August 24, 2007

ACAA Releases 2006 CCP Production and Use Survey

The American Coal Ash Association today released its annual Coal Combustion Products (CCP) Production and Use Survey. CCPs are inorganic materials left over when coal is burned to generate electricity. They include fly ash, bottom ash, boiler slag, cenospheres as well as resulting air emission control system materials from flue gas desulfurization (FGD).

The data, reporting 2006 totals, originates from the voluntary responses of 58 electric utilities (approximately one-half of all coal-fired utility producers), past survey comparisons, U.S. Department of Energy information and other sources.

Results show that 124.8 million tons of CCPs were produced in 2006; slightly more than 43 percent were beneficially used rather than landfilled, an increase of 3 percent over 2005. The EPA and industry have jointly targeted a goal of 50 percent beneficial use by 2011.

Fly ash production in 2006 increased by 1.3 million tons over 2005 to 72.4 million tons. Almost 45 percent (32,423,569 tons) was used in 12 of 15 applications tracked by ACAA; an increase of about 5 percent from the previous year. Of the total used, 46 percent (15,041,335 tons) was consumed in concrete, concrete products and grout; an additional 4.1 million tons were consumed in cement production.

Flue gas desulphurization (FGD) materials include products from forced oxidation scrubbers and other processes that remove sulfur dioxide from the flue gas stream. FGD gypsum production was approximately 12.1 million tons of which 79 percent (9,561,489 tons) was used — mainly in gypsum panel products, such as wallboard. This is a slight increase (2.5%) over 2005.

Bottom ash production was 18.6 million tons of which 45 percent (8,378,494 tons) was used. Structural fills and embankments accounted for the largest application. Production figures increased by more than 1 million tons, while utilization increased about 4.5 percent as compared to 2005. Bottom ash, like fly ash, is widely used in many applications. Its primary applications are in structural fills and road base construction.

Boiler slag reached slightly more than 2 million tons of which 83 percent was used (1,690,999 tons) — a decrease from the 96.6 percent reported in 2005. Boiler slag is used primarily in blasting grit and as roofing granules, with lesser amounts in structural and asphalt mineral fills. The volume of available slag is expected to decline in the coming years as older cyclone and slag-tap boilers units are retired. (Please note that boiler slag statistics were not extrapolated.)

Comparisons of data from year to year are affected by the companies who voluntarily report data as well as the start or completion of projects from year to year. However, 2006 again reconfirms the multi-year trend of increasing utilization as more persons realize the value of using these valuable products.

ACAA is an active sponsor of the U.S. Environmental Protection Agency's Coal Combustion Products Partnership or "C^2P^2." This initiative helps promote awareness and understanding of the benefits of using CCPs to conserve natural resources, support sustainability, reduce greenhouse gas emissions and eliminate the need for added land fill space. Additional information about CCPs can be found at www.acaa-usa.org, www.FGDProducts.org, and www.epa.gov/epaoswer/osw/conserve/c2p2/.

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ACAA INTERNATIONAL

2006 Coal Combustion Product (CCP) Production and Use Survey

CCP Categories (Short Tons)	Fly Ash	Bottom Ash	Boiler Slag*	FGD Gypsum	FGD Material Wet Scrubbers	FGD Material Dry Scrubbers*	FGD Other*	FBC Ash*
CCP Production Category Totals**	72,400,000	18,600,000	2,026,066	12,100,000	16,300,000	1,488,951	299,195	1,580,912
CCP Production Total								**124,795,124**
CCP Used Category Totals***	32,423,569	8,378,494	1,690,999	9,561,489	904,348	136,639	29,341	1,078,291
All CCP Used Total								**54,203,170**
CCP Use By Application******	**Fly Ash**	**Bottom Ash**	**Boiler Slag**	**FGD Gypsum**	**FGD Material Wet Scrubbers**	**FGD Material Dry Scrubbers**	**FGD Other**	**FBC Ash**
1. Concrete/Concrete Products /Grout	15,041,335	597,387	0	1,541,930	0	9,660	0	4,571
2. Cement/ Raw Feed for Clinker	4,150,228	925,888	17,773	264,568	0	0	0	0
3. Flowable Fill	109,357	0	0	0	0	9,843	0	0
4. Structural Fills/Embankments	7,175,784	3,908,561	126,280	0	131,821	0	0	360,115
5. Road Base/Sub-base/Pavement	379,020	815,520	60	0	0	249	0	453,602
6. Soil Modification/Stabilization	648,551	189,587	0	0	0	299	1,503	179,003
7. Mineral Filler in Asphalt	26,720	19,250	45,000	0	0	0	0	0
8. Snow and Ice Control	0	331,107	41,549	0	0	0	0	0
9. Blasting Grit/Roofing Granules	0	81,242	1,445,933	0	232,765	0	0	0
10. Mining Applications	942,048	79,636	0	0	201,011	115,696	0	0
11. Wallboard	0	0	0	7,579,187	0	0	0	0
12. Waste Stabilization/Solidification	2,582,125	105,052	0	0	0	0	27,838	81,000
13. Agriculture	81,212	1,527	0	168,190	0	846	0	0
14. Aggregate	271,098	647,274	416	0	0	0	0	0
15. Miscellaneous/Other	1,016,091	676,463	13,988	7,614	338,751	46	0	0
CCP Category Use Totals	**32,423,569**	**8,378,494**	**1,690,999**	**9,561,489**	**904,348**	**136,639**	**29,341**	**1,078,291**
Application Use To Production Rate	44.78%	45.05%	83.46%	79.02%	5.55%	9.18%	9.81%	68.21%
Overall CCP Utilization Rate								**43.43%**
Cenospheres Sold (Pounds):	**11,146,420**							

* As submitted based on 57 percent coal burn.

** CCP Production totals for Fly Ash, Bottom Ash, FGD Gypsum, and Wet FGD are extrapolated estimates rounded off to nearest 50,000 tons.

*** CCP Used totals for Fly Ash, Bottom Ash, FGD Gypsum, and Wet FGD are per extrapolation calculations (not rounded off).

**** CCP Uses by application for Fly Ash, Bottom Ash, FGD Gypsum, and Wet FGD are calculated per proportioning the CCP Used Category Totals by the same percentage as each of the individual application types' raw data contributions to the as-submitted raw data submittal total (not rounded off).

Coal Combustion: Nuclear Resource or Danger

By Alex Gabbard

Alex Gabbard at the coal pile for ORNL's steam plant.

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.

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

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

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.

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

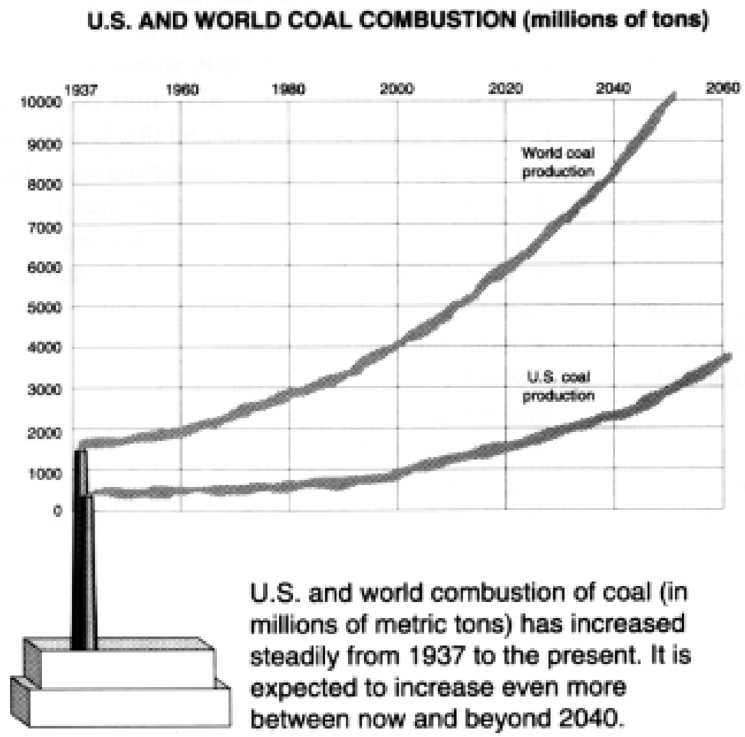
Coal ash is composed primarily of oxides of silicon, aluminum, iron, calcium, magnesium, titanium, sodium, potassium, arsenic, mercury, and sulfur plus small quantities of uranium and thorium. Fly ash is primarily composed of non-combustible silicon compounds (glass) melted during combustion. Tiny glass 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.

