GREENHOUSE GAS EMISSIONS FROM THE NUCLEAR FUEL CYCLE

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Abstract

Emissions of carbon dioxide and methane from the whole fuel-cycle of nuclear power generation are discussed. The low-cost, and therefore low-energy-using, uranium resources suffice to provide a large worldwide nuclear programme with fuel without producing substantial carbon dioxide. very lower emissions of carbon dioxide can be achieved if uranium enrichment is carried out by centrifuging. Methane emissions from uranium mining are negligible or in almost any case virtually zero.

1. INTRODUCTION

When concern about the greenhouse effect began to increase in the late 1980s, it soon became an increasingly important factor in public debate about the relative merits of different sources of electricity. The case of nuclear power seemed clear-cut -- it did not emit any greenhouses gases (GHGs)-- in contrast with fossil fuels. Of course, it was appreciated that some of the energy used in nuclear fuel cycle facilities was itself from fossil fuels, but it seemed self-evident that this resulted in insignificant quantities of GHGs.

However, some nuclear industry opponents began to put forward the view that carbon dioxide emissions attributable to stages in the nuclear fuel cycle were significant, and could even be comparable in magnitude to those from fossil fuel burning. Although this appeared to be an insupportable hypothesis, it was adopted and repeated by other anti-nuclear groups in several countries.

Thus, although the contention that nuclear power indirectly produces significant quantities of carbon dioxide seemed clearly false, the Uranium Institute decided to examine these claims and to attempt to refute them in more detail. What follows is a summary of our findings as a result of that investigation.

2. THE NUCLEAR FUEL CYCLE AND CO_2

The most widely quoted paper putting forward the view that nuclear power indirectly (through its fuel cycle) emitted significant quantities of CO_2 was presented by Friends of the Earth at the UK public inquiry into the construction of the proposed Hinkley Point PWR; it was written by Dr Nigel Mortimer [1]. Several other sources used this paper (known as FOE9) as a reference to support their assertions that nuclear could indirectly produce a large amount of carbon dioxide. The argument put forward by Mortimer rests on the assumption that if the use of nuclear energy were to increase significantly then known uranium resources would be quickly consumed. This would lead to the use of lower grade uranium ores resulting in increased CO_2 emissions, because uranium extraction from lower ore grades would need more fossil energy. Mortimer contends that the CO_2 emissions could reach the same order as those from a coal power station within a few decades.

There are a number of flaws in Mortimer's argument, and a detailed rebuttal was prepared by Donaldson and Betteridge of AEA Technology [2]. In particular, Mortimer assumes that no further low cost reserves of uranium remain to be found, whereas in fact a revival of nuclear construction and an upturn in uranium demand would lead to increased exploration and the definition of additional resources. In addition, any major expansion of nuclear power (as postulated by Mortimer) would involve within a few decades the increased use of recycling and the commercialization of fast reactors.

In any case, even if we assume a modest growth in nuclear output after 2000, then we can calculate that relatively low cost resources (which are of reasonably high ore grade) already identified today would be sufficient until after 2020.

In 1992 worldwide nuclear generation was about 323 GWe, which required about 55 000 tU. The UI expects that by 2000 annual nuclear generation will total 360 GWe, requiring about 64 000 tU/year. If we assume, for example, that nuclear capacity will increase by 20 GWe per year between 2001 and 2010, and by 30 GWe/y between 2011 and 2020, then total nuclear generation will be 560 GWe by 2010 and 860 GWe by 2020. If the uranium requirement is 160 tU per GWe per year, then the cumulative total of uranium demand would be about 670 000 tU by 2010 and nearly 2.5 million tU by 2020.

By comparison, in its most recent appraisal of world uranium resources [3] the UI estimates that the total of already-known low cost uranium resources is over 3 million tonnes of uranium (tU). Of this total, over 2 million tU are "Western World" resources, and over 1 million tU are in the former Soviet Union, Central and Eastern Europe, and China.

Thus the hypothesis that nuclear would contribute significantly to CO_2 emissions can be seen to rely on a highly unlikely scenario. There would have to be a massive programme of new nuclear construction, which would quickly use up known uranium resources, and which would continue even in the absence of significant discoveries of additional economic uranium resources. There would be no significant recycling or use of fast reactors, even after several decades.

2.1. Comparisons with other energy sources

We then looked at what few studies had been done to assess the actual level of CO_2 emissions from the nuclear fuel cycle and to compare this with fossil fuel generation. Two studies, one from Germany and one from the USA, appeared to correctly indicate the magnitude of these emissions.

A detailed study by Weis, Kienle and Hortmann of German utility association VDEW [4] estimated the CO_2 emissions from the nuclear fuel cycle in the former West Germany. They calculated how much energy is used in each of the stages of the fuel cycle, looked at the actual sources of the energy used (i.e. coal, nuclear, hydro, etc.), and then calculated the resulting CO_2 emissions. They also highlighted the fact that energy consumption in the fuel cycle has fallen dramatically in recent years as efficiency has improved.

The study concluded that the energy used in preparing fuel for German reactors is 0.7% of the electrical energy which the fuel will produce in the reactor. By far the largest part of this energy use arises from the electricity used in enrichment plants, with only a small proportion from uranium mining. The carbon dioxide emissions from this energy use, given the actual sources used by German utilities, were about 0.5% of those from a coal fired station of the same capacity. The results are reproduced in Table I.

The study also noted that there will be a reduction in the CO_2 emissions from nuclear in the future (in the German case), due to greater use of gas centrifuge enrichment instead of diffusion, and to the opening of mines with higher uranium concentrations (for example, in Canada). However, it is pointed out that, as the contribution of *uranium mining* and *milling* to total nuclear fuel cycle energy use is only about 15%, even if this component changed significantly the effect on the total would be small.

