Monitoring Nuclear Test Ban Treaties

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With the end of the Cold War, the emphasis on monitoring nuclear weapons tests has shifted from the 1976 Threshold Test Ban Treaty (TTBT), which confined the US and USSR to a limit of 150 kilotons (kt), to the Comprehensive Test Ban (CTB) Treaty, which would ban all nuclear tests by the signatories. 1995 will be a watershed year to control the proliferation of nuclear weapons, as the Nuclear Non-Proliferation Treaty (NPT) must be considered for renewal. The fate of the NPT is dependent on a successful CTB negotiation, because the two treaties are politically linked. This paper will cover one aspect of these broader issues by discussing the monitoring of the TTBT and CTB. It is important to study the past (TTBT) in order to learn for the future (CTB).

TTBT monitoring

TTBT monitoring (1) determined the yields relative to the 150-kt threshold primarily by measurements of teleseismic waves that traveled through Earth's interior. Because the tectonic plate below the Nevada test site (NTS) has been extended and partially melted, seismic waves from the NTS explosions are diminished more than the waves from explosions at Russia's Shagan River test site (STS) which has had no recent geological activity. Because of this difference in magnitude (the "bias"), the US explosions appear relatively smaller in yield compared to Russian explosions of the same yield. By ignoring this difference, the US charged that the Soviets were "likely" violators of the TTBT. As one way to sort out this dispute, the US measured the yield of a Soviet explosion at the STS with electronic CORRTEX equipment in 1988. The magnitude of this explosion was 6.03 (mb), with a yield of 106-118 kt from seismic data. Since a magnitude 6.03 explosion in Nevada corresponds to an explosion of 450 kt, clearly there is a great difference in the geology of the two sites. Using the CORRTEX data and other seismic data, such as the Lg surface wave, the US dropped the noncompliance charge in 1990.

The classification of the seismic data prevented a thorough discussion of the data. Parts of the US policy community purposefully ignored the geological bias determined by its seismologists in order to maintain the "likely violation" charge against the Soviets. This charge greatly retarded negotiations with the Soviets on the TTBT, the CTB and other arms control treaties. For example, in 1988 Acting Assistant Secretary of Defense Frank Gaffney stated (2) "The thinking goes like this: the more time wasted on discussion and experimentation of monitoring techniques irrelevant to the verification of an environment in which there are no legal tests, the easier it will be to stave off demands for the more constraining comprehensive test ban."

Fig. 1. Yields of post-1976 Soviet nuclear tests (3) over 90 kilotons at Shagan River Test Site. The theoretical curves are based on tests at 150 kt and uncertainty factors of 1.6 (wider curve) and 1.4.

With the end of the Cold War, yield data has been obtained from the former USSR. It is important to examine this data because the TTBT noncompliance issue can be used politically by those who do not favor the CTB. We have plotted in Fig. 1 the recent estimates by Ringdal, Marshall and Alewine (3) of the 38 largest post-1976 tests above 90 kt. For comparison, we have plotted the projected distribution for tests at 150 kt using an uncertainty factor of 1.6 (4) and 1.4. When one compares the data with the calculated probability for testing at 150-kt, one can only conclude that the Soviets were in compliance with the TTBT. It is possible that a very few tests could have been slightly above 150 kt, but this situation also prevailed for US testing at the NTS. The value of the mb bias between the NTS and STS was crucial to the interagency process. Using the recently published data, we obtain an average value 0.38 for the three STS regions, which further strengthens the case for compliance. This estimate does not take into account the smaller differences caused by the type of rock next to the explosion. As the former technical lead for the State Department on nuclear testing issues in 1987, I was constrained to use a lower value of the bias value, but even with this value I still concluded (as did CIA and DOE, but not the US government) that the USSR was in compliance to the TTBT. In testimony before the Senate Foreign Relations Committee on 6 October 1988, OTA, LLNL and I stated that the Soviets were in compliance, but, of course, we were not allowed to use the specificity of the data that appears above.

The TTBT lessons for the CTB were that the Soviets were in compliance to the TTBT, and that a multinational compliance process using unclassified data is needed to restrain politization.

CTB monitoring

The CTB requires a different monitoring approach which requires the detection and identification of a nuclear explosion rather than the quantification of nuclear yields. Roughly speaking, a 1 kt explosion, tightly coupled (tamped) in hard rock, will have a seismic magnitude of about mb = 4. It is generally accepted that a coupled explosion of about 0.1 kiloton could be detected and identified with the two types of networks now being proposed. In 1988, the Congressional Office of Technology Assessment (1) concluded: "Based on cautious assumptions for a network of 30 internal arrays [to the USSR] or about 50 three-component internal stations, it appears likely that a detection threshold of 2.5 mb (90% probability of detection at four or more stations) could be reached." Since it is more difficult to identify than detect, one should generally add about 0.5 mb units to the detection level when discussing identification.

