Compact Fluorescents, Radioisotopes and Solid Waste

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The solid waste, general environmental pollution and radionuclide production impacts of compact fluorescent lamps (CFLs) and incandescent lamps are compared, including "ecolight" long-life incandescents. In terms of mass, the environmental impacts of lighting are dominated by the carbon dioxide, air pollutants, solid and radioactive wastes produced during the generation of electricity and not by the disposal of the lamps themselves. While some CFLs contain a trace quantity of a radioisotope as part of their lamp starting circuits, on average the use of incandescent lamps results in the production of almost three times more radioactive waste and emissions than CFLs even including the trace amount of radioactive material in some CFLs. The additional radioactive waste resulting from the use of an incandescent light is between 400,000 and 6.7 million times greater than the radioactivity contained in a CFL, depending upon the point of reference. Similarly, while all fluorescent lamps contain a trace amount of mercury, incandescents, including "ecolights", are ultimately responsible for the release of approximately twice as much mercury, as well as almost three times as much arsenic and lead since their inefficiency results in greater burning of coal, which contains mercury, arsenic and lead as well as other heavy metals. Some CFLs do not contain any Promethium-147 (Pm-147) or Krypton-85 (Kr-85) but many of these are currently "one piece" lamps which have a slightly greater direct solid waste impact. Two piece CFLs have the lowest solid waste and pollution impact, compared to one-piece CFLs or incandescents. Two-piece CFLs with an electronic ballast would further minimize solid waste and pollution production and also avoid the use of radioisotopes in their lamps, but these lamps are not generally available at this writing and present performance challenges.

Introduction

As compact fluorescent lamps (CFL) have become popular as an energy efficiency option, some have questioned whether the bulky bases (ballasts) of the fixtures present a new solid waste problem (Tracy 1992). Others note that some compact fluorescents contain a minute quantity of a radioactive isotope (Promethium-147, "Pm-147" or occasionally Krypton-85, "Kr-85") as part of the lamp starter circuit. All fluorescent lamps contain a trace amount of mercury. Some anti-nuclear activists have found these issues so troubling that they promote the sales of highly inefficient incandescent bulbs as "ecolights", claiming that they are better for the environment.

All lamps and ballasts, whether fluorescent or incandescent, present a solid waste problem since few of them are currently recycled, although pilot projects to recycle fluorescent tubes have begun (Watson 1992; Tracy 1992). Incandescent lamps are manufactured of glass with an internal powder coating, steel, tungsten wire and brass.

Unlike incandescents, compact fluorescent lamps use a "ballast". This component is an electrical or electronic device which transforms normal electric current into a form required by a fluorescent lamp. There are two general types of ballasts: magnetic and electronic. Electronic-ballasted CFLs do not contain radioisotopes. While magnetic ballasts consist mainly of a copper core, electronic ballasts contain semiconductors, such as transistors. In either case, CFL lamps consist of glass, a ceramic base, metal and minute quantities of rare earths, approximately 5 milligrams of mercury per lamp and occasionally, a tiny amount of short-lived radioactive material in the starter circuit of the lamp portion of the unit. CFLs which use electronic ballasts do not contain any radioisotopes.

Compact fluorescent lamps are of two general types. One-piece compact fluorescents incorporate both the lamp and the ballast in one inseparable unit. Although the ballast may be useful for 30-50,000 hours, or three to five times the life of the lamp, the entire unit is discarded when the lamp in a one-piece compact fluorescent "burns out".

The second type of compact fluorescent has separate ballast and lamp sections. The lamp lasts for as long as 10,000 hours, or about ten times the life of a standard incandescent bulb. When it burns out, it can be replaced in the original base with a new lamp, at relatively low cost. These ballasts operate for 30-50,000 hours prior to "burnout".