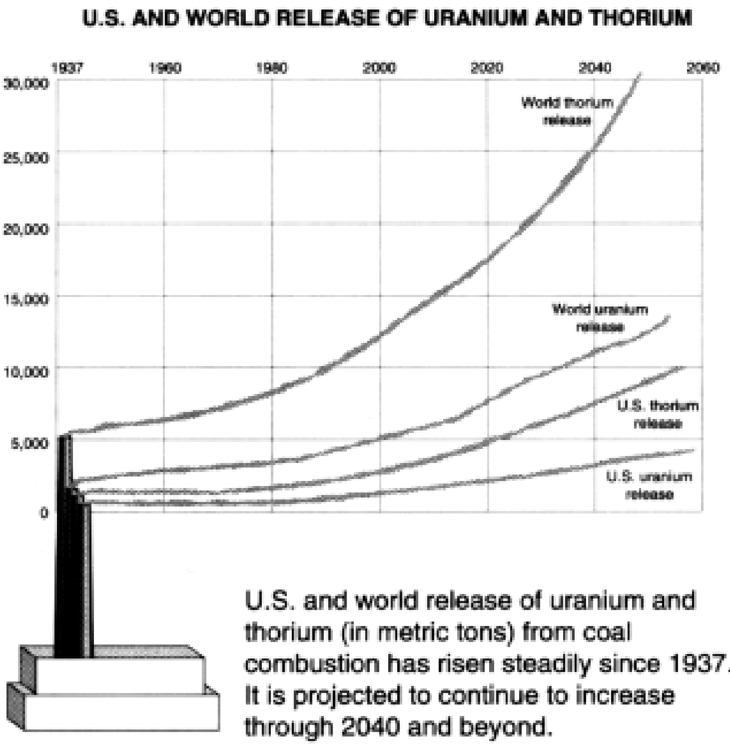
Uranium and Thorium in Coal and Coal Ash

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 1990. 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.



U.S. and world combustion of coal (in millions of metric tons) has increased steadily from 1937 to the present. It is expected to increase even more between now and beyond 2040.

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 above 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 above, the graph below 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 coal combustion can be calculated.



U.S. and world release of uranium and thorium (in metric tons) from coal combustion has risen steadily since 1937. It is projected to continue to increase through 2040 and beyond.

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.

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):*
>
> Uranium: 145,230 tons (containing 1031 tons of uranium-235)
>
> Thorium: 357,491 tons

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

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.

The population effective dose equivalent from coal plants is 100 times that from nuclear plants

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.

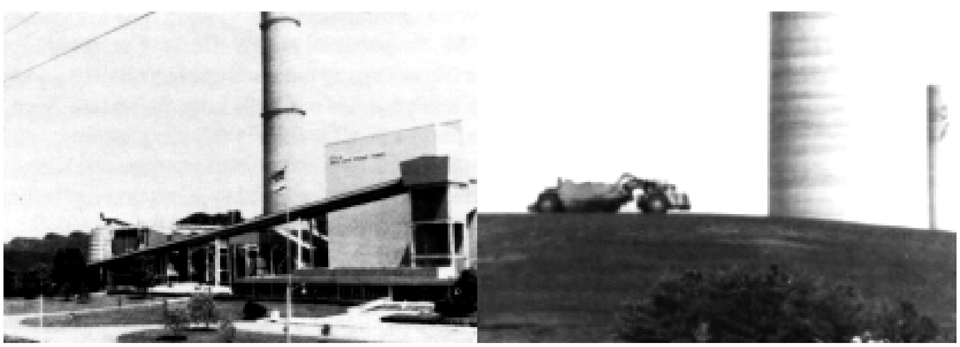
All studies of potential health hazards associated with the release of radioactive elements from coal combustion conclude that the perturbation of natural background dose levels is almost negligible. However, because the half-lives of radioactive potassium-40, uranium, and thorium are practically infinite 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.

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

Energy Content: Coal vs Nuclear

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 x 10E14 kilowatt-hours. The thermal energy released in nuclear fission produces about 2 x 10E9 kWh/ton. Consequently, the thermal energy from fission of uranium-235 released in coal combustion amounts to 2.1 x 10E12 kWh. If uranium-238 is bred to plutonium-239, using these data and assuming a "use factor" of 10%, the thermal energy from fission of this isotope alone constitutes about 2.9 x 10E14 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 with a similar "use factor", the thermal energy capacity of this isotope is approximately 7.2 x 10E14 kWh, or 105% of the thermal energy released from U.S. coal combustion for a century. Assuming 10% usage, the total of the thermal energy capacities from each of these three fissionable isotopes is about 10.1 x 10E14 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.



Views of the Tennessee Valley Authority's Bull Run and Kingston Steam Plants. These coal-fired facilities generate electricity for Oak Ridge and the surrounding area.

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 10E12 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 10E11 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.

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?

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

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?

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.

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

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.--
Alex Gabbard of the Metals and Ceramics Division

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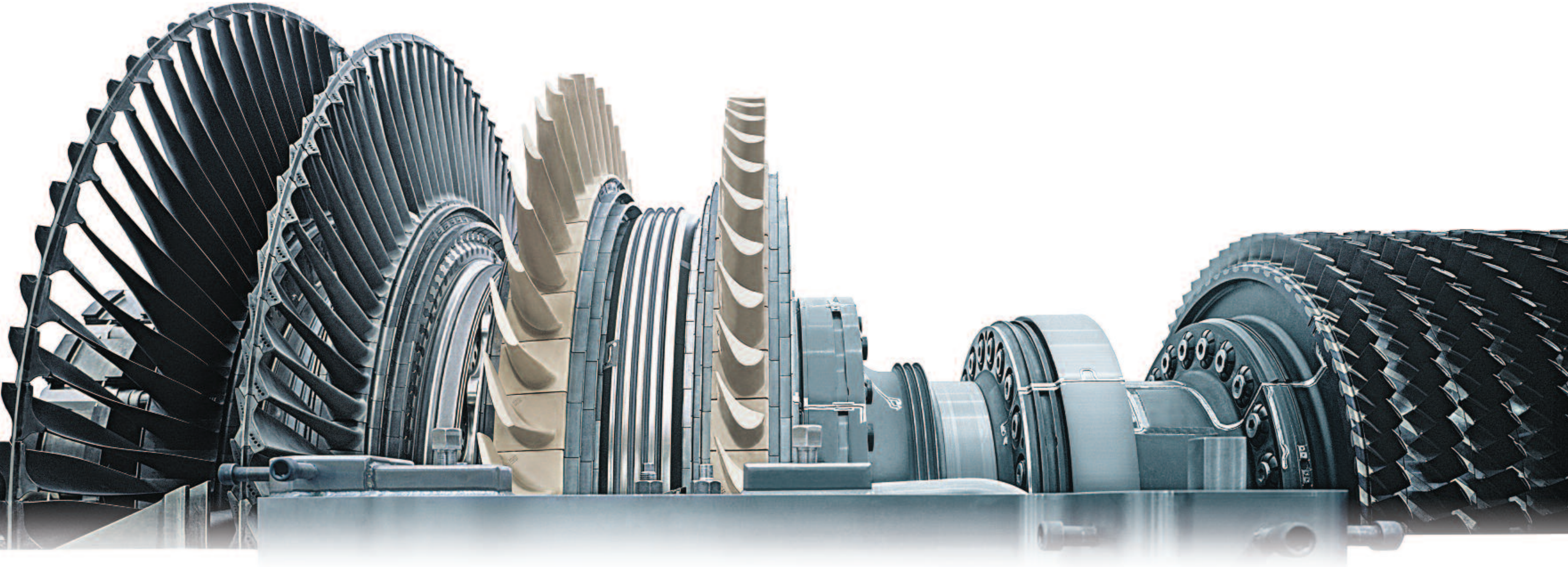
GE
Energy

GAS TURBINE AND COMBINED CYCLE PRODUCTS



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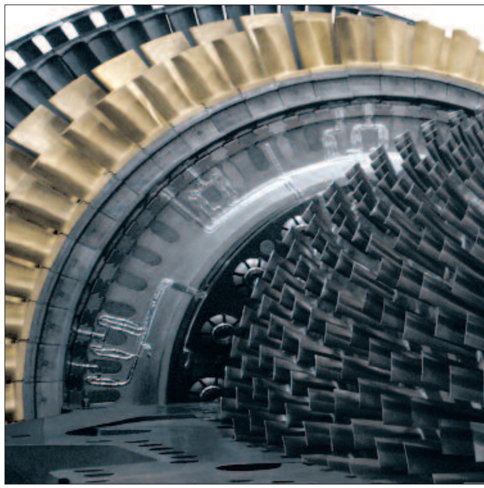

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GAS TURBINE AND COMBINED CYCLE PRODUCTS

