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Coal Combustion: Nuclear Resource or Danger?

Alex Gabbard

Emissions from burning coal include uranium and other nuclear materials—potential hazards and resources.

Preliminary comment added by Ed Greisch on Background Radiation: All rocks, including coal and soil, contain minute amounts [parts per million] of radioactive atoms. This has always been the case. We have always gotten small amounts of radiation from space called "Cosmic Rays". The radiation from natural sources such as rocks, good food and outer space is called "Background Radiation". We use natural radiation to date things that are older than our historical records. For example, we use radioactive carbon dating to date Egyptian mummies and other things that are a few thousand years old. Radioactive carbon is formed when a cosmic ray hits a nitrogen atom in our air and converts the nitrogen atom into a radioactive carbon atom. We date things that are billions of years old by comparing uranium isotopes to lead *isotopes in rocks that have not been melted since the date we are trying to determine. Until the 20th century, we did not know that we had always been living with this background radiation. Natural background radiation varies from place to place on the Earth's surface but averages about 200 millirem/year, mostly from radon. If you live in Denver, you receive more cosmic rays because there is less shielding air above you. Rocks and soil vary in the amount of radioactive atoms they contain. That is why radon test kits are sold in hardware stores. Radon is a radioactive gas produced by the radioactive decay of heavier atoms. The rocks under your house may contain more or less uranium and other radioactive atoms than the rocks under another house. The variation in the rocks can be enough to make a difference. You can minimize your exposure to radiation by not covering your floors with real rocks such as marble or granite.*

Comment added by Ed Greisch on Chernobyl: Alex Gabbard wrote to me: "The reactor that had the accident at Chernobyl was very out-of-date (1st generation) design that has to be precisely controlled to prevent cooling water from boiling. Water carries away heat and moderates far better than bubbles, and as bubbles form in water, the reactor goes increasingly unstable. What caused Chernobyl to blow its top was residual water in the core suddenly going to high pressure steam and erupting into a steam explosion. Since the building top was simply resting by its weight on the walls, not a containment vessel at all, the steam explosion burped the top off its position allowing outside air in, subsequently igniting a carbon fire." The United States and other Western countries DO NOT now build and do not now posses or operate ANY reactors of such *primitive design. Nor do we allow containment buildings to have easily removable tops. Containment buildings in the Western hemisphere are required to be pressure vessels.*

The Chernobyl accident released only 200 tons of radioactive material, as much as a coal-fired power plant would release in 7 years and 5 months. The Chernobyl accident had a shorter "stack" than coal-fired power plants. The radioactive material was released in a short time at ground level. That is why the Chernobyl accident had impact. Only 52 people died at Chernobyl , mostly fire fighters, a hazardous job in any case. The Three Mile Island incident did NOT release a noticeable amount of radiation into its neighborhood, it was just expensive to clean up the inside of the reactor. Nobody died and nobody was injured at Three Mile Island.

{Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations.}

Over the past few decades, the American public has become increasingly wary of nuclear power because of concern about radiation releases from normal plant operations, plant accidents, and nuclear waste. Except for Chernobyl and other nuclear accidents, releases have been found to be almost undetectable in comparison with natural background radiation. Another concern has been the cost of producing electricity at nuclear plants. It has increased largely for two reasons: compliance with stringent government regulations that restrict releases of radioactive substances from nuclear facilities into the environment and construction delays as a result of public opposition. Partly because of these concerns about radioactivity and the cost of containing it, the American public and electric utilities have preferred coal combustion as a power source. Today 52% of the capacity for generating electricity in the United States is fueled by coal, compared with 14.8% for nuclear energy. Although there are economic justifications for this preference, it is surprising for two reasons. First, coal combustion produces carbon dioxide and other greenhouse gases that are suspected to cause climatic warming, and it is a source of sulfur oxides and nitrogen oxides, which are harmful to human health and may be largely responsible for acid rain. Second, although not as well known, releases from coal combustion contain naturally occurring radioactive materials mainly, uranium and thorium. Former ORNL researchers J. P. McBride, R. E. Moore, J. P. Witherspoon, and R. E. Blanco made this point in their article "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants" in the December 8, 1978, issue of Science magazine. They concluded that Americans living near coal fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations. This ironic situation remains true today and is addressed in this article.

