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METHANE EMISSIONS FROM THE NATURAL GAS INDUSTRY

Volume 7: Blow and Purge Activities

Prepared for

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Prepared by

National Risk Management
Research Laboratory
Research Triangle Park, NC 27711

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METHANE EMISSIONS FROM THE NATURAL GAS INDUSTRY, VOLUME 7: BLOW AND PURGE ACTIVITIES

FINAL REPORT

Prepared by:

Theresa M. Shires
Matthew R. Harrison

Radian International LLC
8501 N. Mopac Blvd.
P.O. Box 201088
Austin, TX 78720-1088

DCN: 95-263-081-10

For

GRI Project Manager: Robert A. Lott
GAS RESEARCH INSTITUTE
Contract No. 5091-251-2171
8600 West Bryn Mawr Ave.
Chicago, IL 60631

and

EPA Project Manager: David A. Kirchgessner
U.S. ENVIRONMENTAL PROTECTION AGENCY
Contract No. 68-D1-0031
National Risk Management Research Laboratory
Research Triangle Park, NC 27711

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RESEARCH SUMMARY

Title	Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities Final Report
Contractor	Radian International LLC GRI Contract Number 5091-251-2171 EPA Contract Number 68-D1-0031
Principal Investigators	Theresa M. Shires Matthew R. Harrison
Report Period	March 1991 - June 1996 Final Report
Objective	This report describes a study to quantify the annual methane emissions from blow and purge activities, which are a significant source of methane emissions within the gas industry.
Technical Perspective	The increased use of natural gas has been suggested as a strategy for reducing the potential for global warming. During combustion, natural gas generates less carbon dioxide (CO_2) per unit of energy produced than either coal or oil. On the basis of the amount of CO_2 emitted, the potential for global warming could be reduced by substituting natural gas for coal or oil. However, since natural gas is primarily methane, a potent greenhouse gas, losses of natural gas during production, processing, transmission, and distribution could reduce the inherent advantage of its lower CO_2 emissions. To investigate this, Gas Research Institute (GRI) and the U.S. Environmental Protection Agency's Office of Research and Development (EPA/-ORD) cofunded a major study to quantify methane emissions from U.S. natural gas operations for the 1992 base year. The results of this study can be used to construct global methane budgets and to determine the relative impact on global warming of natural gas versus coal and oil.
Results	The national annual emissions for blow and purge activities for each industry segment are as follows: production, 6.5 ± 340% Bscf; gas processing, 3.0 ± 260% Bscf; transmission, 18.5 ± 180% Bscf; and distribution, 2.2 ± 1,800% Bscf.

Based on data from the program, methane emissions from natural gas operations are estimated to be 314 ± 105 Bscf for the 1992 base year. This is about 1.4 ± 0.5% of gross natural gas production. The overall program also showed that the percentage of methane emitted for an incremental increase in natural gas sales would be significantly lower than the baseline case.

The program reached its accuracy goal and provides an accurate estimate of methane emissions that can be used to construct U.S. methane inventories and analyze fuel switching strategies.

Technical Approach

Blow or blowdown emissions refer to the venting of natural gas contained inside a pressure vessel, pipeline, or other equipment to the atmosphere. Purge is the process of clearing air from equipment by displacing it with natural gas; in the process, some purge gas is emitted as the air is evacuated from the equipment.

The techniques used to determine methane emissions were developed to be representative of annual emissions from the natural gas industry. However, it is impractical to measure every source continuously for a year. Therefore, emission rates for blow and purge activities were determined by developing annual emission factors for typical practices in each industry segment and extrapolating these data based on activity factors to develop a national estimate, where the national emission rate is the product of the emission factor and activity factor.

Maintenance activities and emergency upsets are the two major causes of blow and purge emissions. Natural gas is released (blown) as a safety precaution during maintenance activities conducted on or near the equipment, or to restore an oxygen-free natural gas environment after maintenance are finished (purged). The second source of blowdowns results from emergency or upset conditions that require gas depressuring.

Emission factor data for the various device types were collected from several sources: site visits, company-tracked data, and company studies. The blow and purge emissions for the major production emission categories were calculated from estimates of volume and frequency of releases based on data collected from site visits. Transmission blow and purge emissions were calculated from company totals. Transmission segment emission factors were also applied to gas processing, due to the similarities between the two industry segments and the lack of gas processing plant data. Distribution company unaccounted-for gas studies were used to quantify blow and purge emission factors from the distribution segment.

The development of activity factors for each industry segment are presented in a separate report. In general though, activity factors were based on equipment counts for the production segment, the number of gas plants for the gas processing segment, station counts or pipeline miles for the transmission segment, and pipeline miles for the distribution segment. The national emission factor for each industry segment was then based on the product of the emission factor for a generic pneumatic device and activity factor.

Project Implications

For the 1992 base year the annual methane emissions estimate for the U.S. natural gas industry is 314 Bscf ± 105 Bscf (± 33%). This is equivalent to 1.4% ± 0.5% of gross natural gas production. Results from this program were used to compare greenhouse gas emissions from the fuel cycle for natural gas, oil, and coal using the global warming potentials (GWPs) recently published by the Intergovernmental Panel on Climate Change (IPCC). The analysis showed that natural gas contributes less to potential global warming than coal or oil, which supports the fuel switching strategy suggested by IPCC and others.

In addition, results from this study are being used by the natural gas industry to reduce operating costs while reducing emissions. Some companies are also participating in the Natural Gas-Star program, a voluntary program sponsored by EPA's Office of Air and Radiation in cooperation with the American Gas Association to implement cost-effective emission reductions and to report reductions to the EPA. Since this program was begun after the 1992 baseline year, any reductions in methane emissions from this program are not reflected in this study's total emissions.

Robert A. Lott
Senior Project Manager, Environment and Safety

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1.0 SUMMARY

This report is one of several volumes that provide background information supporting the Gas Research Institute and U.S. Environmental Protection Agency Office of Research and Development (GRI-EPA/ORD) methane emissions project. The objective of this comprehensive program is to quantify the methane emissions from the gas industry for the 1992 base year to within ± 0.5% of natural gas production starting at the wellhead and ending immediately downstream of the customer's meter.

This report quantifies the amount of methane released nationally during blow and purge operations in natural gas production, gas processing, transmission, and distribution. Emission estimates for each industry segment were based on data from one or more of the following source: 1) site-visit data; 2) company-tracked data; 3) company studies; and 4) equipment calculations. The factors that affect the volume of methane released are: frequency, the volume of natural gas emitted per event, and the disposition of the released gas.

Blow and purge activities are a significant source of unsteady emissions (32% of vented emissions). This accounts for 30.2 Bscf of methane emissions which is about 10% of methane emissions from the natural gas industry.

2.0 INTRODUCTION

"Blow" and "purge" are terms that have different definitions in various segments of the natural gas industry. In this report, blow (also called "blowdown") emissions refer to the venting of natural gas contained inside a pressure vessel, pipeline, or other equipment to the atmosphere. Purge is the process of clearing air from equipment by displacing it with natural gas; in the process, some purge gas is emitted as the air is evacuated from the equipment.

The remainder of this report describes the findings of this study. Section 3 summarizes the activities that lead to blow and purge emissions; Section 4 presents the data sources. The calculation methodology is provided in Section 5, and the national estimates for blow and purge emissions from the gas industry are provided in Section 6.

3.0 OVERVIEW OF BLOW AND PURGE EMISSIONS

Maintenance activities and emergency upsets are two major causes of blow and purge emissions in the natural gas industry. Natural gas is released intentionally (blown) as a safety precaution during maintenance activities conducted on or near the equipment, or to restore an oxygen-free natural gas environment after maintenance activities are finished (purged). The second source of blowdown results from emergency or upset conditions that require gas depressuring.

Some additional sources of blow and purge methane emissions are gas required to start a compressor, gas emitted during sampling, and gas released while removing liquid from a drip pot. Compressor start gas is the only significant category; the other categories are negligible. These sources of natural gas are vented to the atmosphere as part of the normal operation of a gas facility. The company may or may not include these in its definition of blow and purge gas.

3.1 Intentional Maintenance Releases

Maintenance activities requiring blowdown provide a safer working environment when it is necessary to enter a vessel, in which case, all flammable gas must be removed. Likewise, a reduction in the internal flammable gas inventory may be required for external equipment maintenance. Conversely, when equipment previously open to the atmosphere is placed back in service, air must be removed (or purged) to prevent a flammable mixture of gas and oxygen. An operator may displace the air directly with natural gas or with an inert gas, such as nitrogen, and then displace the nitrogen with natural gas. Depending on the specific company equipment and practices, an operator may also vent some of the nitrogen and natural gas mixture to the atmosphere to reduce the inert gas concentration before the equipment is placed back in service.

On any maintenance operation that requires blowdown, the equipment may vent from its operating pressure directly to the atmosphere, or partial recovery may be accomplished by moving some gas into a lower-pressure gas system (if available), and then venting the remaining gas. Lower-pressure recovery systems include recovery gas systems, fuel systems, downstream distribution systems, and control systems, such as flares. Equipment configurations and company practices vary widely on the use of recovery steps.

Blowdown from intentional maintenance releases can be put into the following equipment categories:

- Compressor blowdown;
- Compressor starts;
- Pipeline blowdown;
- Vessel blowdown;
- Gas wellbore blowdown;
- Miscellaneous blowdown of small volume sources (meter and pressure regulator blowdown, drip pot blowdown, odorizer blowdown, etc.); and
- Miscellaneous well activities.

Compressor Blowdown

Many facilities have multiple compressors, some of which are idle at any given time. These idle compressors, or "hot spares," are service-ready machines that can be put on line when a compressor is shut down. In general, spare compressors are used when mechanical operating problems develop on the primary machine, to distribute the operating hours equally among several machines, or to perform preventive maintenance. Depending on the reason for the compressor shutdown and on the company's standard practices, the operator may or may not depressure compressors each time they are shut down. Companies may do one of the following:

1. Leave the compressor under full suction pressure (no blowdown);

2. Depressure the compressor to a lower-pressure recovery system, and either leave the compressor at that lower-pressure (no blowdown) or depressure to the atmosphere (partial blowdown); or

3. Depressure the compressor from full operating pressure to the atmosphere (full blowdown).

Naturally, each of these practices results in a different emission rate per event.

Compressor Starts

Most gas compressors in the natural gas industry are started with a gas starter (as opposed to an electric starter, such as used for a car engine). The gas starter uses a small turbine whose blades spin when high-pressure supply gas is introduced to the starter. The supply gas is usually vented to the atmosphere after exiting the starter. Figures 3-1 and 3-2 show typical gas starters for compressors.

Compressed air may power the starters, but natural gas is used more often than air in many facilities. The starter vent gas can also be directed to a control system rather than to the atmosphere, but that practice is not common. Both the gas type (air or natural gas) and the disposition are accounted for in the emission calculations.

Pipeline Blowdown

Pipeline blowdowns may occur when repairs are required, when old pipelines are permanently removed from service, or when new pipelines are placed in service. Large segments of pipeline (on the order of many miles) can be pulled down using a recovery system before atmospheric blowdown occurs.

