

THE NERC-LV BURNER-
A MONITOR FOR RADIOACTIVITY
IN NATURAL GAS

by
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Environmental Surveillance
National Environmental Research Center
U.S. ENVIRONMENTAL PROTECTION AGENCY
Las Vegas, Nevada

Published February 1973

This surveillance performed under a Memorandum of
Understanding No. AT(26-1)-539
for the
U. S. ATOMIC ENERGY COMMISSION

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ABSTRACT

An air-aspirated natural gas combustion/condensation system has been developed for remote location monitoring for radioactivity in natural gas through measurement of tritium. Water of combustion is collected and analyzed for tritium by liquid scintillation techniques in use at the National Environmental Research Center-Las Vegas. This system has operated well for estimated ambient temperatures ranging from -20°F through $+140^{\circ}\text{F}$. Successful absolute tritium concentration determinations have been made for contaminated natural gas with known amounts of tritium. One system has operated with no major malfunctions for a year-and-a-half near the Gasbuggy site, located sixty miles east of Farmington, New Mexico.

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INTRODUCTION

Projects Gasbuggy and Rulison were designed to experimentally test the feasibility of the concept of underground nuclear stimulation of natural gas production. The low permeability rocks of the Lewis Shale formation and the Mesa Verde formation were extensively fractured by these two nuclear tests. This fracturing was intended to allow increased gas flow from these rock formations.

The use of nuclear explosives, however, imposes restrictions on the use of the gas. The inherent radioactivity associated with these detonations requires that a time interval for radioactive decay be allowed before producing the gas, and that the gas be continuously monitored when released. Producing wells in the surrounding area were also monitored to determine if the underground fracturing provides a path for radioactivity to move to their source volume.

To meet this monitoring requirement, the National Environmental Research Center-Las Vegas (NERC-LV)* developed and field tested a system to continuously burn natural gas at the sampling location and collect the combustion water for tritium analysis. Until development of the burner system, measurements were being made of the radioactivity in both the experimental well gas and, in the case of Gasbuggy, in the production gas from surrounding wells by filling high-pressure bottles and shipping them to the NERC-LV for analysis ⁽¹⁾. Tritium analysis was performed on free water collected with molecular sieve used to dry the gas during the sample collection ^(1, 2). Gas analysis was accomplished either by open flame combustion ⁽¹⁾ or by oxidation over hot copper oxide; the combustion water collected in both cases was prepared for liquid scintillation counting for tritium ⁽²⁾.

*At the time this work was performed, the Center was named the Western Environmental Research Laboratory.

However, the pressure bottle methods used were expensive and cumbersome, and provided sampling only at specific points in time. The burner system to be described requires no power and provides unattended, continuous sampling in remote locations with only periodic attention for collection of the condensate samples. The condensate sample still needs to be sent to the NERC-LV for tritium analysis; however, a complete electronic tritium assay system is currently being built which will provide recorded data at the sampling location while requiring even less attention and no sample shipment.

SYSTEM DESCRIPTION

The burner system is a combustion chamber with a condensation column exhaust and control units, as outlined in Figure B-1 of the attached burner component drawings. The gas inlet flow is controlled with a pressure regulator, the optimum operating pressure being determined by the orifice size in the aspirator and the size of flame produced in the combustion chamber. An excessive flame yields a high condenser temperature and low condensate collection efficiency. For gas pressure higher than 30 psig, double pressure regulation is recommended for smooth gas flow.

The aspirator is a Prest-O-Lite* model 402 mixer with a #2 torch, cut and threaded to fit the combustion chamber. The orifice used is determined by the composition of the gas to be combusted. Additional holes were drilled into the aspirator body to allow greater flexibility in mixture control. Air aspiration is a fairly critical function, which is somewhat sensitive to interfering parameters such as the gas composition, associated water, and dirt. Initial operation was not without problems; for example, the Project Rulison gas assayed initially as high as 47 percent carbon dioxide, and high contents of free water and a heavy sludge ⁽³⁾. Since the carbon dioxide fraction is also responsible for some air aspiration, the orifice configuration had to be changed as the carbon dioxide content of the gas

*Registered trademark

decreased. As long as correct mixtures were obtained, no combustion problems occurred as a direct malfunction of the aspirator.

The burner section is made from 1-inch inside diameter stainless steel pipe, flanged near the middle to accommodate a fire screen (Figure B-2). The line carrying the combustible mixture from the aspirator enters the bottom of the burner section. The lower section of the burner assures complete air-gas mixing, and the diffusion screens allow even burning over the entire fire screen surface to reduce the height of the hot combustion region. A spark plug igniter, shown as a dashed circle in the drawing, was installed approximately 1 inch above the fire screen.

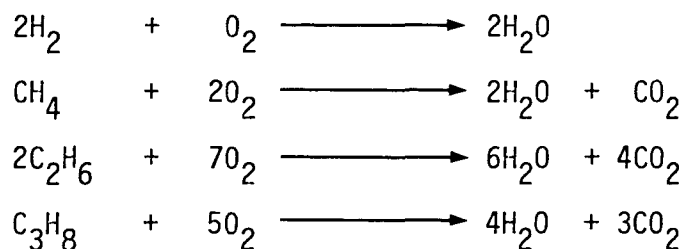
The condenser section, shown in Figures B-3 through B-6, is made from copper tube 1-1/4 inches inside diameter and copper sheets four inches square. All the cooling surfaces are made to take advantage of vertical convection cooling in addition to radiative cooling. The condenser is mounted within the incline angle limits shown to allow condensate flow to the outlet without restricting the exhaust flow. Additional condensing surface is provided in the secondary section by inserting a copper sheet with a tight, slide fit.

OPERATING THEORY

Quantitative use of the burner system depends upon the concept that the true combustion properties of the air/gas mixture follow the classical combustion equations for the assayed components of the gas mixture. For example, an assay of the Rulison gas (February 10, 1971) indicated the following components: (3).