The fact that coal-fired power plants throughout the world are the major sources of radioactive materials released to the environment has several implications. It suggests that coal combustion is more hazardous to health than nuclear power and that it adds to the background radiation burden even more than does nuclear power. It also suggests that if radiation emissions from coal plants were regulated, their capital and operating costs would increase, making coal-fired power less economically competitive.

Finally, radioactive elements released in coal ash and exhaust produced by coal combustion contain fissionable fuels and much larger quantities of fertile materials that can be bred into fuels by absorption of neutrons, including those generated in the air by bombardment of oxygen, nitrogen, and other nuclei with cosmic rays; such fissionable and fertile materials can be recovered from coal ash using known technologies. These nuclear materials have growing value to private concerns and governments that may want to market them for fueling nuclear power plants. However, they are also available to those interested in accumulating material for nuclear weapons. A solution to this potential problem may be to encourage electric utilities to process coal ash and use new trapping technologies on coal combustion exhaust to isolate and collect valuable metals, such as iron and aluminum, and available nuclear fuels.

Makeup of Coal and Ash

{The amount of thorium contained in coal is about 2.5 times greater than the amount of uranium.}

Coal is one of the most impure of fuels. Its impurities range from trace quantities of many metals, including uranium and thorium, to much larger quantities of aluminum and iron to still larger quantities of impurities such as sulfur. Products of coal combustion include the oxides of carbon, nitrogen, and sulfur; carcinogenic and mutagenic substances; and recoverable minerals of commercial value, including nuclear fuels naturally occurring in coal. Coal ash is composed primarily of oxides of silicon, aluminum, iron, calcium, magnesium, titanium, sodium, potassium, arsenic, mercury, and sulfur plus small quantities of uranium and thorium. Fly ash is primarily composed of non-combustible silicon compounds (glass) melted during combustion. Tiny glass spheres form the bulk of the fly ash. Since the 1960s particulate precipitators have been used by U.S. coal-fired power plants to retain significant amounts of fly ash rather than letting it escape to the atmosphere. When functioning properly, these precipitators are approximately 99.5% efficient. Utilities also collect furnace ash, cinders, and slag, which are kept in cinder piles or deposited in ash ponds on coal-plant sites along with the captured fly ash. Trace quantities of uranium in coal range from less than 1 part per million (ppm) in some samples to around 10 ppm in others. Generally, the amount of thorium contained in coal is about 2.5 times greater than the amount of uranium. For a large number of coal samples, according to environmental Protection Agency figures released in 1984, average values of uranium and thorium content have been determined to be 1.3 ppm and 3.2 ppm, respectively. Using these values along with reported consumption and projected consumption of coal by utilities provides a means of calculating the amounts of potentially recoverable breedable and fissionable elements (see sidebar). The concentration of fissionable uranium-235 (the current fuel for nuclear power plants) has been established to be 0.71% of uranium content.

Uranium and Thorium in Coal and Coal Ash

As population increases worldwide, coal combustion continues to be the dominant fuel source for electricity. Fossil fuels' share has decreased from 76.5% in 1970 to