	Heavy Duty		Output		Heat Rate Btu/kWh	Heat Rate kJ/kWh
2	MS9001H	CC	520 MW	50 Hz	5,690	6,000
2	MS7001H	CC	400 MW	60 Hz	5,690	6,000
6	MS9001FB	CC	412.9 MW	50 Hz	5,880	6,202
6	MS7001FB	CC	280.3 MW	60 Hz	5,950	6,276
8	MS6001FA	CC	117.7 MW	50 Hz	6,240	6,582
		CC	118.1 MW	60 Hz	6,250	6,593
		SC	75.9 MW	50 Hz	9,760	10,295
		SC	75.9 MW	60 Hz	9,795	10,332
8	MS7001FA	CC	262.6 MW	60 Hz	6,090	6,424
		SC	171.7 MW	60 Hz	9,360	9,873
8	MS9001FA	CC	390.8 MW	50 Hz	6,020	6,350
		SC	255.6 MW	50 Hz	9,250	9,757
10	MS9001E	CC	193.2 MW	50 Hz	6,570	6,930
		SC	126.1 MW	50 Hz	10,100	10,653
11	MS7001EA	CC	130.2 MW	60 Hz	6,800	7,173
		SC	85.1 MW	60 Hz	10,430	11,002
12	MS6001B	CC	64.3 MW	50 Hz	6,950	7,341
		CC	64.3 MW	60 Hz	6,960	7,341
		SC	42.1 MW	50/60 Hz	10,642	11,226
13	MS6001C	CC	67.2 MW	50 Hz	6,281	6,627
		CC	67.2 MW	60 Hz	6,281	6,627
		SC	45.4 MW	50 Hz	9,315	9,830
		SC	45.3 MW	60 Hz	9,340	9,855

14 Small Heavy-Duty and Aeroderivative Gas Turbine Products Overview

16 IGCC (Integrated Gasification Combined Cycle) Overview

NOTE: All ratings are net plant based on ISO conditions and natural gas fuel.
All CC ratings shown above are based on a 1 GT/1 ST configuration.

H System™

World's Most Advanced Combined Cycle Gas Turbine Technology

GE's H System™—the world's most advanced combined cycle system and the first capable of breaking the 60% efficiency barrier—integrates the gas turbine, steam turbine, generator and heat recovery steam generator into a seamless system, optimizing each component's performance. Undoubtedly the leading technology for both 50 and 60 Hz applications, the H delivers higher efficiency and output to reduce the cost of electricity of this gas-fired power generation system.

Closed-Loop Steam Cooling

Open loop air-cooled gas turbines have a significant temperature drop across the first stage nozzles, which reduces firing temperature and thermal efficiency. The closed-loop steam cooling system allows the turbine to fire at a higher temperature for increased performance. It is this closed-loop steam cooling that enables the H System™ to achieve 60% fuel efficiency capability while maintaining adherence to the strict low NO_x standards and reducing CO_2 emissions. Additionally, closed-loop cooling also minimizes parasitic extraction of compressor discharge air, thereby allowing more air to flow to the combustor for fuel premixing, thereby enabling lower emissions.

An MS9001H is seen during assembly in the factory.

RDC27903-13-03

MS9001H/MS7001H
COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
50 Hz	S109H	520	5,690	6,000	60.0%	1 x MS9001H
60 Hz	S107H	400	5,690	6,000	60.0%	1 x MS7001H

Baglan Bay Power Station is the launch site for GE's H System™.

PSP30462-05

Single Crystal Materials

The use of these advanced materials and Thermal Barrier Coatings ensures that components will stand up to high firing temperatures while meeting maintenance intervals.

Dry Low NO_x Combustors

Building on GE's design experience, the H System™ employs a can-annular lean pre-mix DLN-2.5 Dry Low NO_x (DLN) Combustor System. Fourteen combustion chambers are used on the 9H, and 12 combustion chambers are used on the 7H. GE DLN combustion systems have demonstrated the ability to achieve low NO_x levels in several million hours of field service around the world.

RDC27916-09-09

A 9H gas turbine is readied for testing.

Small Footprint/High Power Density

The H System™ offers approximately 40% improvement in power density per installed megawatt compared to other combined cycle systems, once again helping to reduce the overall cost of producing electricity.

PSP30246-10

World's first H turbine is transported through Wales to Baglan Bay Power Station.

Thoroughly Tested

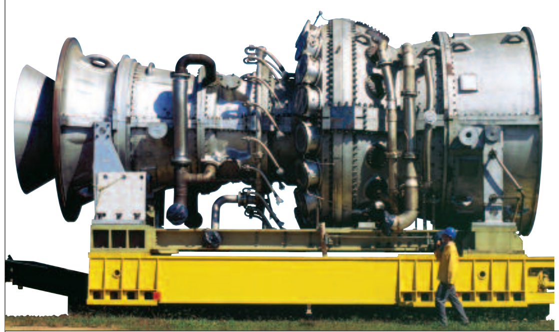
The design, development and validation of the H System™ has been conducted under a regimen of extensive component, sub-system and full unit testing. Broad commercial introduction has been controlled to follow launch units demonstration. This thorough testing approach provides the introduction of cutting edge technology with high customer confidence.

F Class

World's Most Experienced Advanced Technology Gas Turbines

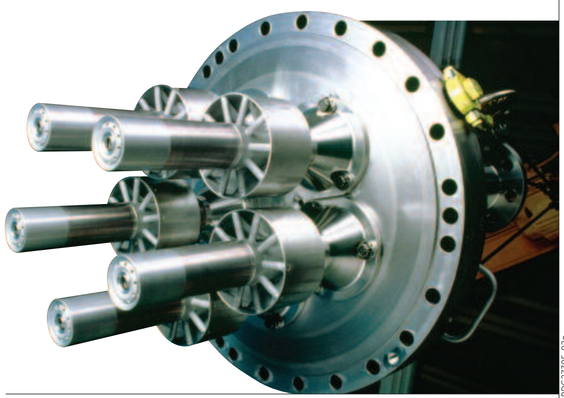
With over twenty million hours of operation, our F class turbines have established GE as the clear industry leader for successful fired hours in advanced technology gas turbines. Representing the world's largest, most experienced fleet of highly efficient gas turbines, designed for maximum reliability and efficiency with low life cycle costs, our F class turbines are favored by both power generators and industrial cogenerators requiring large blocks of reliable power.

Introduced in 1987, GE's F class gas turbines resulted from a multi-year development program using technology advanced by GE's aircraft engine team and GE Global Research. GE continually advances this technology by incrementally improving the F class product to attain ever higher combined cycle efficiencies, while maintaining reliability and availability.



PSP30027-06

An MS9001FA gas turbine ships from the plant.

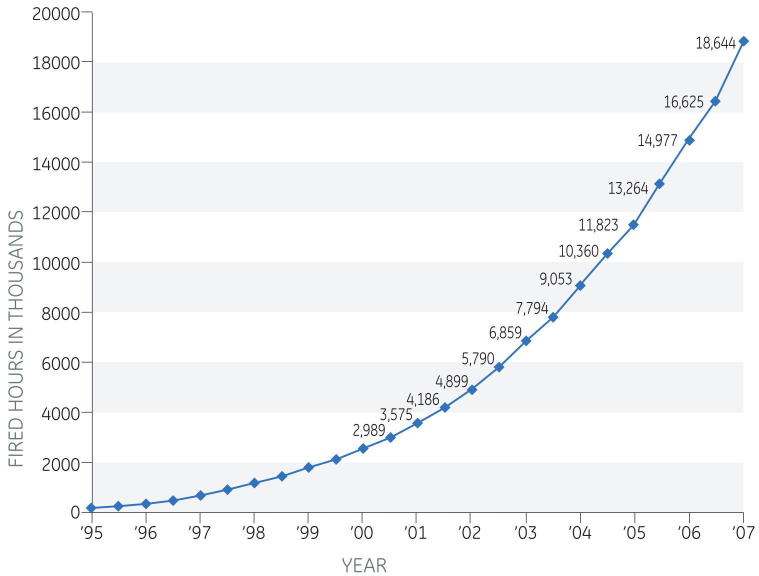


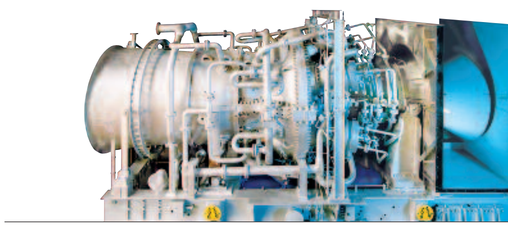
RDC27305-02a

Dry Low NO_x combustor systems allow GE's F Class turbines to meet today's strict environmental emissions requirements.

Our F class gas turbines, including the 6F (either 50 or 60 Hz), the 7F (60 Hz) and the 9F (50 Hz), offer flexibility in cycle configuration, fuel selection and site adaptation. All F class gas turbines include an 18-stage axial compressor and a three-stage turbine, and they feature a cold-end drive and axial exhaust, which is beneficial for combined cycle arrangements where net efficiencies over 58% can be achieved.

F/FA/FB EXPERIENCE




PSP30114


PSP30210-01

Half of all 6FA installations are located in Europe. This CHP plant is owned by Porvoo, Finland.

MS7001FB and MS9001FB

GE's Most Advanced Air-Cooled Gas Turbine

The FB is the latest evolutionary step in GE's proven F series. Taking F technology to a new level of output and efficiency, we've applied our cutting-edge technology, including the materials developed for the H System™, and the experience gained in over twenty million advanced gas turbine fired hours. The result is a large combined cycle system designed to provide high performance and low electrical cost.