N ₂	0.4%
CO ₂	22.5%
H ₂	7.0%
CH ₄	65.8%
C ₂ H ₆	3.2%
C ₃ H ₈	0.79%
Heavy Hydrocarbons	0.4%
Water Content	No value given

The free nitrogen and the carbon dioxide are non-combustibles. The heavy hydrocarbons were neglected and an oily sludge material was taken out with associated water in a trap ahead of the burner. These components of the natural gas may be disregarded for the intent of this paper since they are either a very small fraction of the total, or would normally be removed for consumer use. The combustion equations, then, for the remaining components are:



Calculating on a molar basis and correcting for the assay composition, one liter (STP) of dry natural gas will yield 1.2 milliliters of water. Any water vapor remaining in the gas would be included as an addition to the water of combustion. A direct conversion of radioassay data from a condensate sample will give the tritium activity associated with the dry natural gas on a unit volume basis.

The indicator of residual radioactivity in the gas for both the Gasbuggy and Rulison events was tritium, produced by neutron activation and the

fission process. Being a molecular constituent of the natural gas and the ground water, underground movement of these compounds can be monitored without regard to preferential absorption or natural filtration such as might be noted for other radionuclides produced by the events. Combustion of the natural gas and condensation of the exhaust water into a sample for tritium analysis, then, allows a valid means for detection of underground movement of the contaminated gas and water to nearby clean production wells.

The liquid scintillation procedures ⁽²⁾ used at the NERC-LV yield minimum detectable activity (MDA) values of 400 pCi/l for tritium in water ⁽⁴⁾; and, depending on the background count statistics at the time, the MDA may be well below this. The MDA for gas having the assay indicated above is less than 500 pCi/m³. Having no specific guidelines for maximum allowable tritium concentration in natural gas, one might compare the monitor system sensitivity to the guideline for tritium in air of 6.7×10^4 pCi/m³ in general population areas ⁽⁵⁾. Hence, with the ability to detect two orders of magnitude below this concentration, the burner system is considered to be very suitable for natural gas monitoring purposes.

Since the exhausted gases are saturated, but at a lowered temperature, some of the combustion water is certainly lost and only a fraction of the total production is collected. The basic assumption used in consideration of data from the burner system is that no isotope effect or tritium partition will be noted; the condensate water will have the same tritium concentration as the total water produced by combustion. Some published data indicate that this is not entirely true, that an enrichment of up to about ten percent may be seen at the temperatures considered for the condenser ⁽⁶⁾. However, tabulated data comparing the burner system with two other measurement methods (Appendix A) show that the burner results are within a few percent of matching the best available values for tritium activity in the Rulison gas ⁽³⁾. Had correction been made for more recent gas composition assays, the burner data would more closely align to those data from the other methods. In the final analysis, it is felt that isotope effect may be disregarded for general use of the system. Other influential parameters such

as dilution by atmospheric moisture and activity contribution from atmospheric tritium are thought to have more questionable effect on the data.

OPERATING EXPERIENCE

As mentioned above, two units were built by the NERC-LV and fielded for use at the Gasbuggy and Rulison sites. However, the uses of the two units were different enough to warrant separate discussion. A burner was operated at the Gasbuggy site first, due to the existing gas sampling program there. At the time of completion of the first unit, gas sampling involved monthly collection of gas at two points on trunk lines serving wells in close proximity to the Gasbuggy experimental well. The samples were then sent to the NERC-LV for analysis. This was done to assure the Atomic Energy Commission, El Paso Natural Gas Company (EPNG), and the State of California that no radioactivity was present in that gas being distributed to consumers in southern California.

The initial purpose for the burner installation at the Gasbuggy site was two-fold; an extended operational/lifetime test of the unit, and a comparison of the burner data at the background level to the pressure bottle data were needed. The burner proved successful on both points. The burner was installed at the production line sampling point early in October 1970, in a metal shed provided by EPNG. It was still operating satisfactorily, as of June 1972. Two short down-times were experienced; one was due to extreme cold ($<-20^{\circ}\text{F}$) and condensate freezing, and the other was due to a plugged orifice which restricted the gas flow and altered the combustion mixture. To remedy the problem of freezing condensate, EPNG personnel installed a small catalytic heater in the shed. Data obtained by monitoring non-contaminated gas from wells surrounding the Gasbuggy well indicated concentrations less than the minimum detectable activity for the liquid scintillation procedures at the Center. This is exactly the result seen from laboratory combustion of the pressure bottle samples. The indication is that the use of atmospheric oxygen for combustion presents no problems in the way of sample contamination by atmospheric tritium.

For the gas constituent assay combustion of one cubic meter (STP) of gas will produce 1200 ml of water; this combustion requires approximately ten cubic meters of air. From air sampling experience in the area, a cubic meter of air contains about three milliliters of water. The comparison, then, is that 30 ml of atmospheric water are aspirated for combustion as opposed to more than 1200 ml of water produced by the gas combustion. This is a dilution of only 2.5 percent. Therefore, sample dilution by atmospheric moisture is extremely small as compared to the large amounts of water obtainable through combustion. This is considered to be the generally encountered condition in the western United States. Calculations based on high humidity conditions (97% RH @ 85⁰F) yield up to 30 ml of water per cubic meter of air, giving a dilution up to 25%. However, this does not reduce the usefulness of the burner for monitoring purposes, but does restrict its use for quantitative information. Satisfactory burner-condenser operation was seen for an estimated temperature range of -20⁰F through +140⁰F; however, no continuous observations were made of condensation at these extremes. Some doubt exists on the condenser effectiveness above 130⁰F.

The second unit was constructed to be used at the Rulison site during the third production test flaring operation. The unit was to be used to obtain some experience on known contaminated gas and to get a comparison of the resultant data to that yielded by a pure O₂ oxidizer system operated on-site by Eberline Instrument Corporation (EIC). The EIC oxidizer was a commercially available sample oxidation unit for laboratory use, modified to give continuous gas combustion. Subsequent sample procedures were essentially the same as those employed by the NERC-LV for the burner samples. The EIC oxidizer was operated on the same gas line as the burner and should yield comparable data. The primary differences between the two units are their oxidant supply and their adaptability to remote location use. The burner proved its usefulness for absolute measurement of tritium in natural gas; a comparison of three sampling methods (Table 1, Table A-1) supports this measurement.