66.3% in 1990, while nuclear energy's share in the worldwide electricity pie has climbed from 1.6% in 1970 to 17.4% in l990. Although U.S. population growth is slower than worldwide growth, per capita consumption of energy in this country is among the world's highest. To meet the growing demand for electricity, the U.S. utility industry has continually expanded generating capacity. Thirty years ago, nuclear power appeared to be a viable replacement for fossil power, but today it represents less than 15% of U.S. generating capacity. However, as a result of low public support during recent decades and a reduction in the rate of expected power demand, no increase in nuclear power generation is expected in the foreseeable future. As current nuclear power plants age, many plants may be retired during the first quarter of the 21st century, although some may have their operation extended through license renewal. As a result, many nuclear plants are likely to be replaced with coal fired plants unless it is considered feasible to replace them with fuel sources such as natural gas and solar energy. As the world's population increases, the demands for all resources, particularly fuel for electricity, is expected to increase. To meet the demand for electric power, the world population is expected to rely increasingly on combustion of fossil fuels, primarily coal. The world has about 1500 years of known coal resources at the current use rate. The graph on p. 26 shows the growth in U.S. and world coal combustion for the 50 years preceding 1988, along with projections beyond the year 2040. Using the concentration of uranium and thorium indicated on p. 26, the graph on this page illustrates the historical release quantities of these elements and the releases that can be expected during the first half of the next century, given the predicted growth trends. Using these data, both U.S. and worldwide fissionable uranium-235 and fertile nuclear material releases from coat combustion can be calculated. Because existing coal-fired power plants vary in size and electrical output, to calculate the annual coal consumption of these facilities, assume that the typical plant has an electrical output of 1000 megawatts. Existing coal-fired plants of this capacity annually burn about 4 million tons of coal each year. Further, considering that in 1982 about 616 million short tons (2000 pounds per ton) of coal was burned in the United States (from 833 million short tons mined, or 74%), the number of typical coal-fired plants necessary to consume this quantity of coal is 154.

Using these data, the releases of radioactive materials per typical plant can be calculated for any year. For the year 1982, assuming coal contains uranium and thorium concentrations of 1.3 ppm and 3.2 ppm, respectively, each typical plant released 5.2 tons of uranium (containing 74 pounds of uranium-235) and 12.8 tons of thorium that year. Total U.S. releases in 1982 (from 154 typical plants) amounted to 801 tons of uranium (containing 11,371 pounds of uranium 235) and 1971 tons of thorium. These figures account for only 74% of releases from combustion of coal from all sources. Releases in 1982 from worldwide combustion of 2800 million tons of coal totaled 3640 tons of uranium (containing 51,700 pounds of uranium-235) and 8960 tons of thorium.

{The population effective close equivalent from coal plants is 100 times that from nuclear plants.}

Based on the predicted combustion of 2516 million tons of coal in the United States and 12,580 million tons worldwide during the year 2040, cumulative releases for the 100 years of coal combustion following 1937 are predicted to be:

U.S. release (from combustion of 111,716 million tons [of coal]):

Uranium: 145,230 tons (containing 1031 tons of uranium-235)

Thorium: 357,491 tons

Worldwide release (from combustion of 637,409 million tons [of coal]):

Uranium: 828,632 tons (containing 5883 tons of uranium-235)

Thorium: 2,039,709 tons

Radioactivity from Coal Combustion

The main sources of radiation released from coal combustion include not only uranium and thorium but also daughter products produced by the decay of these isotopes, such as radium, radon, polonium, bismuth, and lead. Although not a decay product, naturally occurring radioactive potassium 40 is also a significant contributor. According to the National Council on Radiation Protection and Measurements (NCRP), the average radioactivity per short ton of coal is 17,100 millicuries /4,000,000 tons, or 0.00427 millicuries/ton. This figure can be used to calculate the average expected radioactivity release from coal combustion. For 1982 the total release of radioactivity from 154 typical coal plants in the United States was, therefore, 2,630,230 millicuries. Thus, by combining U.S. coal combustion from 1937 (440 million tons) through 1987 (661 million tons) with an estimated total in the year 2040 (2516 million tons), the total expected U.S. radioactivity release to the environment by 2040 can be determined. That total comes from the expected combustion of 111,716 million tons of coal with the release of 477,027,320 millicuries in the United States. Global releases of radioactivity from the predicted combustion of 637,409 million tons of coal would be 2,721,736,430 millicuries. For comparison, according to NCRP Reports No. 92 and No. 95, population exposure from operation of 1000-MWe nuclear and coal-fired power plants amounts to 490 person-rem/year for coal plants and 4.8 person-rem/year for nuclear plants. Thus, the population effective dose equivalent from coal plants is 100 times that from nuclear plants. For the complete nuclear fuel cycle, from mining to reactor operation to waste disposal, the radiation dose is cited as 136 person rem/year; the equivalent dose for coal use, from mining to power plant operation to waste disposal, is not listed in this report and is probably unknown. During combustion, the volume of coal is reduced by over 85%, which increases the concentration of the metals originally in the coal. Although significant quantities of ash are retained by precipitators, heavy metals such as uranium tend to concentrate on the tiny glass spheres that make up the bulk of fly ash. This uranium is released to the atmosphere with the escaping fly ash, at about 1.0% of the original amount, according to NCRP data. The retained ash is enriched in uranium several times over the original uranium concentration in the coal because the uranium, and thorium, content is not decreased as the volume of coal is reduced. All studies of potential health hazards associated with the release of radioactive elements from coal combustion conclude that the perturbation of natural background dose levels is almost negligible. However, because the half-lives of radioactive potassium 40, uranium, and thorium are practically infinite in terms of human lifetimes, the accumulation of these species in the biosphere is directly proportional to the length of time that a quantity of coal is burned. Although trace quantities of radioactive heavy metals are not nearly as likely to produce adverse health effects as the vast array of chemical by products from coal combustion, the accumulated quantities of these isotopes over 150 or 250 years could pose a significant future ecological burden and potentially produce adverse health effects, especially if they are locally accumulated. Because coal is predicted to be the primary energy source for electric power production in the foreseeable future, the potential impact of long term accumulation of by-products in the biosphere should be considered.