Methodology

Radioisotope data for the Pm-147 calculation was obtained from USNRC (1979). The radioisotope concentrations in high level radioactive waste are based on twenty years after reactor discharge, the point of reference in the NRC documents cited. The data on nuclear plant gas emissions are from Nero (1979). Data on the impacts of electricity generation came from Appendix A of Pace (1990). Data on heavy metals from coal combustion were obtained from IEA Coal Research (1979). Pollutants were weighted according to average U.S. electricity fuel mix of 54.2% coal, 20.3% nuclear, 4.3% oil and 8.6% natural gas (NAERC 1991). The remainder is composed of hydro-electric power, "new" renewables and miscellaneous non-utility generation. While these have environmental consequences as well, they are both smaller in magnitude and more difficult to quantify than the larger contributors.

Tables 1, 3 and 4 are based on an average U.S. electricity fuel mix. Table 5 reports the analysis based on individual "marginal fuels", since energy savings in individual power pools or utility service territories will generally be reflected in the decreased use of one or perhaps two fuels, but not all. The fuel "at the margin" is the one that is conserved. The marginal fuel differs from region to region and can also vary from season to season and even time of day. Thus an analysis based on a single marginal fuel may not be properly representative since a utility may have more than one marginal fuel over the course of a year. Since lighting is a base load, savings occur throughout the year and may occur at all times of day. Site-specific impacts would require an analysis which includes the specific utility's load shape during different times of the year and the utility's fuel mix at the margin during different periods. That was not the purpose of this analysis.

All calculations were based on 30,000 operating hours, representing the life of a compact fluorescent ballast. Compact fluorescent lamp life was assumed to be 7,500 hours while incandescent bulb life was assumed to be 1,000 hours. The assumptions regarding compact fluorescents are arguably conservative since some manufacturer's rate their lamps at 10,000 hours and their ballasts at 50,000. We have used the lower operating life assumptions to account for premature burnout or planned mass relamping prior to burnout. A 28-watt quad CFL, producing 1800 lumens and consuming a total of 34 watts (including a six-watt ballast loss) is compared to two types of incandescent lamps producing comparable light output: a standard 100-watt incandescent with a rated life of 1000 hours and an "ecolight" incandescent which draws 90-watts and has a rated life of 2500 hours. These three products are actual consumer alternatives providing equivalent quantities of light.

The solid waste analysis considered three types of CFLs in addition to an incandescent lamp. The CFLs were a one-piece "globe type" manufactured by several different companies; a one-piece 27-watt "quad" type lamp and a 28-watt two-piece quad type. The results of the solid waste analysis are presented in Table 2.

Results and Discussion

Radioisotopes

Table 1 compares the different types and quantities of radioactive emissions associated with compact fluorescents, standard incandescents and "ecolight" incandescents. Table 5 makes the same comparison assuming different marginal fuels.

Compact fluorescent lamps which use magnetic ballasts often contain a trace amount of radioactive material to serve as an electron generator for their starting circuits. A commonly used radioisotope is Pm-147, in an amount close to 0.3 microcurie (μCi) per lamp. Based on this fact, some anti-nuclear activists have opposed the use of compact fluorescents. Some have been marketing "ecolights" as an alternative. These are simply "long life" incandescent bulbs, which are claimed to be "ecological, economical and nuclear free". Their claimed 2500-hour rated life, "10%" energy saving and their lack of mercury or radioisotopes are the basis of this claim. Their cost is approximately twice that of a standard incandescent lamp.

Tables 3 and 4 summarize the average national pollution impacts, excepting the solid waste of the bulbs themselves, of CFLs versus standard incandescent lamps and "ecolights", respectively. To avoid the use of 1.2 microcuries (μCi, millionths of a curie) of Pm-147 (contained in four CFLs used during the 30,000-hour life of a CFL ballast), the "ecolight" or standard incandescent is responsible for creating far more radioactivity (and Pm-147) at nuclear plants generating electricity for these lamps. Use of the incandescents requires the creation of 0.4 more curies (400,000 microcuries) of mixed long-lived fission products than occurs when powering a comparable CFL. The incandescent lamp is therefore responsible for creating over 100,000 times more radioactive material than is initially contained in the CFL. Use of an incandescent over a compact fluorescent also results in 522 extra microcuries of radioactive gas

Table 1. Total Radioisotope Burden; Compact Fluorescent, Standard Incandescent and "Ecolight" Incandescent (microcuries over 30,000 hours of operation)