The Emergence of Natural Gas as a Transportation Fuel

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The US is currently importing 8 million barrels per day of crude oil and petroleum products or roughly 50% of the daily use (1). Five countries, Saudi Arabia, Venezuela, Canada, Mexico and Nigeria, account for 73% of the imported crude oil. The cost of the imported oil to the American economy appears to be in excess of $100 billion annually: a tangible cost on the order of $60 billion per year to purchase oil and petroleum products; and an intangible cost of at least $40 billion annually of US military expenditures around the world to secure the imported oil flow (2). Thus, the cost of oil is almost equal to the annual US trade deficit or about 1/3 of the budget deficit in recent years or a little under 2% of the GNP. Moreover, air pollution from the 190 million US vehicles is largely responsible for the fact that some 15 major metropolitan areas have several days annually that exceed the EPA ozone and carbon monoxide standards (3). Natural gas, used as a transportation fuel, has the potential to eliminate $100 billion per year of the deficit, improve air quality in all metropolitan areas, and pave the way to hydrogen, the ultimate clean transportation fuel.

Natural gas in the transportation sector

The ultimate demand for natural gas as a transportation fuel is on the order of 250 billion m3 per year for a practical 98-99% market penetration. This estimate takes into account the expected growth of the US automobile population and assumes that the Corporate Average Fuel Efficiency standard will be raised voluntarily or by legislation to 40 mpg for passenger cars and 30 mpg for vans and light trucks. It should be noted that current US natural gas production is about 500 billion m3/y. Surplus gasoline from the refining of domestic crude oil production, which will be necessary for some time to provide jet fuel and other heavier hydrocarbons, may also be converted to natural gas or exported.

Proven US conventional reserves and resources as well as unconventional recoverable resources (coal-bed methane, western tight sands, eastern gas shales, geopressurized aquifers, and methane calthrates) are on the order of 50 trillion m3 for up to a ceiling production price of $0.25 per m3 (4). It is instructive to note that more than 70% of current US natural gas production is from non-petroleum wells and almost 5% of the production already represents coal-bed methane. Natural gas as a transportation fuel will be predominantly in gaseous compressed form (CNG) and occasionally in liquid form (LNG).

Engine technology, fuel storage, emissions

Natural gas vehicles (NGV) require certain technological changes, including a higher compression ratio, modification of the three way exhaust gas catalyst and fuel storage (5,6). A typical carbon composite cylinder, operating at a 200 bar pressure, has a volume of 50 liters, and a mass of 18 kg and contains 13 m3 natural gas. Stringent safety requirements are imposed on the CNG vehicular fuel cylinders, which are designed for a minimum 15 year operational life (7). The exhaust gas composition of a natural gas engine requires slight modifications of the three-way catalyst.

The most unique advantage of natural gas as a transportation fuel vis-a-vis all other fossil fuels is the potential for air pollution reduction. Table 1 summarizes present and future emissions requirements as well as current NGV performance (5,8,9). Both combustion and evaporative emissions are included. Liquid fuels have evaporative emissions on the order of 0.122 g/km, while with gaseous fuels evaporative emissions are zero. A distinct advantage of natural gas over gasoline is the slower catalyst poisoning due to the virtual absence of sulfur compounds and heavy metals in the former. Thus, natural gas vehicles can have catalysts operational in excess of 100,000 miles compared to only half as long for gasoline. In 1992, the natural gas version of the production Dodge Ram van with a 5.2-L engine became the first vehicle to meet the 1998 California ULEV (Ultra Low Emission Vehicle) standard and was later certified as meeting the 1998 California LEV (Low Emission Vehicle) standard over a 100,000 mile driving life (8). The 1994 Chrysler CNG minivan, which is also now available on the market, has been certified as an ULEV vehicle (9). It is also interesting to note that the reactivity (ozone forming ability) of the exhaust gases from a natural gas vehicle is 20% that for typical gasoline vehicles on a per mass basis (5). Formaldehyde emission from natural gas vehicles is typically under 0.2 mg/km or less than 4% of the 5 mg/km standard. Formaldehyde emission is a serious problem for methanol fueled vehicles. Finally, methane is a non-toxic substance, unlike gasoline and even more so methanol.

Table 1. Comparison of present and future automobile emission standards and current NGV emissions

Emission (g/km)	CO	NOx	NMVOC	CO_2
1994 US and Calif. Standards	2.125	0.250	0.278	240*
1998 Calif. LEV Standard	2.125	0.125	0.168	210*
1998 Calif. ULEV Standard	1.062	0.062	0.168	210*
GM 2.8-L V6 Engine, CNG Fuel	0.142	0.025	0.018	160+
1994 Chrysler CNG Minivan	0.250	0.025	0.013	165+

*CO2 emissions do not constitute part of any standard. Applies to gasoline, reformulated gasoline and M85 (85% methanol, 15% gasoline) fuels. Decrease in value from 1994 to 1998 is the result of increased fuel efficiency as older vehicles are being removed form the fleet.