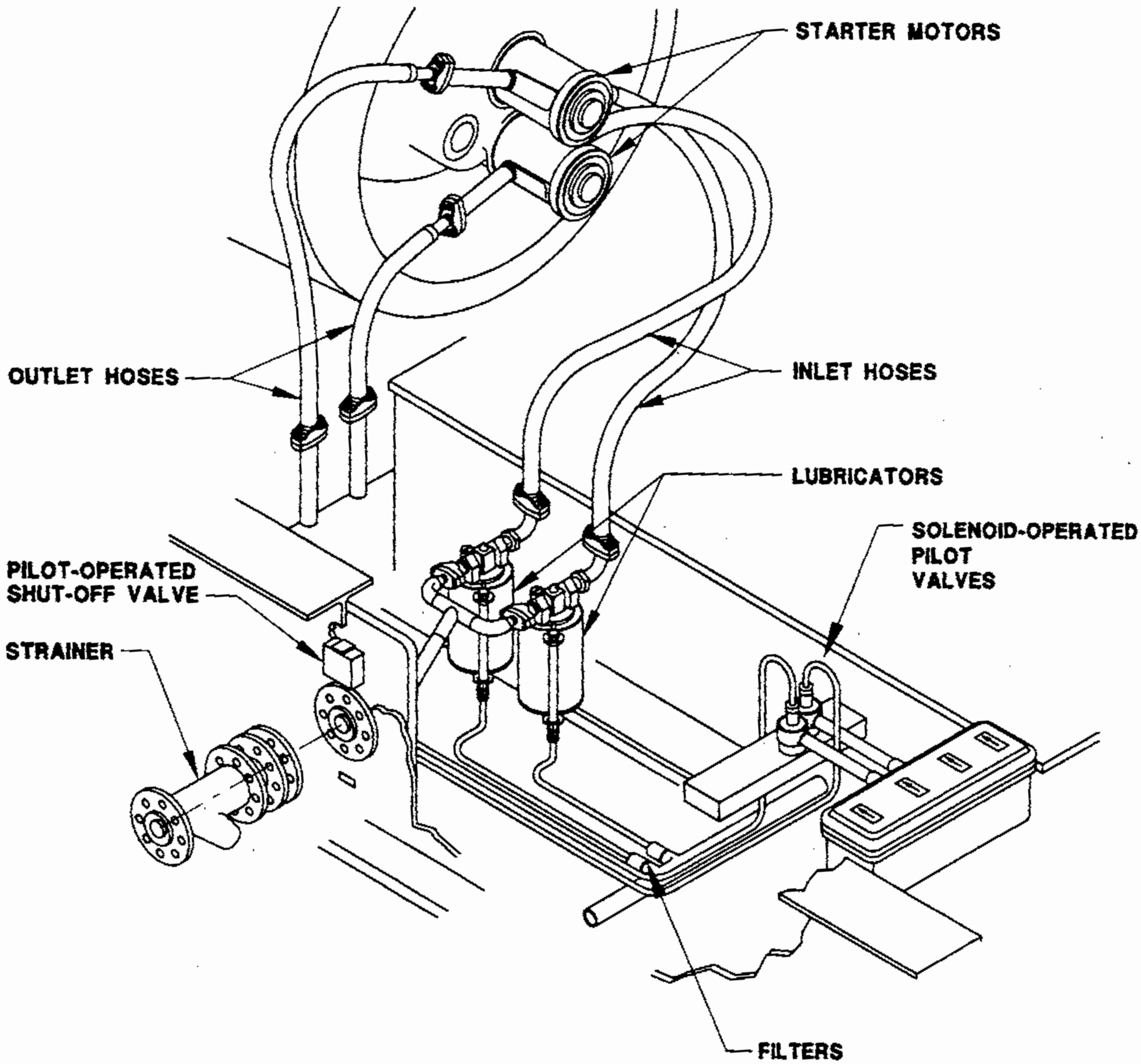

Figure 3-1. Example Compressor Gas Starter

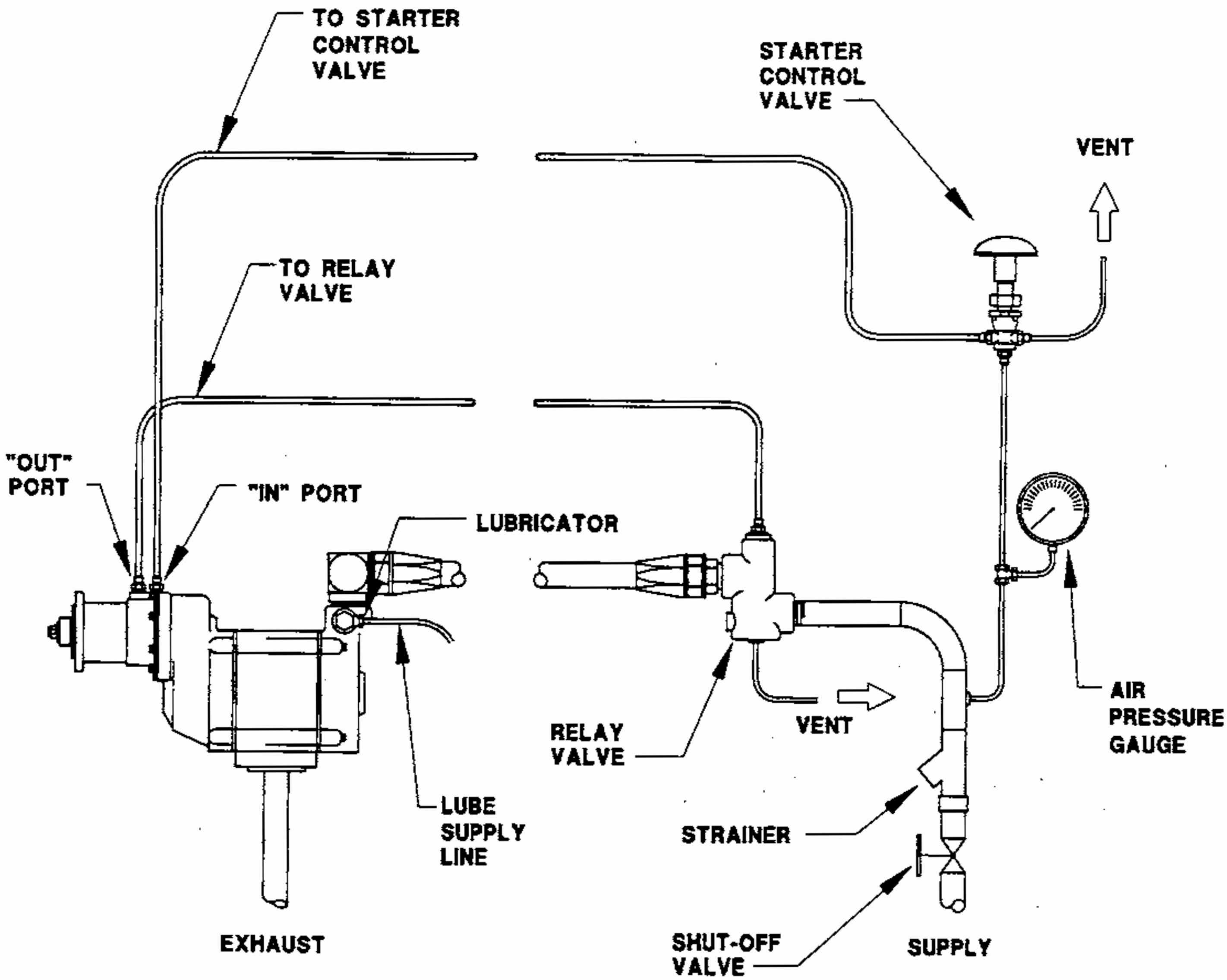

Figure 3-2. Gas Starter Schematic[2]

Vessel Blowdown

Vessels are blown down more frequently than gas pipelines, since vessels usually have more working parts and thus more opportunities for failure. A separator may require blowdown to replace the level control float, service internal elements such as demisters, or clean accumulated solids out of the vessel. Gas may vent directly to the atmosphere or to a flare if available (as in some gas processing plants). In some instances, the gas is partially recovered by moving some gas into a lower-pressure gas system (such as a fuel system, if available) and then venting the remaining gas.

Gas Wellbore Blowdown

Operators may routinely open some low flow rate gas wells to the atmosphere to remove salt water accumulation in the wellbore. Low-pressure natural gas wells can accumulate salt water and other fluids in the wellbore if the gas flow rate is not sufficient to lift out the free liquid. To keep the gas flow from declining, this type of low-pressure gas well is sometimes isolated from the gathering pipeline and opened to a surface tank or pit. The surface tank has no backpressure (as opposed to the pipeline), so the gas flows at a higher rate and lifts out the water. The gas is released directly to the atmosphere during this practice.

Miscellaneous Equipment Blowdown

Operators may also blow down miscellaneous equipment to remove accumulated material. Many small pieces of pipeline equipment are routinely blown down: drip pots that collect liquids, meter runs for orifice plate changeout, and odorizers. Most of the emissions from these miscellaneous categories are insignificant when considered on a national basis.

The factors that affect the volume of methane emissions from maintenance blowdown include:

- Frequency of blowdown (times/yr/equipment);
- Volume (Scf) of methane released per blowdown event (a function of pressure, volume within the equipment, and gas composition); and
- Disposition of the blowdown gas (atmosphere or control system).

Miscellaneous Well Activities

Completion flaring and well workovers are additional maintenance activities associated with gas well production. Drilling operations typically use the hydraulic pressure of drilling mud to overbalance the formation pressure and keep the oil and gas in the formation while drilling. The amount of gas released during drilling is minimal. However, before producing gas from a new well, the facility must either know the reservoir pressure and size or measure the gas flow rate so that the equipment can be sized. To measure the gas flow rate, the gas from the well is routed through a meter and then flared.

Well workovers pull the tubing from the well to repair tubing corrosion or other downhole equipment problems. If the well has positive pressure at the surface, the well is "killed" first by replacing the gas and oil in the column with (heavier) water or mud, thus over-balancing the formation and stopping all oil and gas flow. A small amount of gas is released as the tubing is removed from the open surface casing.

3.2 Blowdown from Emergency and Upset Conditions

For the emergency release of gas, the release is usually caused by a safety device, such as a spring-loaded pressure relief valve (PRV) on a vessel or an automatic blowoff valve on a transmission pipeline station. An example of an emergency blowdown is the shutdown and depressuring of a transmission station that automatically results from the detection of flammable gas in a compressor building. The emergency blowdown category relates to the maintenance blowdown category, in that emergency blowdowns are usually followed by some equipment maintenance to correct or eliminate the emergency situation. PRV lifting is not usually considered a blowdown, since PRV lifts do not depressure an entire vessel or station, but merely relieve pressure above a certain set point. However, since PRV lifts result from unusual, upset, or emergency conditions, they are included in the emergency blowdown category of this report.

Another emergency condition that can result in the release of gas from a pipeline is a "dig-in." Dig-ins are ruptures of gathering pipelines caused by unintentional (often third-party) damage. These ruptures are isolated and repaired by the pipeline operator.

Unlike some maintenance releases, emergency blowdowns by their nature are not recovered, but are typically vented directly to the atmosphere. Blowdown from emergency conditions can be classified as PRV lifts, station automatic blowdown, or pipeline dig-ins.

PRV Lifts

PRVs, which are also called safety valves or pop-off valves, protect a vessel from rupturing due to high pressure. Figure 3-3 shows a sketch of a PRV. If emergency conditions occur, where internal pressures exceed the vessel's design pressure, the valve lifts and allows gas to flow out of the vessel. The pressure at which the valve lifts is set by the size and tension of the spring that holds down the PRV seat. The size of the PRV is set by the flow contingency (emergency scenario) for which the valve is designed.

Some vessels may also use rupture disks (RDs) which are similar to PRVs and perform the same function. These devices act as a secondary protection mechanism for a vessel with a higher release pressure setpoint than the PRV. Should the PRV fail to relieve

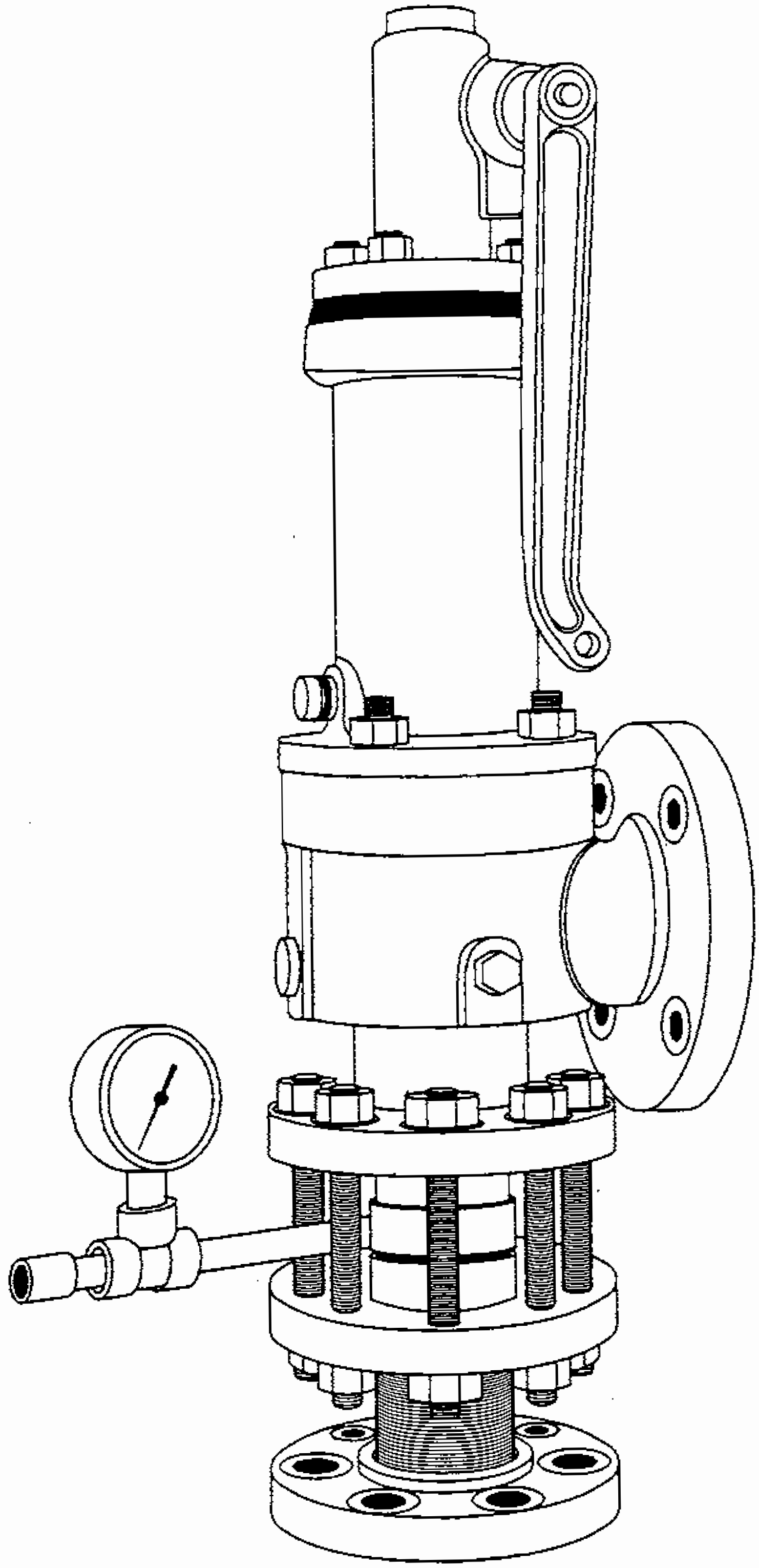

Figure 3-3. Pressure Relief Valve Schematic[3]

PRVs can be routed to control systems such as flares, but they are often vented directly to the atmosphere. The annual methane release rate for a PRV is set by:

- Frequency of lifts (times/yr/PRV);
- Volume (scf) of methane released per event, which is a function of duration, PRV size, lift set pressure, and gas composition; and
- Disposition of the discharge (atmosphere or control system).

Station Automatic Blowdown

Some facilities have manual or automatic safety systems that shut down all rotating equipment when emergency conditions (such as fire or natural gas in the atmosphere) are detected. A few of these systems also depressure the facility by venting gas to the atmosphere, so that natural gas will not feed a fire. An example of such a system is a transmission compressor station emergency shutdown (ESD) and emergency blowdown (EBD) system (see Figure 3-4), where an automatic shutdown and blowdown can be triggered by gas detectors in the compressor building, or it can be triggered manually if a fire starts. The ESD system shuts down the compressors and blocks in the pipelines leading to the facility. The EBD system then may open blowoff valves that depressure the facility to the atmosphere.

Annual methane releases from station blowdowns can be quantified on the basis of the following data:

- Average frequency of station blowdowns (times/yr/station);
- Volume (scf) of methane released per event, which is a function of normal operating pressure, volume within the station, and gas composition; and
- Disposition of the discharge (atmosphere or control system).