Table 1. Tritium Concentrations in Rulison Gas from Various Monitoring Methods.

NERC-LV Burner pCi/l	EIC Oxidizer pCi/l	Pressure Bottle-Lab Oxidation pCi/l	
5.0×10^4	5.0×10^4	5.0×10^4	5.2×10^4
1.2×10^4	1.1×10^4	1.1×10^4	1.2×10^4
1.5×10^3	3.3×10^3	1.0×10^3	3.6×10^3

A continuous comparison of the burner data and the EIC oxidizer data is given in Appendix A (Figure A-1 and Table A-1). These results show that the burner provides good stability in the data and a very close comparison to those data collected with an acceptable method. The divergence of the data toward the later sampling dates is considered to be due to the changing gas composition (reduction of relative CO₂ volume), since all the data presented for the burner employ calculations based on the February 10, 1971, gas composition assay.

CONCLUSION

The described burner-condenser system provides an acceptable, reliable, and inexpensive method to continuously monitor for radioactivity in natural gas produced from wells stimulated by underground nuclear explosives. The sensitivity of the liquid scintillation methods employed by the NERC-LV provides an analysis capability for tritium in the combustion water down to a minimum detectable activity of 400 pCi per liter of water. This is equivalent to 500 pCi of tritium per cubic meter (STP) of natural gas having the same composition as that from the Rulison experimental well. Operational experience indicates reliable operation for estimated ambient temperatures ranging from -20°F through +140°F, and data were obtained for natural gas known to have background or elevated radioactivity levels. Consistent and reliable sampling has been shown by one of the units for a year-and-a-half at a remote location near the Gasbuggy site. Demonstrated applications of the system include monitoring of normally uncontaminated natural gas for possible radioactive contamination, and integrated sampling for quantitative determination of tritium concentration in gas known or suspected to have elevated levels of tritium.

For quantitative determination of the tritium concentration in natural gas, it is necessary to have an accurate gas composition assay. With changing gas makeup, as encountered at Project Rulison, it is necessary to assay often enough to incorporate significant changes. For a relatively stable situation, as would be encountered on a production line, less frequent assays are required. However, if the intended use is to monitor gas for the possibility of contamination, no assay is required since one is looking only for data above the MDA to use as an action guideline. More accuracy would be desirable if positive results are seen.

Limitations on quantitative use of the burner system arise primarily from two sources, (1) ambient air humidity, and (2) ambient air temperature. The severity of the effect from these factors is determined by the use for which the system is intended. Only attempts to measure absolute tritium concentration will be hindered, while general monitoring of production lines for radioactive contamination is unaffected.

The humidity problem mentioned previously can yield discrepancies in the data to as much as 25 percent by dilution. This is resolved by periodic measurement and subtraction of the contributed water volume during data reduction calculations.

The effect of ambient air temperature can be a complex interference. The condenser portion of the burner system depends on ambient air for coolant, and condensation efficiency is therefore a function of ambient air temperature. The problem arises when one considers the possibility of a significant change of the tritium concentration in the natural gas during a sampling period when the ambient air temperature may fluctuate widely. No simple relationship will exist between the tritium concentration of the natural gas and that of the combustion condensate water. This is not considered to be the normally encountered situation; however, should the possibility exist the sampling time can be reduced so that the condensate tritium concentration more nearly reflects that in the gas being monitored.

It is currently necessary to ship water samples (condensate) to the Center for analysis. A project is underway at the NERC-LV to develop and test an electronic tritium detection and printout system capable of remote and independent operation. This unit will automatically measure and record on-site data on the tritium concentration in natural gas at any given location, and will relieve the question of ambient air temperature effect.

REFERENCES

1. Johns, F. B. and Jaquish, R. E., Gas Analysis Capabilities of the Southwestern Radiological Health Laboratory (SWRHL-91), April 1970.
2. Johns, F. B., Southwestern Radiological Health Laboratory Handbook of Radiochemical Methods (SWRHL-11), March 1970.
3. Project Rulison - Final Operational Radioactivity Report - Production Tests (NVO-112), February 1970.
4. Johns, F. B., Unpublished data.
5. Standards for Radiation Protection, USAEC Manual Chapter 0524 (1968).
6. Jones, W. M., Vapor Pressures of Tritium Oxide and Dueterium Oxide. Interpretation of the Isotope Effects, J. Chem. Phys. 48:207-214 (1968).

