BEFORE THE
PUBLIC SERVICE COMMISSION OF UTAH

Application of QUESTAR GAS COMPANY for Recovery of Gas Management Costs in its 191 Gas Cost Balancing Account	Docket Nos. 04-057-04, 04-057-09, 04-057-11, 04-057-13 and 05-057-01

DIRECT TESTIMONY OF

CHARLES BENSON

FOR

QUESTAR GAS COMPANY

APRIL 15, 2005

QGC Exhibit 6

TABLE OF CONTENTS

I. INTRODUCTION

Q. Please state your name, employer, and business address.

A. My name is Charles Benson. I am employed by ENVIRON International Corporation and work in their office located at 8 Hollis Street, Groton, Massachusetts 01450.

Q. Please state your employment position.

A. I am a Principal of ENVIRON International Corporation.

Q. Please describe your educational background and employment history.

A. My educational background is in mechanical engineering. I received a Bachelor of Science degree in mechanical engineering from Bucknell University and a Master of Engineering degree in mechanical engineering from the University of Florida. My career has focused on the development and application of combustion-based energy technologies for the residential, commercial, and industrial sectors. Prior to joining ENVIRON, I was Managing Director of the Energy and Transportation Technology Sector at TIAX, LLC and a Vice President of Arthur D. Little, Inc. Prior to those positions, I was employed by Exxon Research and Engineering Company, where I managed combustion R&D activities and consulted in combustion technology for Exxon's worldwide operations. Attached as QGC Exhibit 6.1 is a copy of my resume, describing in more detail my educational background and experience.

II. PURPOSE

Q. What is the purpose of your direct testimony in this proceeding?

A. I will provide an overview of natural gas interchangeability analysis and describe how I have applied these principles to help other companies successfully manage gas quality. I will discuss issues related to introducing a new gas supply into a distribution system that has historically been supplied with gas having significantly different quality characteristics. One of the most important issues I will discuss is the safety impact on individual customers' appliances that have not been properly adjusted for a new gas supply. I will review the technical work Questar Gas Company (Questar Gas) has performed to identify and manage the gas interchangeability issues it has encountered over the past eight years. I will show that the interchangeability operating limits Questar Gas developed in 1998 are based on technically sound analyses and are consistent with limits other companies have developed. Finally, I will describe appliance tests demonstrating that coal bed methane gas (CBM) cannot be safely utilized, without modification, in an appliance that has been adjusted to operate on Questar Gas' historical gas supply.

Q. Please describe the work you have performed in the area of gas interchangeability.

A. I have directed projects that established guidelines for compositions of imported liquefied natural gas (LNG) that can be distributed through three existing (Everett, Cove Point, Elba Island) and three proposed North American terminals. In these projects, workshops were held with key stakeholders to identify LNG interchangeability issues. To establish guidelines, gas interchangeability analyses were performed; residential appliances were tested; and key industrial, transportation and power generation applications that utilize natural gas were evaluated. I have also assessed standards for natural gas interchangeability and have developed interchangeability guidelines for propane-air peak shaving operations for several local natural gas distribution companies (LDC).

Q. Please describe your experience with the testing of natural gas appliances.

A. As part of the interchangeability projects described above, I directed the testing in a laboratory of about 30 residential appliances, including space heating, water heating and cooking equipment. This work focused on determining the impact of changes in natural gas composition on appliance performance. I also directed the testing of about 2500 appliances in homes to characterize the performance of entire populations of appliances.

III. COMBUSTION AND INTERCHANGEABILITY

Q. Would you briefly define the term interchangeability as it applies in this case?

A. The term interchangeability, as recently defined by the Natural Gas Council Plus (NGC+) Work Group on interchangeability, is “the ability to substitute one gaseous fuel for another in a combustion application without materially changing operational safety, efficiency, performance or materially increasing air pollutant emissions." [1]

Q. Is there an index commonly used in the United States and in other parts of the world to predict gas interchangeability?