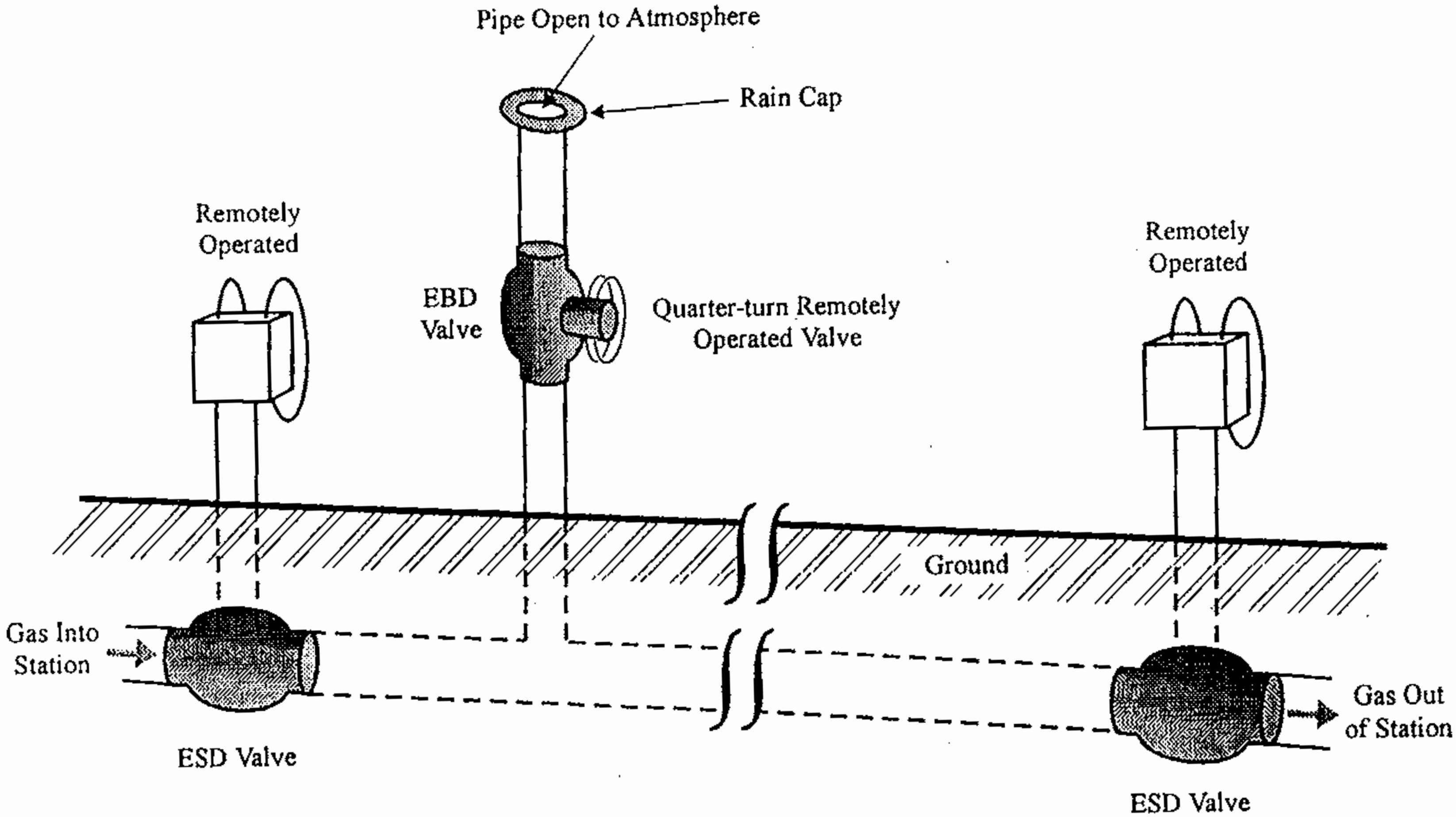

Figure 3-4. Transmission Station ESD/EBD System

Pipeline Dig-ins

Dig-ins are unintentional damage to a buried gas pipeline. Gas is released when a pipeline is punctured or ruptured during excavation or construction work, usually by earth-moving construction equipment excavating near the buried gas pipeline. Gas emissions from pipeline dig-ins can be estimated by quantifying the flow rate and duration of the release before the pipeline segment was isolated for repair.

3.3 Results

This report quantifies methane blowdown emissions for each natural gas industry segment by estimating releases from the various types of blowdowns. The estimates are based on data provided by natural gas companies or on data collected during site visits conducted for this project. The resulting estimates of national emissions from blow and purge activities are shown in Table 3-1.

TABLE 3-1. EMISSION SUMMARY

Industry Segment	Annual Methane Emissions, Bscf	90% Confidence Upper Bound
Production	6.5	340%
Transmission and Storage	18.5	180%
Gas Processing	3.0	260%
Distribution	2.2	1,800%

The basis for these numbers is explained in Sections 4 through 6.

4.0 EXISTING STUDIES AND DATA SOURCES

The data used for this project came from one of three sources:

1. **Site visit data** — During site visits, data were collected on the frequency of release events, internal volumes, and pressures through observation and interviews. Data on well workovers were collected during site visits by Pipeline Systems Incorporated (PSI).[4]

2. **Company-tracked data** — This includes data already internally tracked by a company on a regular basis. The data apply to all of the company's facilities.

3. **Company studies** — Some companies, although they might not regularly track all vented volumes of gas, may perform one-time studies to estimate such volumes for their system. Two examples of such studies were conducted by Pacific Gas and Electric (PG&E)[5] and Southern California Gas Company[6] (SoCal) on unaccounted-for (UAF) gas.

The quality of company-tracked data is believed to be the best of the three sources since it entails a regular accounting of the frequency of release events and uses detailed company data for the gas volumes. Company studies have a slightly lower quality since the results are calculated only once, but they do use detailed company data to produce the estimate. Site visit data are acceptable, but the quality of the data is the lowest of the three blowdown estimation techniques because it relies on operators' recollections of the frequency of release events.

In the production segment, none of the companies had company-tracked data or company reports. Therefore, all the blowdown calculations for that segment are based on site visit data. In the transmission, storage, and distribution segments, many companies did have company-tracked data or company studies, so company data were used for these segments. Site visit data were collected for the transmission and storage segments, but those data were not used as the basis for the methane emission estimates because of the lower quality of the data (operator recollection). In the gas processing segment, no companies had similar to the compressor sections of gas plants, data from the transmission and storage segment were used as the basis for gas plant emission estimates. Site visit data were available for the gas processing segment, but were not used.

The techniques used to calculate methane emission volumes for each of the three data sources are described in Sections 4.1 through 4.4. The characteristics of the emissions for each release type were discussed in Section 3. In general, annual emission averages are generated by estimating the frequency of the releases, the volume per event, and the disposition of the gas.

4.1 Site Visit Data

Blowdown practices vary from company to company and even from site to site within a company. The hardware installed at a facility has a large effect on blowdown emissions, and local regulations may also affect practices. Because of variability in company practices within the industry, averages were established by visiting a number of facilities.

The site data were collected as follows:

1. From interviews during site visits, the frequency of maintenance and emergency blowdowns was determined.
2. For maintenance blowdowns, the major types (compressor blowdown, compressor start, pipeline, vessel, gas wellbore, or other) were determined from interviews and observation during a site visit. The volume of gas released per event and the disposition of the released gas (i.e., the amount vented to the atmosphere) were established from interviews or company records.
3. For emergency blowdowns, the following information was gathered:
   - For emergency ESD shutdowns, the existence and design operation of any ESD system (activity factor data);
   - Total count of PRVs to the atmosphere at a facility (activity factor data);

- From operator recollection or records, the average frequency of PRV lifts and station depressuring that occurs at the facility, and the disposition and duration of the events (emission factor data);

- PRV lift data from company records: size, lift set pressure, disposition (for mass emission factor data);

- Station blowdown volume from company records or from the actual station volume and operating pressure; and

- Emissions due to dig-ins from company records.

4.2 Company-Tracked Data

Company-tracked data consist of the annual gas volumes tracked by a company's accounting department. These volumes are made up of some combination of the following categories:

- Compressor station venting — compressor blowdown, compressor starts, and emergency station blowdown (ESD/EBD);

- Pipeline venting;

- Other maintenance activities — completion flaring, well workovers, etc.; and

- Miscellaneous equipment — sampling, drip blowdown, odorizer blowdown, orifice plate blowdown, etc.

Companies that tracked vented gas volumes did so by one of two methods: 1) calculations were performed monthly at each compressor station, and total monthly volumes were reported to the company's main accounting department, or 2) the frequency of events (compressor blowdowns) was reported monthly to the accounting department, which used a predetermined volume per event to determine total volumes. Both methods may use a volume per event calculated from the exact internal dimensions of the equipment and the particular station's operating pressure.

Company-tracked data were provided by six transmission companies that operated pipelines, transmission compressor stations, and storage stations. Only one of the six companies tracked miscellaneous volumes, but the miscellaneous volumes are considered to be insignificant. A company might only track pipeline blowdown volumes or compressor station blowdown volumes; only four of the six companies tracked both.

4.3 Company Studies

Two companies, PG&E and SoCal, performed unaccounted-for (UAF) gas studies that quantified the blowdown volumes for the same categories listed previously: [5,6]

- Compressor station venting;
- Pipeline venting; and
- Miscellaneous equipment.

The miscellaneous equipment category was found to be insignificant (< 0.66% of total company blow and purge). However, both companies found the first two categories to be significant.

The studies actually sought to quantify the amount of blowdown not currently being accounted for by the company's system. At PG&E, this was all of the blowdown gas, since PG&E did not previously account for vented losses. At SoCal, some of the blowdown events were accounted for, and some were not. The SoCal accounted-for and unaccounted-for blowdown volumes were combined to obtain the total vented quantity for SoCal. Summaries of the PG&E and SoCal studies appear in Appendix A. The results of these UAF studies were used along with tracked data from other companies to develop several blow and purge emission factors.

4.4 Other Studies

This study of the blow and purge emissions focused on the major contributors to these emissions (e.g., station blowdown, pipeline blowdown, compressor/vessel blowdown, ESD/PRV releases). However, for completeness, minor emission sources were also considered using data from studies:[6,7,8]

- Well workover emissions were estimated by Pipeline Systems Incorporated (PSI) on the basis of information from two gas production facilities.
- The Energy Information Agency and a gas production company provided information on the gas production of exploratory wells and drilling practices, respectively, which was used to estimate completion flaring emissions.
- Six distribution companies participating in a cooperative underground leak measurement program provided data on the volume of blowdown gas in the routine company reports on unaccounted-for gas.

5.0 EMISSION FACTOR CALCULATIONS

This section describes the emission calculations for the maintenance and emergency blowdowns in each industry segment. Blowdown volumes vary widely from site to site. The exact state of equipment repair, available control and recovery equipment resources, and company procedures cause the emissions for a similar blowdown to vary from one company to another and from one site to another.

5.1 Field Gas Production

The production segment contains wells, separation stations, gathering lines, and gathering compressor stations. Blowdown emissions result from the maintenance of these units. Maintenance blowdowns of low-pressure gas wells, gathering pipelines, compressors, and vessels are usually vented to the atmosphere. Piloted flares are rare. Many well sites have a vent line that the company may call a "flare" in the production field, but this is a misnomer, since it is most often a simple open-ended pipe with no pilot or igniter and does not burn gas.

Emergency or upset condition releases result primarily from ESD system blowdowns for offshore production platforms and from PRV or RD discharges for the onshore field production segment. Most ESD, PRV, and RD blowdowns are vented directly to the atmosphere. Field automatic station blowdown devices are rare, and manual emergency shutdowns of gathering lines are extremely infrequent. Dig-ins of production gathering lines, though minor, are a source of emissions due to mishaps.

The blowdown emissions for the major production emission categories were calculated from estimates of the volume and frequency of releases based on data collected from 25 site visits. The volume of gas released times the frequency of events resulting in released gas equals the annual emissions. Volumes were calculated for each site using equations of state, observed vessel dimensions, and pre-blowdown pressures. Frequencies were gathered at each site from interviews with operators. The annual emission factor (scf/blowdown) for each site was calculated as follows:

$$EF = \text{Volume} \times \text{Frequency} \times \% \text{ Methane} \quad (1)$$

where:

Volume	=	Gas released to the atmosphere during a release event (scf/event).
Frequency	=	Number of events annually.
% Methane	=	78.8 mol % ± 5% for the production segment.

The volume of gas released was calculated differently for each type of blowdown event. The volume calculation methods are described below.

- **Low-Pressure Gas Well Unloading** — The volume of gas released due to unloading was based on a scaled gas flow rate and the time required to unload the well. To account for the changing gas flow rate as water accumulates in these wells, the average gas flow rate was scaled assuming that 25% of the time the well operated at 25% of the average gas flow rate, 50% of the time the well operated at 50% of the average gas flow rate, and 25% of the time the well operated at the average gas flow rate. This results in a scaling factor of 0.5625 which was multiplied by the gas well flow rate to estimate the volume of gas released per unloading event.

- **Compressor Blowdown** — The volume of gas inside the block valves (scf) is a function of pressure and volume. Compressor blowdown volumes were also corrected for the fraction of compressors that release gas to the atmosphere. (Some compressors vent gas to control systems.)

- **Compressor Starts** — Some general company data were available on compressor starter gas consumption rates. Several sites provided estimates for reciprocating engines of 200 scf/minute for all starters. The total volume of gas per start was calculated using this emission rate, the time required to start the compressor, the fraction of compressor starters powered by natural gas, and the fraction of starters that vent gas to the atmosphere.

- **Pipeline Blowdown** — The volume of gas released due to blowdown per mile, corrected for the pipeline pressure, was based on the diameter and length of various pipe segments.

- **Vessel Blowdown** — Vessel blowdown emissions were estimated from the internal dimensions of the vessel and corrected for the vessel pressure. This value includes blowdowns from separators, dehydrators, and in-line heaters. (Compressor blowdowns and starts are considered separately.)

- **PRV Discharge** — The average volume released at the lift pressure was calculated for an average-size PRV and an average duration, and corrected for the fraction of PRVs that release gas to the atmosphere.