APPENDIX A

Tritium Concentrations in Natural Gas - Project Rulison

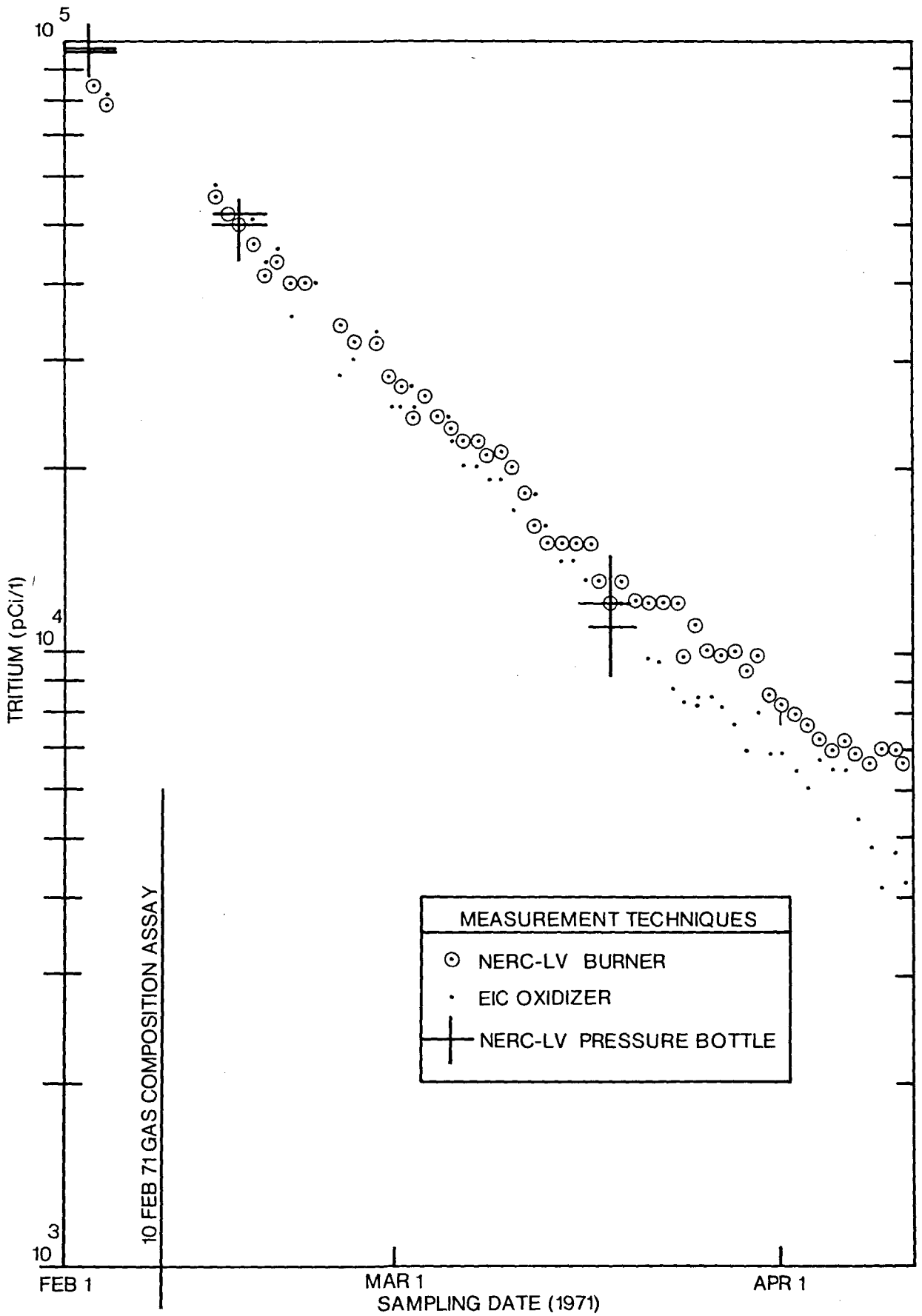


Figure A-1. Tritium in Natural Gas - Project Rulison

Table A-1. Tritium in Natural Gas - Project Rulison

Sampling Period	NERC-LV Burner (x10 ³ pCi/l gas)	EIC Oxidizer ⁽³⁾ (x10 ³ pCi/l gas)	NERC-LV Pressure Bottles (x10 ³ pCi/l gas)	
02/02 - 02/03			97	98
02/04 - 02/05	84	83		
02/05 - 02/06	78	80		
02/14 - 02/15	55	57		
02/15 - 02/16	52	52		
02/16 - 02/17	50	50	50	52
02/17 - 02/18	46	51		
02/18 - 02/19	41	43		
02/19 - 02/20	43	44		
02/20 - 02/21	40	35		
02/21 - 02/22	40	40		
02/24 - 02/25	34	28		
02/25 - 02/26	32	30		
02/27 - 02/28	32	33		
02/28 - 03/01	28	25		
03/01 - 03/02	27	25		
03/02 - 03/03	24	25		
03/03 - 03/04	26	25		
03/04 - 03/05	24	24		
03/05 - 03/06	23	22		
03/06 - 03/07	22	20		
03/07 - 03/08	22	20		
03/08 - 03/09	21	19		
03/09 - 03/10	21	19		
03/10 - 03/11	20	17		
03/11 - 03/12	18	18		
03/12 - 03/13	16	16		
03/13 - 03/14	15	15		
03/14 - 03/15	15	14		
03/15 - 03/16	15	14		
03/16 - 03/17	15	13		

Table A-1. Tritium in Natural Gas - Project Rulison (continued)

Sampling Period	NERC-LV Burner (x10 ³ pCi/l gas)	EIC Oxidizer ⁽³⁾ (x10 ³ pCi/l gas)	NERC-LV Pressure Bottles (x10 ³ pCi/l gas)	
03/17 - 03/18	13	13		
03/18 - 03/19	12	11	11	12
03/19 - 03/20	13	12		
03/20 - 03/21	12	11		
03/21 - 03/22	12	9.7		
03/22 - 03/23	12	9.6		
03/23 - 03/24	12	8.7		
03/24 - 03/25	9.8	8.3		
03/25 - 03/26	11	8.4		
03/26 - 03/27	10	8.4		
03/27 - 03/28	9.9	8.1		
03/28 - 03/29	10	7.6		
03/29 - 03/30	9.3	6.9		
03/30 - 03/31	9.8	7.9		
03/31 - 04/01	8.5	6.7		
04/01 - 04/02	8.2	6.7		
04/02 - 04/03	7.9	6.4		
04/03 - 04/04	7.6	6.0		
04/04 - 04/05	7.2	6.6		
04/05 - 04/06	6.9	6.4		
04/06 - 04/07	7.1	6.4		
04/07 - 04/08	6.8	5.3		
04/08 - 04/09	6.6	4.8		
04/09 - 04/10	6.9	4.1		
04/10 - 04/11	6.9	4.7		
04/11 - 04/12	6.6	4.2		
04/12 - 04/13	6.1	3.9		
04/13 - 04/14	5.9	3.9		
04/14 - 04/15	6.2	3.7		
04/15 - 04/16	6.0	4.0		

Table A-1. Tritium in Natural Gas - Project Rulison (continued)

Sampling Period	NERC-LV Burner (x10 ³ pCi/l gas)	EIC Oxidizer ⁽³⁾ (x10 ³ pCi/l gas)	NERC-LV Pressure Bottles (x10 ³ pCi/l gas)	
04/16 - 04/17	6.1	3.7		
04/17 - 04/18	5.5	3.5		
04/18 - 04/19	2.9	3.4		
04/19 - 04/20	4.8	3.3		
04/20 - 04/21	4.1	3.3		
04/21 - 04/22	4.6	3.2		
04/22 - 04/23	4.3	3.3		
04/23 - END	1.5	3.3	1.0	3.6