A. Yes. The Wobbe number has been broadly accepted as a key index of natural gas interchangeability. It is representative of the fuel energy input to combustion equipment when the gas supply pressure is held constant (as is typical of residential appliances). As the Wobbe number of a gas supply decreases, the amount of fuel energy flowing through a typical metering orifice to an appliance decreases. On the other hand, an increase in the Wobbe number for a gas supply results in an increase in the amount of fuel energy supplied. Therefore, key combustion characteristics can be related to the Wobbe number.

Q. How is the Wobbe Number calculated?

A. The Wobbe number is calculated by dividing the gas' Higher Heating Value (HHV) by the square root of its specific gravity. In the United States, HHV is typically expressed as British thermal units (Btu) per standard cubic foot of natural gas volume.

Q. Please explain the concepts of gas heating value and specific gravity.

A. The higher heating value of natural gas represents the amount of energy per unit volume of gas that is released through complete combustion in air at standard

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[1] *White Paper on Natural Gas Interchangeability and Non-Combustion End Use*, Interchangeability Work Group, February 28, 2005 (White Paper).

pressure, with the products of combustion cooled to standard temperature and with water in the liquid state. The specific gravity of a gas is the ratio of the gas' density at standard conditions of pressure and temperature to that of air at standard conditions.[2] A gas with specific gravity less than 1.0 has a density less than that of air, while a gas with specific gravity greater than 1.0 has a density greater than that of air. Specific gravity is calculated by dividing the molecular weight of natural gas by the molecular weight of air.

Q. Please discuss how the Wobbe number can be used to establish interchangeability limits for a region or a market area.

A. Through field experience, appliance testing, and interchangeability analyses, a range of Wobbe numbers may be determined that will ensure acceptable end-use equipment performance as well as the safety of customers in a given service area. Typically, this range is expressed as an allowable increase and decrease in Wobbe number relative to the Wobbe number that is representative of the natural gas characteristics for which the population of equipment has been adjusted.

Q. What other parameters or indices are used in the gas industry to predict if a gas supply is interchangeable?

A. To provide better measures of interchangeability for appliances, two multiple index systems were developed from combustion theory and extensive testing: the American Gas Association (AGA) Multiple Index Method and the Weaver Multiple Index

[2] Standard conditions are 14.73 psia and 60° F.

Method. These methods are commonly used in the United States and include indices that characterize the impact of gas composition changes on the following combustion phenomena:

- AGA multiple index method: characterization of lifting, flashback, and yellow-tipping.
- Weaver multiple index method: characterization of lifting, flashback, yellow-tipping, heat rate, and incomplete combustion.

These combustion phenomena are concisely described below:

- *Lifting*: movement of the flame front downstream and away from burner ports as a result of decreases in flame speed relative to flow velocity. This condition can cause delayed or failed ignition of an appliance burner. With delayed ignition, flames can temporarily flash outside of the appliance enclosure and ignite nearby flammable materials. Lifting can also produce elevated carbon monoxide emissions.
- *Flashback*: movement of the flame front upstream through the burner ports as a result of flame speed increasing relative to flow velocity. This condition can result in combustion upstream of the burner head and cause unsafe appliance operation.
- *Yellow tipping*: generation of soot particles within a flame that radiate incandescently, exhibiting a yellow color. This condition can result in soot deposition on downstream surfaces (*e.g.*, heat exchangers, flues) and can ultimately cause flue gas passages to be restricted or blocked.

- *Incomplete combustion*: presence of carbon monoxide (CO) in the exhaust because carbon in the fuel gas was not fully oxidized to carbon dioxide. If flue gases are vented into the living space, either by design or through a flue failure, excessive CO levels can be the cause of illness or death of occupants.
- *Heat rate*: change in energy input (firing rate). This index is the ratio of the Wobbe numbers for the two gases. Decreases in energy input, if too large, can hinder the ability of an appliance to perform its intended heating function. Increases in energy input, if too large, can result in overheating of components.

The index calculations require the specification of two gas compositions. The first, called the *adjustment gas*, is the fuel for which combustion equipment adjustments (orifice size, air-shutter setting, and gas pressure) have been made to achieve the desired flame characteristics. The second, referred to as the *substitute gas*, is the fuel for which relative combustion-equipment performance is estimated. Guidelines for acceptable index values have been proposed by the index developers as well as by several local distribution companies. The use of these indices, in conjunction with the Wobbe number, is warranted as the Wobbe number alone does not always predict important flame characteristics such as flame lifting, yellow tipping, incomplete combustion, or flashback.