Energy Content: Coal vs Nuclear

{Views of the Tennessee Valley Authority's Bull Run and Kingston steam plants. These facilities burn coal to produce steam for generating electricity for Oak Ridge and the surrounding area. Photographs by Alex Gabbard}

{Ash pond at Bull Run Steam Plant. Ash produced by coal combustion contains radioactive elements, including fissionable fuels such as uranium and plutonium.}

{The energy content of nuclear fuel released in coal combustion is greater than that of the coal consumed.}

An average value for the thermal energy of coal is approximately 6150 kilowatt-hours kWh/ton. Thus, the expected cumulative thermal energy release from U.S. coal combustion over this period totals about 6.87×10^{14} kilowatt-hours. The thermal energy released in nuclear fission produces about 2×10^{9} kWh/ton. Consequently, the thermal energy from fission of uranium-235 released in coal combustion amounts to 2.1×10^{12} kWh. If uranium-238 is bred to plutonium-239, using these data, the thermal energy from fission of this isotope alone constitutes about 2.9×10^{14} kWh, or about half the anticipated energy of all the utility coal burned in this country through the year 2040. If the thorium-232 is bred to uranium 233 and fissioned, the thermal energy capacity of this isotope is approximately 7.2×10^{14} kWh, or 105% of the thermal energy released from U.S. coal combustion for a century. The total of the thermal energy capacities from each of these three fissionable isotopes is about 10.1×10^{14} kWh, 1.5 times more than the total from coal. World combustion of coal has the same ratio, similarly indicating that coal combustion wastes more energy than it produces.

Consequently, the energy content of nuclear fuel released in coal combustion is more than that of the coal consumed! Clearly, coal-fired power plants are not only generating electricity but are also releasing nuclear fuels whose commercial value for electricity production by nuclear power plants is over $7 trillion, more than the U.S. national debt. This figure is based on current nuclear utility fuel costs of 7 mils per kWh, which is about half the cost for coal. Consequently, significant quantities of nuclear materials are being treated as coal waste, which might become the cleanup nightmare of the future, and their value is hardly recognized at all.

How does the amount of nuclear material released by coal combustion compare to the amount consumed as fuel by the U.S. nuclear power industry? According to 1982 figures, 111 American nuclear plants consumed about 540 tons of nuclear fuel, generating almost 1.1 x 10^{12} kWh of electricity. During the same year, about 801 tons of uranium alone were released from American coal-fired plants. Add 1971 tons of thorium, and the release of nuclear components from coal combustion far exceeds the entire U.S. consumption of nuclear fuels. The same conclusion applies for worldwide nuclear fuel and coal combustion.

Another unrecognized problem is the gradual production of plutonium-239 through the exposure of uranium-238 in coal waste to neutrons from the air. These neutrons are produced primarily by bombardment of oxygen and nitrogen nuclei in the atmosphere by cosmic rays and from spontaneous fission of natural isotopes in soil. Because plutonium-239 is reportedly toxic in minute quantities, this process, however slow, is potentially worrisome.