TABLE I. CARBON DIOXIDE EMISSIONS ATTRIBUTABLE TO VARIOUS STAGES OF THE NUCLEAR FUEL CYCLE, FROM THE GERMAN PROGRAMME

Nuclear fuel cycle process	Specific energy consumed (kWh/kg Unat)	Energy consumed as % of electric energy content	Specific CO_2 emissions from energy consumed (kg CO_2/kg Unat)	Annual CO_2 emissions to fuel a typical 1300 MWe LWR (tonnes)
Mining and milling	59	0.1	47	9 100
Conversion	7	0.01	<7	<1400
Enrichment	310	0.6	140	27 200
Fuel fabrication	7	0.01	3	600
Total	383	0.7	197	38 300

From Weiss *et al.* [4].

A further analysis was carried out by Science Concepts for the US Council for Energy Awareness (now the Nuclear Energy Institute) [5]. This calculated the CO_2 emissions attributable to nuclear plants in the United States, on the assumption that the only significant contribution was from energy used in enrichment (other fuel cycle steps were not considered). It was assumed that the total US nuclear capacity of about 100 GWe requires some 12 million SWU per year, and that each SWU requires 2500 kWh of electricity (using the gas diffusion process). Thus the total electricity required annually for enrichment was around 30 billion kW.h. In the region where uranium is enriched, 65% of electricity is generated by coal, 6% by natural gas, and 29% by nuclear and hydro. Thus, the study concluded that nuclear generation produces emissions at a rate of about 4% of the equivalent coal generation.

The principal reason for the difference in the German and American figures is that, while US enrichment is virtually all gas diffusion, only 17% of German enrichment is in diffusion plants. The lower energy consumption of centrifuges accounts for the lower CO_2 emissions. The introduction of laser enrichment technology, now under development, will result in still lower energy use than with centrifuges.

2.2. Methane emissions from uranium mining

The Uranium Institute also made an examination of possible methane emissions from uranium mining. Again, although it seemed self-evident that these were insignificant compared to those from fossil fuels, it was decided to examine the available evidence.

In general, methane is formed from the decomposition of organic material. When such material is trapped beneath the Earth's surface, the methane itself often becomes trapped underground in small gaps in the rocks. Mining in such areas allows the methane to escape, and if it is not collected it seeps into the atmosphere. Underground coal seams inevitably contain significant amounts of methane. In some cases it is possible to collect this from the mine and burn it as a fuel; however, in other mines the ventilation system expels it to the atmosphere.

Methane can also be released from other types of mining in rock associated with organic material. Potentially therefore, some methane could be emitted as a result of uranium mining in certain areas. However, such emissions are very rare and consequently few studies have been carried out. The information on which this report is based relates to Australia, Canada and the United States, which account for about 40% of world uranium production.

In Australia and Canada, although underground mines are routinely monitored for explosive gases (including methane) it appears that none have been detected in any uranium mines. The underground uranium mines in these countries are situated in very old rock formations which contain virtually no organic material.

In the United States, information is available on one underground uranium mine in which methane was detected. This mine, which closed in September 1988, appears to be the only recent example of a methane producing uranium mine in the USA. The mine in which methane was detected was the Lisbon Mine in La Sal, Utah, operated by Rio Algom Corporation. The mine was classified as "gassy" by the US Department of Labor Mine Safety and Health Administration (MSHA) in 1973 following an ignition incident and the subsequent detection of methane. Further incidents involving outbursts of methane occurred in 1979 [6]. In an investigation of conditions in the mine conducted in December 1978 [7], the MSHA reported that the total volume of methane being liberated was 91 920 ft^3/day (2600 m^3/day). A paper by MSHA staff on methane occurrence [8] provides estimates of the rate of methane emission per ton of ore mined. For the Lisbon Mine, this is estimated to be about 100 ft^3/ton (3 m^3/tonne).

The Uranium Institute was unable to find any other reports of any further uranium mines in any country which have had similar problems with methane. Neither were we able to discover any other references to methane emissions from uranium mining in published sources. Of course, this does not rule out the possibility that there have been additional instances of methane production, but it seems likely that any such instances have been very few in number.

It should be pointed out in this context that little historical information is available about uranium mining in the former Soviet Union, and in some other countries. Therefore it is unlikely that the Institute would be aware of any methane emissions from uranium mining in those countries.

2.3. Potential methane emissions

The above information relates only to actual uranium mines (both shut down and operating), and not to the potential methane emissions from uranium deposits which have not yet been exploited. Uranium deposits do exist in a wide range of different geological formations, including carbon-bearing rocks, but often not in economically recoverable concentrations. In the past, studies have been performed on the viability of extracting uranium from low-grade coal [9]. In fact, during the period 1963-67 several small US mines in the Williston Basin area of North and South Dakota and Montana produced uranium from ore associated with lignite, which may have contained methane. However, such deposits do not form a significant part of total uranium reserves, and in any case are unlikely to be economic in the foreseeable future.

3. CONCLUSION

Studies of the carbon dioxide emissions from the nuclear fuel cycle under the different circumstances prevailing in two different countries show that these emissions are in the region of 0.5% to 4% of the emissions from the equivalent coal-fired generating capacity. Assertions that nuclear power could indirectly produce significant quantities of CO_2 depend on a highly improbable scenario.

On the question of methane from uranium mining, the information available indicates that the vast majority of uranium is produced with little or no associated methane. In isolated instances, methane may be associated with uranium mining and uranium-bearing ores. But considering that world production of uranium involves the annual extraction of rather less than 10 million tonnes of ore, compared with annual coal production of around 4500 million tonnes, it would seem that methane production from uranium mining can be accurately described as negligible.

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