT STUDIES

The three main objectives of the radiotracer test program conducted by the Exxon Research and Engineering Company at the EDS Pilot Plant were to: (1) determine phase holdups, residence times, and backmixing in the three reactors; (2) develop the basis for reactor hydrodynamics scaleup to commercial size reactors; and (3) correlate the reactor hydrodynamics with conversion differences between the three reactors.[14]

Radiotracer techniques were selected as the only workable means for characterizing hydrodynamics of the reactors. Using the criteria that the radiotracer should be chemically and physically stable, allow detection through process piping, and have a known distribution among

phases, ^{41}Ar was selected as the gas phase tracer; ^{82}Br-tagged bromoadamantane was selected as the liquid tracer.[14] The candidate liquid and slurry tracers evaluated were the following: bromophenanthrene, tribromobenzene, bromoadamantane, hexabromobenzene, tetraphenyl germanium, and colloidal gold (water suspension).[11,13] The bromoorganics apparently were not stable at operating temperatures of 440°C (820°F) because thermolysis of the carbon-bromine bond resulted in loss of bromine via wall reactions.[11] In the later phases of the radiotracer tests, ^{198}Au-tagged colloidal gold was used as the slurry tracer.[13]

2.2.1 Experimentation

Radiotracer tests were conducted in the EDS Pilot Plant reactors during a Wyodak coal bottoms recycle operation to obtain information on holdups, residence times, and the degree of backmixing.[11] The monitoring system consisted of a Nuclear Data Model 66 multichannel analyzer. The detectors were covered with 5–15 cm (2–6 in.) of lead for collimation and shielding from high background levels.[11,15] Tracer data were recorded on magnetic tapes in digital form. Analog data from rate meters were recorded and the data quality determined by analysis on a minicomputer (HP-85 computer/plotter). The data was subsequently analyzed by mainframe computer also (Fig. 12).[11,14,15] Detector locations for the EDS reactors are shown in Fig. 13.

The radiotracers were neutron-activated in the Texas A&M University's nuclear reactor located at Austin, Texas, 145 km (90 miles) distance from the EDS Pilot Plant site. Because of its short half-life, the ^{41}Ar was delivered to the test site on the day of injection. To optimize the logistics of handling, three containers of each tracer were generally transported to the test site at the same time.[15,16] The tracers were added to the systems by impulse injection techniques.[11]

2.2.2 Calculations and Results

Typical data curves for the gas (^{41}Ar) and liquid (^{82}Br-phenanthrene) tracers, are shown in Figs. 14 and 15.[11] The apparent noise shown was principally due to radiation, but some amplitude spikes superimposed on the RTD curves were attributable to operation of the effluent separator. The noise did not interfere with our

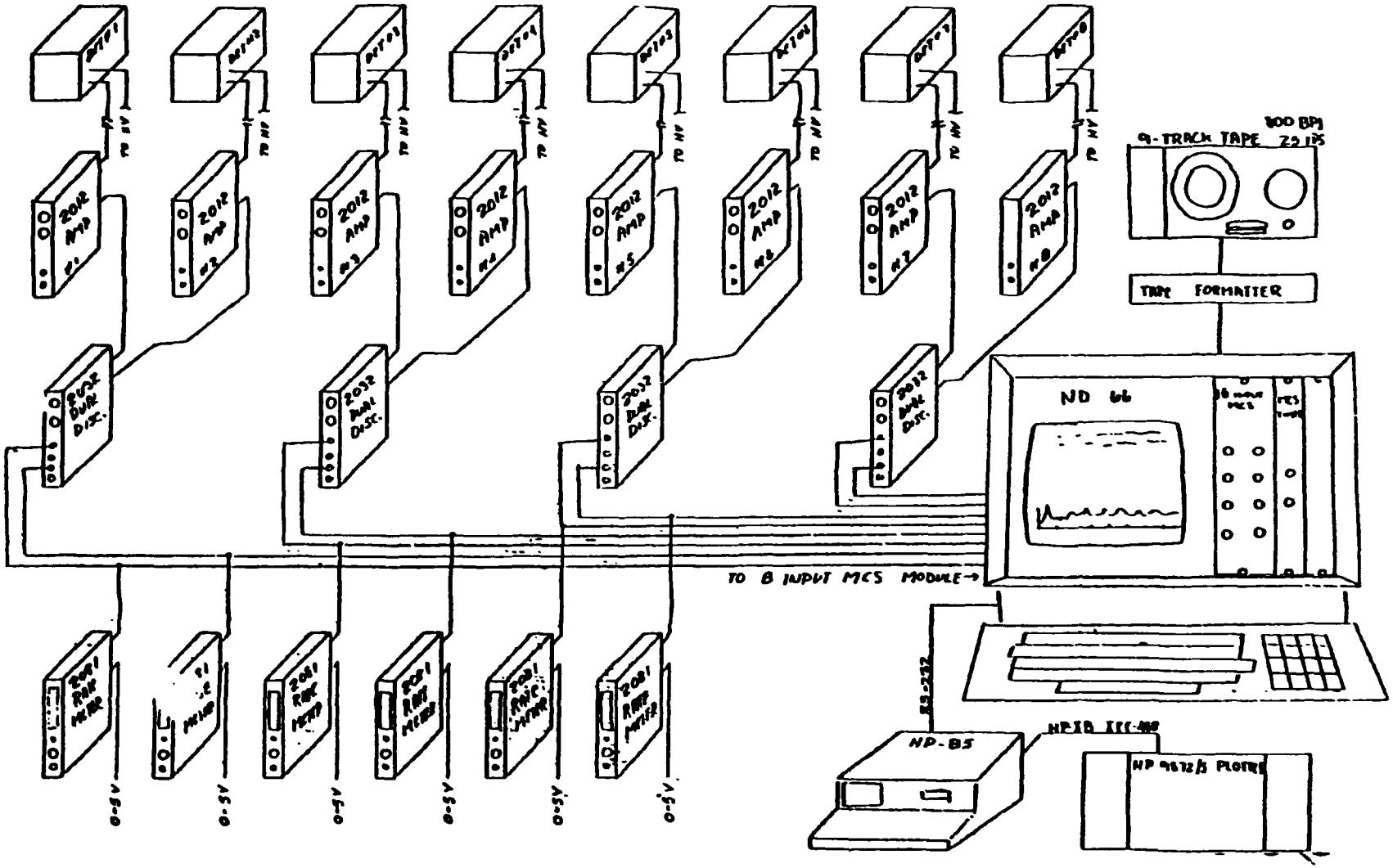


Fig. 12. Tracer data acquisition system for the Exxon Donor Pilot Plant studies. Source: M. Chang, P. R. Ponzi, and C. A. Coulaloglou, EDS Liquefaction Tracer Test Program, April 22, 1982, Synthetic Fuels Research, EDS Coal Liquefaction Project, Exxon Research and Engineering Co., Florham Park, N.J.

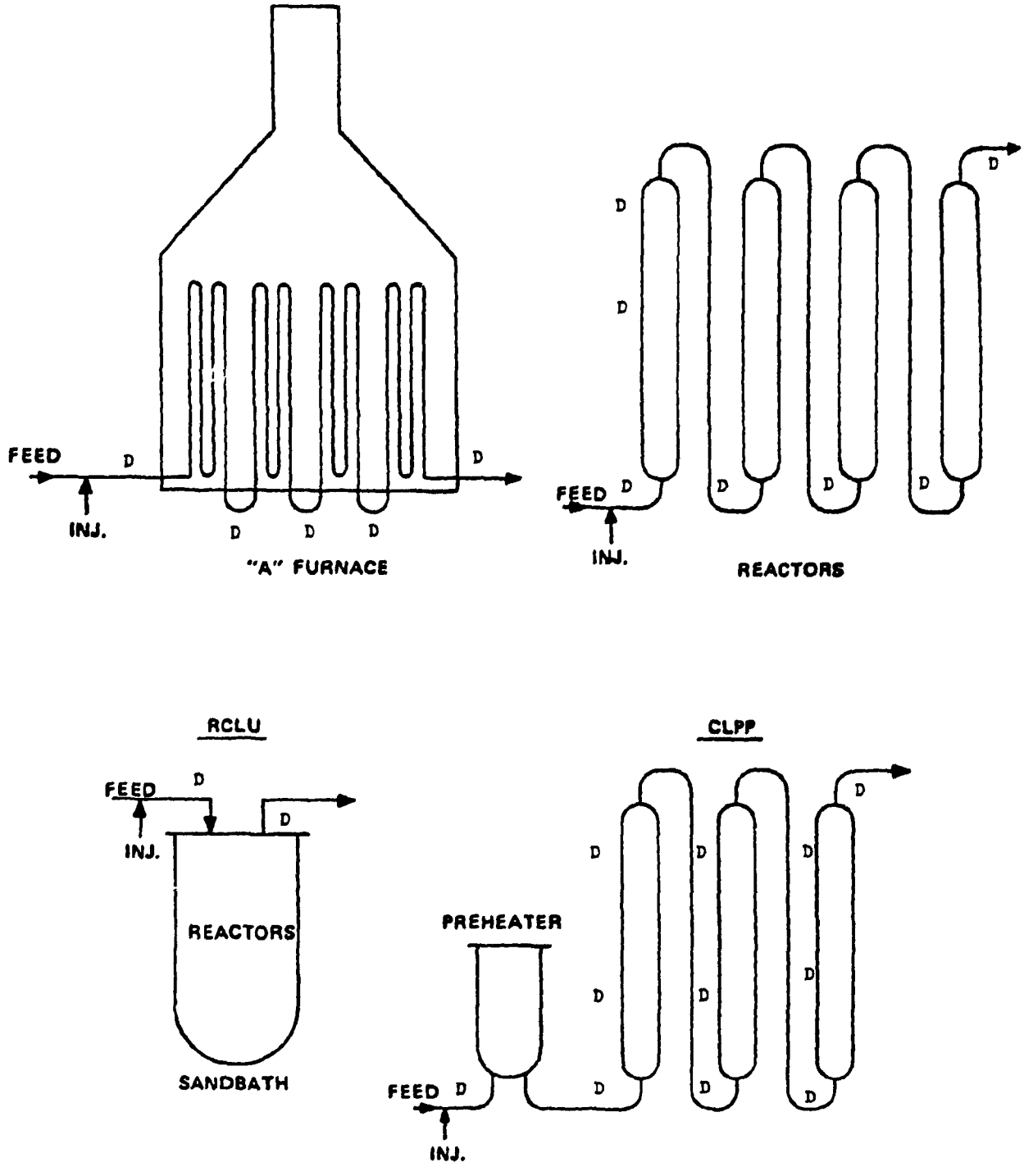


Fig. 13. Tracer detector locations for preheater and reactors in the Exxon Donor Solvent Pilot Plant studies. Source: M. Chang, P. R. Ponzi, and C. A. Coulaloglou, EDS Liquefaction Tracer Test Program, April 22, 2982, Synthetic Fuels Research, EDS Coal Liquefaction Project, Exxon Research and Engineering Co., Florham Park, N.J.