Q. Please explain in more detail the concepts of incomplete combustion and flame lifting.

A. Incomplete combustion of natural gas occurs when the carbon in the fuel is not fully oxidized to carbon dioxide (CO_2). A portion of that carbon is then emitted as CO. This phenomenon can be caused by an insufficient supply of combustion air, quenching of the flame, or flame lifting. Lifting occurs when the flame speed is low relative to the flow velocity through a burner's ports. Under these conditions, a portion of or the entire flame front moves downstream from the burner's ports. Lifting can result in fuel bypassing the reaction zone, leading to increased CO emissions.

Q. Do these indices take into account the effects of elevation?

A. Yes. The AGA and Weaver indices are measures of the relative performance of two different gas supplies. They are based on the premise that appliances have been tuned to perform on the adjustment gas at the elevation of interest.

Q. For a system like Questar Gas', is it important to take elevation into account when adjusting appliances?

A. Yes. Due to the decrease in air density with increased elevation, it is common practice to derate (reduce energy input into) appliances to compensate for the reduction in combustion air flow at higher elevations. For installations above an elevation of 2,000 feet, the appliance gas input rate is typically reduced by 4% per 1,000 feet of elevation above sea level.

Q. Briefly explain how these indices were derived.

A. The AGA interchangeability indices were developed through extensive testing at the AGA Testing Laboratories in the 1930s and 1940s, culminating in AGA Research Bulletin #36, "Interchangeability of Other Fuel Gases with Natural Gases" (1946). These tests were conducted using the AGA precision burner as well as a range of appliances selected to "represent extreme conditions of utilization." A range of gases were used to compare flame characteristics and a set of indices were developed that describe the burner or appliance flame characteristics on a substitute gas with respect to an adjustment gas for which the burner or appliance was initially tuned to operate. The Weaver indices were also developed through appliance testing, and are an expansion to the AGA indices. The inclusion of flame speed in this empirical set of indices improved the prediction of lifting and flashback. This research was conducted in the early 1950s at the U.S. Bureau of Mines by E.R. Weaver and is documented in a report entitled "Formulas and Graphs for Representing the Interchangeability of Fuel Gases" (1951).

Q. Are these indices still applicable?

A. Yes. In 2003 I directed the testing of many new and used appliances to develop interchangeability guidelines for the Cove Point, Maryland LNG import terminal. This work validated use of the multiple-index method for current appliance populations. Indeed, Weaver Index limits are specified in the Cove Point Tariff.

Q. Can the Wobbe number be substituted for these other more complex indices to establish a safe operating limit?

A. Although the Wobbe number provides a good measure of energy input to appliances, it does not fully characterize all important flame characteristics. Thus, the Wobbe number should be used in conjunction with the multiple index methods for determination of safe operating limits.

Q. **Are calculated gas interchangeability indices alone sufficient to predict if a gas supply is interchangeable?**

A. The Wobbe number, AGA, and Weaver index methods are useful tools for determining gas quality limits. However, since service areas may differ with respect to historical gas supplies, maintenance practices, as well as types and ages of end use combustion equipment, testing is often warranted to verify the acceptability of a new gas supply.

Q. Are you familiar with the White Paper on Natural Gas Interchangeability and Non-combustion End Use produced by the NGC+ Interchangeability Work Group.

A. Yes.

Q. Please describe the participants in the NGC+ Interchangeability Work Group.

A. A wide range of natural gas industry stakeholders having experience with interchangeability issues participated in the preparation of the White Paper. These included representatives from LNG suppliers local distribution companies, pipeline companies, energy supply companies, industrial consumers, power producers, industry associations, natural gas equipment manufacturers, and one state official.

Q. What was the purpose of this group?

A. The Federal Energy Regulatory Commission requested the group to examine and update natural gas interchangeability standards.