The radiotoxicity of plutonium-239 is 3.4 x 10^{11} times that of uranium-238. Consequently, for 801 tons of uranium released in 1982, only 2.2 milligrams of plutonium-239 bred by natural processes, if those processes exist, is necessary to double the radiotoxicity estimated to be released into the biosphere that year. Only 0.075 times that amount in plutonium-240 doubles the radiotoxicity. Natural processes to produce both plutonium-239 and plutonium-240 appear to exist.

Conclusions

For the 100 years following 1937, U.S. and world use of coal as a heat source for electric power generation will result in the distribution of a variety of radioactive elements into the environment. This prospect raises several questions about the risks and benefits of coal combustion, the leading source of electricity production.

First, the potential health effects of released naturally occurring radioactive elements are a long term issue that has not been fully addressed. Even with improved efficiency in retaining stack emissions, the removal of coal from its shielding overburden in the earth and subsequent combustion releases large quantities of radioactive materials to the surface of the earth. The emissions by coal-fired power plants of greenhouse gases, a vast array of chemical by-products, and naturally occurring radioactive elements make coal much less desirable as an energy source than is generally accepted.

Second, coal ash is rich in minerals, including large quantities of aluminum and iron. These and other products of commercial value have not been exploited.

Third, large quantities of uranium and thorium and other radioactive species in coal ash are not being treated as radioactive waste. These products emit low-level radiation, but because of regulatory differences, coal-fired power plants are allowed to release quantities of radioactive material that would provoke enormous public outcry if such amounts were released from nuclear facilities. Nuclear waste products from coal combustion are allowed to be dispersed throughout the biosphere in an unregulated manner. Collected nuclear wastes that accumulate on electric utility sites are not protected from weathering, thus exposing people to increasing quantities of radioactive isotopes through air and water movement and the food chain.

Fourth, by collecting the uranium residue from coal combustion, significant quantities of fissionable material can be accumulated.

In a few year's time, the recovery of the uranium-235 released by coal combustion from a typical utility anywhere in the world could provide the equivalent of several World War II type uranium-fueled weapons. Consequently, fissionable nuclear fuel is available to any country that either buys coal from outside sources or has its own reserves. The material is potentially employable as weapon fuel by any organization so inclined. Although technically complex, purification and enrichment technologies can provide high-purity, weapons-grade uranium-235. Fortunately, even though the technology is well known, the enrichment of uranium is an expensive and time-consuming process.

Because electric utilities are not high-profile facilities, collection and processing of coal ash for recovery of minerals, including uranium for weapons or reactor

fuel, can proceed without attracting outside attention, concern, or intervention. Any country with coal-fired plants could collect combustion by-products and amass sufficient nuclear weapons material to build up a very powerful arsenal, if it has or develops the technology to do so.

Of far greater potential are the much larger quantities of thorium-232 and uranium-238 from coal combustion that can be used to breed fissionable isotopes. Chemical separation and purification of uranium-233 from thorium and plutonium-239 from uranium require far less effort than enrichment of isotopes. Only small fractions of these fertile elements in coal combustion residue are needed for clandestine breeding of fissionable fuels and weapons material by those nations that have nuclear reactor technology and the inclination to carry out this difficult task.

Comment by Ed Greisch: Since 9/11 we can say that this means that this is a way that a terrorist group with lots of time available could obtain plutonium to make a crude nuclear bomb. The uranium enrichment step is avoided since plutonium is separable by ordinary means.

Fifth, the fact that large quantities of uranium and thorium are released from coal-fired plants without restriction raises a paradoxical question. Considering that the U.S. nuclear power industry has been required to invest in expensive measures to greatly reduce releases of radioactivity from nuclear fuel and fission products to the environment, should coal-fired power plants be allowed to do so without constraints?

This question has significant economic repercussions. Today nuclear power plants are not as economical to construct as coal-fired plants, largely because of the high cost of complying with regulations to restrict emissions of radioactivity. If coal-fired power plants were regulated in a similar manner, the added cost of handling nuclear waste from coal combustion would be significant and would, perhaps, make it difficult for coal-burning plants to compete economically with nuclear power.