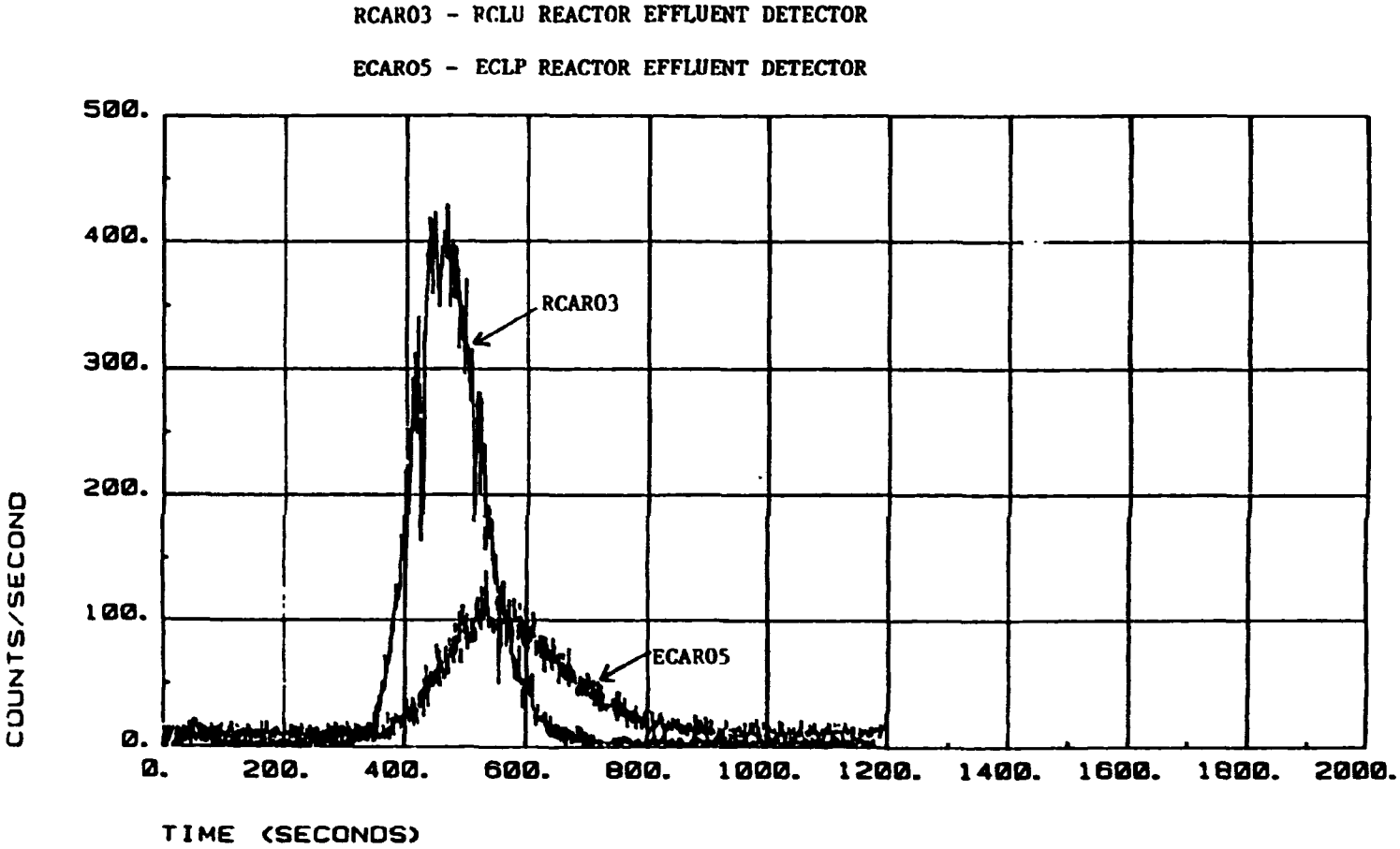


Fig. 14. Comparison of gas-phase tracer in ECLP and RCLU reactors of Exxon Donor Solvent Pilot Plant studies. Source: EDS Coal Liquefaction Process Development, Phase V, Quarterly Technical Progress Report, October 1–December 31, 1981, FE-2893-83, Exxon Research and Engineering Co., Florham Park, N.J.

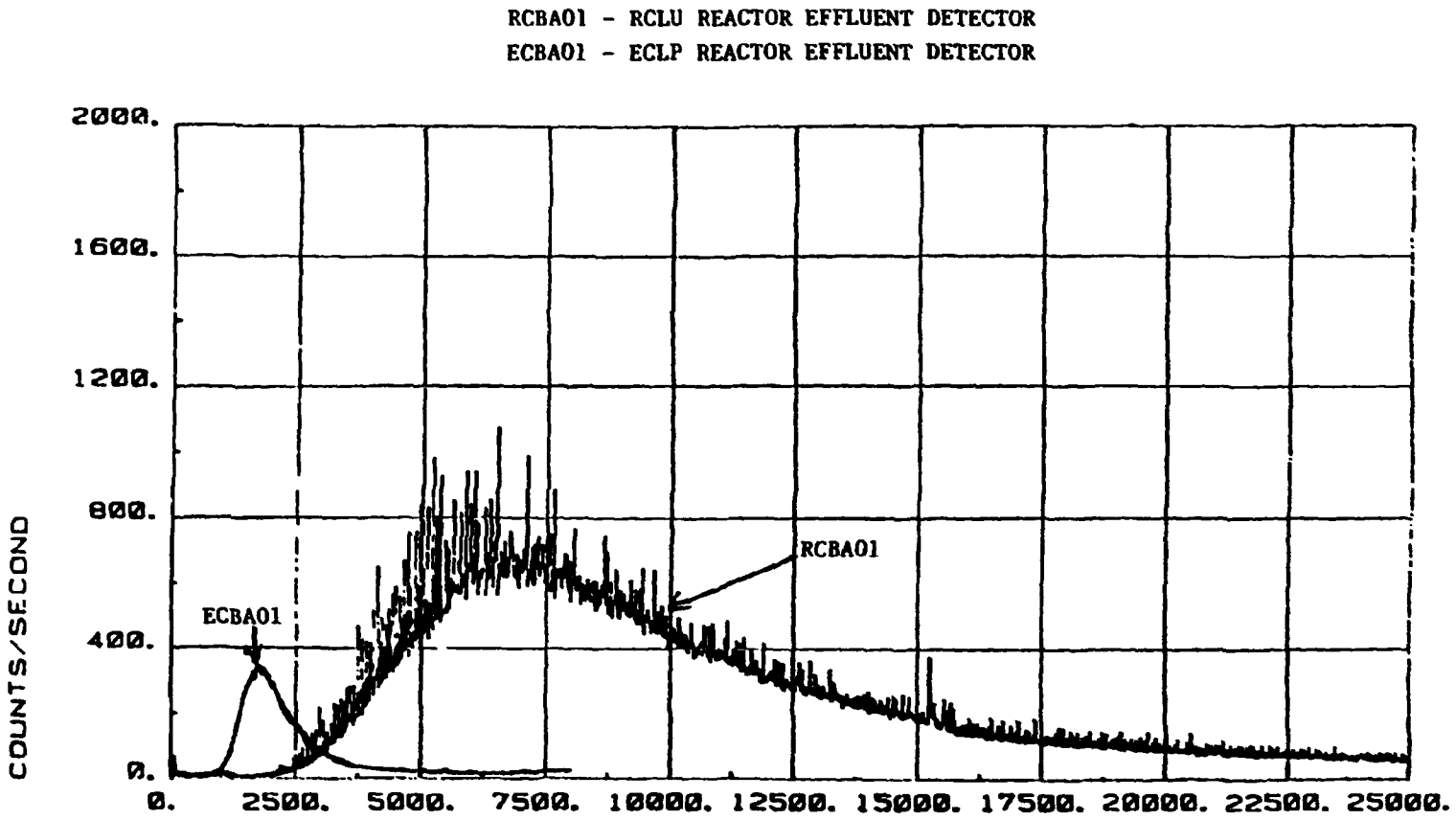


Fig. 15. Comparison of liquid-phase tracers in ECLP and RCLU reactors of Exxon Donor Solvent Pilot Plant studies. Source: EDS Coal Liquefaction Process Development, Phase V, Quarterly Technical Progress Report, October 1–December 31, 1981, FE-2893-83, Exxon Research and Engineering Co., Florham Park, N.J.

obtaining RTD times and dispersion data. It was concluded that the actual gas-phase residence times are shorter than indicated by the raw tracer curves because of argon solubility in the liquid phase.[11]

Since the gas tracer partially dissolves in the coal liquid, a two-phase dispersion model was developed to analyze the data. The model consists of two partial differential equations describing the backmixing and mass transfer. Model details and methodology are presented in detail in Refs. 11 and 14.

Phase holdups in three reactors, based on data for both liquid and gas tracers, are shown in Fig. 16.

Using the two-phase dispersion model and the liquid-tracer data, a dispersion parameter (the liquid Peclet number, Pe_e) was determined for each reactor. The Peclet number is defined as

$$Pe_e = \frac{U_c L}{E_l D_l} ,$$

where U_c is the liquid superficial velocity (cm/s), L is the reactor length (cm), E_l is the liquid holdup fraction, and D_l is the liquid dispersion coefficient (cm^2/s). As an example, selected data are presented in Table 2. The tracer test dispersion estimates agree well with literature correlations.[12,17-19]

Liquid tracer injections using colloidal gold were not successful with the small [33 kg/h (75 lb/h)] reactor because of poor dispersion of the tracer in the slurry. The tracer injections were performed during unsteady operating conditions which obscured the results.[16]

The tracer studies and pressure differential measurements indicated large void volumes in both EDS reactors. Gas void volume fractions in the large [1.8×10^5 kg/d (200 t/d)] unit at standard operating conditions ranged from 0.3 at 0.045 m/s (0.15 fps) gas velocity to 0.5 at 0.15 m/s (0.25 fps).[12] Tracer studies in the 2-ft ID EDS dissolver indicated dispersion coefficients between 0.028 and 0.074 m^2/s (0.3 and 0.8 ft^2/s) at gas velocities of 0.045 and 0.067 m/s (0.15 and 0.22 fps).[12] The high dispersion coefficients and high void fractions suggest frothy flow conditions.

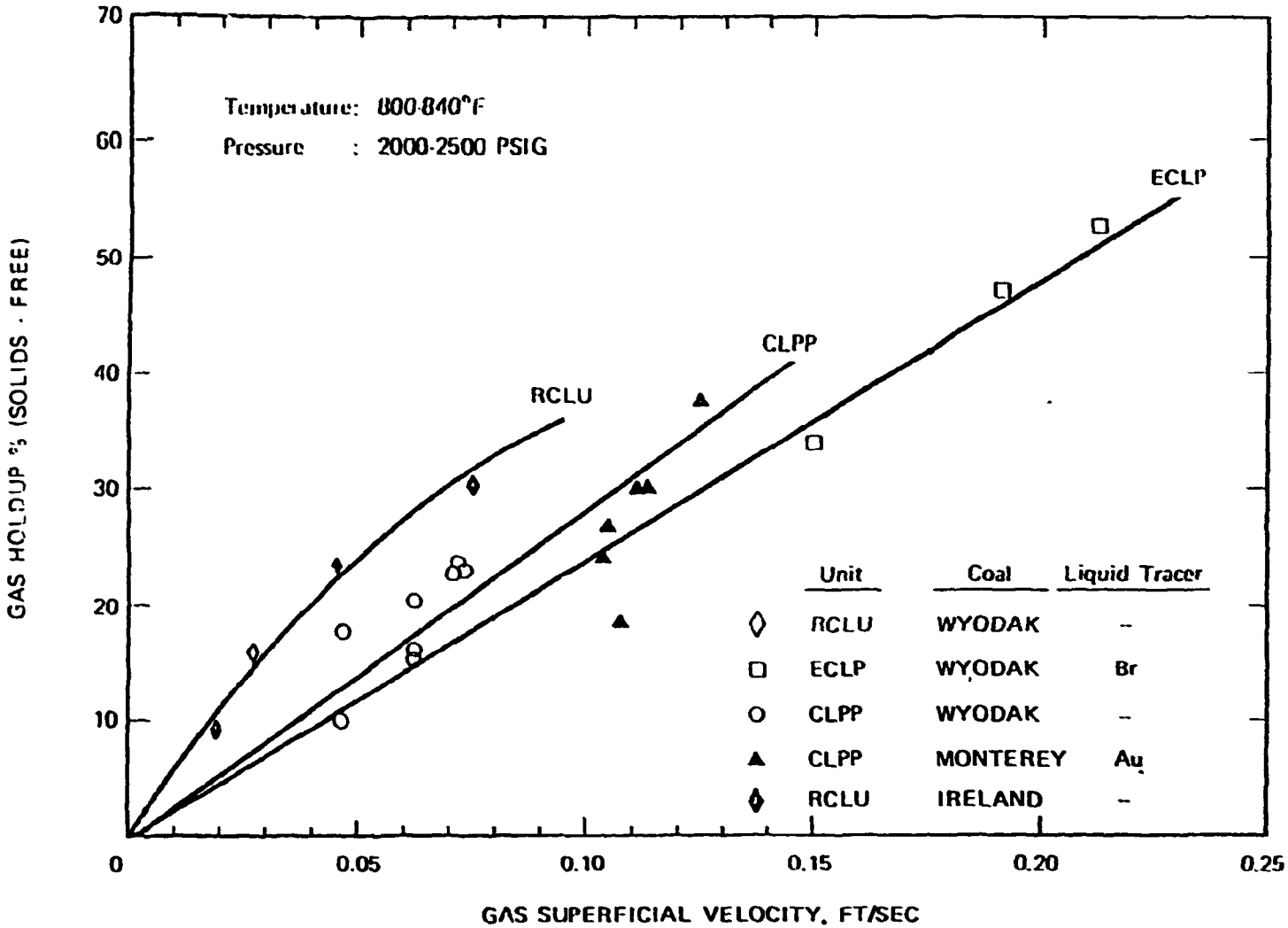


Fig. 16. Gas-phase holdups in RCLU, CLPP, and ECLP reactors from tracer data (Wyodak bottoms recycle) in Exxon Donor Solvent Pilot Plant studies. Source: EDS Coal Liquefaction Progress Development, Phase V, Quarterly Technical Progress Report, July 1–September 30, 1982, FE-2893-99, Exxon Research and Engineering Co., Florham Park, N.J.