APPENDIX B

Burner Component Drawings

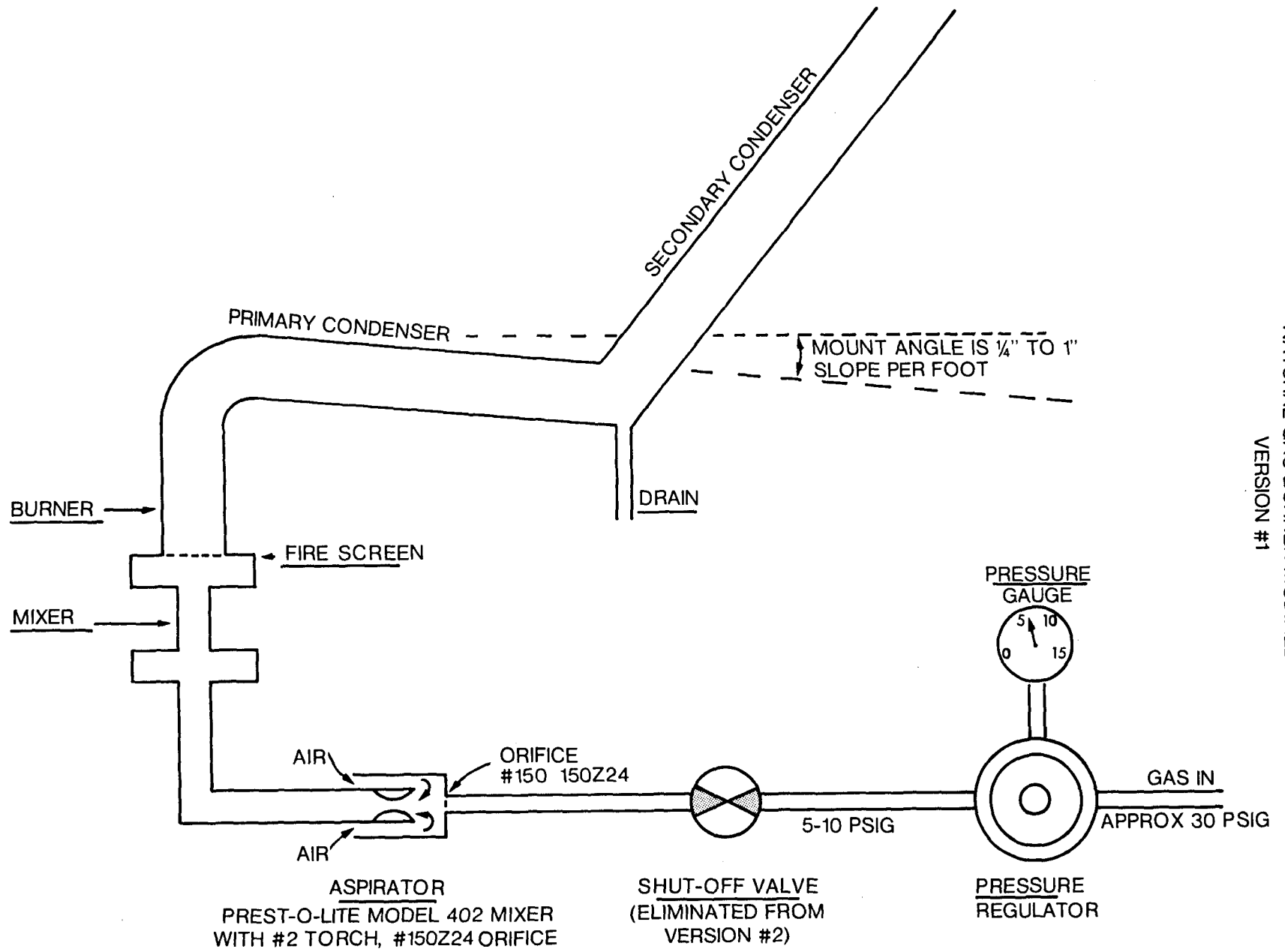


Figure B-1. NERC-LV Burner - Schematic Representation

NATURAL GAS BURNER

BURNER ASSEMBLY-MODIFICATION #2

BURNER ASSEMBLY
OVERALL
CROSS SECTION

EXHAUST-CONDENSER
DWG. E

COMBUSTION CHAMBER
DWG. B

FLANGE (DWG. C)
BRASS GASKET (DWG. 6-BODY)
AND FIRE SCREEN (20 MESH SS)
FLANGE (DWG. C)

MIXER
DIFFUSION
SCREENS
(20 MESH SS)