+Reflects measured values and includes the greenhouse effect of the methane gas in the emissions.

Infrastructure development

The infrastructure for natural gas vehicle refueling is largely already in place (3). The only missing element is the very last refueling component, namely the final compression, metering and dispensing of the fuel (10). High flow rate compressors and dispensers for public CNG stations with a 5-10 minute fill time as well as low flow compressors for overnight residential CNG use are already available, albeit at a relatively high cost because of limited production. The unique advantage of natural gas as a transportation fuel, shared also with electricity, over gasoline and methanol is that it can be available at home and place of work. In the future, there will be no need for the massive centralized refueling system associated with present transportation fuels. Central public refueling stations will no longer be necessary in cities but rather along freeways to accommodate intercity driving. Instead small refueling facilities at every residential and commercial building should become the norm for more convenient and efficient refueling.

Economics

The economics of natural gas as a transportation fuel become viable in the short (10 year) run, because of available tax incentives already in effect both at the federal and several state levels. The 1992 National Energy Policy Act allows a tax deduction of $2,000 to $50,000 per vehicle, depending on vehicle weight, and up to $100,000 per refueling facility. As of the end of 1994, 38 states offered some form of conversion incentive, including tax credits. Natural gas utilities are offering cash rebates for vehicle acquisitions.

Finally, the home CNG refueling unit has a present price of about $3,000 that may be reduced to $1,500 with increased demand, a $750 installation cost, and a $150 maintenance cost every 2,000 hours of operation (11). Thus, the added cost of home refueling to the base fuel price delivered at home amounts to a total of $0.33 ($0.27 long term) per gge. The typical price of natural gas delivered to residential and small commercial customers is currently $0.16 per m3 or $0.51 per gge ($013 per liter). The convenience of home refueling far outweighs in the minds of most people the four cents per gallon equivalent price differential between home and public station natural gas fuel price.

Strategies to facilitate introduction of the new fuel

The slow penetration of natural gas vehicles into the market (some 30,000 in the US) is not the result of technological limitations and is not due to unfavorable economics. Rather, it stems from the lack of concerted effort among the government, automotive manufacturers, and gas suppliers. Both the Clean Air Act Amendment of 1990 promoting the use of cleaner fuels in air quality non-attainment areas of the country and the Energy Policy Act do not treat preferentially any alternative fuel, even though they will ultimately affect more than 10 million vehicles owned by the federal, state and local governments, public utilities, and private fleets.

On the positive side, however, useful operational experience is being collected by various agencies across the country that is used to demonstrate the clear superiority of natural gas over other alternative fuels as well as gasoline. Thus methanol, heavily promoted in the past by the Department of Energy and the California Energy Commission, among others, has not lived up to expectations. In 1994, for example, the Los Angeles Metropolitan Transit Authority announced plans to abandon methanol buses, because they need engine overhaul twice as frequently as diesel buses, and to acquire instead several hundred CNG buses.

The active involvement of government at all levels, but most importantly at the local level, will pave the way for the mass introduction of natural gas vehicles as it will remove the uncertainty prevailing today. It should be noted that in 1993 the revenue-hungry federal government took a giant step backward in its clean air and energy security policies by instituting the first natural gas fuel tax. The Omnibus Budget Reconciliation Act of 1993, signed into law by President Clinton in August 1993, imposes a tax of 5.9 cents per gge.

Automotive manufacturers and natural gas suppliers are displaying lack of leadership as well. The former are reluctant to market a large number of NGVs because of concern about limited sales due to the lack of the infrastructure. The latter are reluctant to build a large infrastructure because there are not enough NGVs on the road to justify the investment. Oil companies, which have been sideline observers, can and must have a role in this transition. Crude oil and petroleum products will not disappear from the market even after natural gas becomes the dominant transportation fuel. As mentioned earlier, natural gas liquids can be converted to a natural gas composition fuel along with other limited demand petroleum products.

It is worth noting that there must exist a critical number of NGVs on the road and a critical number of home refueling appliances around the country before the expansion and substitution becomes self-sustaining. This critical number may be on the order of a few percent of the respective ultimate numbers for each one. Thus, the critical number of natural gas vehicles and home fueling stations may be on the order of several million.

The emergence of natural gas as the motor fuel of choice will signal the shift toward production of dedicated, fully optimized NGVs only as well as the availability of home refueling equipment as a new standard household appliance. Previous experience regarding technology substitution shows that the transition from one fuel to another can take place in two to three decades following a logistic type of penetration (12). Thus, practically all US vehicles can be running on natural gas as early as 2020 and no later than 2030. Switching from gasoline and diesel fuel to natural gas constitutes, therefore, a feasible solution to the elimination of the foreign oil dependency, the reduction of the deficit by at least $100 billion per year (1990 dollars), and a cleaner environment within the lifetime of more than three-quarters of all the Americans living today.

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