Table 2. Measured and predicted Peclet numbers for reactors at the Exxon Donor Solvent Pilot Plant

	Peclet numbers				
	Measured		Predicted		
Reactor	10/29/81	10/28/81	Two-phase[a]	Three-phase[b]	Three-phase[c]
1	13.1	11.7	4.6	4	9.8
2	6.4	8.7	4.8	4.5	
3	4.1	8.1	4.1	3.8	

[a]Reference 17.

[b]Reference 18.

[c]Reference 19.

Source of table: EDS Coal Liquefaction Progress Development, Phase V, Quarterly Progress Report, January 1-March 31, 1982, FE-2893-89, Exxon Research and Engineering Company, Florham Park, N. J., September 1982.

Major disadvantages of bromoorganics as tracers at temperatures of 400°C and higher are the thermal degradation of the tracer compound and the reaction of thermolyzed bromine with the reactor walls. Colloidal gold was satisfactory as the slurry tracer for the 1.8×10^5 kg/d (200 t/d) and the 907 kg/d (1 t/d) reactors. Argon was a satisfactory tracer for the gas phase, although its solubility in the coal liquids was a factor in the data analysis.[16]

3. PROPOSED PLAN DETAILS

3.1 PROJECTED RTD RUNS: EXPERIMENTAL DESIGN

The EDS Pilot Plant management will decide on the experimental regimen (i.e., plant operating conditions) during the RTD tracer studies. A suggested experimental design is given in Table 3. If the slurry feed rate is considered to be an important factor, the experimental design can be modified to examine the effects of feed-rate variation.

Table 3. Experimental design

Run phase	Vessel	Dissolver operating condition	Slurry rate	Relative gas velocity	Injections ^{133}Xe	Injections ^{198}Au	Length of run (d)
1[a]	Preheater (B102)	-	Optimum design	High	2	2	3
	Preheater (B102)	-	Optimum design	Intermediate	2	2	
	Preheater (B102)	-	Optimum design	Low	2	2	
2	Dissolver (R101)	100% Takeoff	Optimum design	High	2	2	3
	Dissolver (R101)	100% Takeoff	Optimum design	Intermediate	2	2	
	Dissolver (R101)	100% Takeoff	Optimum design	Low	2	2	
3	Dissolver (R101)	100% Takeoff (solids withdrawal)	Optimum design	High or Intermediate	2	2	2
	Dissolver (R101)	100% Takeoff (solids withdrawal)	Optimum design	Low	2	2	
4[b]	Dissolver (R101)	50% Takeoff	Optimum design	High		2	2
	Dissolver (R101)	50% Takeoff	Optimum design	Intermediate	2	2	
	Dissolver (R101)	50% Takeoff	Optimum design	Low	—	2	—
	Total				18	22	10

[a]When preheater tests are made, the tracers will be monitored at the dissolver sites also, providing additional information.

[b]When operating using takeoff at the 50% point, the large void volume may reduce the information obtained from the gas-tracer injections.

A total of 18 gas-tracer and 22 liquid-tracer injections are predicted, based upon this experimental design. The manpower requirements for a 10-d run (not including travel time) are estimated as follows:

Instrument engineer	10 d
Health Physicist	10 d
Technician	10 d
Scientist-supervisor	10 d
Total	40 d

3.2 ONSITE CHECKOUT

It is proposed that the injection apparatus be thoroughly tested onsite to ensure safe injection of the radiotracers. Several injections will be made using surrogate tracers (e.g., nitrogen gas for ^{133}Xe; oil dispersion of carbonized resin for ^{198}Au-carbonized resin) in the radiotracer sample vessels to thoroughly test the injection methodology. Procedural details and team interactions will be worked out and systematized during an estimated 12 man-days (not including travel time).

Instrument engineer	3 d
Health Physicist	3 d
Technician	3 d
Scientist-supervisor	3 d
Total	12 d

3.3 PRELIMINARY RADIOTRACER TESTS

After onsite checkout, the system should be tested with two to four radiotracer injections (a minimum of one gas- and one slurry-phase tracer injection). These preliminary tests will permit further evaluation of the injection apparatus and procedures and will permit determination of the quantities of tracer necessary to ensure collection of statistically significant data in the experimental series. Manpower requirements for the preliminary radiotracer tests (not including travel time) will be approximately 12 man-days.

Instrument engineer	3 d
Health physicist	3 d
Technician	3 d
Scientist-supervisor	3 d
Total	12 d

3.4. TRACER INJECTION APPARATUS

The proposed injection system is shown schematically in Fig. 17. All system connections will be checked for leaks before injections, and nitrogen gas will be injected prior to tracer additions to ensure that the line into the process stream is not plugged. The pressurization cylinder has a small volume of gas that pushes the tracer into the system without significant perturbation to the flowing process stream. The assembly of the injection apparatus and pressure testing of the system valves, fittings, charge gas container, radiotracer sample containers, and gauges should be accomplished under an appropriate quality assurance program. Two man-days will be required for the leakage and operational check by a technician.

The entire apparatus will be mounted on a portable, free-standing unistrut frame, with a pan to catch possible radioactive spills. The frame and pan will be mounted on rollers (with roller locks) to permit movement from the preheater injection site to the dissolver injection site.

The estimated cost of the injector system, including mounting, is $5,500. These cost estimates are itemized as shown here:

Check valves and 0.25 in. ball valves (0-5000 psig)	$1000
Pressurization cylinder (500-mL)	500
Pressure gauges and pressure regulator (0-5000 psig)	600
0.25-in. SS tubing and fittings	600
High-pressure nitrogen cylinders	500
Pipefitting labor (3 d)	1000
Unistrut frame and pan	1000
Plastic shield	300
Total	$5500

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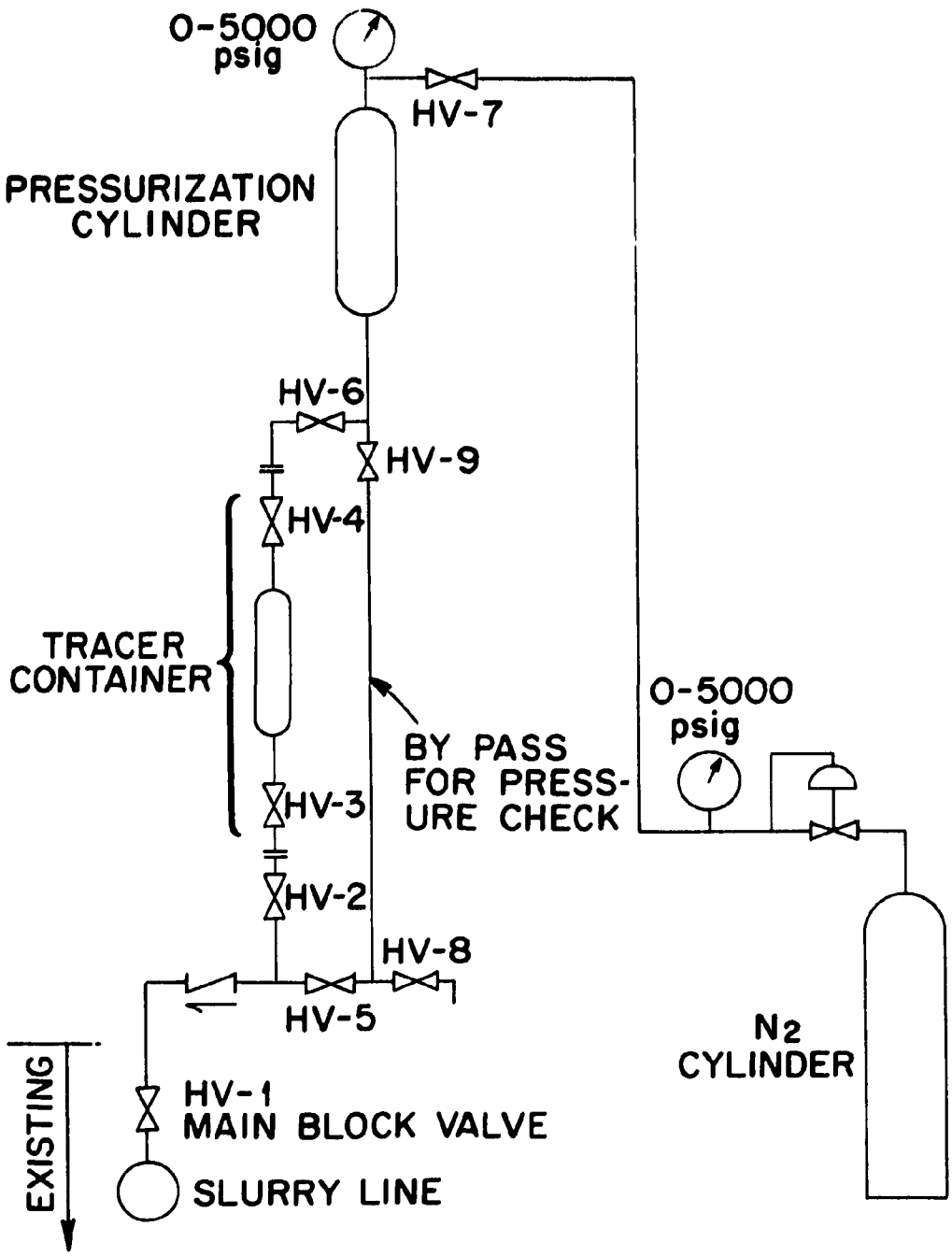

Fig. 17. Liquid-slurry tracer injection system.

3.5. TRACER INJECTION

The injection system's purpose is to inject the tracer as a spike into the process stream as near as practical to the vessel under study and with the least possible perturbation to the processing system.

3.5.1 Installation of Apparatus

It is desirable to make injection system connections to the Wilsonville plant with a minimum of piping changes. Existing taps into the slurry process line were found for the RTD studies of the dissolver (Fig. 18) and the preheater (Fig. 19). The tracer for the dissolver RTD experiments will be injected approximately 7.3 m (24 ft) from the inlet (see Fig. 18) through an existing 1-in. line with a valve connecting it to the 2-in. dissolver feed line. In the preheater RTD experiments, tracer will be injected ~1.2 m (~4 ft) from the inlet (see Fig. 19). The injection system is to be connected to an existing 0.5-in. tubing line by a valve connecting to the 1.25-in. preheater feed line.

Manpower requirements (not including travel time) will be:

Technician	1 d
Scientist-supervisor	1 d

Estimated costs are:

Fittings	$100
Pipefitting labor (1 d)	200
Total	$300

3.5.2 Injection Methodology

Before actual tracer injection, the methodology will have been tested in (1) dry runs in the laboratory, and (2) onsite testing using surrogate tracer samples. It is imperative that the injection system be thoroughly checked for leaks and be clear of all plugs prior to injection of radiotracers to avoid any release of radioactivity. Personnel making the tracer injection will wear respirators and protective clothing.