Q. Are the recommendations of this group consistent with your experience?

A. Yes. Specifically, the group concluded that interchangeability indices represent the best starting point for developing gas quality guidelines. They found that the Wobbe number is the most "efficient and robust" single index. However, they recognized that additional parameters are required. They stated that appropriate processes for establishing gas quality guidelines incorporate the following elements: historical gas-supply characteristics, end-use equipment test data, interchangeability management options and costs, and development of numerical specifications. They established interim guidelines that include a Wobbe number range of "plus or minus 4% from Local Historical Average Gas or, alternatively, Established Adjustment or Target Gas for the service territory."

IV. APPLIANCE SAFETY

Q. Can natural gas appliances safely and efficiently use natural gas with widely varying heating values and specific gravities?

A. Natural gas appliances, when properly tuned and maintained, are typically tolerant of moderate variations in natural gas composition. However, a subset of the appliance population in a typical service area is less tolerant due primarily to improper adjustment or lack of maintenance. Gas quality limits should be established with consideration of these appliances.

Q. What would be the results of introducing a non-interchangeable gas supply into a region?

A. The introduction of a non-interchangeable gas could create significant performance and safety issues. For example, certain appliances will emit significantly higher levels of CO.

Q. Could the results of the problems you describe cause serious health concerns for customers with natural gas appliances?

A. Appliances with elevated CO emissions represent a significant safety risk. If an appliance is unvented or if a vented appliance experiences a flue failure or cracked heat exchanger, higher levels of CO can be introduced into the living space. This, in turn, can lead to CO poisoning of the occupants.

Q. In your experience, what Wobbe range is acceptable to ensure natural gas appliances operate safely and efficiently?

A. My experience has shown that an increase in Wobbe number of 3% or a decrease of 5% relative to the adjustment Wobbe number is acceptable. As discussed previously, the NGC+ Interchangeability Work Group has provided a similar guideline of plus or minus 4%. Operation outside this range can result in significant performance and safety issues.

V. EXPERIENCE WITH NEW GAS SUPPLY SOURCES

Q. Would you please describe your involvement in evaluating the impact of introducing LNG into different regions of the United States?

A. For the past 15 years, I have been involved in addressing imported LNG interchangeability issues for residential, commercial, and industrial applications. I have led many projects that characterized and resolved end use equipment performance issues through interchangeability analyses, laboratory testing and field testing. My recommendations have been implemented at the Cove Point, Maryland and Everett, Massachusetts LNG terminals, and my recommendations are expected to be implemented by the Elba Island, Georgia terminal, as well as other North American locations.

Q. What similarities do you see with the interchangeability issues faced by areas of the country receiving LNG and the interchangeability issues faced by Questar Gas with CBM production?

A. The issues faced by Questar Gas are similar to those of other areas of the country that receive LNG from foreign sources in three regards. First, the new gas supply under consideration has a composition that is outside of the historical experience base of the service area. Second, the impact of this new supply on appliance performance (including incomplete combustion, lifting, and yellow tipping) must be assessed to determine an acceptable range of compositions to be accommodated. Third, an analysis of the new gas supply must be performed to determine whether any compositional modifications are required to render it suitable for distribution.

Q. Does LNG need to be processed for purposes of interchangeability?

A. Sometimes. LNGs received from foreign sources typically have higher concentrations of ethane and propane than domestic natural gas. Consequently, the introduction of certain unmodified LNG may cause increased CO emissions and yellow tipping in appliances. To render these LNGs interchangeable with the domestic supply, dilution with air or nitrogen is often employed. Alternatively, hydrocarbon stripping may be implemented to remove butane, propane and some ethane.

Q. Does CBM gas need to be processed for purposes of interchangeability?

A. Sometimes. CBM gas typically has elevated concentrations of CO_2, which lowers the

Wobbe number and increases the tendency for flame lifting. Appliances adjusted for traditional domestic natural gas can experience flame lifting, delayed ignition, flames flashing outside of enclosures, and increased CO emissions when operated on certain CBM gases. To preclude these problems the CBM can be modified, for example, by removing a portion of the CO_2.

VI. MR. SCHROEDER'S ANALYSIS

Q. Have you reviewed the testimony of George Schroeder previously filed by Questar Gas in Docket No. 98-057-12?

A. Yes.

Q. Briefly describe Mr. Schroeder's analysis.

A. Mr. Schroeder described the methodology and supporting evidence for establishing interchangeability standards for Questar Gas' distribution area. He conducted interchangeability analyses using industry-accepted methods, including the Wobbe number, the AGA indices, and the Weaver indices.