REDUCER

ALL PARTS STAINLESS STEEL

DRILL AND TAP TO $\frac{1}{4}'' \times 28'$

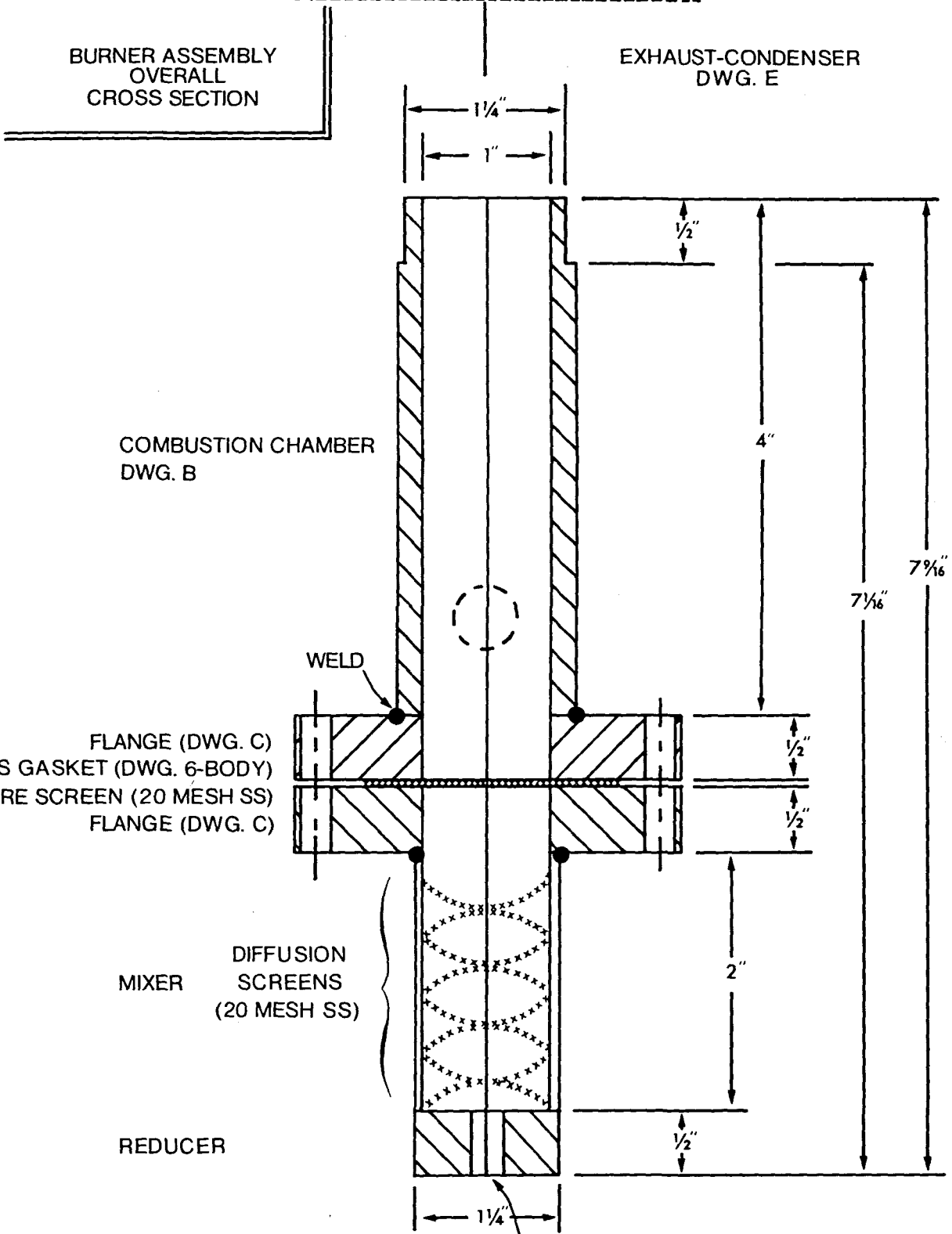
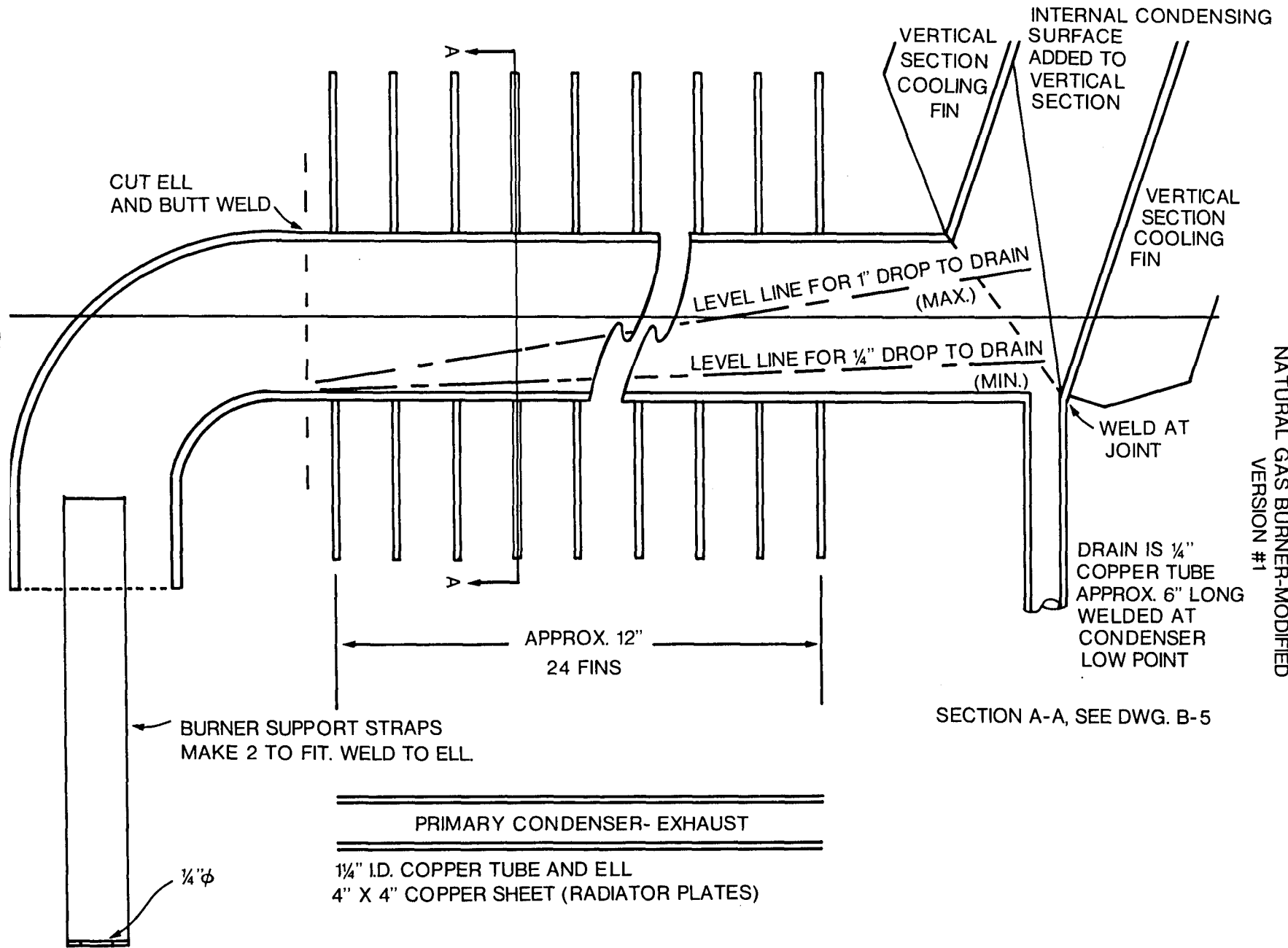