The step-by-step injection procedure will be:

1. Pressure-check tracer container prior to loading tracer sample.

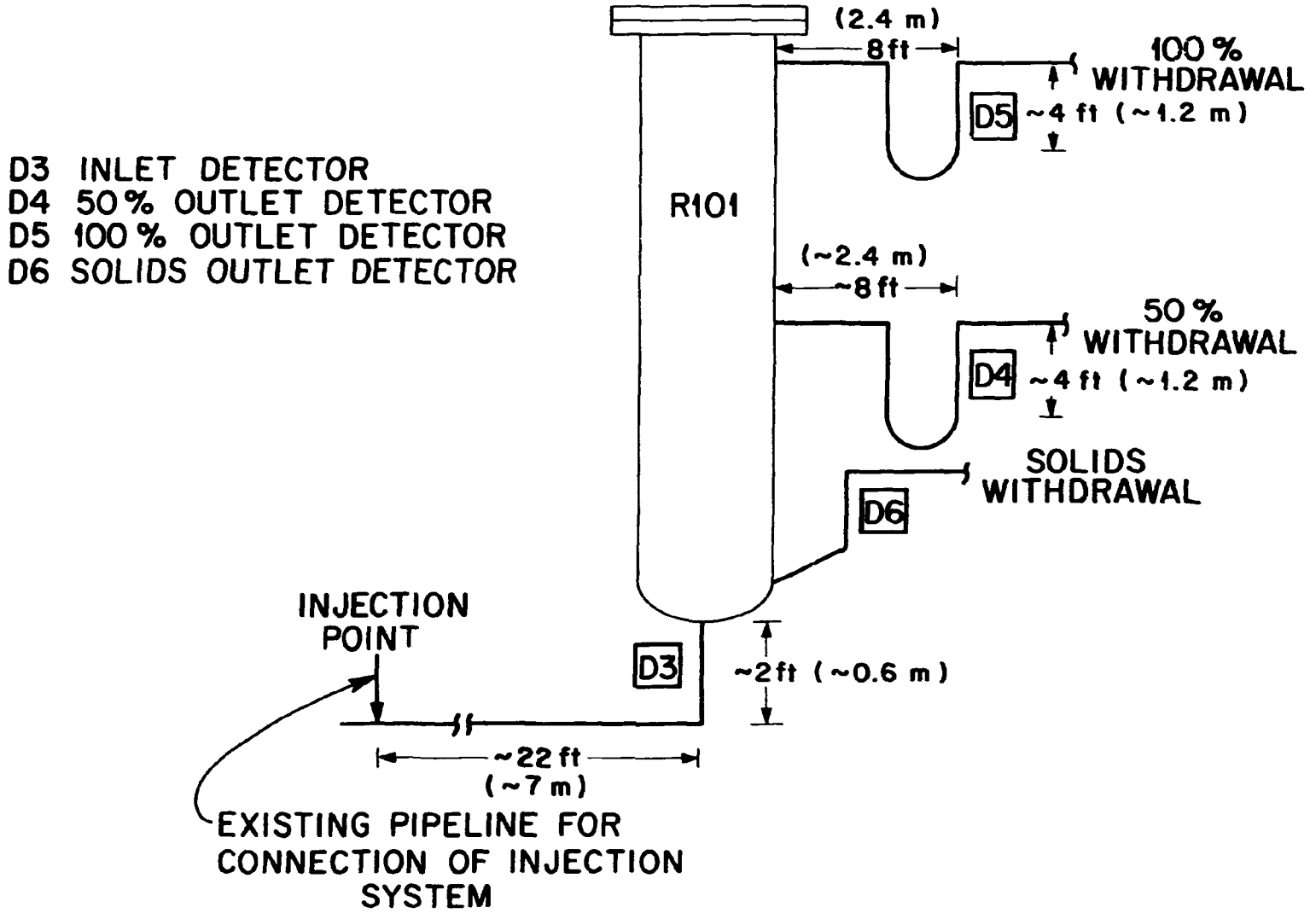

Fig. 18. Dissolver (R101) injection point and detector locations.

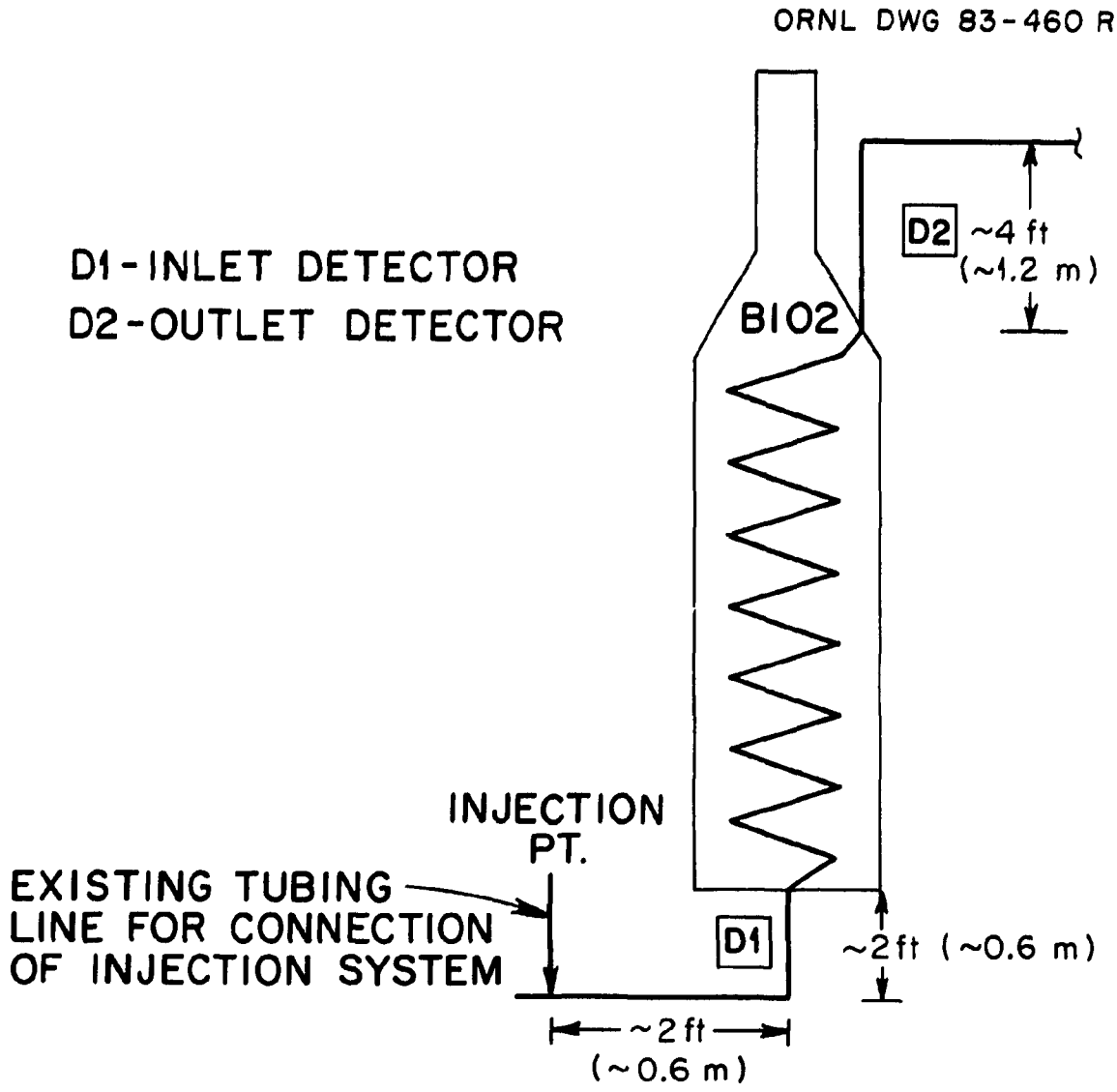

Fig. 19. Preheater (B102) injection point and detector locations.

2. Fill tracer container with radioactive tracer at supply location.
3. Attach tracer container (with lead shielding) to injection system (see Fig. 17).
4. Check to see that all valves on injection are closed.
5. Open HV-9, HV-6, HV-2, and HV-5.
6. Open HV-7 and pressure test the system to 3000 psig excluding tracer container.
7. Close HV-7.
8. Open HV-1.
9. Watch the pressure gauge on the pressurization cylinder decrease to system pressure, which indicates injection line is open.
10. Close HV-1.
11. Close HV-5 and HV-9.
12. Open HV-7.
13. Open HV-3 and HV-4 to pressurize tracer container.
14. Close HV-7.
15. Open HV-1 to make injection.
16. Watch the pressure gauge on the pressurization cylinder decrease to system pressure, which indicates injection has been accomplished.
17. Close HV-1.
18. Close HV-2, HV-3, HV-4, and HV-6.
19. Repeat Steps 12—18 as a precautionary flush to remove activity from the tracer container. This can be monitored by Health Physics personnel.
20. Place 25-mL polyethylene bottle filled with cotton waste or vermiculite under vent, and insert the vent ~6 cm (~2 in.) into the waste. Open valve HV-8. Open valve HV-5, permitting the gas to vent slowly through the cotton waste. In turn, open valves HV-2, HV-3, and HV-4, permitting the gas to vent slowly through the cotton waste. Remove and cap the polyethylene bottle; store it in a lead container, if activity is present.
An alternative venting procedure is to pipe the vent tubing through an activated carbon filter several feet from the

immediate work area. This would permit the venting filter to remain in place throughout the run series. If necessary, the filter could be shielded using a small amount of lead foil or lead bricks.

21. Close valves HV-4, HV-3, HV-2, HV-5, and HV-8.
22. Remove tracer container (with lead shielding).

3.6 TRACER DETECTION

It is desirable to position the detector as near the vessel under study as practical and on a line with vertical upflow. The tracer is monitored on a line with vertical upflow to avoid the false detector readings due to changes in flow patterns and stratified flow in horizontal and vertical downflow lines.

Each detector and its shielding will require a custom-designed bracket attached to the existing support structure for the dissolver and preheater. The types of detectors used to trace the radioactive materials through the process system are discussed in Sect. 3.10.

3.6.1 Dissolver Detector Positions

The inlet tracer pulse will be measured by a detector positioned directly below the dissolver ~2.5 cm (~1 in.) from the inlet on a vertical run of a 2-in. schedule 160 pipe (see Fig. 18). The slurry-gas flow is upward at the detection point. Since there is not a section of piping with vertical upflow within ~1 m (~3 ft) of the R101 outlets, it is suggested that a U-shaped piping section be constructed to replace the horizontal piping ~1.2 m (~4 ft) from the takeoff point. If it is desirable to check the RTD with the reactor operation at 50% takeoff and 100% takeoff points, U-shaped piping will be necessary at both takeoff positions. When these U-shaped piping sections are installed as suggested, the detector will be located on the vertical upflow section of the new piping ~2.4 m (~8 ft) from the vessel outlet (see Fig. 18). It is important to determine whether the reactor's fluid dynamics are affected when solids are intermittently removed from the dissolver. Thus, in addition to gas and slurry measurements, it is necessary to detect any tracer that is removed in the solids stream. A tracer detector for monitoring the solids takeoff line is positioned ~1 m (~3 ft)

from the dissolver on a vertical section of 0.5-in. pipe. The flow of the slurry is upward at the point of detection.

3.6.2 Preheater Detector Positions

The inlet tracer pulse will be measured by a detector positioned directly below the preheater, ~0.5 m (~18 in.) from the inlet, on a vertical run of 1.2[illegible] schedule 160 pipe (see Fig. 19). The slurry-gas flow is upward at the detection point. The radioactive tracer will be monitored leaving the preheater by a detector on a vertical 1.5-in. line ~1 m (~3 ft) from the top of the preheater (B102). Since the preheater is upstream in the processing train from the dissolver (R101), additional information about the flow patterns in the piping between B101 and R101, and within the dissolver, could be obtained if the detectors described in Sect. 3.6.1 for the dissolver were in position and operational during the preheater RTD studies.