	Compact Fluorescent	Standard Incandescent	"Ecolight" Incandescent
High-level Radwaste	210,000	610,000	550,000
Radioactivity in Lamp	1.2	0	0
Radioactive Gases	533	1570	1410
Uranium in coal	0.106	0.314	0.283
Total	**210,534**	**611,570**	**551,410**

Notes:

1. "Radioactive Gases" include regulated operating emissions from nuclear power plants. Krypton-85 (half-life = 10.8 years) and Xenon-133 (half-life = 5.3 days) predominate. The curies are at the time of release.
2. "High-level Radwaste" is composed of a large variety of fission products and transuranic elements with half-lives ranging up to thousands of years. The curies listed are at a point 20 years after discharge from the nuclear power plant; i.e. the earliest likely interval prior to removal from the power plant.
3. "Radioactivity in Lamp" is composed of Pm-147 or Kr-85. The curie level is at the time of lamp manufacture. This level drops significantly by the time the lamp is discarded. See the Discussion for further information.
4. "Uranium in coal" is composed of U-238 (half-life = 4.5 billion years) and U-235 (half-life = 710 million years)

emissions (primarily Kr-85 and Xenon-122) as part of the normal regulated operation of a nuclear power plant. This gaseous emission alone is over 400 times as much radioactive material as is initially contained in the CFL.

The qualitative effects paint an even worse picture for use of incandescent lamps. Pm-147 is a short (2.6-year) half-life, low activity, low energy beta emitter. If a CFL is discarded after ten years (based on typical residential usage), the Pm-147 will have passed through about four half-lives, with only 0.06 μCi remaining, instead of the original 1.2 microcuries. The extra 400,000 μCi of mixed fission products generated to fuel the incandescent, on the other hand, will be around for anywhere from hundreds to millions of years. When the incandescent's extra curies and the CFL's Pm-147 are both viewed from an equal point twenty years after reactor discharge of the high-level radioactive waste, the extra radioactivity due to the use of the incandescent is actually 6.7 million times greater than the Pm-147 left in the discarded CFL.

Table 4 compares the pollution impacts of the CFL and the "ecolight" incandescent. While the "ecolight's" excess pollution is about 15% less than that resulting from the use of standard incandescents, it is still far inferior to the CFL.

Similarly, while CFLs contain a trace amount of mercury (about 5 mg per lamp, 20 mg.over four lamps), more than twice as much mercury is contained in the coal burned to supply the necessary extra electricity for the less efficient incandescent lamps. Since coal also contains arsenic, lead and other heavy metals (which are released to the atmosphere or contained in coal ash from power production), using incandescents instead of CFLs results in additional pollution by these contaminants.

In a few years the CFL radioisotope issue may become moot as CFL manufacturers move toward the use of electronic ballasts, which do not utilize any radioactive materials. For the time being, some degree of tradeoff will exist. While many magnetic ballasted CFLs are two-piece, almost all CFLs with an electronic ballast are one-piece models. Two-piece CFLs with an electronic ballast which meet utility standards for minimum harmonic distortion and proper transient protection are not available at this writing may be excessively bulky.

Solid Waste

The direct solid waste from the disposal of incandescent, one-piece CFLs and two-piece CFLs is illustrated in Table 2. One piece CFLs are the largest solid waste source since they are rated at 7,000-10,000 hours, at the end of which the entire lamp/ballast assembly is discarded. Although "quad" type lamps with an electronic ballast are relatively light, their volume is equivalent to other one-piece CFLs and volume is a critical issue in landfills. Two-piece (i.e., lamp plus ballast) CFLs require only the replacement of the lamp after that same period. The more massive ballast lasts for three to five times as long a period of time.

This analysis assumed standard incandescent bulbs at 1,000-hour rated life and the "ecolight" at 2500 hours.

General Pollution

The results presented here are arguably conservative. The manufacturers of compact fluorescent lamps rate their ballasts at 50,000 hours and their lamps at 10,000. We assumed shorter lives to account for intentional early replacements or premature burnout. Most lamp manufacturers would probably dissent from this assumption. We consider it a conservatism.