- **ESD Blowdown** — This category was only observed for off-shore platforms. The emission volume was based on the platform volume and corrected for the fraction of platforms with ESDs and the fraction that vent gas to the atmosphere.

Tables 5-1 through 5-7 show the site values used in the calculations. The volume of gas released per year weighted by the count of each equipment category became the emission factor for each source. The emission factors were then multiplied by the volume percent of methane in natural gas (78.8% for production).[9]

Determination of the emission factor for well workovers was based on data from two gas production fields collected by Pipeline Systems Incorporated (PSI).[4] PSI estimated that the methane emissions due to workovers at the first site were 670 scf/well, on the basis of 1 of 21 gas wells being worked over annually. For the second site, 8 of the approximately 400 wells are worked over each year. PSI assumed that four of the wells were high-pressure wells, at depths of 12,000 ft and that four wells were low-pressure wells at depths of 5000 ft. For a well tubing size of 2-3/8 inches, the annual methane emissions due to well workovers were estimated to be 4,238 scf/workover. Averaging these two estimates, results in the workover methane emission factor of 2,454 $\pm$ 459% scf/well workover.

TABLE 5-1. PRODUCTION MAINTENANCE RELEASES GAS WELL UNLOADING

Site	Number of Gas Wells	Number of Wells Requiring Unloading	Number of Events/Year/ Site	Scf/Event based on Scaled Flow	Annual Natural Gas Emissions Scf/Site
1	0	0			
2	80	80	12	52,500	630,000
3	0	0			
4	13	13	1	37,969	37,969
5	12	0		0	
6	6	0		0	
7	130	43	103.2	28,125	2,902,500
8	26	5	2.5	2,524	6,310
9	138	55	193.2	938	181,125
10	321	25	72	703	50,625
11	500	0			
12	500	0			
13	600	0			
14	53	53	1	10,631	10,631
15	800	600	3600	3,516	12,656,250
16	1,000	1,000	2600	39,375	102,375,000
17	520	520	6240	675	4,212,000
18	1,439	245	89,425	471	42,102,408
19	100	0			
20	15	0			
21	2	2	24	41,006	984,150
22	12	0			
23	80	0			
24	40	0			
25					
TOTALS	6,387	2,641			166,148,968
% WELLS REQUIRING UNLOADING					41.4% ± 45%
AVERAGE ANNUAL UNLOADING EMISSIONS, scf natural gas/unloading well					62,907 ± 343%

TABLE 5-2. PRODUCTION MAINTENANCE RELEASES COMPRESSOR BLOWDOWN

Site	Company Compressor Count	Blowdown/Year/ Compressor (All Compressors)	Percent to Atmosphere	Scf/Event Basis	Scf/Event	Annual Natural Gas Emissions Scf/Site
1	56		0			0
2	4	4	0			0
3	11	23	100	Site data	612	154,836
4	12	19	93.8	Average	421.3	90,101
5	1	4	0			0
6	1	36	0			0
7	37	12	100	Site data	40	17,760
8	0					
9	31	8	100	Average	421.3	104,482
10	50	24	100	Average	421.3	505,560
11	5	2.5	100	Site data	9,200	115,000
12	3	1.7	100	Site data	9,200	46,000
13	2	13.3	100	Average	421.3	11,207
14	17	13.3	100	Average	421.3	95,256
15						
16						
17						
18						
19						
20						
21	1	12	100	Site data	612	7,344
22	2		0		0	0
23	4	13.3	30	Average	421.3	6,739
24	4		0		0	0
25						
TOTALS	241					1,154,285
ANNUAL AVERAGE, scf natural gas/compressor						4,790 ± 147%

TABLE 5-3. PRODUCTION MAINTENANCE RELEASES COMPRESSOR STARTS

Site	Company Compressor Count	Percent On Gas	Starts/ Compressor/ Year	Percent To Atmosphere	Duration,- minute	Starters/ Compressor	Annual Natural Gas Emissions Scf/Site
1	56	0		100		1	0
2	4	100	26	100	0.5	1	10,400
3	11	0	26	100		1	0
4	12	92	56	100	0.17	1	20,608
5	1	0	12	0		1	0
6	1	100	36	0		1	0
7	37	95	12	100	10	1	840,000
8	0						
9	31	100	8	100	10	1	496,000
10	50	100	24	100	5	1	1,200,000
11	5						
12	3						
13	2						
14	17	100	7.3	100	0.17	0.647	2,730
15							
16							
17							
18							
19							
20							
21	1	100	12	100	5.13	1	12,320
22	2						
23	4						
24	4						
25							
TOTALS	241						2,582,058
ANNUAL AVERAGE, scf natural gas/compressor							10,714 ± 156%

TABLE 5-4. PRODUCTION MAINTENANCE RELEASES PIPELINE BLOWDOWNS

Site	Total Company Miles	Blowdown/ Yr/Mile	Percent to Atmosphere	Natural Gas Emissions Scf/Event	Annual Natural Gas Emissions Scf/Site
1	150	0			0
2	50	0			0
3	50	0			0
4	50	0.120	100	20,000	120,000
5	15.4	0.016	100	17,817	4,454
6	11	0	100	25,514	0
7	40	0.025	100	50,000	50,000
8	8	0			0
9	5	0.026	100	1,318	176
10	9	0			0
11					
12					
13	5	0.067	100	400	133
14	20	0.017	100	400	133
15	25	0.080	100	400	800
16					
17					
18					
19					
20	10	0.030	100	400	120
21					
22					
23					
24					
25					
TOTALS	449				175,817
ANNUAL AVERAGE, scf natural gas/mile					392 ± 32%

TABLE 5-5. PRODUCTION MAINTENANCE RELEASES VESSEL BLOWDOWNS

Site	Vessel Count/Site	Blowdown/ Yr/Vessel	Percent to Atmosphere	Natural Gas Emissions Scf/Event	Annual Natural Gas Emissions Scf/Site
1	973	0.01	100	13	157
2	136	2.50	100	221	75,140
3	90	0.58	100	618	32,260
4	120	0.10	87.5	379	3,980
5	39	0.21	0	956	0
6	20	0.20	0	956	0
7	107	0.5	100	365	19,528
8	78	0.06	100	1,896	8,532
9	296	0.5	100	715	105,820
10	865	0.01	100	2,047	20,470
11					
12					
13	502	0.02	100	905.9	9,059
14					
15					
16					
17					
18					
19	125	0.5	100	905.9	56,618
20					
21					
22					
23					
24					
25					
TOTALS	3,351				331,562
ANNUAL AVERAGE, scf natural gas/vessel					99 ± 265%

TABLE 5-6. PRODUCTION EMERGENCY RELEASES PRV RELEASES

	Pressure Relief Valve (PRV) Releases							
Site	No. PRV	Lift/Yr/ PRV	Percent To Atmosphere	Min./ Lift	Avg. Size	Avg. Set Press	Scf NG/ hr	Annual Scf NG/Site
On-Shore								
1	1,694		100				0	0
2	80	2	100	1	1 × 1	250	38,674	103,131
3	80	0.5	100	1	3 × 3	100	15,223	10,149
4	101	0.0099	100	60	1.5 × 2	100	15,223	15,223
5	30	0.0030	50	2	1.5 × 2	1,440	247,408	375
6	20	0.05	50	2	1.5 × 2	1,440	247,408	4,123
7	84	0	100	1	1 × 1	1,000	162,103	0
8	52	0.0577	100	1	1 × 1	1,500	247,408	12,370
9	156	0	100	1	1 × 1	1,000	162,103	0
10	541	0	100	0	1 × 1	1,500	147,408	0
11								
12								
13								
14	500	0.0004	100	1			38,674	129
15								
16								
17								
18								
19								
20								
Off-shore								
21								
22								
23								
24								
25								
ON-SHORE TOTALS	3,338							145,500
ANNUAL ON-SHORE AVERAGE, scf natural gas/PRV								44 ± 252

TABLE 5-7. PRODUCTION EMERGENCY RELEASES
ESD RELEASES

	Emergency Shutdown (ESD) Releases				
Site	ESD Exists	BD/y/ Station	Percent to Atmosphere	Scf NG/ Yr/BD	Annual Scf NG/ Platform
On-Shore					
1	NO				
2	NO				
3	NO				
4	NO				
5	NO				
6	NO				
7	NO				
8	NO				
9	NO				
10	NO				
11	NO				
12	NO				
13	NO				
14	NO				
15	NO				
16	NO				
17	NO				
18	NO				
19	NO				
20	NO				
Off-Shore					
21	NO			0	0
22	YES		0	0	0
23	YES	1.2	30	4,500	1,620,000
24	YES		0	0	0
25	YES	0.0022	100	4,500	10,000
OFF-SHORE TOTALS					1,630,000
ANNUAL OFF-SHORE AVERAGE, scf natural gas/platform					326,000 ± 200%

Completion flaring is necessary to measure the flow rate of an exploratory well to size the production equipment. The length of time required to complete the flow measurement is approximately one day, according to an industry contact experienced in drilling practices. The flow rate of gas at completion is the highest that the well will produce. For the purposes of estimating emissions, maximum gas flow rates were not available. Instead, an average natural gas production per gas well of 16.97 MMcfy was used.[10] Assuming a flaring efficiency of 98% and adjusting for the methane composition of production gas (78.8 mol%), the annual completion flaring emission factor is 733 ± 200% scf/completion well. (The confidence interval was based on engineering judgement of the data quality.)

No production records were available on gathering pipeline dig-ins. However, several transmission and distribution companies track this emission source. Table 5-8 summarizes the distribution segment dig-in emissions. Assuming that production dig-ins occur less frequently than distribution dig-ins, the distribution emission factor per mile was reduced by one-half. This is a reasonable assumption, given that the human activity level (and the resulting likelihood of a dig-in) near most production facilities is low, while human activity near most distribution networks is high. The resulting annual methane emission factor for production dig-ins is 669 ± 1,925% scf/mile (adjusted for the methane composition in production of 78.8 mol%).

The production emission factors, adjusted for the production methane composition of 78.8 mol%, are summarized in Table 5-9. In addition, the number of sites used to develop the emission factors is provided for each category.

5.2 Gas Transmission

Gas transmission systems are mostly pipelines and therefore have fewer "facilities" than the production and gas processing segments of the natural gas industry.

TABLE 5-8. PRODUCTION GATHERING PIPELINE DIG-IN EMISSIONS

Company	Annual Dig-in Emissions, Mscf	Pipeline Miles	Annual Dig-in Methane Emission Factor, scf/mile
1	91,178	58,024	1.57
2	170,457	82,337	2.07
3	19,581	24,916	0.79
4	10,543	18,713	0.56
TOTALS	291,669	183,990	
ANNUAL EF FOR DISTRIBUTION, Mscf methane/mile			1.59 ± 1,900%
ANNUAL EF FOR PRODUCTION, Mscf methane/mile			0.67 ± 1,900%

TABLE 5-9. SUMMARY OF PRODUCTION EMISSION FACTORS

Category	Annual Methane Emission Factor	Number of Sites
Gas Well Unloading	49,570 scf/LP well ± 344%	12 sites
Compressor Blowdown	3,774 scf/compressor ± 147%	17 sites
Compressor Starts	8,443 scf/compressor ± 157%	12 sites
Vessel Blowdown	78 scf/vessel ± 266%	12 sites
Pipeline Blowdown	309 scf/mile ± 32%	18 sites
Completion Flaring	733 scf/completion well ± 200%	1 site
Well Workovers	2,454 scf/workover ± 459%	2 sites
PRV Blowdown	34 scf/PRV ± 252%	13 sites
ESD Blowdown	256,888 scf/platform ± 200%	6 platforms
Dig-ins	669 scf/mile ± 1,925%	4 sites

There are two common types of above-ground pipeline transmission facilities: meter and pressure regulation (M&PR) stations and compressor stations. The compressor stations usually have PRVs vented to the atmosphere and ESD/EBD systems that isolate the site and depressure it to the atmosphere. Flare systems are rare, but some compressor station sites do have lower-pressure gas recovery systems (such as fuel saver systems) that can be used to recover some of the blowdown gas. In the United States, M&PR stations typically do not have ESD/EBD systems, flare systems, nor gas recovery.

Gas storage facilities that are considered part of the gas transmission segment can be located below or above ground. The below-ground facilities are similar to transmission compressor stations and production fields and therefore can be characterized in the same way. The above-ground, liquefied natural gas (LNG) facilities are similar to gas plants in their general maintenance venting practices.

Compressor stations (for storage or transmission) typically have ESD and EBD systems. These systems are tested at least annually, but practices and regulations concerning full EBD testing (which vents gas) vary. Therefore, some stations do not emit any gas during this practice.

Blowdown volumes and frequencies were calculated from company totals for multiple stations from tracked or studied totals. The company-tracked data were available from either company gas use estimates reported to accounting departments from each site (accounted-for gas), or from special UAF gas studies that searched for unmetered company gas use. Most of the company data could be separated into two event types: station blowdowns (includes compressor blowdowns, compressor starts, PRV lifts, ESD activation, and other venting sources) and pipeline blowdowns. These data are summarized in Table 5-10.

TABLE 5-10. TRANSMISSION COMPANY DATA

Company	Annual Station Blowdown Emissions, Mscf	Annual Pipeline Blowdowns, Mscf	Total Annual Blowdowns, Mscf	Total Number of Stations	Total Number of Pipeline Miles
1	120,757	189,044	309,801	11	3,857
2	272,589	11,358	283,947	15	4,000
3	33,731	138,988	172,719	27	5,886
4	--	--	172,776	(19)[a]	(5,450)
5	325,418	Unknown	Unknown	47	(4,725)
6	Unknown	161,628	Unknown	(48)	7,896
7	60,956	750,000	810,956	69	14,666
8	194,541	315,058	509,599	47	9,915
TOTALS	1,007,992	1,566,076		216	46,220
ANNUAL AVERAGE, Mscf natural gas/station					4,667 ± 262%
ANNUAL AVERAGE, Mscf natural gas/mile					33.9 ± 236%

[a]Parentheses indicate that the value is not included in the total count because a station or pipeline emission rate was not available.