Manpower requirements (not including travel time) are:

Technician (supervisory)	3 d

Estimated costs of the detector support are:

D1 - Inlet B102 ~1 m (~3 ft) from ground	$50
D2 - Outlet B102 (support from ladder)	300
D3 - Inlet R101 [1.8 m (6 ft) above ground (suspend from I-beam)]	300
D4 - Outlet R101 at 50% takeoff (support on floor of platform)	50
D5 - Outlet R101 at 100% takeoff (support on floor of platform)	50
D6 - Solids withdrawal R101 (suspend from I-beams)	300
Labor for assembly (3 d)	1000
Total	$2050
Wilsonville piping modifications	
Labor	1500
Materials [5.1 cm (2-in.) fittings and pipe]	1500
Total	$3000

3.7 RADIOTRACER EVALUATION AND SELECTION

Experience at the EDS Pilot Plant indicated the best tracer choices were ^{41}Ar (half-life = 1.83 h; 3–5 mCi per injection) for the gas phase and an aqueous colloidal suspension of ^{198}Au (half-life = 2.69 d; 3–4 mCi per injection) for the slurry phase.[15] Several brominated organic compounds (e.g., bromophenanthrene and bromoadamantane) tagged with ^{82}Br (half-life = 35.4 h) were evaluated, but each appeared to have disadvantages at the high temperatures and reaction conditions in the dissolvers (e.g., thermolysis and reaction with reactor walls).

Radionuclides selected for this study are ^{133}Xe for the gas tracer and ^{198}Au for the slurry tracer. These selections were based primarily on availability and time required for transport to the site. Because of the great distance from the Wilsonville Pilot Plant to the nuclear reactors that might be used to prepare the radiotracers [414 km (257 miles) to Oak Ridge; 233 km (145 miles) to Atlanta], it was not feasible to use ^{41}Ar as the gas-phase tracer. The half-life of ^{133}Xe (5.31 d) makes it more suitable for long-distance transport. Table 4 summarizes information on the radiotracer characteristics.

Table 4. Radiotracer characteristics

Radionuclide	Half-life (d)	γ-radiation (J)	γ-radiation (Mev)	Transformation (γ/disintegration)	Injection activity (mCi)
^{133}Xe	5.31	1.31×10^{-14}	0.081	0.365	400
^{198}Au	2.69	6.58×10^{-14}	0.411	0.955	4

The amount of ^{133}Xe required per injection (~400 mCi) is based on ~4 mCi of ^{41}Ar required at the Baytown, Texas experiment, correcting for an average 0.36 γ per ^{133}Xe disintegration and 2.9% transmission of the 1.3×10^{-14} J (81 Kev) gamma-ray through schedule 160 SS 316 pipe. Xenon-133 can be obtained commercially with specific activities up to 20 Ci/mL.

Approximately 4 mCi of ^{198}Au, adsorbed absorbed on 1–2 cm^3 of 1– to 2-μm ion-exchange resin and then carbonized, should be adequate tracer for both the preheater and dissolver at Wilsonville.

The EDS runs with aqueous colloidal gold were essentially successful, but that may be attributable to the high liquid and gas velocities, which gave adequate dispersion of the gold colloid. If the aqueous suspension of colloidal gold does not form a very fine dispersion during the flash water vaporization as the tracer sample enters the process stream, there may not be sufficient dispersion and mixing at the low velocities used at the Wilsonville SRC plant. Thus, it is recommended that the gold tracer be added as an oil suspension for the Wilsonville runs.

To more closely simulate the coal slurry particles, ^{198}Au tracer on carbonized 1- to 2-μm resin particles is recommended. It should be essentially inert, having been fired to 300°C (572°F) for 1 h in an inert atmosphere. As an upper limit, the settling velocity of 12-μm particles (assumed specific gravity of 1.2) has been calculated to be 1.5×10^{-4} m/s (0.0005 fps) at 420°C (820°F) in a hypothetical Wilsonville oil [(sp. gr. ~0.9 to 1.0; viscosity $>110^{-4}$ Pa/s (>0.1 cp); absolute velocity ~0.03 m/s (~0.1 fps)]. Therefore the 12-μm or smaller particles of 1.2–1.5 specific gravity should closely follow the liquid flow.[8]

Preliminary tests of ^{198}Au-tagged carbonized resin particles should be conducted to confirm the suitability of this material. It is recommended that the dispersion characteristics of these carbonized resin particles be determined in laboratory tests at elevated temperatures. The tests can be conducted in stirred autoclaves and dispersion characteristics determined by optical measurement. If the laboratory dispersion tests indicate there is no problem with agglomeration and settling, the decision will be made to proceed with the use of ^{198}Au-tagged carbonized resin as the slurry tracer. If problems are apparent, we have the option of using ^{198}Au-tagged colloidal gold (in aqueous suspension). However, it is believed that the flashing and resultant pressure surge of the water (in the colloidal gold) as it vaporizes on injection into the 297°C (600°F) process line may contribute to distortion of the tracer impulse.

A Monte Carlo calculation was made that provided supporting evidence that 4-mCi injections of ^{198}Au would give statistically satisfactory tracer measurements. The following assumptions were used: background and electronic noise were not contributing factors; clean 2-in. schedule 160 pipe with 7.63-cm (3.0-in.) insulation; a 2-in. photomultiplier tube shielded by 5.1-cm (2-in.) lead; a (2 x 2 in.) NaI crystal detector with 1.3 x 5.1 cm (0.5 x 2 in.) collimating slit; and 0.8 g/mL slurry density. For a hypothetical 4-mCi injection of ^{198}Au (and postulating 180-fold dilution), the activity level would be 2.26 $\mu Ci/cm^3$ at the detector location. The total count in the detector for the 6.58×10^{-14} J (411 Kev) gamma radiation would be 7,947 $\pm$ 524 counts per second (cps). Of this total, 5,980 $\pm$ 453 cps would be compton and 1,993 $\pm$ 262 cps would be photoelectric. Based on these calculations, it was concluded that if the amount of ^{198}Au activity in the injection had to be increased, the maximum increase would probably be by no more than a factor of three. Recommended preliminary radiotracer tests will permit evaluation of the proposed quantities to ensure statistically significant data.

3.8 TRACER CONTAINERS

The 10-mL tracer containers will consist of 30.5 cm (12 in.) of 0.375-in. SS tubing (0.065-in. thick walls) with two 3/8-in. SS ball valves (rated to 6000 psig), as shown in Fig. 20. Each container will be pressure tested to 2.1×10^7 Pa (3000 psig) prior to loading with the radiotracer, and each will be capped with a plug after loading.

Shielding for the radiotracer containers will consist of 2.54-cm (1-in.) thick, clam-shell lead shields and lead end caps (Fig. 21). The lead carrier will fit inside the approved 4-in. diam x 28-in. pipe shipping container (Fig. 22).[20] Total weight of the sample carrier, including tracer container, is estimated to be 17.4 kg (40 lb). End shields and bolts will be removed at the site, and the tracer container with clam-shell shields will be mounted on the tracer injection assembly.

Eight to twelve sample containers, lead shield carriers, and shipping containers will be necessary for a single set of tracer

ORNL DWG 83-461 R

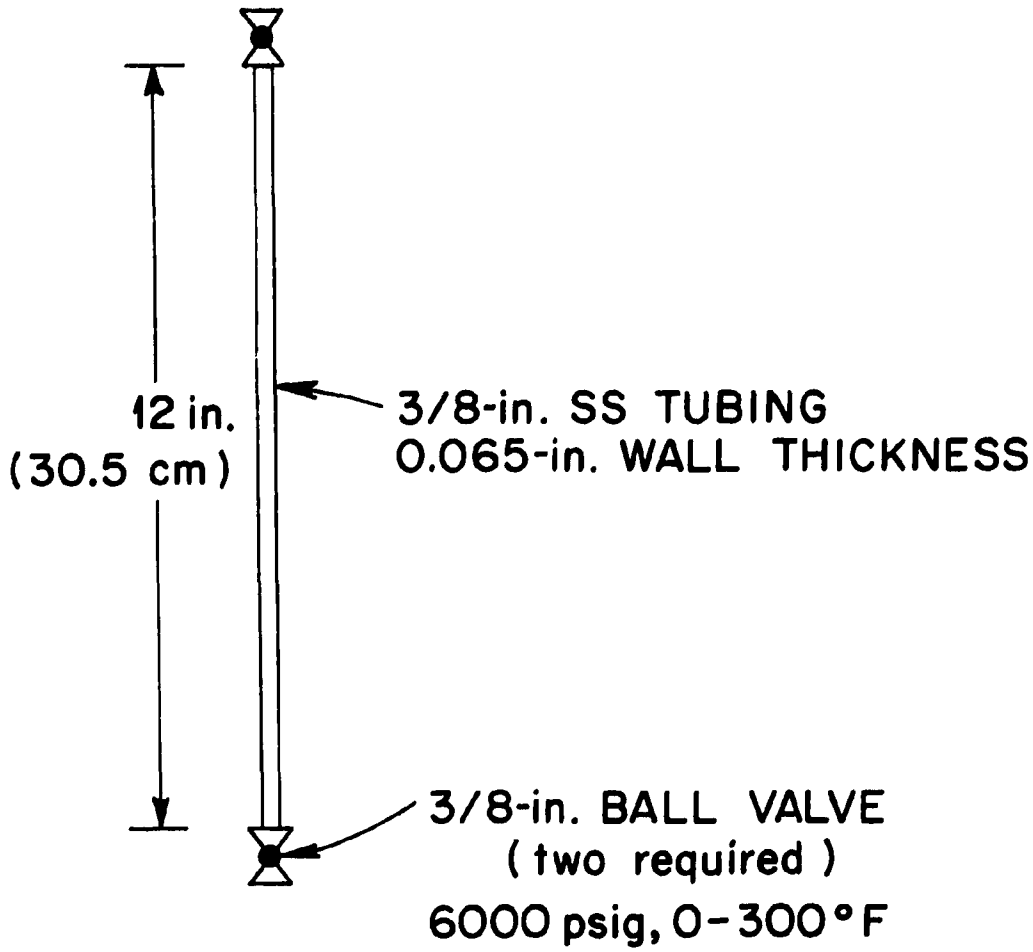

Fig. 20. Tracer container.