Because of increasing public concern about nuclear power and radioactivity in the environment, reduction of releases of nuclear materials from all sources has become a national priority known as "as low as reasonably achievable" (ALARA). If increased regulation of nuclear power plants is demanded, can we expect a significant redirection of national policy so that radioactive emissions from coal combustion are also regulated?

{If increased regulation of nuclear power plants is demanded, then we can expect a significant redirection of national policy in regulation of radioactive emissions from coal combustion.} 31

{The amount of uranium 235 alone dispersed by coal combustion is the equivalent of dozens of nuclear reactor fuel loadings.}

Although adverse health effects from increased natural background radioactivity may seem unlikely for the near term, long-term accumulation of radioactive materials from continued worldwide combustion of coal could pose serious health hazards. Because coal combustion is projected to increase throughout the world during the next century, the increasing accumulation of coal combustion by-products, including radioactive components, should be discussed in the formulation of energy policy and plans for future energy use.

One potential solution is improved technology for trapping the exhaust (gaseous emissions up the stack) from coal combustion. If and when such technology is developed, electric utilities may then be able both to recover useful elements, such as nuclear fuels, iron, and aluminum, and to trap
greenhouse gas emissions. Encouraging utilities to enter mineral markets that have been previously unavailable may or may not be desirable, but doing so appears to have the potential of expanding their economic base, thus offsetting some portion of their operating costs, which ultimately could reduce consumer costs for electricity. Both the benefits and hazards of coal combustion are more far-reaching than are generally recognized. Technologies exist to remove, store, and generate energy from the radioactive isotopes released to the environment by coal combustion. When considering the nuclear consequences of coal combustion, policymakers should look at the data and recognize that the amount of uranium-235 alone dispersed by coal combustion is the equivalent of dozens of nuclear reactor fuel loadings. They should also recognize that the nuclear fuel potential of the fertile isotopes of thorium-232 and uranium-238, which can be converted in reactors to fissionable elements by breeding, yields a virtually unlimited source of nuclear energy that is frequently overlooked as a natural resource. In short, naturally

occurring radioactive species released by coal combustion are accumulating in the environment along with minerals such as **mercury, arsenic,** silicon, calcium, **chlorine**, and **lead,** sodium, as well as metals such as aluminum, iron, lead, magnesium, titanium, boron, chromium, and others that are continually dispersed in millions of tons of coal combustion by-products. The potential benefits and threats of these released materials will someday be of such significance that they should not now be ignored.

Comment added by Ed Greisch on coal piles and Geiger counters: There is no point in checking a pile of coal with a Geiger counter or other common radiation measuring instrument. A pile of coal is just a pile of rocks. The same applies to a pile of cinders or fly ash. Cinders and fly ash are only slightly "refined". You won't find radiation readings noticeably different from background. You have to recognize that large numbers are involved. It is millions of tons of coal for tons of uranium. If you want to get the minerals out of cinders and fly ash, you have to do further refining. Or you could let Nature, including biology, do some of the refining. The trouble is that Nature may refine the poisons into your food or drink.

References and Suggested Reading

J. F. Ahearne, "The Future of Nuclear Power," American Scientist, Jan.-Feb.. 1993: 24-35.

E. Brown and R. B. Firestone, "Table of Radioactive Isotopes", Wiley Interscience, 1986.

J. O. Corbett, "The Radiation Dose From Coal Burning: A Review of Pathways and Data," Radiation Protection Dosimetry, 4 (1~: 5-19.

R. R. Judkins and W. Fulkerson, "The Dilemma of Fossil Fuel Use and Global Climate Change," Energy & Fuels, 7 (1993) 14-22.

National Council on Radiation Protection. Public Radiation Exposure From Nuclear Power Generation in the U.S., Report No. 92, 1987, 72-112.

National Council on Radiation Protection, Exposure of the Population in the United States and Canada from Natural Background Radiation, Report No. 94, 1987, 90-128.