The transmission segment emission factors are calculated from the average of the site values for blowdown emissions per station and blowdown emissions per pipeline mile. Correcting the values shown in Table 5-10 for the methane composition of gas in the transmission and storage segment (93.4% ± 1.5%)[9] results in annual emission factors of 4,359 ± 262% Mscf/station and 31.6 ± 236% Mscf/mile.

5.3 Gas Processing Plants

Gas plants recover hydrocarbon liquids (such as propane, butane, and NGLs) from "wet" natural gas and send the "dry" residue gas to sales. The liquid portion of the gas plant handles very little methane; therefore, blowdowns from the liquid-side of the plant are not considered in this report. The major areas of interest for methane emissions are limited to the front end operation of the plant: dehydration, liquids recovery, gas compression and residue gas handling. Most of the gas blowdown from a gas plant comes from the natural gas compressors, which are nearly identical to those of transmission compressor stations.

Plant blowdown practices in gas processing vary considerably. Many gas plants have piloted flare systems. However, very few plants route all PRVs and maintenance blowdown lines to the flare. Some gas plants have gas recovery systems (such as the fuel saver system) that allow for some maintenance blowdown to be partially recovered, but most gas compressor blowdown vents are routed to the atmosphere.

Many gas plants have emergency shutdown (ESD) systems that can isolate the plant and stop the gas compressors; however, most of these systems do not depressure the plant.

Similar to the transmission segments, maintenance blowdowns at gas plants consist primarily of the following events: compressor blowdown, compressor starts, and miscellaneous vessel blowdown. Table 5-11 compares the blowdown practices of the two industry segments. The practices were determined from company data and site visits. The gas plant and transmission practices are comparable.

Because of the similarities in station blowdown practices between the gas processing and transmission segments, company-tracked data for transmission stations were applied to the gas plants. It is believed that the quality of the transmission company data is superior to that of the individual site blowdown data gathered for 11 gas plants. Therefore, the emission factor for gas processing plants was based on the annual transmission compressor station emission factor (4,667 scf natural gas/plant) but corrected for the methane composition in gas processing of 87% ± 5%, rather than the transmission methane composition of 93.4% ± 1.5%.[9] The resulting methane emission factor for gas processing is 4,060 ± 262% Mscf/plant for 1992.

TABLE 5-11. GAS PROCESSING AND TRANSMISSION COMPRESSOR BLOWDOWN OPERATING PRACTICES

Blowdown Operating Practice	Gas Processing (Based on 11 Sites)	Transmission (Based on 8 Companies)
Reciprocating Engines:		
% with blowdown lines to the atmosphere	62.5%	100%
% that are depressured to the atmosphere when idle	25%	29%
% that are held at operating pressure when idle	75%	65%
% that are partially depressured to a lower pressure system when idle	0%	6%
% with gas starters that vent to the atmosphere	25%	0%
Turbine Engines:		
% with blowdown lines to the atmosphere	100%	100%
% that are depressured to the atmosphere when idle	100%	92%
% that are held at operating pressure when idle	0%	8%
% that are partially depressured to a lower pressure system when idle	0%	0%
% with gas starters that vent to the atmosphere	67%	100%

5.4 Distribution

The distribution segment consists primarily of pipeline networks. Blow and purge emissions in distribution pipelines are mainly due to PRV releases, dig-ins, or pipeline blowdowns. PRVs are used in the distribution network to prevent the over-pressure of pipelines. Typically, PRVs are used in conjunction with pressure regulators as a secondary protection mechanism in the event of regulator failure. Gas is released during any emergency actuation of the PRVs.

Two distribution companies quantified losses from PRVs as part of UAF gas studies.[5,6] The results are shown in Table 5-12. The emission factor was determined based on the ratio of natural gas released per mile of distribution main from the two companies. Correcting for the methane composition in distribution (93.4 mol % $\pm$ 1.5%),[9] the annual emissions due to PRV releases are 0.050 $\pm$ 3,900% Mscf/mile of main.

TABLE 5-12. DISTRIBUTION PRV EMISSIONS

Company	Annual PRV Emissions, Mscf	Main Miles	Annual PRV Natural Gas Emission Factor, Mscf/mile
1	2,262	31,730	0.071
2	141	13,248	0.011
TOTALS	2,403	44,978	
ANNUAL PRV EF FOR DISTRIBUTION, Mscf methane/mile main			0.050 ± 3,900%

As discussed in Section 3.2, dig-ins are pipeline ruptures caused by unintentional third-party damage. Some distribution companies estimate and record the quantity of gas lost during a dig-in event. From the annual records of four companies (Table 5-8), the average methane emissions due to dig-ins is 1.59 ± 1,900% Mscf/mile of distribution pipeline.

The high uncertainties of the distribution blowdown emission factors are the result of the limited database (two to four sets of company data).

Pipeline blowdowns are a maintenance activity and may release methane to the atmosphere as a result of pipeline abandonment, installation, or repair. The emission factor for pipeline blowdowns is based on data from four companies, shown in Table 5-13. The emission factor was calculated from the ratio of the blowdown methane losses per mile of distribution mains and services for the four sites. The estimated gas loss was adjusted for 93.4% methane, resulting in an annual emission factor of 0.102 ± 2,500% Mscf methane per mile of distribution pipeline.

TABLE 5-13. DISTRIBUTION PIPELINE BLOWDOWN EMISSIONS

Company	Annual Blowdown Methane Emissions, Mscf	Pipeline Miles	Annual Blowdown Methane Emission Factor, scf/mile
1	8,972	58,024	0.155
2	5,688	82,337	0.069
3	2,360	24,916	0.095
4	1,695	18,713	0.091
TOTALS	18,715	183,990	
ANNUAL BLOWDOWN EF, Mscf methane/mile			0.102 ± 2,500%

6.0 NATIONAL ANNUAL EMISSIONS

National annual emissions for each industry segment were calculated by combining the emission factor and activity factor:

$$\text{National Annual Emissions} = \text{Emission Factor} \times \text{Activity Factor} \qquad (2)$$

These results are summarized in Table 6-1 and presented in the following sections. The activity factors for the production, transmission, gas processing, and distribution segments are discussed briefly. (Details are provided in Volume 5 on activity factors.[9])

6.1 Field Gas Production

The activity factors for equipment in the production segment were compiled from site visit averages.[9] The number of production vessels was assumed to be the sum of separators, heaters, and dehydrators within the gas industry boundaries. The count of gas wells requiring unloading was based on the number of all active gas wells observed at 22 sites corrected for the fraction of wells requiring unloading from these site (41.4% ± 45%, from Table 5-1). The count of PRVs in production is based on an average number of PRVs determined for each type of equipment: 2 PRVs/separator, 1 PRV/heater, 2 PRVs/dehydrator, and 4 PRVs/compressor.[9,11] The count of platforms is from Offshore Data Services and the Minerals Management System Outer Continental Databases.[9,12]

The final production blowdown emissions were determined by multiplying the emission factor (rate per average unit) for each category by the activity factor (population) of the category. Emission factors for production were previously discussed in Section 5.1. Table 6-1 and source sheets P-8, P-9, and P-10 in Appendix B summarize these calculations. The results were added to give the annual national production emission rates of 6.0 Bscf ± 359% for maintenance blowdowns and 0.53 Bscf ± 840% for emergency releases.

TABLE 6-1. BLOW AND PURGE EMISSION RESULTS

Industry Segment	Annual Emission Factor	Activity Factor	National Annual Methane Emission Rate, Bscf
Production:			
Gas Wells Unloading	49,570 ± 344% scf/well	114,139 ± 45% wells	5.66 ± 380%
Compressor Blowdowns	3,774 ± 147% scf/comp.	17,112 ± 52% compressors	0.065 ± 173%
Compressor Starts	8,443 ± 157% scf/comp.	17,112 ± 52% compressors	0.144 ± 184%
Pipeline Miles	309 ± 32% scf/mile	340,000 ± 10% miles	0.105 ± 34%
Production Vessels	78 ± 266% scf/vessel	255,996 ± 26% vessels	0.020 ± 276%
Completion Flaring	733 ± 200% scf/completion	844 ± 10% completions	0.0006 ± 201%
Well Workovers	2,454 ± 459% scf/workover	9,329 ± 258% workovers	0.023 ± 1,296%
PRV Releases	34 ± 252% scfy/PRV	529,440 ± 53% PRVs	0.018 ± 289%
ESD Releases	256,888 ± 200% scf/platform	1,115 ± 10% platforms	0.286 ± 201%
Dig-ins	669 ± 1,925% scf/mile	340,000 ± 10% miles	0.23 ± 1,934%
Gas Processing	4,060 ± 322% Mscf/plant	726 ± 2% plants	2.95 ± 262%
Transmission and Storage:			
Stations	4,359 ± 322% Mscf/station	2,175 ± 8% stations	9.48 ± 263%
Pipeline Miles	31.6 ± 343% Mscf/mile	284,500 ± 5% miles	9.00 ± 236%
Distribution:			
PRV Releases	0.050 ± 3,914% Mscf/main mile	836,760 ± 5% miles main	0.04 ± 3,919%
Dig-ins	1.59 ± 1,922% Mscf/mile	1,297,569 ± 5% miles	2.06 ± 1,925%
Blowdowns	0.102 ± 2.521 Mscf/mile	1,297,569 ± 5% miles	0.13 ± 2,524%

6.2 Gas Transmission

The activity factors for the transmission segment were compiled from company data, site visit averages, and published statistics on the gas industry.[9] The total count for transmission compressor stations is 1,700; the total storage station count is 475.[13] This results in 2,175 ± 8% compression facilities. The number of transmission pipeline miles is reported in A.G.A. *Gas Facts*, Table 5-1, which shows 284,500 ± 5% miles of pipeline in the United States for 1992.[14] Multiplying the respective activity factors by the station methane emission factor of 4,359 ± 262% Mscf/station and the pipeline emission factor of 31.6 ± 236% Mscf/mile, results in the annual station emissions of 9.5 ± 263% Bscf and the pipeline blowdown emissions of 9.0 ± 236% Bscf. Combining these produces the national annual transmission emissions of 18.5 ± 177% Bscf.

6.3 Gas Processing

The number of gas processing plants, as reported in a 1992 edition of *Oil and Gas Journal*,[15] is 726 ± 2%. (The confidence bound is assigned by engineering judgement.[9]) The annual emissions were determined by multiplying the transmission station blowdown emission factor by the number of gas plants. The resulting national annual emissions for gas processing are 3.0 ± 262% Bscf for 1992.

6.4 Distribution

The activity factor for distribution PRV releases is based on the total miles of distribution main pipeline in the United States (836,760 ± 5%). Combining the activity factor with the annual emission factor (0.050 ± 3,914% Mscf/main miles from Section 5.4) yields the national annual methane emissions of 0.042 ± 3,919% Bscf.

The activity factor for distribution pipeline dig-ins and blowdowns is based on the total miles of distribution pipeline in the United States (1,297,569 ± 5%).[9] For pipeline dig-ins, multiplying the annual emission factor (1.59 ± 1,922% Mscf/mile from Section 5.4) and activity factor results in the national annual methane emissions of 2.06 ± 1,925% Bscf for dig-ins. Likewise for pipeline blowdowns, the national annual methane emissions of 0.13 ± 2,524% Bscf result from the product of the activity factor and annual emission factor (0.102 ± 2,521% Mscf/mile from Section 5.4). The annual national methane emissions for the distribution segment are then 2.2 ± 1,783% Bscf.

7.0 REFERENCES

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APPENDIX A

Unaccounted-For Gas Studies

A.1 PG&E UAF Study

The Pacific Gas & Electric (PG&E) unaccounted-for (UAF) gas study[1] estimated blow and purge gas for the entire PG&E transmission and distribution system. The study estimated the 1987 blow and purge (blowdown) gas for PG&E's system to be 310 MMcf. This accounts for 2.3% of the 13,259 MMcf of UAF gas estimated in the PG&E report for 1987 and 0.04% of the total 857,346,771 Mcf PG&E gas receipts for 1987.

In the PG&E study, UAF is defined as the difference between total gas receipts (input) and total gas deliveries (output). Because of PG&E's accounting procedures, even though a quantity of purge gas may be well documented and reported, it may still be classified as "unaccounted-for" because it was not reported to accounting as having been "delivered" to anyone. Therefore all of PG&E's blow and purge quantities were classified as UAF, and were estimated by the UAF study. PG&E attempted to systematically account for blowdown gas emitted from their system using pipeline records, documentation of blow and purge occurrences (for instance with their standard form "Report of Gas Blown to Atmosphere"), and from interviews with engineers and operators. Blowdown sources of UAF gas included in the report are listed in Table A-1. These sources are discussed briefly below.

Boiler Purge

Boiler purge UAF gas was estimated using the dimensions of the purged piping and the frequency of purges. Pipe dimensions were measured manually and the frequency of purges was obtained from accounting records.

Pipeline Blow and Purge

Purge gas for pipelines taken out of service was estimated by calculating the internal volume of the pipeline, estimating a working pressure, and using the Ideal Gas

TABLE A-1. PG&E BLOWDOWN SOURCES

Type Blow/Purge	1987 Amount (Mcf)	% of 1987 Blow/Purge	% of 1987 Receipts
Boiler purge	57	0.0	0.0000
Pipeline blow and purge	198,000	63.9	0.0231
Drip Operations	2,600	0.9	0.0003
Compressor blow and purge (including start-ups)	107,000	34.5	0.0125
Dehydrator blow and purge	544	0.2	0.0001
Meter and regulator replacement and insp-ection	1,300	0.4	0.0002
Odorizer blow and purge	196	0.1	0.0000
TOTAL	310,000	100	0.0362

Law. Volume measurements were obtained from 1987 pipeline statistics. Transmission and gathering pipe are not mentioned in this section of the report.

Estimates for purge gas from new pipelines put into service were broken into two categories by pipe diameter and therefore, purge method. When purging small diameter pipes, PG&E used a method which allows more natural gas to escape than the purge method for larger diameter pipes. However, interviews with pipeline engineers/ operators indicated that UAF resulting from either purge method was very small. UAF gas from pipes with small diameters was estimated by assuming an orifice size for the purge valve, assuming a pressure in the pipeline, and assuming the valve was left open for 20 seconds with 100% natural gas being purged. UAF gas emissions from the newly installed pipelines with larger diameters were not calculated.