Table 2. Direct Solid Waste Production; Three Varieties of Compact Fluorescents and Two Varieties of Incandescent Lamps (kg. over 30,000 hours of operation)

Globe type compact fluorescent (one piece)	1.8
"Quad" type compact fluorescent (one piece)	0.78
"Quad" type compact fluorescent (two piece)	0.63
Standard incandescent	1.34
"Ecolight" incandescent	0.34
Excess solid wastes created during production of power for "ecolight", for comparison	239.4

An analysis based on delivered lumens instead of wattage might also have produced different results, or at least a lively debate about the actual delivered lumens of compact fluorescents and incandescents in theoretical and actual situations. We feel that very few people purchase lamps based on comparing lumens. The reason for conducting this analysis was to examine the result of promoting 90-100 watt incandescents over comparable CFLs. Those individual consumer choices are clearly not made on a theoretical examination of delivered lumens. The products compared here are equivalent consumer choices.

Marginal Fuel Analysis

Table 5 summarizes the same analysis but assumes that only one fuel is used for the generation of electricity to power the respective lighting technologies. Substitution of CFLs for incandescents will result in fuel savings in each utility's marginal fuel, although that marginal fuel might be different at different times of year or even times of day. The results for coal, oil, natural gas and nuclear fuel are listed individually.

Even if natural gas is assumed to be the marginal fuel, solid wastes produced from the generation of additional electricity to power the incandescent overwhelm the additional mass of discarded CFLs by a factor of 15. If coal is the marginal fuel, additional powerplant solid wastes associated with the inefficiency of the "ecolight" outweigh the incremental mass of discarded CFLs by a factor of almost 1300.

Except in the cases of oil and natural gas, the use of "ecolights" always results in production of more radioactivity production than CFLs. Even in the case of oil and gas the minuscule amount of radioactivity in the CFL should be weighed against the substantial mass of additional Sox, Nox, carbon dioxide and solid wastes entailed by the use of the "ecolight." The radioisotopes in coal are dominated by uranium-235 and -238 with half-lives of 710 million and 4.5 billion years, respectively, compared to 2.6 years for Pm-147 and 10.7 years for Kr-85. While the initial 1.02 μCi in each of a series of CFLs is greater than the radiation in the additional coal burned to support the "ecolight's" inefficiency, by the time the CFLs are discarded much of the lamp radioactivity has decayed. Twenty years after the beginning of the lamp lifecycle, the CFL radioactivity is about one-fifth that resulting from the additional coal required to support the "ecolight". The additional mercury released as a result of operating the "ecolight" is five times greater than the mercury contained in the CFLs.

Table 3. Pollution from Lighting Technologies; Compact Fluorescent versus Standard Incandescent (kg. per 30,000 hours of operation, unless noted otherwise)

Pollutant	Compact Fluorescent	Incandescent	Excess Due to Use of Incandescent
Sulfur dioxide (gm.)	370.1	1088.6	718.5
Nitrogen oxide	2.0	5.94	3.94
Carbon dioxide	657.3	1933.6	1276.3
Solid wastes	145.5	427.7	282.2
Mercury (gm.)	0.059	0.114	0.06
Arsenic (gm.)	2.72	7.98	5.26
Lead (gm.)	6.73	19.79	13.06
Radioactive Gases (microcuries, μCi)	533	1570	1033
Radwaste (Ci)	0.21	0.61	0.4

Note: "Solid Wastes" include ashes, scrubber sludge, "low-level" radioactive wastes, etc.

Table 4. Pollution from Lighting Technologies; Compact Fluorescent versus "Ecolight" Incandescent (kg. per 30,000 hours of operation, unless noted otherwise)

Pollutant	Compact Fluorescent	"Ecolight" Incandescent	Excess Due to Use of Incandescent
Sulfur dioxide (gm.)	370.1	979.7	609.6
Nitrogen oxide	2.0	5.35	3.35
Carbon dioxide	657.3	1740.24	1082.9
Solid wastes	145.5	384.9	239.4
Mercury (gm.)	0.059	0.10	0.04
Arsenic (gm.)	2.72	7.18	4.46
Lead (gm.)	6.73	17.81	11.08
Radioactive Gases (microcuries, μCi)	533	1410	877.3
Radwaste (Ci)	0.21	0.55	0.34

Note: "Solid Wastes" include ashes, scrubber sludge, "low-level" radioactive wastes, etc.