National Council on Radiation Protection, Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources, Report No. 95, 1987, 32-36 and 62-64.

Serge A. Korff, "Fast Cosmic Ray Neutrons in the Atmosphere", Proceedings of International Conference on Cosmic Rays, Volume 5: High Energy Interactions, Jaipur, December 1963.

C. B. A. McCusker, "Extensive Air Shower Studies in Australia," Proceedings of International Conference on Cosmic Rays, Volume 4: Extensive Air Showers, Jaipur, December 1963.

T. L. Thoem, et al., Coal Fired Power Plant Trace Element Study, Volume 1: A Three Station Comparison, Radian Corp. for USEPA, Sept. 1975.

W. Torrey, "Coal Ash Utilization: Fly Ash, Bottom Ash and Slag," Pollution Technology Review, 48 (1978) 136.

Nuclear Materials for Fuels

As coal is burned, thorium-232 (232Th) and uranium-238 (238U) are released as exhaust products in coal ash. What could be done with these isotopes if they were recovered? At least one scenario is readily apparent.

Because atoms of 232Th and 238U do not split, or "fission," when bombarded with slow (thermal) neutrons, they are referred to as "fertile," rather than fissionable, materials that can be used to "breed" nuclear fuel by the addition of a neutron to each atomic nucleus. For example, when the nucleus of a thorium atom absorbs neutron, it becomes 233Th, which decays in relatively short order to 233U, a nuclear fission fuel. Similarly, plutonium-239 (239PIJ), an efficient fuel for both reactors and nuclear weapons, can be bred by the capture of neutrons from fissioning Uranium-235 (235U) in a blanket of 238U.

A potential source of the neutrons required to breed nuclear fuels from these isotopes is the fission of 235U -the reaction that powers nuclear power plants. The fission of each 235U nucleus releases 2 or 3 neutrons that either produce more fissions, breed new fuel through capture in fertile materials, or (decay into a proton, an electron, and an anti-neutrino. In a "breeder" reactor environment 238U or 232Th can capture enough of these neutrons to breed more fissionable material than is consumed during fission of the original 235U fuel in the reactor.

Typical nuclear power plants rely on the heat produced from the splitting of 235U and heat from its "daughters," radioactive elements formed in the process. This heat converts the water circulating through the reactor to steam, which drives turbines for generating electricity. The same process could be fueled by the fission of 233U or 239Pu isotopes that could be bred from the discarded leftovers of coal combustion.

Biographical Sketch W. Alex Gabbard is leader of the High Temperature Fuel Behavior Group in the Nuclear Fuel Materials Section of ORNL's Metals and Ceramics Division. He is a principal investigator for the Laboratory's Nuclear Energy Program. He served in the U.S. Navy during the war in Vietnam and earned an M.S. degree in physics from North Carolina State University. He came to ORNL in 1980 to work in the Fusion Energy Division where he held leadership positions in support of two experimental fusion devices, the Impurity Study Experiment and the Advanced Toroidal Facility. When he transferred to the Metals and Ceramics Division in 1990, Gabbard became a group leader in charge of design and development of the Core Conduction Cooldown Test Facility for testing ceramic-coated nuclear fuel under simulated accident conditions. In addition to his technical publications, Gabbard has published seven books and a number of magazine articles. He has written both fiction and nonfiction, covering subjects ranging from Southern humor to world-class automobiles.

At least 73 elements found in coal-fired plant emissions are distributed in millions of pounds of stack emissions each year. They include:
Uranium, **Arsenic**, **Mercury**, **Lead**, Aluminum, Chromium, Molybdenum, Antimony, Cobalt, Nickel, Copper, Selenium, Barium, Fluorine, Silver, Beryllium, Iron, Sulfur, Boron, Titanium, Cadmium, Magnesium, Calcium, Manganese, Vanadium, Chlorine and Zinc.

Final comment by Ed Greisch: Chinese industrial grade coal is sometimes stolen by peasants for cooking. The result is that the whole family dies of arsenic poisoning because Chinese industrial grade coal contains large amounts of arsenic. Coal from Perry, Illinois contains up to 103 parts per million of uranium.