Estimates of purge gas resulting from pipeline repair were also broken into two categories. If the repair was done on a distribution and service pipe, a worst case length was assumed. If the repair was done on transmission and gathering pipelines, the amount of purge gas was estimated and reported at the time of repair. Other types of blow and purge due to pipeline repair were not included in the report because interviews with engineers/operators indicated the amount to be insignificant.

For transmission and gathering pipe, estimates of blow and purge due to emergency shutdowns were reported at the time of shutdown and were included in the estimate for pipeline repair. For distribution and service pipe, emergency shutdowns were too infrequent and the volumes too small to warrant UAF gas estimation.

Drip Operations

Drip points along the pipeline are periodically opened to clear the line of condensation. PG&E operators were interviewed to determine a typical blow operation and its frequency. UAF gas due to drip operations was then estimated.

Compressor Blow and Purge (including start-ups)

Compressor blow and purge occurs when a compressor is brought down for emergency or maintenance reasons. In addition, most compressors require compressed gas to bring them up to starting speed. For compressor purge and blow estimations, piping sizes were obtained from engineering drawings and blow and purge frequencies were obtained from records. Purge volumes were estimated by compressor engineers to be about 2% of the associated pipe volume at operating pressure. The volume of gas needed to start a turbine compressor was measured, prior to 1980, to be about 35 Mcf per start-up attempt and each turbine requires about 4 attempts to start. Assuming the turbines required the same amount of gas to start in 1987 as prior to 1980, PG&E estimated a final blow volume from this source. Reciprocating compressors were not mentioned in the PG&E report.[1]

Dehydrator Blow and Purge

In estimating blowdown gas from dehydrators, PG&E obtained dehydrator volumes, operating pressures, and the frequency of gas vents to the atmosphere. No estimate was made of purge gas because of the infrequency of shutdowns (about once every two years) and the low volume of purge needed. Additionally, seven of PG&E's 37 dehydrators were not included in the estimate because they service underground storage, which was beyond the scope of their report.

Meter and Regulator Replacement and Inspection

To arrive at an estimate for blow and purge from gas meters, PG&E interviewed operators for estimates of the lengths of purge and the flow rates used during installations and maintenance. They then obtained the total number of operations from company records, and calculated a final estimate. Many of the steps involved in installing a gas meter or connecting a new customer require releasing gas to the atmosphere while metering the flow. These volumes are typically charged to the customer and, therefore, are not considered UAF gas.

Odorizer Blow and Purge

PG&E obtained estimates from operators of how much gas is purged from odorizers each year. The estimated volumes were so low that they decided not to investigate this source of UAF gas any further.

Sources Not Included In Study

Several UAF gas sources were not included in the study because they were beyond the scope of work or deemed insignificant. These sources and the reasons for not including them in the study are listed in Table A-2.

TABLE A-2. SOURCES NOT INCLUDED IN UAF

UAF Source	Reason for Non-inclusion
Start-up purge of pipes over 8 inches in diameter	The method of purge yields little UAF gas
Blow and purge due to maintenance, repair, and hydrostatic testing of pipelines	Operator estimate determined amount to be insignificant
Emergency shutdown blow of distribution and service pipe	Volume of pipe was small and frequency of emergency shutdown was low
All purge gas from all dehydrators	Volume was small and shutdown infrequent (blow gas was included)
All blow gas from three compressor stations and seven dehydrators at underground storage fields	Beyond the scope of the report
All blow gas from orifice meters with senior fittings	Volume was insignificant (orifice meters with junior fittings were included)
All blow and purge from meters and regulators on California producer wells and PG&E purchase meters	Outside of PG&E system, except downstream of PG&E purchase meters, which was a small volume

Conclusions

There are some differences in definitions, comprehensiveness, and accuracy between the results of the PG&E study and the needs of the GRI/EPA methane emissions project. PG&E includes turbine compressor starts in the blow and purge category, while the GRI/EPA study separates starts from blowdowns. PG&E's report seems to be comprehensive with one notable exception. They fail to account for blowdowns from reciprocating compressors, which could be a significant source of UAF gas. Other omissions are relatively low-volume sources. The accuracy of the estimates in the study can be broken into two qualitative categories, those which were done using anecdotal evidence (such as operator guesses) and those which were done using measurements or easily estimated volumes, pressures, and times. Table A-3 breaks the estimates into these categories.

TABLE A-3. PG&E UAF ESTIMATE METHODS

Type Blow/Purge Estimate	Accounted-for Gas Measured	Non-rigorous UAF Gas Estimate	Rigorous UAF Gas Estimate	Volume Estimates
Boiler			X	
Retired Pipeline			X	214 Mcf
New Pipeline		X		9392 Mcf
Repaired Pipe			X	20 Mcf
Drip Operations		X		
Comp. B&P		X		73,797 Mcf
Comp. Starts			X	32,890 Mcf
Dehydrator			X	
Meter and Regulator	X	X		UAF volume not reported
Odorizer		X		

A.2 SoCal UAF Study

The SoCal UAF gas study[2] was modeled after the 1987 PG&E UAF study, but it was conducted on 1991 inventories. This study estimated total UAF gas for the SoCal system of 9,516 MMcf in 1991, with 12,514 Mcf, or 0.13%, coming from blowdown operations. The blowdown UAF gas estimate accounts for 0.0012% of the 1,052 Bcf total 1991 receipts to the SoCal System. Specific operations included in the SoCal study are listed in Table A-4. Each type of blow and purge emission source is discussed briefly.

TABLE A-4. SoCal UAF SUMMARY

Type Blow/Purge	1987 Amount (Mcf)	% of Total Blow/Purge	% of 1991 Receipts
Blow & purge of abandoned pipe	827	6.6	0.000079
Purge from newly installed pipe	5,180	41.4	0.000492
Turbine meter spin test blow	100	0.8	0.000010
Calibration purge of meters ≥ size 4	2,669	21.3	0.000254
Hydrostatic test blowdown	2,498	20.0	0.000237
Drip operations	1,0	9.9	0.000118
TOTAL	12,514	100	0.001190

Blow and Purge of Abandoned Pipe

To estimate the UAF gas volume due to old pipe abandonment, SoCal obtained pipe dimensions from records, assumed a pressure inside the pipe, and applied the Ideal Gas Law.

Purge From Newly Installed Pipe

In estimating the UAF gas due to installation of new pipe, SoCal used the pipe radial dimensions and length, the pressure inside the pipe, the duration that air/gas was purged, and the size of the purge orifice. The pipe radial dimensions were obtained from company records and the pipe length and the duration of purge were obtained from Industrial Engineering standards. Both the pressure in the pipe and the purge orifice were assumed. With these assumptions and data, SoCal estimated the volume of gas purged to the atmosphere starting with a pipe full of air at atmospheric pressure, and ending with a pipe full of natural gas at 40 psig.

Turbine Meter Spin Test Blow

For turbine meter test purges, SoCal identified 323 turbine meters and segregated them into five pressure groups. They then assumed a turbine meter run from a standard drawing and assumed each meter was inspected three times per year. The Ideal Gas Law was used to calculate the final estimate of UAF gas due to turbine meter inspection.

Calibration Purge of Large Meters

In estimating the amount of purge gas due to calibrating diaphragm and rotary meters, SoCal limited their investigations to size 4 meters and larger. The diaphragm and rotary meter purges were calculated separately due to differing field test procedures. Observations were made in the field to determine the length of purge per meter test. The flow rates used during testing were taken from published company procedures. Often meters require multiple tests to achieve calibration, so to calculate a purge estimate, SoCal assumed four tests per calibration for diaphragm meters and three tests per calibration for rotary meters.

Hydrostatic Test Blowdown

When SoCal performs hydrostatic pipe strength tests, they sometimes record the amount of gas purged to the atmosphere in accounting records. In these cases, the purge is not considered "unaccounted-for" and is not included in their UAF gas total (presumably it is accounted-for as delivered to themselves). To calculate the UAF gas for their report, they obtained the lengths and diameters of all pipe tested from company records, assumed a pressure, applied Boyle's Law to obtain a total volume, and subtracted the "accounted-for" volume (284 Mcf in 1991) to obtain a final UAF volume.

Drip Operations

To estimate UAF purge from drip operations, several field operators were interviewed to establish a typical drip procedure. Further, they estimated the number of drip points, a drip point distribution according to pipeline pressure, and a drip point purge frequency. Using these assumptions and the Pacific Coast Gas Association orifice equation, they calculated a final UAF purge volume.

Sources Not Included

The SoCal report[2] does not mention several sources of UAF gas which are included in the PG&E report.[1] Most of these were very small: boiler purge, dehydrator blow and purge, and odorizer blow and purge. However, compressor blow and purge contributed over one-third of the blowdown UAF reported in the PG&E study, but was not mentioned in the SoCal study.

Conclusions

SoCal's UAF volume does not represent all of the blowdown gas that reached the atmosphere. Due to accounting procedures, SoCal does not include gas blown to the atmosphere from some hydrostatic strength in their UAF estimates. The 284 Mcf of natural gas from this source should be included in the present study to get a better picture of the amount of methane lost from their system to the atmosphere.

The SoCal report[2] apparently does not take into account compressor start-up gas or compressor shut-down blow and purge gas, as the PG&E study did. These were substantial sources in the PG&E report[1] and should be accounted for.

Most of SoCal's estimates were done in a reasonably rigorous manner, but for comparison to the PG&E report, their estimates are broken-down by qualitative accuracy in Table A-5.

TABLE A-5. SoCal UAF ESTIMATE METHODS

Type Blow/Purge Estimate	AF Gas Measured	Non-rigorous UAF Gas Estimate	Rigorous UAF Gas Estimate	Volume Estimates
Abandoned Pipe			X	
New Pipeline			X	
Turb. Meter Test			X	
Large Meter Calib.			X	
Hydostat. Tests	X		X	UAF = 284 Mcf
Drip Operations		X		

REFERENCES

1. Pacific Gas & Electric Company and Gas Research Institute. *Unaccounted-For Gas Project.* Volume 1, Final Report, San Ramon, CA, June 7, 1990.

2. Southern California Gas Company and Gas Research Institute. *A Study of the 1991 Unaccounted-For Gas Volume at the Southern California Gas Company*, Final Report, Los Angeles, CA, April 1993.

APPENDIX B

Source Sheets

B.1 Production

P-8
PRODUCTION SOURCE SHEET

SOURCES:	Various Production Equipment (wells, vessels, compressors, pipelines)
OPERATING MODE:	Maintenance
EMISSION TYPE:	Unsteady, Vented
ANNUAL EMISSIONS:	6.0 Bscf ± 359%

BACKGROUND:
Maintenance activities can emit gas to the atmosphere through blowdown or through purge. Blowdown is the direct, intentional venting to the atmosphere of gas contained inside operating equipment. The gas is released to provide a safer working environment for maintenance activities around or inside the equipment. After the equipment is serviced, the oxygen inside the equipment is often cleared to the atmosphere by purging natural gas through the equipment.

Another type of maintenance venting is associated with low pressure gas wells that sometimes accumulate water in the wellbore due to their low flow rate. This water chokes the flow of the well, reducing gas production. To clear the water, the well is blown to a tank at atmospheric pressure where the gas is vented.

EMISSION FACTORS:

Gas Well Unloading 49,570 ± 344% scf/unloading gas well
Compressor Blowdown 3,774 ± 147% scf/compressor
Compressor Starts 8,443 ± 157% scf/compressor
Pipeline Blowdown 309 ± 32% scf/mile
Vessel Blowdown 78 ± 266% scf/vessel
(Emission factors were adjusted for the production methane fraction of natural gas of 78.8 mol%)

Blowdown volumes and frequencies were averaged from calculations for each GRI/EPA site visit. The volume times the frequency results in the annual emissions. The volumes were calculated at each site using equations of state, observed vessel dimensions, and pre-blowdown pressures. Frequencies were gathered at each site from operator interview. The annual emission factor (scf/unit) for each category was calculated as follows:

$$EF = Volume \times Frequency \times \%\ Methane$$

where:

Volume	=	Gas released to the atmosphere during an event (scf/event/unit);
Frequency	=	Number of events annually;
% Methane	=	78.8 mol % ± 5% for the production segment.

More details are available in the *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities* (1).

EF DATA SOURCES:

1. The blow and purge report establishes emission affecting characteristics of blow-down practices.
2. Volume and frequency data were available from the following number of sites:
   LP Gas Well Unloading (12 sites)

Compressor Starts	(12 sites)
Vessel BD	(12 sites)
Pipeline BD	(18 sites)

3. The count of equipment at each site was gathered during the site visits by observation, record search, or interview.

EF PRECISION: ± 32% to 344%

Basis:

The accuracy was calculated from the variance of the site data. A 90% confidence interval is calculated for the sites using the method outlined in the *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology* (2).

ACTIVITY FACTORS:

114,139 ± 45% gas wells requiring unloading
17,112 ± 52% compressors
340,000 ± 10% miles of pipeline
255,996 ± 26% production vessels

The activity factors for equipment in the production segment were compiled from GRI/EPA site visit averages as well as published statistics on the gas industry (see activity factor sections in previous sheets). The number of production vessels was assumed to be the sum of separators, heaters, and dehydrators.

AF DATA SOURCES:

1. The well, compressor, and vessel counts came from the activity factor extrapolation based on GRI/EPA site visits or surveys (previously discussed in the production fugitives sheet). The count of "vessels" is from the addition of dehydrator, separator, and in-line heater counts.
2. The miles of production gathering pipelines were determined from a site extrapolation of seven sites and data from *Gas Facts* Table 5-3 (3). This extrapolation was previously discussed in the production gathering pipeline fugitive leaks sheet, P-3.
3. The number of gas wells requiring unloading is based on the ratio of gas wells requiring unloading to all active gas wells from 25 GRI/EPA sites (41.4% ± 162%).

AF PRECISION: Range ± 10% to 52%

Basis:

The accuracy for all equipment types is based on error propagation from the spread of available production site data.

ANNUAL METHANE EMISSIONS: 6.0 Bscf ± 359%

The annual methane emissions were determined by multiplying an emission factor (rate per average unit) for each category by the activity factor (population) of the category.