Table 5. Pollution, Radioisotopes and Solid Wastes Based on Marginal Fuels; Compact Fluorescent (CFL) Versus "Ecolight" Incandescent (kg. per 30,000 hours of operation, unless noted otherwise)

	Compact Fluorescent	"Ecolight"	Additional Due to the Use of Ecolight
Coal			
Sulfur dioxide	0.463	1.23	0.767
Nitrogen oxide	3.25	8.59	5.34
Carbon dioxide	1028.6	2723.2	1694.6
Powerplant solid wastes	253.7	671.6	417.9
Lamp solid wastes	0.63	0.34	(0.29)
Mercury (mg.)	91.4	188.9	97.5
Arsenic (gm.)	5.02	13.25	8.23
Lead (gm.)	12.42	32.86	20.44
Lamp radioactivity (μCi)	0.06-1.02	0	(0.06-1.02)
Coal radioactivity (μCi)	0.196	0.522	0.326
Oil			
Sulfur dioxide	2.78	7.36	4.58
Nitrogen oxide	2.32	6.14	3.82
Carbon dioxide	1008.4	2669.3	1660.9
Powerplant solid wastes	28.0	74.1	46.1
Lamp solid wastes	0.63	0.34	(0.29)
Natural Gas			
Nitrogen oxide	1.85	4.90	3.05
Carbon dioxide	526.7	1394.2	867.5
Powerplant solid wastes	2.99	7.91	4.92
Lamp solid wastes	0.63	0.34	(0.29)
Nuclear			
Radioactive gases (μCi)	2611	7680	5069
High-level radwaste (μCi)	1,020,000	2,700,000	1,680,000
Lamp radioactivity (μCi)	0.06-1.2	0	(0.06-1.2)
Powerplant solid wastes	707.7	1873.3	1165.6
Lamp solid wastes	0.63	0.34	(0.29)

The marginal fuel analysis provides another perspective on this issue but it does not reflect the specific conditions of any individual utility service territory or power pool. The heat and emission rates of individual power plants varies significantly. Some utilities have different marginal fuels at different times of year or even times of day. The emissions and solid waste data in Pace (1990) reflects relatively new fossil fuel technologies which have lower emission rates than the average generating capacity in service today.

The goal of this particular analysis was to place the issues of CFL radioactivity and disposal in some perspective. With 250 million CFLs expected to be sold annually by the year 2000 (Tracy 1992), the question is not whether the commercialization of CFLs that lack radioisotopes would be worthwhile, but whether avoiding the small amount of CFL pollutants should weigh more than the tons of other pollutants that CFLs will avoid. Similarly, the disposal of CFLs is an important issue, but while dealing with that issue the much larger mass of avoided powerplant solid wastes must not be ignored.

> *"When we try to pick out anything by itself, we find it hitched to everything else in the universe."*
>
> *John Muir*

Need for Additional Research

This paper examines the increased quantities of radioisotopes, solid waste and general pollution produced by the operation and use of incandescent, instead of compact fluorescent lamps. A useful extension of this work would be a full lifecycle impact study, including the energy and materials required to manufacture each technology and the technological potential for recycling of spent lamps and ballasts and the actual pathways of different pollutants to the biosphere. For example, the disposal of lamps in a modern landfill compared with the disposal practices for powerplant ash and sludges. This analysis could also be specialized for the conditions of a particular utility service territory or power pool. Our conclusion that the pollution impacts of these lighting technologies are dominated by the air and solid waste pollutants generated during the production of electricity does not eliminate the need to develop methods to recycle portions of CFL, as well as incandescent lamps or to eliminate unnecessary packaging for lamps. Since efficiency programs should be approached with "open eyes", environmental impacts that may be minor by comparison need to be addressed if the use of a technology is to be truly sustainable.

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