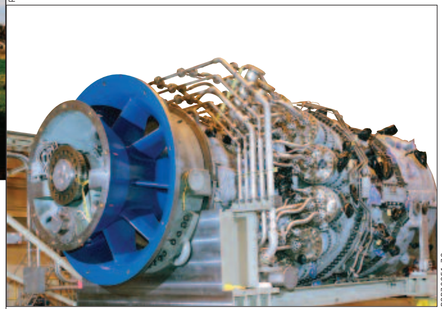
Improved output and efficiency means better fuel economy and reduced cost of producing electricity. With today's competitive markets and unpredictable fuel prices, this—now more than ever—is the key to success.

This MS9001FB is seen on half shell during assembly.

PSP30510-01

PSP30371-02

Hunterstown, PA 7FB launch site.



PSP30251-39

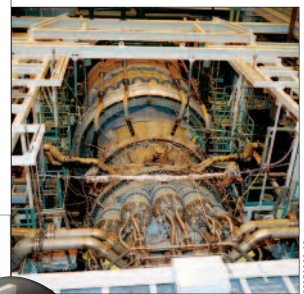
This MS7001FB is shown in the factory.

In developing the FB, we followed a specific course that significantly improved the key driver of efficiency—firing temperature. The FB firing temperature was increased more than 100 degrees Fahrenheit over GE's FA technology, resulting in combined cycle efficiency rating improvements of better than one percentage point. Output improvements of more than 5% were also achieved. These improvements equate to more MW per MBtu of natural gas burned.

The use of advanced turbine materials, such as Single Crystal First Stage Buckets, ensures that components can stand up to the higher firing temperatures of the FB without an increase in maintenance intervals. Providing the basis of process rigor, Six Sigma methodologies were used to assure a highly reliable robust design optimized for lowest cost of electricity. Indeed, in developing the FB, we were able to maintain many of the proven features of the world's most successful advanced technology turbine, the F/FA.

MS7001FB/MS9001FB COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
50 Hz	S109FB	412.9	5,880	6,202	58.0%	1 x MS9001FB
50 Hz	S209FB	825.4	5,884	6,206	58.0%	2 x MS9001FB
60 Hz	S107FB	280.3	5,950	6,276	57.3%	1 x MS7001FB
60 Hz	S207FB	562.5	5,940	6,266	57.5%	2 x MS7001FB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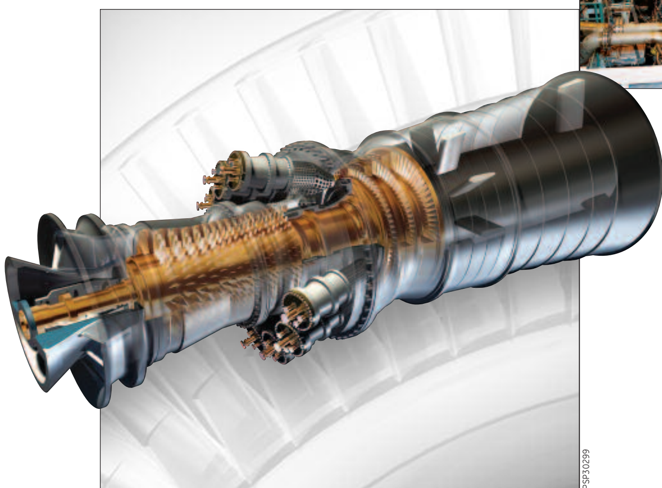
An MS7001FB is seen in test cell.


PSP30299

MS6001FA, MS7001FA and MS9001FA

Proven Performance in a Mid-Size Package

The highly efficient gear-driven 6FA gas turbine is a mid-size version of the well-proven 7FA and 9FA. Its output range, high exhaust energy, full packaging and robust design ideally suit applications ranging from cogeneration and district heating to pure power generation in combined cycle and Integrated Gasification Combined Cycle (IGCC).

To meet the need for mid-size power blocks with high performance in combined heat and power applications, the high-speed 6FA produces 75.9 MW of simple cycle power at 35% efficiency and 117 MW of combined cycle power at 54.7% net efficiency. In IGCC operation, gross plant efficiencies can reach up to 46%.

A classic example of GE's evolutionary designs, the 6FA is a 2/3 scale of the 7FA. Its aerodynamically scaled 18-stage axial design reduces combustion chambers from 14 to 6. A cold-end drive allows exhaust gases to be directed axially into the HRSG. With over 860,000 operating hours and 61 units installed or on order, the 6FA provides major fuel savings over earlier mid-range units in base-load operation. Adaptable to single or multi-shaft configurations, it burns a variety of fossil fuels, which can be switched after start-up without sacrificing performance. On natural gas the available Dry Low NO_x (DLN) system can achieve NO_x emissions of 15 ppm.

Industry Standard for 60 Hz Power in All Duty Cycles

The wide range of power generation applications for the 7FA gas turbine includes combined cycle, cogeneration, simple cycle peaking and IGCC in both cycle and base load operation with a wide range of fuels. Its high reliability—consistently 98% or better—provides customers more days of operation per year while minimizing overall life cycle cost.

MS6001FA SIMPLE CYCLE PERFORMANCE RATINGS

		50 Hz Power Generation	60 Hz Power Generation
Output	(MW)	75.9	75.9
Heat Rate	(Btu/kWh) (kJ/kWh)	9,760 10,295	9.795 10,332
Pressure Ratio		15.6:1	15.7:1
Mass Flow	(lb/sec) (kg/sec)	447 203	449 204
Turbine Speed	(rpm)	5,231	5,254
Exhaust Temperature	(°F) (°C)	1,117 603	1,118 603
Model Designation		PG6111FA	PG6111FA

MS6001FA COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
50 Hz	S106FA	117.7	6,240	6,582	54.7%	1 x MS6001FA
50 Hz	S206FA	237.9	6,170	6,508	55.3%	2 x MS6001FA
60 Hz	S106FA	118.1	6,250	6,593	54.6%	1 x MS6001FA
60 Hz	S206FA	237.5	6,210	6,550	54.9%	2 x MS6001FA

RDC27834-34

KEPCO's Seoinchon Plant, one of the world's largest combined cycle plants, has operated for more than 40,000 hours in daily start/stop cyclic duty.

As an industry leader in reducing emissions, the 7FA's DLN-2.6 combustor (proven in hundreds of thousands of operating hours) produces less than 9 ppm NO_x and CO—minimizing the need for exhaust cleanup systems and saving millions for our customers.

With over 640 units in operation, GE continually makes incremental design enhancements to improve output, efficiency, reliability and availability—for new units and upgrades to existing units. GE adds customer value with power augmentation equipment that provides additional gas turbine performance in summer peak demand periods—including inlet cooling, steam injection, and peak firing.

Proven Excellence in Reliable 50 Hz Combined Cycle Performance

Power producers around the world require reliable power generation—which makes the 9FA the 50 Hz gas turbine of choice for large combined cycle applications. As an aerodynamic scale of the highly successful 7FA gas turbine, the 9FA provides key advantages that include a fuel-flexible combustion system and higher output performance.

The 9FA gas turbine is configured with the robust DLN2.6+ combustion system. This combustor is quickly becoming an industry leader in low NO_x emissions, achieving less than 15 ppm NO_x, while also providing extended turn down capability for superior part load performance.

The 9FA can be configured to meet site and power requirements. For re-powering applications with space limitations, it can be configured in a single-shaft combined cycle arrangement with the generator and steam turbine. For large combined cycle or cogeneration plants where flexible operation and maximum performance is the prime consideration, it can be arranged in a multi-shaft configuration where one or two gas turbines are combined with a single steam turbine to produce power blocks of 390 or 786 MW.

MS7001FA SIMPLE CYCLE PERFORMANCE RATINGS

		60 Hz Power Generation
Output	(MW)	171.7
Heat Rate	(Btu/kWh) (kJ/kWh)	9,360 9,873
Pressure Ratio		16.0:1
Mass Flow	(lb/sec) (kg/sec)	981 445
Turbine Speed	(rpm)	3,600
Exhaust Temperature	(°F) (°C)	1,114 601
Model Designation		PG7241FA

MS7001FA COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
60 Hz	S107FA	262.6	6,090	6,424	56.0%	1 x MS7001FA
60 Hz	S207FA	529.9	6,040	6,371	56.5%	2 x MS7001FA

MS9001FA SIMPLE CYCLE PERFORMANCE RATINGS

		50 Hz Power Generation
Output	(MW)	255.6
Heat Rate	(Btu/kWh) (kJ/kWh)	9,250 9,757
Pressure Ratio		17.0:1
Mass Flow	(lb/sec) (kg/sec)	1,413 641
Turbine Speed	(rpm)	3,000
Exhaust Temperature	(°F) (°C)	1,116 602
Model Designation		PG9351FA

MS9001FA COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
50 Hz	S109FA	390.8	6,020	6,350	56.7%	1 x MS9001FA
50 Hz	S209FA	786.9	5,980	6,308	57.1%	2 x MS9001FA

MS9001E

Fuel-Flexible 50 Hz Performer

The MS9001E gas turbine is GE's 50 Hz workhorse. With more than 430 units, it has accumulated over 18 million fired hours of utility and industrial service, many in arduous climates ranging from desert heat and tropical humidity to arctic cold. Originally introduced in 1978 at 105 MW, the 9E has incorporated numerous component improvements. The latest model boasts an output of 126 MW and is capable of achieving more than 52% efficiency in combined cycle.