REFERENCES

1. Shires, T.M. and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities*, Final Report, GRI-94/0257.24 and EPA-600/R-96-080g, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

2. Williamson, H.J., M.B. Hall, and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology*, Final Report, GRI-94/0257.21 and EPA-600/R-96-080d, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

3. American Gas Association. *Gas Facts, 1992 Data* (Table 5-3), Arlington, VA, 1993.

P-9
PRODUCTION SOURCE SHEET

SOURCES:	Various Production Equipment (vessels)
OPERATING MODE:	Upsets
EMISSION TYPE:	Unsteady, Vented
ANNUAL EMISSIONS:	0.3 Bscf ± 190%

BACKGROUND:

Upsets in process conditions can cause pressure rises that exceed the maximum design pressure for equipment. To prevent equipment overpressure and damage, pressure relief valves (PRVs) open and vent the excess gas to the atmosphere. These PRVs are spring loaded or pilot actuated valves that are designed to handle the upset conditions. A few offshore production facilities (but no onshore facilities) have Emergency Shutdown Systems (ESDs) that depressure the entire facility to a vent or a flare.

EMISSION FACTORS: **PRV Discharge Blowdown 34 ± 252% scf/PRV**
ESD Blowdown 257 ± 200% Mscf/platform
(Corrected for the production methane composition of 78.8 mol%)

Emergency blowdown volumes and frequencies were estimated at each site visited. The average volume of gas released at lift pressure was calculated for a typical PRV size and duration, and corrected for the fraction of PRVs that release gas to the atmosphere. ESD blowdown volumes were based on the platform volume and corrected for the fraction of platforms with ESDs and the fraction that vent gas to the atmosphere. The annual emission factor (scf/unit) for each category was calculated as follows:

$$EF = Volume \times Frequency \times \%\ Methane$$

where:

Volume	=	Gas released to the atmosphere during an event (scf/event/unit);
Frequency	=	Number of events per year;
% Methane	=	78.8 mol % ± 5% for the production segment.

EF DATA SOURCES:

1. The GRI/EPA *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities* (1) establishes emission affecting characteristics of blowdown practices.
2. Volumes (duration, release rate, % to atmosphere) and frequencies were calculated from each site visit based on data collection, observation, and interview. Data were available from the following number of sites:
   PRV discharge (11 sites)
   ESD activation (5 platforms)
3. The count of equipment at each site was gathered during the site visits by observation, record search, or interview.

EF PRECISION:

Basis:
The accuracy was propagated from the spread of the site data. A 90% confidence interval is calculated using the method presented in the *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology* (2).

ACTIVITY FACTORS: **529,440 ± 53% Production PRVs**
1,115 ± 10% Platforms

The activity factors for equipment types in the segment were compiled from GRI/EPA site visit data as well as published statistics on the gas industry.

AF DATA SOURCES:

1. The count of platforms is from Offshore Data Services and the Minerals Management System Outer Continental Activity Database as reported in *Methane Emissions from the Natural Gas Industry, Volume 5: Activity Factors* (3).
2. The number of production PRVs is based on counts of PRVs per equipment type from site visit data:

Equipment Type	PRV Count	Number of Sites
Separators	2 ± 68%	20
Heaters	1 ± 89%	11
Dehydrators	2 ± 53%	10
Compressors	4 ± 84%	13

Details are provided in the *Methane Emissions from the Natural Gas Industry, Volume 8: Equipment Leaks* report (4).

AF PRECISION: Range ± 10% to 53%

Basis:

1. Confidence intervals for the platform count were assumed and assigned based upon an excellent recorded source of data [see *Methane Emissions from the Natural Gas Industry, Volume 5: Activity Factors* (3)].
2. Ninety percent confidence limits for production vessels with PRVs were calculated from the confidence intervals of each type of equipment. See *Methane Emissions from the Natural Gas Industry, Volume 5: Activity Factors* (3) for details of equipment count determination.

ANNUAL METHANE EMISSIONS: 0.30 Bscf ± 190%

The annual methane emissions were determined by multiplying an emission factor (rate per avg unit) by the activity factor (population) of the category. Each emission factor was adjusted for the average methane content in the production segment of 78.8 mol%.

REFERENCES

1. Shires, T.M. and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities*, Final Report, GRI-94/0257.24 and EPA-600/R-96-080g, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

2. Williamson, H.J., M.B. Hall, and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology*, Final Report, GRI-94/0257.21 and EPA-600/R-96-080d, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

3. Stapper, B.E. *Methane Emissions from the Natural Gas Industry, Volume 5: Activity Factors*, Final Report, GRI-94/0257.22 and EPA-600/R-96-080e, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

4. Hummel, K.E., L.M. Campbell, and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 8: Equipment Leaks*, Final Report, GRI-94/0257.25 and EPA-600/R-96-080h, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

P-10
PRODUCTION SOURCE SHEET

SOURCES:	Pipeline
OPERATING MODE:	Mishaps (Dig-ins)
EMISSION TYPE:	Unsteady, Fugitive
ANNUAL EMISSIONS:	0.2 Bscf ± 1,934%

BACKGROUND:

Dig-ins are gathering pipeline ruptures caused by unintentional (sometimes third-party) damage. Production companies do NOT estimate and record the quantity of gas lost during a dig-in event; therefore, distribution data has been used.

EMISSION FACTOR: **669 ± 1,925% scf/mile**
(Corrected for the production methane composition of 78.8 mol%)

The emission factor was derived from four distribution company estimates of the losses from dig-ins: the Pacific Gas and Electric unaccounted-for (UAF) gas study (1) results showed that losses from dig-ins were estimated at 91,178 Mscf for 58,024 miles of distribution mains and services; the Southern California Gas Company estimate (2) of losses from dig-ins was 170,457 Mscf for 82,337 miles of distribution mains and services; a third company estimate of losses from dig-ins was 19,581 Mscf for 24,916 miles of distribution mains and services; and a fourth company reported dig-in losses of 10,453 Mscf for 18,713 miles of distribution mains. The ratio of the total dig-in emissions to the total pipeline miles from these companies was used to estimate the annual national methane emission factor, resulting in 2.06 Mscf/mile.

This value was halved (and adjusted for the different methane compositions of the two industry segments) based upon an engineering assumption that production dig-ins occur much less frequently than distribution dig-ins, and so account for approximately one-half of the distribution emission rate per mile. This is supported by the fact that most production sites are remotely located, while distribution sites are by definition located in population centers where third-party dig-ins are more likely.

ACTIVITY FACTOR: 340,000 ± 10% miles of production gathering pipeline

The annual number of miles of gathering pipeline in the U.S. gas industry was derived from site data. See P-3 and *Methane Emissions from the Natural Gas Industry, Volume 5: Activity Factors* (3) for more details.

ANNUAL METHANE EMISSIONS: **0.23 Bscf ± 1,934%**

REFERENCES

1. Pacific Gas & Electric Company and Gas Research Institute. *Unaccounted-For Gas Project.* Volume 1, Final Report, San Ramon, CA, June 1990.

2. Southern California Gas Company and Gas Research Institute. *A Study of the 1991 Unaccounted-For Gas Volume at the Southern California Gas Company*, Final Report, Los Angeles, CA, April 1993.

3. Stapper, B.E. *Methane Emissions from the Natural Gas Industry, Volume 5: Activity Factors*, Final Report, EPA-600/R-96-080e, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

P-11
PRODUCTION SOURCE SHEET

SOURCES:	Gas Wells
OPERATING MODE:	Maintenance
EMISSION TYPE:	Venting and Flaring
ANNUAL EMISSIONS:	0.02 Bscf ± 1,263%

BACKGROUND:
Two minor sources of maintenance releases are completion flaring and well workover. Completion flaring occurs at a new well's open ended pipe flare immediately following the drilling process. During completion testing, the gas is flared to determine the available pressure and flow rates at the surface. This allows proper sizing of meters and surface equipment. Most completion flaring occurs at exploratory wells, since the production rates and needed facilities for in-fill wells (also called development wells) are often available or can be determined before the well is completed.

Well workovers are another type of maintenance venting. During a well workover, the tubing is pulled from the well to repair tubing corrosion/erosion or other downhole equipment problems. The well is "killed" by replacing the gas in the column with water or mud, thus stopping all production flow. The well can then be opened to the atmosphere.

EMISSION FACTORS: **Completion Flaring 733 ± 200% scf/completion well**
Well Workovers 2,454 ± 459% scf/well workover
(Emission factors were adjusted for the production methane fraction of natural gas of 78.8 mol%.)

The flow rate of gas at completion is the highest that the well will produce. For emission estimate purposes, the maximum gas flow rate was not available. Instead, the completion flaring emission factor was calculated based on the average annual natural gas production per well and an assumed flaring efficiency as shown:

$$EF_{completion\ flaring} = \text{Average Annual Volume} \times \text{Duration} \times \text{\% Methane} \times \text{Flaring Efficiency}$$

where:

Average Annual Volume	=	16.97 MMscf for natural gas
Duration	=	Flaring duration is one day/completion well
% Methane	=	78.8 mol% for production
Flaring Efficiency	=	98% efficient (2% methane not burned)

This results in an emission factor of 733 ± 200% scf/completion well for completion flaring.

The emission factor for well workovers was determined from two gas production fields. Data from these fields are shown in the following table:

	Site 1	Site 2
Total number of wells	21	400
Number of workovers/year	1	8
Methane emissions/workover, scf/workover	670	4,238
Average scf methane/workover	2,454 ± 459%	

EF DATA SOURCES:

1. One operator provided data on the typical duration of completion flaring and which types of completions were flared. Average is one day/exploratory completion well.
2. Average gas production per well from *Gas Facts* (1).
3. Multiple reports on methane flare combustion efficiency support 98% combustion.
4. Pipeline Systems Incorporated (PSI) reported gas well workover emissions from two sites (2).

EF PRECISION: ± 200% to 459%

1. Engineering judgement was used to establish the upper confidence limit for the completion flaring emission factor.
2. Confidence bound for well workover emission factor is based on the average of data from two sites.

ANNUAL ACTIVITY FACTORS:

844 ± 10% completed gas wells
9,329 ± 258% well workovers

AF DATA SOURCES:

1. Number of exploratory wells completed per year based on data from the Energy Information Administration (EIA) Drilling and Production under Title I of the Natural Gas Policy Act (3). This data excludes Alaska.
2. PSI data showed 1 workover/yr per 21 wells at Site 1 and 1 workover/yr per 50 wells at Site 2.
3. The Activity Factors Report (4) provides details on the total number of gas producing wells (276,014 ± 5%).

AF PRECISION: Range ± 10% to 258%

1. 10% upper confidence bound for completion wells is assigned based on good precision from national statistics of 1987 data.
2. Well workover confidence interval is based on the average of data from two sites combined with the confidence bound for the total number of gas producing wells.

ANNUAL METHANE EMISSIONS: **Completion Wells: 619 ± 201% Mscf**
Well Workovers: 22.9 ± 1296% MMscf

The annual methane emissions were determined by multiplying an emission factor (methane emissions per event) for each category by the activity factor (events/year) of the category.

REFERENCES

1. American Gas Association. *Gas Facts: 1992 Data* (Table 3-3), Arlington, VA, 1993.

2. Pipeline Systems Incorporated. *Annual Methane Emission Estimate of the Natural Gas Systems in the United States, Phase 2.* For Radian Corporation, September 1990.

3. Energy Information Administration. *Annual Energy Review 1994*, Table 4.5 "Oil and Gas Exploratory Wells, 1949-1994." EIA, Office of Oil and Gas, U.S. Department of Energy, DOE/EIA-0384(94), Washington, DC, July 1995.

4. Stapper, B.E. *Methane Emissions from the Natural Gas Industry, Volume 5: Activity Factors,* Final Report, GRI-94/0257.22 and EPA-600/R-96-080e, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

B.2 Gas Processing

GP-4
PROCESSING SOURCE SHEET

SOURCES:	All Equipment (vessels, compressors, pig traps, manifolds)
OPERATING MODE:	Maintenance
EMISSION TYPE:	Unsteady, Vented
ANNUAL EMISSIONS:	3.0 Bscf ± 262%

BACKGROUND:

Blowdown is the direct, intentional venting to the atmosphere of gas contained inside operating equipment. The gas is released to provide a safer working environment for maintenance activities around or inside the equipment.

EMISSION FACTORS: 4,060 ± 262% Mscf/gas plant
(Corrected for the gas processing methane composition of 87 mol%)

Blowdowns at gas plants consist primarily of the following types of events: compressor blowdown, compressor starts, pipeline pig receiver blowdown, and miscellaneous vessel blowdown. Due to the similarities in station blowdown practices between the gas processing and transmission segments, transmission station company tracked data were applied to gas plants. Blowdown volumes per station were provided based on company tracked data from 9 transmission companies.

EF DATA SOURCES:

1. The *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities* (1) establishes emission affecting characteristics of blowdown practices.
2. Company tracked data were provided from 9 transmission companies representing a total of 328 stations.

EF ACCURACY: ± 262%

Basis:
The accuracy was calculated from the spread of the company tracked data. A 90% confidence interval is calculated for the data using the method presented in *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology* (2).

ACTIVITY FACTOR 726 ± 2% gas plants

AF DATA SOURCES:

1. The number of gas processing plants for 1992 is reported in the *Oil and Gas Journal* (3).

AF ACCURACY:

Basis:
An accurate count of gas plants by the *Oil and Gas Journal* is very likely since counting such large, discrete facilities should be straightforward. The ± 2% was assigned by engineering judgement.

ANNUAL METHANE EMISSIONS: 2.95 ± 262 Bscf

The annual methane emissions were determined by multiplying an emission factor by the activity factor (population). Each emission factor was adjusted for the average methane content in the gas processing segment of 87 mol%.