ORNL DWG 83-462 R

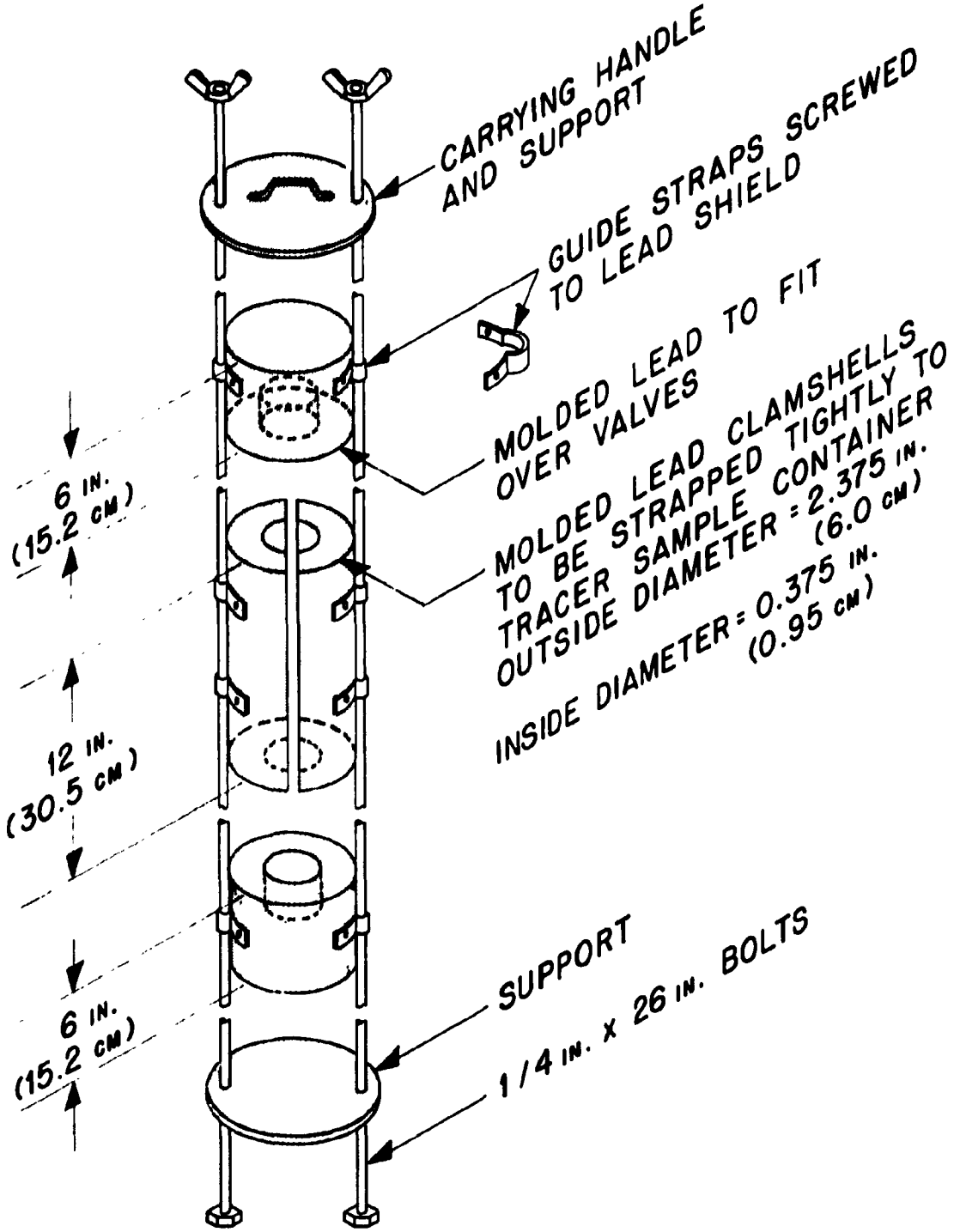

Fig. 21. Lead shielding for tracer carrier.

ORNL DWG 83-463 R

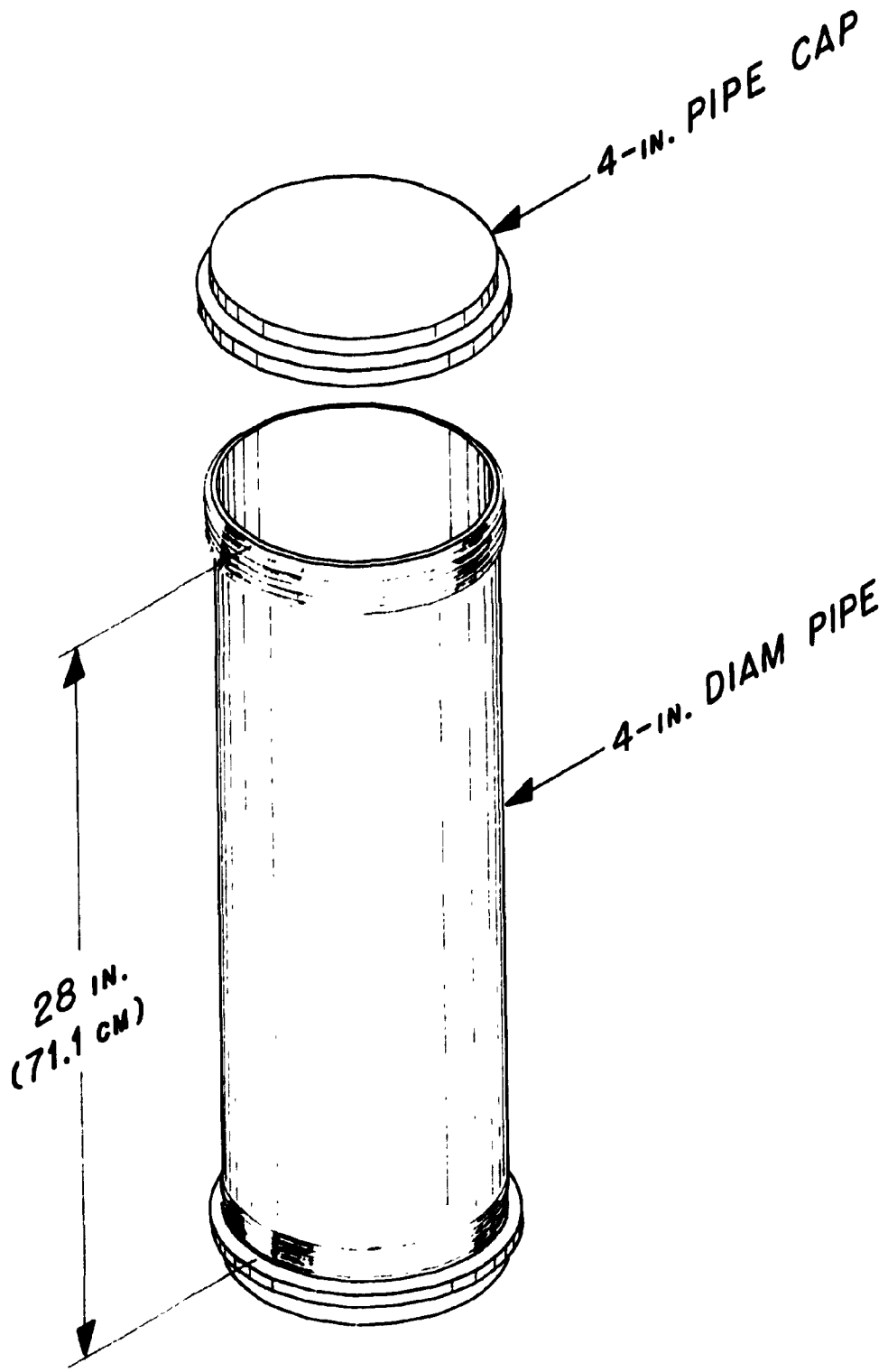

Fig. 22. Approved tracer shipping container.

experiments. The sample containers can be recycled for subsequent experimental sets. Estimated costs for twelve 10-mL sample containers, lead sample carriers, and shipping containers are:

3/8-in. ball valves and tubing	$1600
Pipefitting labor	400
Pressure and leak testing	600
12 lead sample carriers	1200
12 shipping containers	800
Total	$4600

3.9 RADIOISOTOPE PREPARATION

3.9.1 General Requirements

Tracer requirements for a chemical reaction involving three phases (solids, liquids, and gases) have been described previously. In some cases, it is possible to prepare a tracer by neutron irradiation of the compounds involved in the reactions, although this usually results in a mixture of radionuclides that make monitoring difficult and contamination problems unpredictable. In this study, ^{198}Au was selected as the radionuclide for slurry-phase tracing and ^{133}Xe for the gas phase. Gold-198 is prepared by neutron irradiation of elemental gold ($^{197}Au \xrightarrow{n,\gamma} {}^{198}Au$). A small quantity (<5%) of ^{199}Au is produced by a secondary reaction of the product ^{198}Au; however, the isotope is short-lived (half-life = 3.14 d), and should not cause difficulties. A 1-g sample of gold irradiated for ~1 h at 2×10^{14} n/cm^2.s will yield ~20 Ci of ^{198}Au.

The two methods of choice for introduction of the tracer (preparing a colloid in a neutral solution or placing the tracer on microbeads of carbonized organic resin) have been discussed in previous sections of this report. In both cases, packaging is required that will permit injection into the system. The resin beads could be injected as a slurry in oil (e.g., Wilsonville process solvent) or in water from a double-valved container that is shielded for shipping and handling. An ~10-mL container volume will be required.

Gas tracer (^{133}Xe) may be introduced in the same manner with a double-valved shielded cylinder and flushed into the system with an inert gas (nitrogen or helium).

Up to 40 Ci of ^{198}Au, 5 Ci of ^{133}Xe (as compressed gas), and 1000 Ci of ^{133}Xe (as uncompressed gas) may be shipped in Type A packages.[20]

3.9.2 Preparation Methods

The lead time requirement for tracer preparation is 3 weeks. The gold will be prepared for tracer use either as a cabonized resin or as a colloidal suspension.

3.9.1.1 Gold-198 Carbonized Resin Beads

1. Prepare irradiation target (100-mg gold foil) and irradiate for 10 h at 2 x 10^{14} $n/cm^2.s$.
2. Remove from reactor and dissolve in minimum quantity of aqua regia.
3. Fume with HCl to remove nitrates.
4. Prepare an anion-exchange resin — 200 mesh in HCl form (5 cm^3).
5. Adjust gold solution to 3 M HCl concentration (sample the solution for ^{198}Au content).
6. Add gold solution to resin beads and stir for 1 h.
7. Decant excess solution and sample for gold content (difference between starting solution and bead effluent = gold content of beads).
8. Dry resin beads under heat lamp at low temperature.
9. Transfer to a crucible and heat in an inert atmosphere at 300°C for 1 h.
10. Depending upon tracer requirements, disperse beads in oil (Wilsonville process solvent) or water for transfer to injection shipping container.

3.9.1.2 Gold Colloidal Suspension

1. Starting at step 3 above, evaporate solution to near dryness. Fume with HCl to remove nitrates and again evaporate to near dryness.

2. Make solution to 50 mL (pH 4) by water dilution.
3. Add 1 g gelatin dissolved in a water solution containing ascorbic acid.
4. Stir and observe for purple gold colloid formation.
5. Sample solution for ^{198}Au determination.
6. Transfer to shipping injection cylinder.

3.9.3 Xenon-133

Xenon-133 tracer is commercially available from Atomic Energy of Canada Limited (AECL)* and the Sterling Forest (Union Carbide Corporation)† reactor. The vendor could be requested to fill the shipping cylinder that would be used for injection. A single batch preparation at ORNL would be more expensive than commercial procurement. However, the numerous gas injections and required loadings of several sample containers may make it essential to transfer the ^{133}Xe to sample and shipping containers at ORNL. Xenon-133 is also available from General Electric Company** for shipment in glass ampules.

3.9.4 Shipment to Test Site

Two options are available: (1) transport from ORNL by the test team via auto or pickup, or (2) shipment by Federal Express into Atlanta or Birmingham. The second option will require pickup and transport to the site by auto or truck; therefore, half-life considerations make the first option preferable. Standard Type-A packaging is required in either case.[20]

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*Atomic Energy of Canada Limited, Chalk River Nuclear Laboratory, Chalk River, Ontario, Canada KOJ 1JO.

†Union Carbide Corporation, Sterling Forest Research Center, P.O. Box 324, Tuxedo, NY 10989.

**General Electric Company, Nuclear Energy Division, Irradiation Processing Operation, Vallecitos Nuclear Center, Vallecitos Road, Pleasanton, CA 94566

Estimated Costs:

Gold-198 beads or colloid	10 Ci	$1,800
Xenon-133 (commercially available)	20 Ci	2,000
Tracer transfer and container loading		2,000
Shipping charges		200
Miscellaneous costs, fittings, latorabory materials, etc.		1,000
Total		$7,000

3.10 DETECTOR SYSTEM

The experiments will require 6 detector locations. Each will be a 2 x 2 in. NaI(Tl) scintillation detector of the Integral Line Harshaw type, although the actual manufacturer is yet to be determined. At each location, a shield will be installed to surround the sensitive region of each detector with at least 5 cm (2 in.) of lead. In addition, the shield will have a slit collimator oriented along the pipe. The entire assembly of shield and collimator will be placed at the surface of the insulation on the pipe. The physical dimensions of the slit will be based on sensitivity calculations that are not completed at this date.

The selection of the detector system was predicated on the use of ^{133}Xe and ^{198}Au as the radioisotopes. Xenon-133 has a gamma emission of $\sim 1.31 \times 10^{-14}$ J (~80 Kev) and ^{198}Au has a gamma emission of 6.58×10^{-14} J (411 Kev).