Whether for simple cycle or combined cycle application, base load or peaking duty, 9E packages are comprehensively engineered with integrated systems that include controls, auxiliaries, ducts and silencing. They are designed for reliable operation and minimal maintenance at a competitively low installed cost.

Like GE's other E-class technology units, the Dry Low NO_x combustion system is available on 9E, which can achieve NO_x emissions under 15 ppm when burning natural gas.

With its flexible fuel handling capabilities, the 9E accommodates a wide range of fuels, including natural gas, light and heavy distillate oil, naphtha, crude oil and residual oil. Designed for dual-fuel operation, it is able to switch from one fuel to another while running under load. It is also able to burn a variety of syngases produced from oil or coal without turbine modification. This flexibility, along with its extensive experience and reliability record, makes the 9E well suited for IGCC projects.

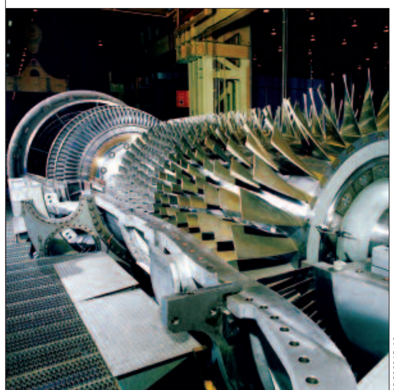
In simple cycle, the MS9001E is a reliable, low first-cost machine for peaking service, while its high combined cycle efficiency gives excellent fuel savings in base load operations. Its compact design provides flexibility in plant layout as well as the easy addition of increments of power when a phased capacity expansion is required.

MS9001E SIMPLE CYCLE PERFORMANCE RATINGS

		50 Hz Power Generation
Output	(MW)	126.1
Heat Rate	(Btu/kWh) (kJ/kWh)	10,100 10,653
Pressure Ratio		12.6:1
Mass Flow	(lb/sec) (kg/sec)	922 418
Turbine Speed	(rpm) 3,	000
Exhaust Temperature	(°F) (°C)	1,009 543
Model Designation		PG9171E

MS9001E COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
50 Hz	S109E	193.2	6,570	6,930	52.0%	1 x MS9001E
50 Hz	S209E	391.4	6,480	6,835	52.7%	2 x MS9001E



RDC26213-12

The MS9001E gas turbine is designed to attain high availability levels and low maintenance costs, resulting in extremely low total cost of ownership.

MS7001EA

Time-Tested Performer for 60 Hz Applications

With over 1080 units in service, the MS7001 fleet has accumulated over thirty million hours of service and is well recognized for high reliability and availability.

With strong efficiency performance in simple and combined cycle applications, this 85 MW machine is used in a wide variety of power generation, industrial and cogeneration applications. It is uncomplicated and versatile; its medium-size design lends itself to flexibility in plant layout and fast, low-cost additions of incremental power.

With state-of-the-art fuel handling equipment, dry low NO_X combustion, advanced bucket cooling, thermal barrier coatings and a multiple-fuel combustion system, the 7EA can accommodate a full range of fuels. It is designed for dual-fuel operation, able to switch from one fuel to another while the turbine is running under load or during shutdown. 7E/EA units have accumulated millions of hours of operation using crude and residual oils.

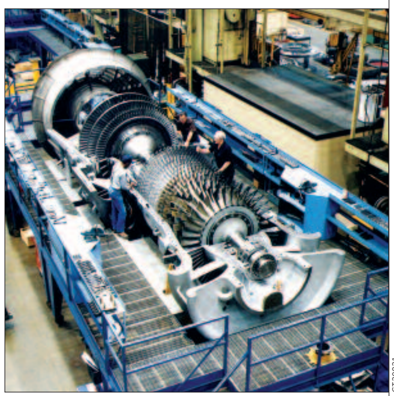
In addition to power generation, the 7EA has demonstrated its strong capability for mechanical drive applications, and has become a standard for the Oil & Gas industry LNG mechanical drive application.

MS7001EA SIMPLE CYCLE PERFORMANCE RATINGS

	60 Hz Power Generation		Mechanical Drive	
Output	(MW)	85.1	(hp)	115,630
Heat Rate	(Btu/kWh) (kJ/kWh)	10,430 11,002	(Btu/shp-hr)	7,720
Pressure Ratio		12.7:1		11.9:1
Mass Flow	(lb/sec) (kg/sec)	648 294	(lb/sec) (kg/sec)	659 299
Turbine Speed	(rpm)	3,600	(rpm)	3,600
Exhaust Temperature	(°F) (°C)	997 536	(°F) (°C)	999 537
Model Designation		PG7121EA		M7121EA

MS7001EA COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
60 Hz	S107EA	130.2	6,800	7,173	50.2%	1 x MS7001EA
60 Hz	S207EA	263.6	6,700	7,067	50.9%	2 x MS7001EA


GT20821

An MS7001EA is shown on half shell during assembly.

MS6001B

Reliable and Rugged 50/60 Hz Power

The MS6001B is a performance proven 40 MW class gas turbine, designed for reliable 50/60 Hz power generation and 50,000 hp class mechanical drive service. With availability well documented at 97.1% and reliability at 99.3%, it is the popular choice for efficient, low installed cost power generation or prime movers in mid-range service.

With over 1,000 units in service, the versatile and widely used 6B gas turbine has accumulated over 50 million operating hours in a broad range of applications: simple cycle, heat recovery, combined cycle, and mechanical drive. It can be installed fast for quick near-term capacity.

The rugged and reliable 6B can handle multiple start-ups required for peak load. It can accommodate a variety of fuels and is well suited to IGCC. In combined cycle operation the 6B is a solid performer at nearly 50% efficiency. It is also a flexible choice for cogeneration applications capable of producing a thermal output ranging from 20 to 400 million Btu/hr.

Like all GE heavy-duty gas turbines, the 6B has earned a solid reputation for high reliability and environmental compatibility. With a Dry Low NO_x combustion system, the 6B is capable of achieving less than 15 ppm NO_x on natural gas.

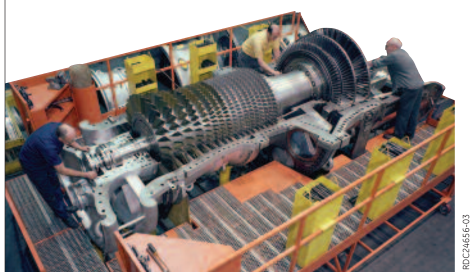
With its excellent fuel efficiency, low cost per horsepower and high horsepower per square foot, the MS6001B is an excellent fit for selective mechanical applications.

MS6001B SIMPLE CYCLE PERFORMANCE RATINGS

	50/60 Hz Power Generation		Mechanical Drive	
Output	(MW)	42.1	(hp)	58,380
Heat Rate	(Btu/kWh) (kJ/kWh)	10,642 11,226	(Btu/shp-hr)	7,650
Pressure Ratio		12.2:1		12.0:1
Mass Flow	(lb/sec) (kg/sec)	311 141	(lb/sec) (kg/sec)	309 140
Turbine Speed	(rpm)	5,163	(rpm)	5,111
Exhaust Temperature	(°F) (°C)	1,018 548	(°F) (°C)	1,011 544
Model Designation		PG6581B		M6581B

MS6001B COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
50 Hz	S106B	64.3	6,950	7,341	49.0%	1 x MS6001B
	S206B	130.7	6,850	7,225	49.8%	2 x MS6001B
	S406B	261.3	6,850	7,225	49.8%	4 x MS6001B
60 Hz	S106B	64.3	6,960	7,341	49.0%	1 x MS6001B
	S206B	130.7	6,850	7,225	49.8%	2 x MS6001B
	S406B	261.3	6,850	7,225	49.8%	4 x MS6001B



An MS6001B rotor is seen on half shell.

MS6001C

High Efficiency and Performance in a 45 MW Class

The 6C meets the need for low-cost electricity production in heat recovery operations for both 50 and 60 Hz—including industrial cogeneration, district heating, and mid-sized combined-cycle power plants.

Consistent with GE's evolutionary design philosophy, the 6C incorporates technologies that have been validated in service worldwide. This evolutionary approach ensures users of the 6C that they are receiving advanced but well-proven technology. The Frame 6C builds on the experience and performance of GE's Frame 6B technology, proven in more than 50 million hours of service, and also incorporates key features of GE's advanced F technology.