Q. Contrast the similarities and differences between Mr. Schroeder's analysis and the interchangeability analyses you conducted in regards to LNG.

A. The methods are identical.

Q. Did Mr. Schroeder follow what you consider to be industry-accepted methods and standards in his analysis?

A. Yes.

Q. Are the interchangeability limits Mr. Schroeder derived in QGC Exhibit 2.2 of Docket No. 98-057-12 consistent with limits you have recommended for other companies?

A. Yes. The Wobbe number range specified by Mr. Schroeder is identical to the range that I recommend. The key Weaver and AGA index limits utilized by Mr. Schroeder are consistent with my recommendations.

VII. APPLIANCE TESTS

Q. Are you familiar with the appliance testing conducted for Questar Gas on March 12, 2005?

A. Yes. Questar Gas commissioned the testing of a residential furnace (Armstrong model G65-80D-1). This work was conducted by Gas Consultants, Inc., a well-qualified, independent testing firm.

Q. What was the purpose of this test?

A. The test was structured to determine the impact of CBM (having a Wobbe number of 1289) on the performance of an appliance that had been tuned for the Questar Gas adjustment gas (having a Wobbe number of 1380).

Q. Did you witness this test?

A. Yes. I was present for the entire test and was able to monitor the procedures and observe the results.

Q. Please describe the test process and key results.

A. The furnace was initially inspected to confirm that it was configured with the correct gas orifice size for operation on the Questar Gas adjustment gas. Then it was tested using procedures consistent with American National Standards Institute (ANSI) Z21.47 Standards for Gas Fired Central Furnaces. When tested on the 1380 Wobbe number adjustment gas, the unit performed satisfactorily. When tested on the 1289 Wobbe number CBM, significant performance problems occurred. Specifically, the appliance experienced delayed ignition, flames flashing outside of the appliance, and flame lifting. A copy of the test report that was submitted by Gas Consultants, Inc. is attached to my testimony as QGC Exhibit 6.2.

Q. Did you witness the supplemental tests conducted on this appliance on April 11, 2005.

A. Yes.

Q. Please describe the test process and key results.

A. The furnace was initially tuned by Questar Gas service staff, using procedures identical to those applied in customers' homes, for proper operation on the 1380 Wobbe number adjustment gas. It was then alternately operated on the adjustment gas and the 1289 Wobbe number CBM gas. When the furnace was operated on the adjustment gas, flame appearance was acceptable and CO emissions were relatively low at 85-90 parts per million (ppm), air-free. However, when the furnace was operated on the CBM gas, significant flame lifting was observed and CO concentration increased to levels above 400 ppm, air-free.

Q. Do the furnace performance problems exhibited when operating on CBM gas during these two test periods present safety risks to Questar Gas' customers?

A. Yes. Flame flashing outside of the appliance can ignite flammable material adjacent to the appliance. Elevated CO emissions, when coupled with a flue failure, can cause CO poisoning.

VIII. CONCLUSION

Q. In your opinion, was Questar Gas prudent in its analysis and actions in recognizing and addressing the interchangeability issues it faced regarding the CBM gas?

A. Yes. The actions taken by Questar Gas are consistent with my experience and with the recommendations of the NGC+ Interchangeability Work Group. Furthermore, sound experimental evidence exists to state unequivocally that, had Questar Gas not taken these actions, their customers would be exposed to unacceptable safety risks.

State of ____________)
) ss.
County of __________)

I, Charles Benson, being first duly sworn on oath, state that the answers in the foregoing written testimony are true and correct to the best of my knowledge, information and belief. Except as stated in the testimony, the exhibits attached to the testimony were prepared by me or under my direction and supervision, and they are true and correct to the best of my knowledge, information and belief. Any exhibits not prepared by me or under my direction and supervision are true and correct copies of the documents they purport to be.

____
Charles Benson

SUBSCRIBED AND SWORN TO this ______ day of April 2005.

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Notary Public