REFERENCES

1. Shires, T.M. and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities*, Final Report, GRI-94/0257.24 and EPA-600/R-96-080g, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

2. Williamson, H.J., M.B. Hall, and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology*, Final Report, GRI-94/0257.21 and EPA-600/R-96-080d, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

3. Bell, L. "Worldwide Gas Processing," *Oil and Gas Journal*, July 12, 1993, p. 55.

B.3 Transmission and Storage

T-5
TRANSMISSION AND STORAGE SOURCE SHEET

SOURCES:	Various Equipment
OPERATING MODE:	Maintenance/Upsets
EMISSION TYPE:	Unsteady, Vented
ANNUAL EMISSIONS:	18.5 Bscf ± 177%

BACKGROUND:

Maintenance activities can release gas to the atmosphere through blowdown or through purge. Blowdown is the direct, intentional venting to the atmosphere of gas contained inside operating equipment. The gas is released to provide a safer working environment for maintenance activities around or inside the equipment. After the equipment is serviced, the oxygen inside the equipment is often cleared to the atmosphere by purging natural gas through the equipment.

Upsets can also emit gas directly to the atmosphere. Upsets in process conditions can cause pressure rises that exceed the maximum design pressure for equipment. To prevent equipment overpressure and damage, pressure relief valves (PRVs) or remotely actuated valves open and vent the excess gas to the atmosphere. PRVs are spring loaded or pilot actuated valves that are designed to handle the upset conditions. Remotely actuated valves are usually designed to vent entire compressor stations or areas (such as compressor piping) in the event of a station emergency such as a fire or a large gas release.

EMISSION FACTORS: **Station Blowdowns 4,359 ± 262% Mscf/station**
Pipeline Blowdowns 31.6 ± 236% Mscf/mile
(Corrected for the transmission methane composition of 93.4 mol%)

Company tracked data were available from either company gas use estimates reported to accounting departments from each site (accounted-for), or from special "unaccounted-for" studies that searched for unmetered company gas use. Most of the company data could be separated into two event types: station blowdowns (includes compressor blowdowns, compressor starts, PRV lifts, ESD activation, and other venting sources) and pipeline blowdowns. These data are summarized in the following table.

EF DATA SOURCES:

1. GRI/EPA *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities* (1) establishes emission affecting characteristics of blowdown practices.
2. Company tracked data were available from 8 companies.

EF ACCURACY: Range ± 236% to 262%

Basis:
The accuracy was calculated from the spread of the company data. A 90% confidence interval is calculated for the 8 companies using the method presented in the *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology* (2).

Company	Annual Station Blowdown Emissions, Mscf	Annual Pipeline Blowdowns, Mscf	Total Annual Blowdowns, Mscf	Total Number of Stations	Total Number of Pipeline Miles
1	120,757	189,044	309,801	11	3,857
2	272,589	11,358	283,947	15	4,000
3	33,731	138,988	172,719	27	5,886
4	—	—	172,776	(19)[a]	(5,450)
5	325,418	Unknown	Unknown	47	(4,725)
6	Unknown	161,628	Unknown	(48)	7,896
7	60,956	750,000	810,956	69	14,666
8	194,541	315,058	509,599	47	9,915
TOTALS	1,007,992	1,566,076		216	46,220
ANNUAL AVERAGE, Mscf natural gas/station					4,667 ± 262%
ANNUAL AVERAGE, Mscf natural gas/mile					33.9 ± 236%

[a]Parentheses indicate that the value was not included in the total because a station or pipeline emission rate was not available.

ACTIVITY FACTORS: **2,175 ± 8% compression facilities**
284,500 ± 5% transmission pipeline miles

The activity factors for the segment were compiled from published statistics on the gas industry. The total count for transmission compressor stations was 1700; the total underground and liquefied natural gas storage station count was 475. The number of transmission pipeline miles comes from A.G.A. *Gas Facts* (3) which shows 284,500 miles of pipeline in the United States for 1992.

AF DATA SOURCES:

1. The number of transmission compressor stations was compiled from FERC Form No. 2: Annual Report of Major Natural Gas Companies (4).
2. The number of underground storage facilities is taken directly from A.G.A. *Gas Facts*, Table 4-5, "Number of Pools, Wells, Compressor Stations, and Horsepower in Underground Storage Fields" (3).
3. The number of liquefied natural gas storage facilities was summed from A.G.A. *Gas Facts*, Table 4-3, "Liquefied Natural Gas Storage Operations in the U.S. as of December 31, 1987" (3). The table lists 54 complete plants, 32 satellite plants, and 3 import terminals for a total of 89 facilities.
4. The number of transmission pipeline miles comes from A.G.A. *Gas Facts* which shows 284,500 miles of pipeline in the U.S. for 1992 (3).

AF ACCURACY: Range ± 5% to 8%

Basis:

Extremely tight confidence limits are expected due to the well documented and reviewed DOE numbers published in A.G.A. *Gas Facts* (3).

ANNUAL METHANE EMISSIONS: 18.5 Bscf ± 177%

The annual methane emissions were determined by multiplying an emission factor (rate per avg unit) for each category by the activity factor (population) of the category. Each emission factor was adjusted for the average methane content in the transmission segment of 93.4 mol%.

REFERENCES

1. Shires, T.M. and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 7: Blow and Purge Activities,* Final Report, GRI-94/0257.24 and EPA-600/R-96-080g, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

2. Williamson, H.J., M.B. Hall, and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology,* Final Report, GRI-94/0257.21 and EPA-600/R-96-080d, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

3. American Gas Association. *Gas Facts: 1992 Data*, Arlington, VA, 1993.

4. Department of Energy. FERC Form No. 2: Annual Report of Mayor Natural Gas Companies. OMB No. 1902-0028, Department of Energy, Federal Energy Regulatory Commission, Washington, DC, December 1994.

B.4 Distribution

D-3
DISTRIBUTION SEGMENT SOURCE SHEET

SOURCES: Pressure Relief Valves
OPERATING MODE: Maintenance/Upsets
EMISSION TYPE: Unsteady, Vented
ANNUAL EMISSIONS: 0.04 Bscf ± 3,919%

BACKGROUND:

Pressure relief valves (PRVs) are often used in the distribution network to prevent the over-pressure of distribution main pipelines. Typically, PRVs are used in conjunction with pressure regulators as a secondary protection mechanism in the event of regulator failure. Gas is released during any emergency actuation of the PRVs.

EMISSION FACTOR: 0.050 ± 3,914% Mscf/mile
(Adjusted for the distribution methane fraction of natural gas of 93.4 mol%)

The estimated emission factor was based on two separate distribution company studies which quantified losses from PRVs as part of unaccounted-for (UAF) gas studies. The studies calculated PRV releases per mile of pipeline mains. The GRI/EPA emission factor was estimated as the ratio of emissions per mile of main from the two companies, and corrected for the methane composition in distribution.

EF PRECISION: ± 3,914%
Basis:
The precision was calculated using the method outlined in the *Statistics Report* (1).

ACTIVITY FACTOR: 836,760 ± 5% miles of main

The activity factor is based on the total miles of distribution main pipeline in the U.S.

AF PRECISION: ± 5%
Basis:
The accuracy was assigned based on engineering judgement.

ANNUAL METHANE EMISSIONS: 0.042 ± 3,919% Bscf

The annual methane emissions were determined by multiplying an emission factor (annual methane emissions per mile of main) by the activity factor (miles of distribution main pipeline nationally).

REFERENCES

1. Williamson, H.J., M.B. Hall, and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology,* Final Report, GRI-94-0257.21 and EPA-600/R-96-080d, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

D-4
DISTRIBUTION SEGMENT SOURCE SHEET

SOURCES:	Pipeline
OPERATING MODE:	Mishaps (Dig-ins)
EMISSION TYPE:	Unsteady, Fugitive
ANNUAL EMISSIONS:	2.1 Bscf ± 1,925%

BACKGROUND:

Dig-ins are distribution main or service pipeline ruptures caused by unintentional third-party damage. Some distribution companies estimate and record the quantity of gas lost during a dig-in event; therefore, they keep records of estimated annual losses due to dig-ins. From these annual records, a national emission rate for dig-ins was determined.

EMISSION FACTOR: **1.59 ± 1,922% Mscf/mile**
(Adjusted for the distribution methane fraction of natural gas of 93.4 mol%)

The emission factor was derived from four distribution company estimates of the losses from dig-ins: the Pacific Gas and Electric unaccounted-for (UAF) gas study (1) results showed that losses from dig-ins were estimated at 91,178 Mscf for 58,024 miles of distribution mains and services; the Southern California Gas Company estimate (2) of losses from dig-ins was 170,457 Mscf for 82,337 miles of distribution mains and services; a third company estimate of losses from dig-ins was 19,581 Mscf for 24,916 miles of distribution mains and services; and a fourth company reported dig-in losses of 10,453 Mscf for 18,713 miles of distribution mains. The ratio of the total dig-in emissions to the total pipeline miles from these companies was used to estimate the national methane emission factor, resulting in 2.06 Mscf/mile.

EF PRECISION: ± 1,922%

Basis:

The precision was calculated from the spread of the company data using the method presented in the *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology* (3).

ACTIVITY FACTOR: **1,297,569 ± 5% miles of mains and services**

The total number of miles of main pipeline in the U.S. gas industry was based on U.S. Department of Transportation, Research and Special Projects Administration (4). The total miles of service pipeline was reported in A.G.A.'s *Gas Facts*, 1990 (5).

AF PRECISION: ± 5%

Basis:

A 5% confidence bound was assigned on the basis of good precision from national statistics of 1990 data.

ANNUAL METHANE EMISSIONS: **2.06 ± 1,925% Bscf**

The annual methane emissions were determined by multiplying an emission factor (annual methane emissions per mile of pipeline) by the activity factor (number of miles).

REFERENCES

1. Pacific Gas & Electric Company and Gas Research Institute. *Unaccounted-For Gas Project.* Volume 1, Final Report, San Ramon, CA, June 7, 1990.

2. Southern California Gas Company and Gas Research Institute. *A Study of the 1991 Unaccounted-For Gas Volume at the Southern California Gas Company,* Final Report, Los Angeles, CA, April 1993.

3. Williamson, H.J., M.B. Hall, and M.R. Harrison. *Methane Emissions from the Natural Gas Industry, Volume 4: Statistical Methodology,* GRI-93/0257.21 and Final Report, EPA-600/R-96-080d, Gas Research Institute and U.S. Environmental Protection Agency, June 1996.

4. U.S. Department of Transportation, Research and Special Projects Administration, Washington, DC, 1991.

5. American Gas Association. *Gas Facts, 1992 Data,* Arlington, VA, 1993.

D-6
DISTRIBUTION SEGMENT SOURCE SHEET

SOURCES: Pipeline
OPERATING MODE: Maintenance
EMISSION TYPE: Unsteady, Vented
ANNUAL EMISSIONS: 0.13 Bscf ± 2,524%

BACKGROUND:
Gas is blown to the atmosphere as a result of pipeline abandonment, installation, and repair.

EMISSION FACTOR: **0.102 ± 2,521 Mscf/mile**
(Adjusted for the distribution methane fraction of natural gas of 93.4 mol%)

The emission factors for pipeline blowdown are based on estimates from four companies: the Pacific Gas & Electric Unaccounted-for Gas (UAF) Project, 1987 (1); the Southern California Gas Company (SoCal) project (2); and two additional company estimates. The estimated total gas losses were adjusted for 93.4 volume percent methane. The annual methane emissions per mile of mains and services for each of the four companies was calculated based on the ratio of emissions to miles of distribution mains and services. The following table summarizes the individual company estimates and the national emission factor. The precision of the estimate is based on the 90 percent confidence level for the four companies providing data.

Company	Annual Blowdown Methane Emissions, Mcsf	Pipeline Miles	Annual Blowdown Methane Emission Factor, scf/mile
1	8,972	58,024	0.155
2	5,688	82,337	0.069
3	2,360	24,916	0.095
4	1,695	18,713	0.091
TOTALS	18,715	183,990	
ANNUAL BLOWDOWN EF, Mscf methane/mile			0.102 ± 2,521%

ACTIVITY FACTOR: (1,297,569 ± 5% miles mains and services)

The total number of miles main pipeline in the U.S. gas industry was based on U.S. Department of Transportation, Research and Special Projects Administration (3). The total miles of service was reported in *Gas Facts* (4). The precision, or 90 percent confidence level, was estimated to be ± 5%, based on engineering judgement.

ANNUAL METHANE EMISSIONS: 0.13 ± 2,524% Bscf

The annual methane emissions were determined by multiplying an emission factor (annual methane emissions per mile of pipeline) by the activity factor (number of miles).

REFERENCES

1. Pacific Gas & Electric Company and Gas Research Institute. *Unaccounted-For Gas Project.* Volume 1, Final Report, San Ramon, CA, June 7, 1990.

2. Southern California Gas Company and Gas Research Institute. *A Study of the 1991 Unaccounted-For Gas Volume at the Southern California Gas Company,* Final Report, Los Angeles, CA, April 1993.

3. U.S. Department of Transportation, Research and Special Projects Administration, Washington, DC, 1991.

4. American Gas Association. *Gas Facts, 1992 Data,* Arlington, VA, 1993.

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16. ABSTRACT The 15-volume report summarizes the results of a comprehensive program to quantify methane (CH4) emissions from the U.S. natural gas industry for the base year. The objective was to determine CH4 emissions from the wellhead and ending downstream at the customer's meter. The accuracy goal was to determine these emissions within +/-0.5% of natural gas production for a 90% confidence interval. For the 1992 base year, total CH4 emissions for the U.S. natural gas industry was 314 +/- 105 Bscf (6.04 +/- 2.01 Tg). This is equivalent to 1.4 +/- 0.5% of gross natural gas production, and reflects neither emissions reductions (per the voluntary American Gas Association/EPA Star Program) nor incremental increases (due to increased gas usage) since 1992. Results from this program were used to compare greenhouse gas emissions from the fuel cycle for natural gas, oil, and coal using the global warming potentials (GWPs) recently published by the Intergovernmental Panel on Climate Change (IPCC). The analysis showed that natural gas contributes less to potential global warming than coal or oil, which supports the fuel switching strategy suggested by the IPCC and others. In addition, study results are being used by the natural gas industry to reduce operating costs while reducing emissions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Emission	Stationary Sources	14G
Greenhouse Effect	Global Warming	04A
Natural Gas		21D
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