The turbine includes components that provide high reliability and maintainability, such as a 12-stage compressor with fewer parts and removable blades and vanes. NO_x emissions are limited to 15 ppm dry when operating on natural gas, and 42 ppm when burning light distillate with water injection.

Improved operability features include less than 50% turndown while maintaining emissions guarantees, fast and reliable starts in 13 minutes, and three stages of compressor guide vanes for high efficiency at part load. The 6C also features an F-class modular arrangement and a Mark VI Speedtronic control system.

PSP30646-02

Akenerji Kemalpasa-Izmir Turkey
206C Combined-Cycle—COD since November 2005
Rigorous field validation tests conducted at the Kemalpasa 6C launch site confirmed the outstanding operability of the turbine—high efficiency and low emissions.

MS6001C SIMPLE CYCLE PERFORMANCE RATINGS

		50 Hz	60 Hz
Output	(MW)	45.4	45.3
Heat Rate	(Btu/kWh) (kJ/kWh)	9,315 9,830	9,340 9,855
Pressure Ratio		19.6:1	19.6:1
Mass Flow	(lb/sec) (kg/sec)	270 122	270 122
Turbine Speed	(rpm)	7,100	7,100
Exhaust Temperature	(°F) (°C)	1,078 581	1,078 581
Model Designation		PG6591C	

MS6001C COMBINED CYCLE PERFORMANCE RATINGS

		Net Plant Output (MW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Net Plant Efficiency	GT Number & Type
50 Hz	S106C	67.2	6,281	6,627	54.3%	1 x MS6001C
50 Hz	S206C	136.1	6,203	6,544	55.0%	2 x MS6001C
60 Hz	S106C	67.2	6,281	6,627	54.3%	1 x MS6001C
60 Hz	S206C	136.1	6,203	6,544	55.0%	2 x MS6001C

Small Heavy-Duty and Aeroderivative Gas Turbines

A Broad Portfolio of Packaged Power Plants

GE provides a broad range of power packages from 10 MW to nearly 100 MW for simple cycle, combined cycle or cogeneration applications in the utility, private and mobile power industries. Marine applications for these machines range from commercial fast ferries and cruise ships to military patrol boats, frigates, destroyers and aircraft carriers.

Oil & Gas

GE is a world leader in high-technology turbine products and services for the oil & gas industry. We offer full turnkey systems and aftermarket solutions for production, LNG, transportation, storage, refineries, petrochemical and distribution systems.

LMS100 flexible power.

SMALL HEAVY-DUTY GAS TURBINES

		Output (kW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (lb/sec)	Exhaust Flow (kg/sec)	Exhaust Temp. (°F)	Exhaust Temp. (°C)
Generator Drive*	GE10	11,250	10,892	11,489	15,5:1	11,000	104.7	47.5	900	482
	MS5001	26,830	12,000	12,657	10,5:1	5,094	276.1	125.2	901	483
	MS5002E	31,100	9,758	10,292	17,0:1	5,714	225.0	102.1	952	511
		Output (shp)	Heat Rate (Btu/shp-h)		Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (lb/sec)	Exhaust Flow (kg/sec)	Exhaust Temp. (°F)	Exhaust Temp. (°C)
Mechanical Drive**	GE10	16,068	7,649	—	15,5:1	7,900	103.3	46.9	896	480
	MS5002C	38,005	8,814	—	8,8:1	4,670	274.1	123.4	963	517
	MS5002D	43,690	8,650	—	10,8:1	4,670	311.7	141.4	948	509
	MS5002E	42,910	7,074	—	17,0:1	5,714	225.0	102.1	952	511

*ISO conditions – natural gas – electrical generator terminals
**ISO conditions – natural gas – shaft output

AERODERIVATIVE GAS TURBINES

		Output (kW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (lb/sec)	Exhaust Flow (kg/sec)	Exhaust Temp. (°F)	Exhaust Temp. (°C)
50 Hz Power Gen	LMS100PA	102,998	7,777	8,250	41.0:1	3,000	470	213	765	407
	LMS100PB	98,440	7,563	7,979	40.0:1	3,000	456	207	783	417
	LM6000PC Sprint*	50,041	8,461	8,925	31.5:1	3,627	302	137	813	434
	LM6000PC	42,890	8,173	8,621	29.2:1	3,627	284	129	817	436
	LM6000PD Sprint	46,903	8,272	8,725	30.9:1	3,627	292	132	834	446
	LM6000PD	41,711	8,374	8,833	29.3:1	3,627	279	127	838	448
	LM6000PD (liquid fuel)	40,400	8,452	8,915	28.5:1	3,627	272	123	853	456
	LM2500RC	32,916	8,880	9,369	23:1	3,600	202	92	976	524
	LM2500RD	32,689	8,901	9,391	23:1	3,600	201	91	977	525
	LM2500PH	26,463	8,673	9,148	19.4:1	3,000	168	76	927	497
	LM2000PE	22,346	9,630	10,158	18.0:1	3,000	154	70	1001	538
	LM2000PS	17,674	9,779	10,315	16.0:1	3,000	142	64	894	479
	LM1600PE	13,748	9,749	10,283	20.2:1	7,900	104	47	915	491
60 Hz Power Gen	LMS100PA	103,045	7,773	8,201	41.0:1	3,600	470	213	763	406
	LMS100PB	98,396	7,566	7,983	40.0:1	3,600	456	207	783	417
	LM6000PC Sprint*	50,080	8,434	8,896	31.3:1	3,600	299	136	819	437
	LM6000PC	43,471	8,112	8,557	29.1:1	3,600	282	128	824	440
	LM6000PD Sprint	46,824	8,235	8,686	30.7:1	3,600	290	132	837	447
	LM6000PD	42,336	8,308	8,763	29.3:1	3,600	278	126	846	452
	LM6000PD (liquid fuel)	40,200	8,415	8,876	28.1:1	3,600	268	122	857	458
	LM2500RC	33,394	8,753	9,235	23:1	3,600	201.9	91.6	976	524
	LM2500RD	33,165	8,774	9,257	23:1	3,600	201	91	977	525
	LM2500PH	27,763	8,391	8,850	19.4:1	3,600	167	76	922	494
	LM2500PE	23,292	9,315	9,825	19.1:1	3,600	153	69	992	533
	LM2000PS	17,606	9,587	10,112	15.6:1	3,600	139	63	886	474
	LM1600PE	13,769	9,735	10,268	20.2:1	7,900	104	47	894	479
		Output (hp)	Heat Rate (Btu/shp-h)		Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (lb/sec)	Exhaust Flow (kg/sec)	Exhaust Temp. (°F)	Exhaust Temp. (°C)
Mechanical Drive	LM6000PC	59,355	5,941	—	29.1:1	3,600	282	127.9	824	440
	LM2500RC	45,740	6,435	—	23:1	3,600	202	92.0	980	527
	LM2500RD	45,417	6,450	—	23:1	3,600	200.9	91.1	981	527
	LM2500PE	31,164	6,780	—	19.5:1	3,600	152	69.0	976	524
	LM2000PE	24,146	6,992	—	15.6:1	3,600	138.6	62.9	885	474
	LM1600PE	19,105	7,016	—	20.2:1	7,900	104.3	47.3	915	491

*Sprint 2002 deck is used with water injection to 25 ppmvd for power enhancement.
NOTE: Performance based on 59°F amb. Temp., 60% RH, sea level, no inlet/exhaust losses on gas fuel with no NO_X media, unless otherwise specified.

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GT06543


PSP30305

The Next Generation Power Plant

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Integrated Gasification Combined Cycle (IGCC) technology is increasingly important in the world energy market, where low cost opportunity feedstocks such as coal, heavy oils and pet coke are the fuels of choice. And IGCC technology produces low cost electricity while meeting strict environmental regulations.

The IGCC gasification process "cleans" heavy fuels and converts them into high value fuel for gas turbines. Pioneered by GE almost 30 years ago, IGCC technology can satisfy output requirements from 10 MW to more than 1.5 GW and can be applied in almost any new or re-powering project where solid and heavy fuels are available.

Optimal Performance

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GE GAS TURBINES FOR IGCC APPLICATIONS

Gas Turbines		IGCC	
Model	Syngas Power Rating	Model	Syngas CC Output Power
GE10	10 MW (50/60 Hz)	GE10	14 MW (50/60 Hz)
6B	42 MW (50/60 Hz)	106B	63 MW (50/60 Hz)
7EA	90 MW (60 Hz)	107EA	130 MW (60 Hz)
9E	150 MW (50 Hz)	109E	210 MW (50 Hz)
6FA	90 MW (50/60 Hz)	106FA	130 MW (50/60 Hz)
7FA	197 MW (60 Hz)	107FA	280 MW (60 Hz)
9FA	286 MW (50 Hz)	109FA	420 MW (50 Hz)
7FB	232 MW (60 Hz)	207FB	750 MW (60 Hz)

PSP30120

This 550 MW IGCC is located at the Saras oil refinery in Sardinia. The three GE 109E single-shaft combined cycle units have accumulated over 12,000 hours of syngas operation.