The detector system includes both detection and data collection components. The detectors and associated electronics components include:

1. six 5.1 x 5.1 cm (2 x 2 in.) NaI(Tl) scintillation detectors
2. six divider networks for the photomultiplier tube
3. six preamplifiers
4. six amplifiers
5. high-voltage power supplies
6. lead shielding for the six detectors

The data collection components for the system include:

1. an HP-87 microcomputer with 128 K RAM memory and two disk drives
2. a dot matrix printer

3. a plotter
4. three NIM bin/low-voltage power supplies
5. three scaler/timers (quad type)
6. six single-channel analyzers
7. six count-rate meters
8. a 6-pen strip-chart recorder
9. a multichannel phase-height analyzer

3.11 DATA COLLECTION SYSTEM

Radiation data will be in the form of processed voltage pulses as the output of the single-channel analyzer in each detector location. Redundancy of data collection will be provided by two systems, each with a different experimental purpose (Fig. 23). One system, which includes the count-rate meters and the strip-chart recorder, is to present data in real time. The gross count-rate vs time will be recorded and can be viewed as the experiment is in progress. The second system will be used to accumulate digital data and store it on a floppy disk. This data will also be available at the experimental site but not immediately. The system consists of two quad timer/scalers, each with four channels — one of them serving as an internal time base and three channels capable of accumulating data from three detectors. Data collection times will probably be once per second, although the scaler/timer is capable of data collection 10 times per second. At the end of each counting period, the accumulated data is transferred to the HP-87 via the HP-IB built into the computer. When each set of data is transferred to the computer, it will be placed into an array. As each of the data sets are placed in the arrays, time from the computer will also be placed in the array such that any dead time from the data transfer will be known. At the conclusion of a run, the data will be transferred to a floppy disk and also printed or plotted. Other types of preliminary data reduction may be done onsite, such as total accumulated counts. The multichannel analyzer will be available to check energy spectra and serve as a backup for part of the computer system. However, the analyzer specified will not have the capability of the analyzers used in previous experiments (Ft. Lewis and Exxon EDS) and will only cost a fraction of the cost of earlier models.

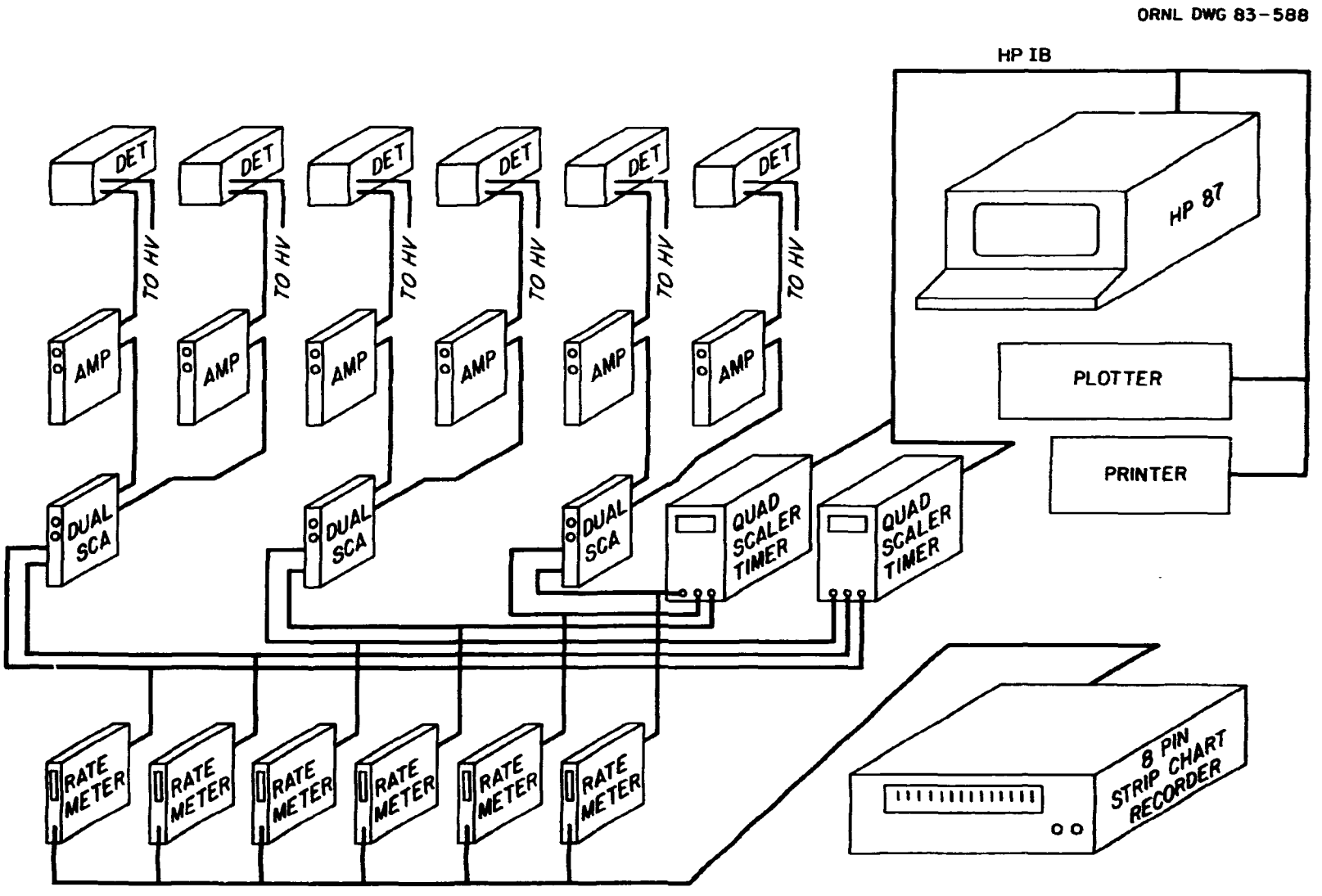


Fig. 23. Tracer data collection system.

Hardware costs of the detector and data handling system are projected to be:

Component	Unit cost	Total cost
Detectors (7)	$ 495	$3,465
Tubebase/preamplifiers (7)	295	2,065
Amplifiers (7)	425	2,975
High-voltage power supplies (6)	660	3,960
Single channel analyzers (7)	340	2,380
Scalers, quad (3)	1,500	4,500
NIM bins (6)	895	5,370
Count-rate meters (6)	455	2,730
HP computer with 2 disk drives	4,300	4,300
Dot matrix printer	775	775
Plotter	1,300	1,300
Computer accessories	600	600
Strip-chart recorder	8,000	8,000
Single-channel analyzers (6)	4,900	4,900
Cables	900	900
Shields (6)	300	1,800
Cabinets (2)	900	1,800
Subtotal		$51,820
Shipping from vendors		470
Sales tax (6%)		3,110
Total materials*		$55,400

Labor costs estimates are:

Assembly of system and checkout	$3,000
Programming	3,000
Documentation	1,800
Total labor	$7,800
Total system costs	$63,200

Estimated manpower requirements (not including travel time) include:

Instrument engineer	3 d
Engineering aid	3 d

Miscellaneous materials for checkout and installation should cost about $500.

*Assuming capital (no overhead).

3.11.1 Instrumentation Shelter

Electronic instruments and computers must be protected from inclement weather; therefore, it is recommended that the electronic equipment, computer hardware, recorders, and associated equipment be housed either in a temporary shelter or in a mobile van that can be parked adjacent to the work area. The van could also provide for transportation of the equipment to the work site.

Estimated costs:

Van rental (9 weeks @ $333/week)	$3,000

3.11.2 Calibration Measurements

Calibration measurements are important for quantitative comparisons of trace measurements made with various sizes of tubing and with tubing having differing amounts of deposits on the inside walls. Spectrophotometric measurements and count-rate measurements should be made on known quantities of ^{198}Au and ^{133}Xe inside representative specimens of the tubing on which measurements will be made at the Wilsonville Pilot Plant. This should include mockups of the tubing containing deposited materials. These measurements are important for meaningful analysis of the collected data.

Manpower Requirements:

Instrument engineer	0.5 man-month
Engineering aid	0.5 man-month

Estimated costs:

Materials	$200

3.12 RADIOLOGICAL SAFETY CONSIDERATIONS

3.12.1 Health Physics Surveillance

At the plant site, all phases of the study that involve handling of radioactive material or contaminated equipment will be under the surveillance of a health physicist. Personnel monitoring and permissible radiation exposure limits will be based on recommendations of the NCRP (National Council on Radiation Protection and Measurements) and ICRP (International Commission on Radiological Protection) and will conform to applicable state and federal regulations.

3.12.2 Radiological Safety at Site: Personnel Exposure Control

Emphasis will be placed on complying with the as low as reasonably achievable (ALARA) philosophy, which requires that all operations be conducted so that personnel exposure to radiation is maintained at an ALARA level. The primary control of radiation exposure will be through the use of physical barriers and exclusion zones. Restricted access areas, determined by radiation monitoring, will be established. These areas will be delineated by ropes and/or warning signs, as the circumstances may require. A secondary safety system will be the establishment of administrative controls over personnel access to the area during the duration of the tests.

All personnel that may be exposed to any significant radiation will be monitored. Planned exposures will be within DOE standards for radiation protection and as far below those limits as is practicable. Protective clothing, as well as respiratory protection, will be provided for personnel who may be exposed to hazardous quantities of radioactivity. A health physicist will be available on site to perform radiation surveys and specify protective equipment requirements.

Gamma radiation levels of the ^{198}Au-tagged material (without shielding) at the time of injection will be 2.3 μSv/h (0.23 mrem/h) at 1 m per 37 MBq (1 mCi), or about 0.01 mSv/h (1 mrem/h) for the expected loading of 148 MBq (4 mCi). Radiation levels at the surface of the injection assembly, assuming 2.54 cm (1.0 in.) of lead shielding, will be about 0.06 μSv/h (6 mrem/h). For the ^{133}Xe, radiation levels will be higher for the bare source but, because of the low gamma energy [1.31×10^{-14} J (81 keV)], the dose from the shielded assembly will be negligible. At a distance of 1 m, assuming no shielding, the injection of 400 mCi of ^{133}Xe will give a gamma radiation field of about 0.04 μSv/h (4 mrem/h). At contact with the shielded source assembly, the dose rate is expected to be inconsequential.

3.12.3 Environmental Release of Radioactivity

Because of their short half-lives, ^{198}Au (half-life = 2.69 d) and ^{133}Xe (half-life = 5.31 d) present a relatively low hazard to the environment. During normal operations, none of the ^{198}Au-tagged resin will be

released. Only a small fraction of the activity may be entrained in the liquid or gaseous phase of the facility. It is expected that >99% will be trapped in, and discharged with, the ash concentrate. For routine operations, this material is placed in metal drums, sealed, and shipped offsite for disposal. Radiotagged ash will be packaged in the same manner. The CSD ash containing ^{198}Au will be isolated and collected in separate, tagged ash containers for a period of 30 min before and 30 min after the calculated time for discharge of the contaminated ash. It will then be monitored, appropriately labeled as radioactive, and placed in a secure area onsite until the radioactivity has decayed to negligible levels. For the ^{198}Au tagging, this holding period would be about 3 weeks. After this time, the ash concentrate can be handled like that generated during normal operations.

Calculations were made of the radiological consequences of the release of ^{133}Xe from the stack. Using the conservative assumptions of a wind speed of 1 m/s in a uniform direction and the diffusion coefficients for Pasquill Type-F turbulence, an injected dose of 14.8 GBq (400 mCi) will result in average air concentrations at ground level that are below the MPC_a levels listed in 10CFR20, Appendix B, for occupational exposures.[21,22]

A credible incident would involve the accidental release of some of the ^{198}Au-tagged material during the injection phase. The probable location of a leak would be at the injector assembly connections or at a valve assembly. To minimize the possible consequences, the area beneath the injection site will be covered with a plastic barrier, and a plexiglas shield will be mounted around the injection apparatus to prevent the operator from getting sprayed if leakage occurs. In addition, if surface temperatures permit, a thick polyethylene sleeve will be fitted over the sample injection equipment to provide further containment. Radioactivity will be continuously monitored in the working environment at the injection site and at other selected sites.