Figure B-2. Combustion Chamber

Figure B-3. Primary Condenser



NATURAL GAS BURNER-MODIFIED
VERSION #1

NATURAL GAS BURNER-MODIFIED
VERSION #1

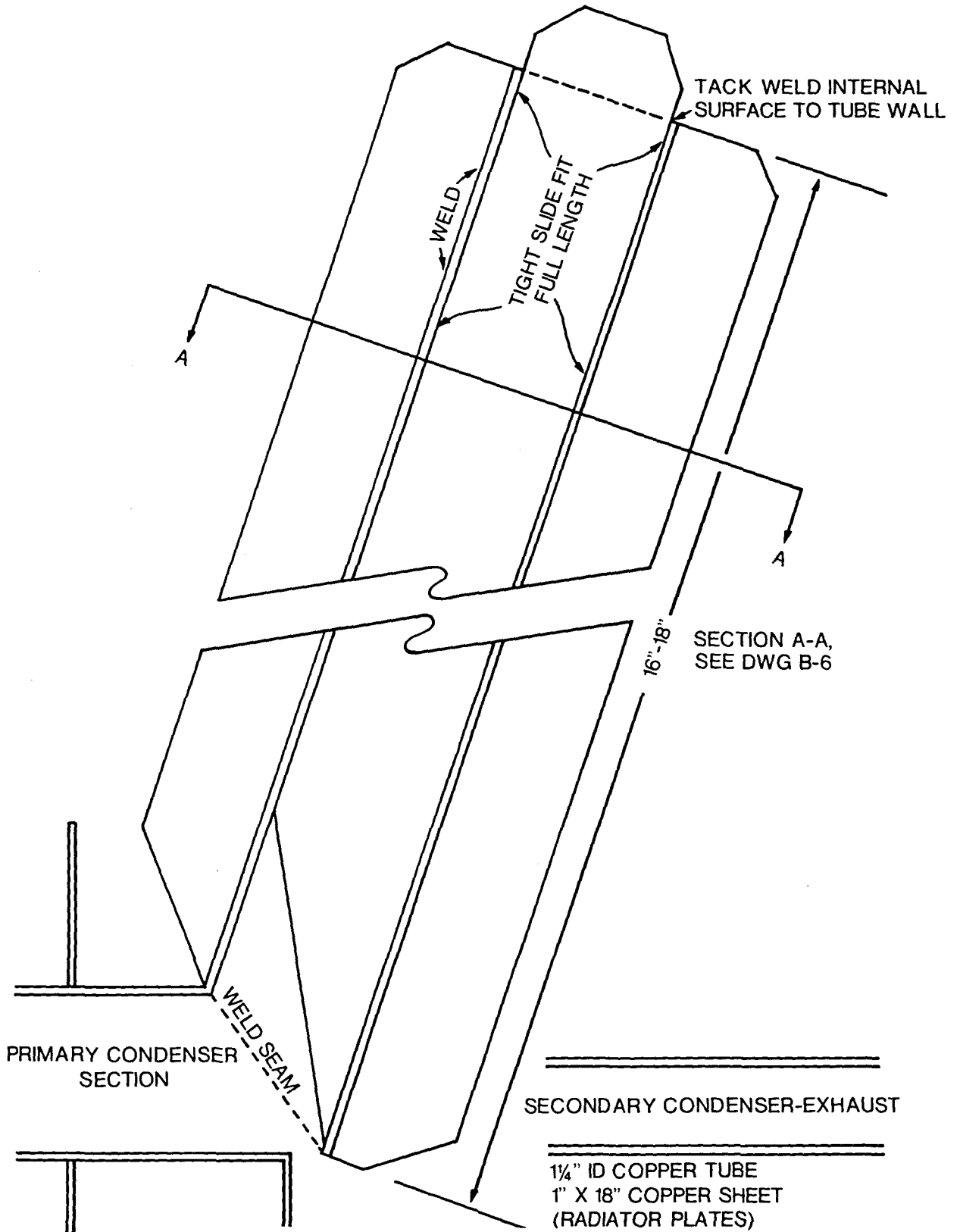
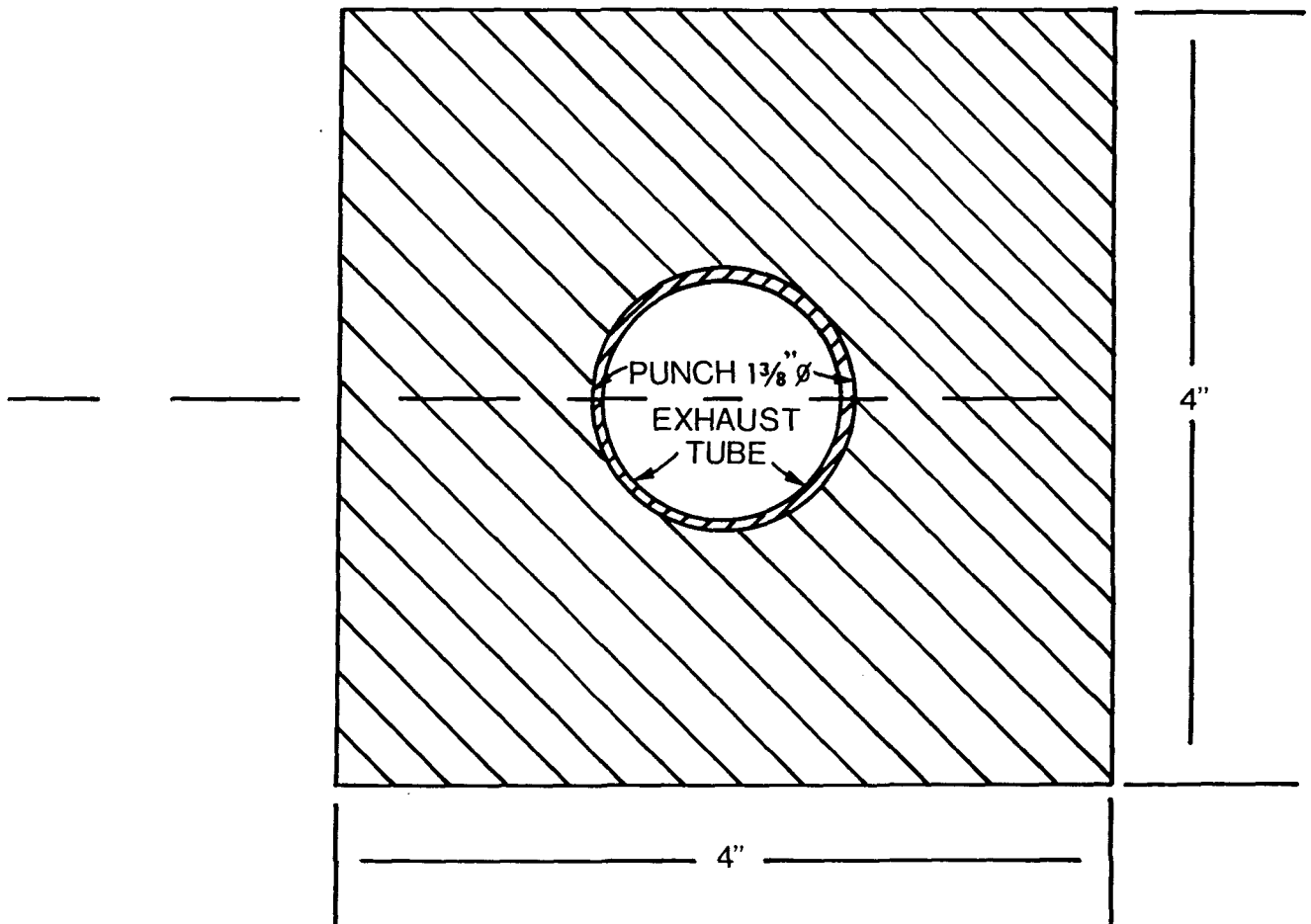