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Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance

U.S. Geological Survey Fact Sheet FS-163-97 October, 1997

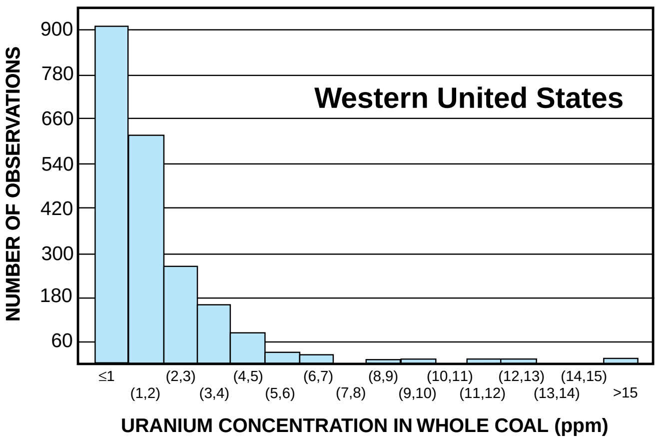
Introduction

Coal is largely composed of organic matter, but it is the inorganic matter in coal—minerals and trace elements—that have been cited as possible causes of health, environmental, and technological problems associated with the use of coal. Some trace elements in coal are naturally radioactive. These radioactive elements include uranium (U), thorium (Th), and their numerous decay products, including radium (Ra) and radon (Rn). Although these elements are less chemically toxic than other coal constituents such as arsenic, selenium, or mercury, questions have been raised concerning possible risk from radiation. In order to accurately address these questions and to predict the mobility of radioactive elements during the coal fuel-cycle, it is important to determine the concentration, distribution, and form of radioactive elements in coal and fly ash.

Abundance of Radioactive Elements in Coal and Fly Ash

Assessment of the radiation exposure from coal burning is critically dependent on the concentration of radioactive elements in coal and in the fly ash that remains after combustion. Data for uranium and thorium content in coal is available from the U.S. Geological Survey (USGS), which maintains the largest database of information on the chemical composition of U.S. coal. This database is searchable on the World Wide Web at: **http://energy.er.usgs.gov/products/databases/CoalQual/intro.htm**. Figure 1 displays the frequency distribution of uranium concentration for approximately 2,000 coal samples from the Western United States and approximately 300 coals from the Illinois Basin. In the majority of samples, concentrations of uranium fall in the range from slightly below 1 to 4 parts per million (ppm). Similar uranium concentrations are found in a variety of common rocks and soils, as indicated in figure 2. Coals with more than 20 ppm uranium are rare in the United States. Thorium concentrations in coal fall within a similar 1–4 ppm range, compared to an average crustal abundance of approximately 10 ppm. Coals with more than 20 ppm thorium are extremely rare.

During coal combustion most of the uranium, thorium, and their decay products are released from the original coal matrix and are distributed between the gas



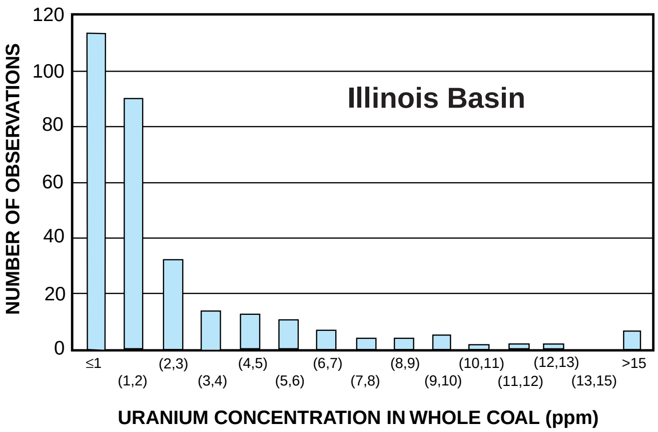


Figure 1. Distribution of uranium concentration in coal from two areas of the United States.

phase and solid combustion products. The partitioning between gas and solid is controlled by the volatility and chemistry of the individual elements. Virtually 100 percent of the radon gas present in feed coal is transferred to the gas phase and is lost in stack emissions. In contrast, less volatile elements such as thorium, uranium, and the majority of their decay products are almost entirely retained in the solid combustion wastes. Modern power plants can recover greater than 99.5 percent of the solid combustion wastes. The average ash yield of coal burned in the United States is approximately 10 weight percent. Therefore, the concentration of most radioactive elements in solid combustion wastes will be approximately 10 times the concentration in the original coal. Figure 2 illustrates that the uranium concentration of most fly ash (10 to 30 ppm) is still in the range found in some granitic rocks, phosphate rocks, and shales. For example,

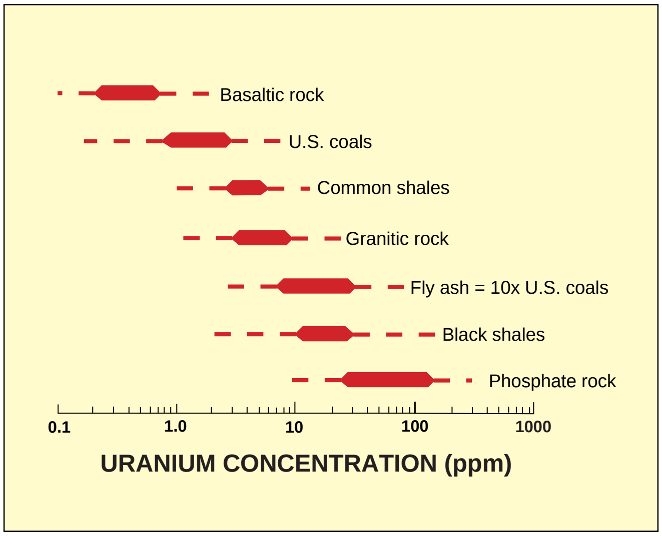


Figure 2. Typical range of uranium concentration in coal, fly ash, and a variety of common rocks.

the Chattanooga Shale that occurs in a large portion of the Southeastern United States contains between 10 and 85 ppm U.

Forms of Occurrence of Radioactive Elements in Coal and Fly Ash

The USGS has a current research project to investigate the distribution and modes of occurrence (chemical form) of trace elements in coal and coal combustion products. The approach typically involves (1) ultra sensitive chemical or radiometric analyses of particles separated on the basis of size, density, mineral or magnetic properties, (2) analysis of chemical extracts that selectively attack certain components of coal or fly ash, (3) direct observation and microbeam analysis of very small areas or grains, and (4) radiographic techniques that identify the location and abundance of radioactive elements.

Most thorium in coal is contained in common phosphate minerals such as monazite or apatite. In contrast, uranium is found in both the mineral and organic fractions of coal. Some uranium may be added slowly over geologic time because organic matter can extract dissolved uranium from ground water. In fly ash, the uranium is more concentrated in the finer sized particles. If during coal combustion some uranium is concentrated on ash surfaces as a condensate, then this surface-bound uranium is potentially more susceptible to leaching. However, no obvious evidence of surface enrichment of uranium has been found in the hundreds of fly ash particles examined by USGS researchers.

The above observation is based on the use of fission-track radiography, a sophisticated technique for observing the distribution of uranium in particles as small as 0.001 centimeter in diameter. Figure 3 includes a photograph of a hollow glassy sphere of fly ash and its corresponding fission track image. The diameter of this relatively large glassy sphere is approximately 0.01 cm. The distribution and concentration of uranium are indicated by fission tracks, which appear as dark linear features in the radiograph. Additional images produced by USGS researchers from a variety of fly ash particles confirm the preferential location of uranium within the glassy component of fly ash particles.

Health and Environmental Impact of Radioactive Elements Associated With Coal Utilization

Radioactive elements from coal and fly ash may come in contact with the general public when they are dispersed in air and water or are included in commercial products that contain fly ash.

The radiation hazard from airborne emissions of coal-fired power plants was evaluated in a series of studies conducted from 1975–1985. These studies concluded that the maximum radiation dose to an individual living within 1 km of a modern power plant is equivalent to a minor, perhaps 1 to 5 percent, increase above the radiation from the natural environment. For the average citizen, the radiation dose from coal burning is considerably less. Components of the radiation environment that impact the U.S. population are illustrated in figure 4. Natural sources account for the majority (82 percent) of radiation. Man-made sources of radiation are dominated by medical X-rays (11 percent). On this plot, the average population dose attributed to coal burning is included under the consumer products category and is much less than 1 percent of the total dose.

Fly ash is commonly used as an additive to concrete building products, but the radioactivity of typical fly ash is not significantly different from that of more conventional concrete additives or other building materials such as granite or red brick. One extreme calculation that assumed high proportions of fly-ash-rich concrete in a residence suggested a dose enhancement, compared to normal concrete, of 3 percent of the natural environmental radiation.