In the event of an accidental release, decontamination efforts would be instituted at once. Continuous health physics surveillance will insure that the radioactive material is confined to the immediate

area of the injection. The possibility of accidentally transporting significant quantities of radioactivity outside the site boundary is minimal.

3.13 XENON SOLUBILITY IN COAL LIQUIDS

To more accurately determine the phase holdups and residence times, it may be necessary to determine the solubility of xenon in coal liquids at operating temperatures. Equilibrium measurements may be made in the laboratory using ^{133}Xe-labeled xenon gas in autoclave systems, sampling and measuring the radioactive xenon in both the gas and liquid phases.

Manpower requirements for these solubility tests are:

Scientist	1 man-month

Estimated costs:

Materials	$1,000
(Autoclave facilities will also be required)	

3.14 DATA ANALYSIS

The data from this series of radiotracer experiments should be analyzed to obtain as much information as possible from the RTD measurements. The amount of information which can be extracted from the RTD curves will, of course, depend on the accuracy of the data, and attempts have been made to involve those with experiences related to all phases of the experiment, including data analysis, in planning of the experiment. The aim has been to provide the best opportunity for the experiment to produce the most accurate and meaningful data practical. The analysis can involve conventional methods to assess flow patterns within the vessels to be studied.

The simplest results will be the mean residence times of both the slurry and gas phases measured and thus the holdup of each phase in the process. The holdup measurements are important in reactor modeling and can be useful in detecting internal changes in the reactor units from accumulation of char or other solids that reduce fluid residence times. When multiple measurements can be made at different positions in the unit, data can be obtained for different portions of the reactor.

The shapes of the RTD curves will give greater insight into the flow patterns. Using the internal structure of the unit(s) studied, relatively simple flow models should be tested to see whether they predict the observed RTD curves and are consistent with reasonable flow patterns within the unit. Such models can be useful, for instance, to quantify dispersion and to locate by-passing and stagnant regions within the reactor.

The more accurate and precise the data, the more detailed and useful the resulting analyses. If the results should be less accurate than anticipated, only simple analyses of holdup and dispersion numbers (or coefficients) may be justified. In this case, approximately one man-month should be expected to analyze the data for two units and contribute to the final report. With better data, estimations of the amount of by-passing or stagnant area, as well as the amount of solids accumulation may be obtained with a modest increase in analysis time. Modest computer costs (~$1000) should be anticipated for the calculations and for preparation of several tables and graphs.

Estimated costs are:

Manpower requirements	1.5 man-month
Computer charges	$1000

3.15 FINAL REPORT

The supervising engineer-scientist will be responsible for preparation of the final report. Writing, preparing a draft copy, coordinating input from coauthors, incorporating reviewer criticisms, preparing engineering drawings, and other tasks will require approximately 1 man-month.

Manpower requirements are:

Engineer-scientist	1 man-month

Estimated costs are:

Editing, printing, drafting and materials	$3000

3.16 SUMMARY OF PERSONNEL, LOGISTICS, AND ANCILLARY ONSITE COSTS

Accomplishing the objectives of the proposed RTD tracer experiments will require full time engineer-scientist supervision. It is estimated

that 3.0 man-months will be required to complete procurement, construction, experimentation, data analysis, and report writing. Approximately 1.5 man-months of technician time will be required for testing equipment, laboratory experimentation, and onsite experimental assistance. An instrument engineer will be required for development of the detector system, experimental assistance, calibration measurements, data interpretation, and report writing (estimated 1.5 man-months). An instrument engineering aide will be required for calibration measurements and onsite installation assistance (estimated 1 man-month). A health physicist will be required for consultation, procurement and use of radioactivity monitoring instruments, and onsite experimentation (estimated 1 man-month). A second technician will be required to transport the radiotracer containers and shuttle the empty tracer containers for reuse (estimated 12 man-days). Transportation of up to 12 loaded and shielded tracer containers can be accomplished in a standard automobile or station wagon.

All personnel will be involved in dismantling the experimental apparatus and completing cleanup details. Protective clothing and miscellaneous cleaning materials will be required.

An engineer-computer scientist will be required for data analysis, data interpretation, preliminary model development, and report writing (estimated 1.5 man-months).

A proposed RTD schedule to accomplish the experimental work is presented in Table 5, and a projected time schedule for completion of the entire test program within 21 weeks is given in Table 6.

Total estimated manpower requirements are:

Engineer-supervisor	3 man-months
Technician	1.5 man-months
Instrument-engineer	.5 man-months
Instrument-engineering aide	1 man-month
Health physicist	1 man-month
Technician (transportation and utility)	12 man-days
Computer scientist	1.5 man-months
Estimated total costs	$99,800

Table 5. Proposed RTD work schedule[a]

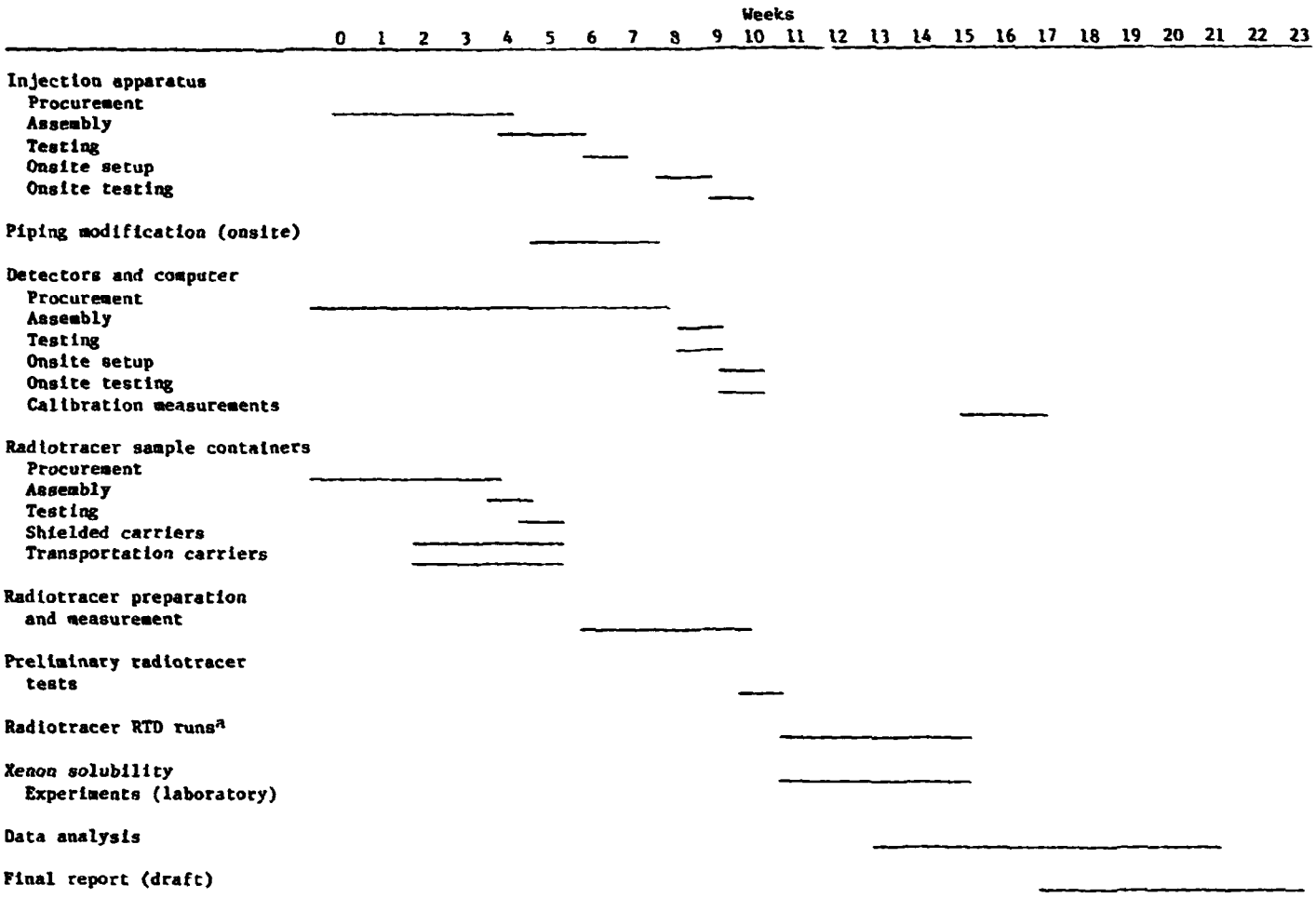
	Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Travel round trips	Nights lodging	Days per diem
Scientist-Supervisor	T(C1)	←	IC		→	←	R1		→	←	R2		→	←	R3	→	←	R4	→	←	CD	→	T(C1)	1(C1)	20	21
Technician	T(C1)	←			→	←			→	←			→	←		→	←		→	←		→	T(C1)		20	21
Instrument-Engineering Aid		T(V)	←	IC	→	T(C2)																		1(C2)	4	5
Instrument-Engineer		T(V)	←	IC	→	←			→	←			→	←		→	←		→	←		→	T(V)	1(V)	19	20
Health Physicist		T(C2)	←		→	←			→	←		→		←		→	←		→	←		→	T(V)		19	20
Technician (Radiotracer and utility)					T(C3)			T(C3)	T(C3)			T(C3)	T(C3)		T(C3)	T(C3)		T(C3)						4(C3)	10	14

[a] Assuming prior installation of detector mounts, which requires 3 d supervision, travel, and lodging for 4 nights.

T = Travel
IC = Installation and checkout
R1 = RTD Phase 1

Vehicles Required (if ORNL conducted)
C1 = Car 1 or truck with injection apparatus
C2 = Car 2

Table 6. Projected time schedule



[a]If experimental problems should occur after this sequence has started, this could possibly require termination of the experiment and starting again with radiotracer preparation and procurement. A time shift would then result for all subsequent tasks.

Table 7. Summary of total costs

Manpower	$99,800
Ancillary onsite costs	7,900
Tracer injection	
System apparatus	5,500
Onsite installation	300
Detector mounts and installation	2,050
Wilsonville piping modifications (cost to Catalytic, Inc.)	3,000
Tracer containers, lead containers, and shipping containers	4,600
Tracer preparation and packaging	7,000
Detector system (hardware, assembly, programming)	63,200
Detector system installation	500
Van rental	3,000
Calibration measurements	200
Xenon solubility studies	1,000
Radiation monitoring	1,000
Computer charges	1,000
Final report (editing and materials)	3,000
Contingency (15%)	30,450
Total	$233,500

Ancillary onsite expenses include:

Transportation (est. 9 round trips @ 520 miles)	$1,000
Lodging (total 110 d)	3,500
Per diem (total 120 d)	2,400
Miscellaneous materials (rubber gloves, blotter paper, protective clothing, plastic bags, etc.)	1,000
Total costs	$7,900

4. WORK PERFORMANCE

The portion of this proposed RTD tracer test series that involves handling and use of radioactivity must be accomplished, monitored, and controlled by an approved, licensed contractor.

5. STATE AND FEDERAL APPROVALS

The State of Alabama is an "agreement state." Therefore, a contractor with a federal license does not have to obtain a federal permit to conduct radiotracer studies within the state. However, state approval must be obtained to conduct the tracer RTD experiments at the Wilsonville, Alabama site. Application for approval should be made to the Alabama State Department of Public Health at the following address:

Dr. Aubrey Godwin
Alabama State Department of Public Health
Division of Radiological Health
State Office Building
Montgomery, AL 36130-1701

6. RECOMMENDATIONS

If the proposed radiotracer experiments proceed well and high-quality data are obtained, other tracer experiments may be considered while the equipment is in place, for economic reasons. For example, with the system in a two-stage liquefaction mode using recycle of hydrotreated solvent, a set of RTD experiments would permit evaluation

of the effects of solvent recycle on the dissolver behavior. In this alternate mode, it will be important to run one test at a high gas velocity. Other experiments may be suggested by the results of this study.

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