Figure B-4. Secondary Condenser

NATURAL GAS BURNER-MODIFIED
VERSION #1

CROSS SECTION A-A OF DWG. B-3
PRIMARY CONDENSER
RADIATOR PLATE



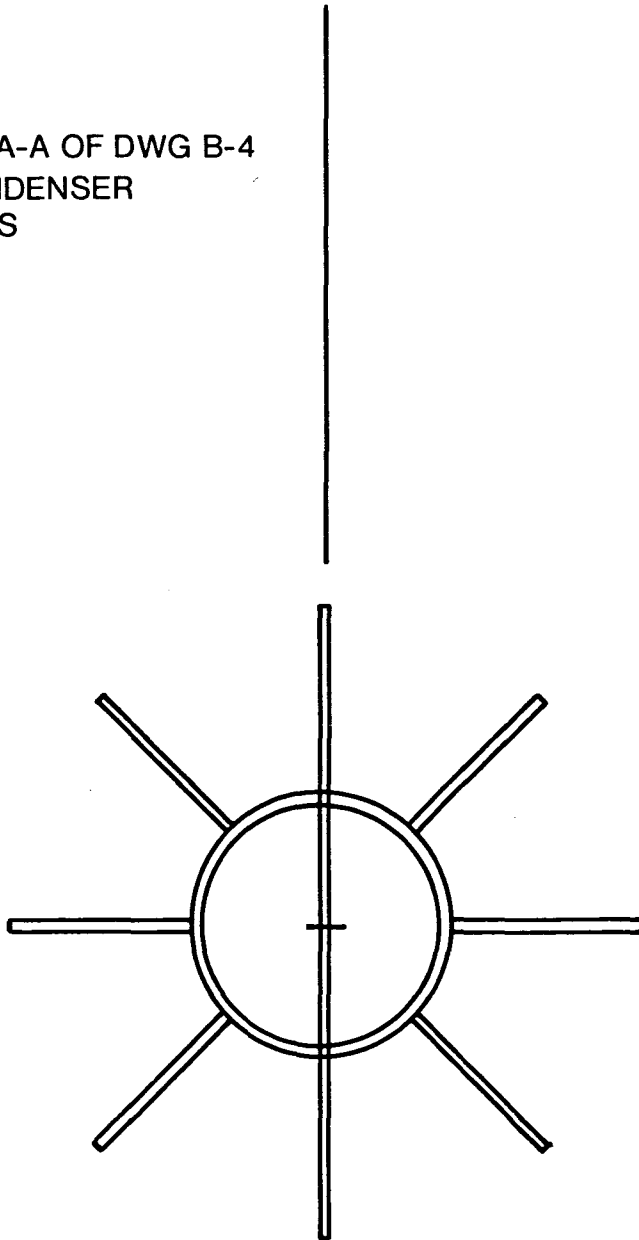
FINS ARE .063 COPPER WITH $1\frac{3}{8}$ " \varnothing ;
WELDED APPROX. $\frac{1}{2}$ " APART
ALONG $\frac{1}{4}$ " I.D., $\frac{1}{16}$ " WALL COPPER TUBE.

MAKE 24

Figure B-5. Primary Condenser Radiator

NATURAL GAS BURNER-MODIFIED
VERSION #1

CROSS SECTION A-A OF DWG B-4
SECONDARY CONDENSER
RADIATOR PLATES



FINS ARE .063 COPPER 1" WIDE AND
APPROX 18" LONG; WELDED TO 1 1/4" I.D.
1/8" WALL COPPER TUBE.

MAKE 8

INTERNAL SURFACE PIECE .063
COPPER APPROX 18" LONG, TO FIT I.D.

MAKE 1

Figure B-6. Secondary Condenser Radiator

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