Another consideration is that low-density, fly-ash-rich concrete products may be a source of radon gas. Direct measurement of this contribution to indoor radon is complicated by the much larger contribution from underlying soil and rock (see fig. 4). The emanation of radon gas from fly ash is less than from natural soil of

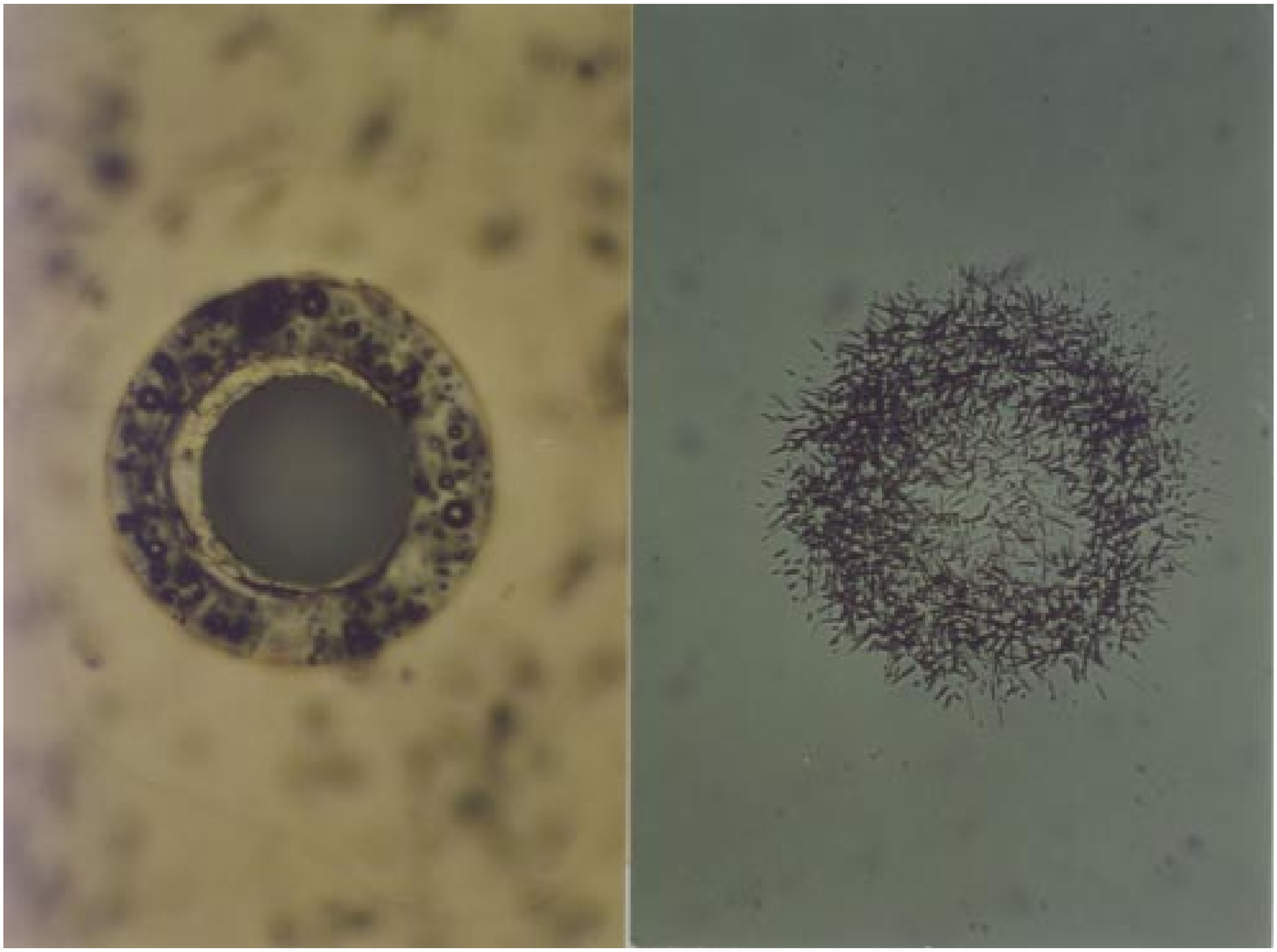


Figure 3. Photograph (left) of a hollow glassy fly ash particle (0.01 cm diameter) and its fission track radiograph (right). Uranium distribution and concentration are indicated by the location and density of dark linear fission tracks in the radiograph.

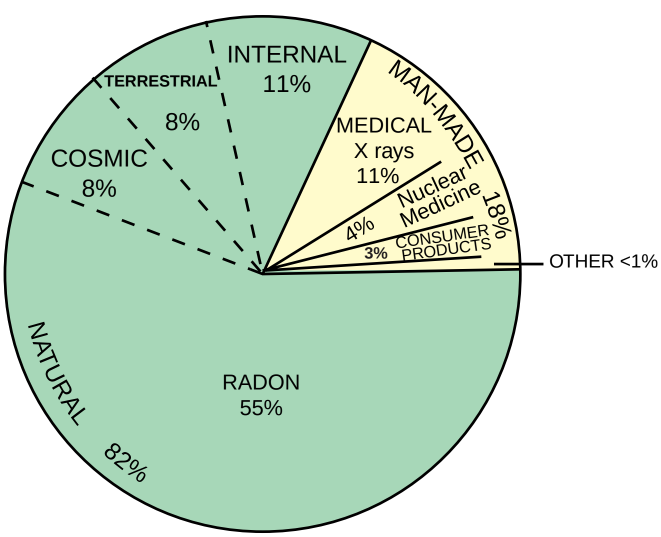


Figure 4. Percentage contribution of various radiation sources to the total average radiation dose to the U.S. population.

similar uranium content. Present calculations indicate that concrete building products of all types contribute less than 10 percent of the total indoor radon.

Approximately three-fourths of the annual production of fly ash is destined for disposal in engineered surface impoundments and landfills, or in abandoned mines and quarries. The primary environmental concern associated with these disposal sites is the potential for groundwater contamination. Standardized tests of the leachability of toxic trace elements such as arsenic, selenium, lead, and mercury from fly ash show that the amounts dissolved are sufficiently low to justify regulatory classification of fly ash as nonhazardous solid waste. Maximum allowable concentrations under these standardized tests are 100 times drinking water standards, but these concentration limits are rarely approached in leachates of fly ash.

The leachability of radioactive elements from fly ash has relevance in view of the U.S. Environmental Protection Agency (USEPA) drinking water standard for dissolved radium (5 picocuries per liter) and the proposed addition of drinking water standards for uranium and radon by the year 2000. Previous studies of radioelement mobility in the enviroment, and in particular, in the vicinity of uranium mines and mills, provide a basis for predicting which chemical conditions are likely to influence leachability of uranium, barium (a chemical analog for radium), and thorium from fly ash. For example, leachability of radioactive elements is critically influenced by the pH that results from reaction of water with fly ash. Extremes of either acidity ($\text{pH}<4$) or alkalinity ($\text{pH}>8$) can enhance solubility of radioactive elements. Acidic solutions attack a variety of mineral phases that are found in fly ash. However, neutralization of acid solutions by subsequent reaction with natural rock or soil promotes precipitation or sorption of many dissolved elements including uranium, thorium, and many of their decay products. Highly alkaline solutions promote dissolution of the glassy components of fly ash that are an identified host of uranium; this can, in particular, increase uranium solubility as uranium-carbonate species. Fortunately, most leachates of fly ash are rich in dissolved sulfate, and this minimizes the solubility of barium (and radium), which form highly insoluble sulfates.

Direct measurements of dissolved uranium and radium in water that has contacted fly ash are limited to a small number of laboratory leaching studies, including some by USGS researchers, and sparse data for natural water near some ash disposal sites. These preliminary results indicate that concentrations are typically below the current drinking water standard for radium (5 picocuries per liter) or the initially proposed drinking water standard for uranium of 20 parts per billion (ppb).

Summary

Radioactive elements in coal and fly ash should not be sources of alarm. The vast majority of coal and the majority of fly ash are not significantly enriched in radioactive elements, or in associated radioactivity, compared to common soils or rocks. This observation provides a useful geologic perspective for addressing societal concerns regarding possible radiation and radon hazard.

The location and form of radioactive elements in fly ash determine the availability of elements for leaching during ash utilization or disposal. Existing measurements of uranium distribution in fly ash particles indicate a uniform distribution of uranium throughout the glassy particles. The apparent absence of abundant, surface-bound, relatively available uranium suggests that the rate of release of uranium is dominantly controlled by the relatively slow dissolution of host ash particles.

Previous studies of dissolved radioelements in the environment, and existing knowledge of the chemical properties of uranium and radium can be used to predict the most important chemical controls, such as pH, on solubility of uranium and radium when fly ash interacts with water. Limited measurements of dissolved uranium and radium in water leachates of fly ash and in natural water from some ash disposal sites indicate that dissolved concentrations of these radioactive elements are below levels of human health concern.

Suggested Reading:

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