# NOMINATION OF CADMIUM TELLURIDE TO THE NATIONAL TOXICOLOGY PROGRAM

## Introduction

Brookhaven National Laboratory (BNL) and the U.S. Department of Energy (DOE) are nominating Cadmium Telluride (CdTe) for inclusion in the National Toxicology Program (NTP). This nomination is strongly supported by the National Renewable Energy Laboratory (NREL) and First Solar Inc. The material has the potential for widespread applications in photovoltaic energy generation that will involve extensive human interfaces. Hence, we consider that a definitive toxicological study of the effects of long-term exposure to CdTe is a necessity.

## I. Chemical Identification

a. CAS name: Cadmium Telluride (CdTe)
b. Common name: Cadmium Telluride (CdTe)
c. CASRN: 1306-25-8
d. Chemical Class: Cadmium compounds
e. Physical properties
   i. Physical description:
      Cadmium telluride is a black, dense, cubic crystalline compound that does not occur naturally.
   ii. Formula: CdTe; MW=240
   iii. Melting and boiling points:
      The melting point of CdTe is 1041°C, and evaporation starts at 1050°C. Sublimation occurs at lower temperatures, but its vapor pressure at 800ºC is only 2.5 torr (0.003 atm).
   iv. Solubility:
      CdTe is insoluble in water;
   v. Stability & Reactivity:
      CdTe may decompose on exposure to atmospheric moisture and can react with $H_2O$ and $O_2$ at elevated temperatures
   vi. Comparisons of CdTe with the parent compounds Cd and Te:
      CdTe is more stable than its parent compounds Cd and Te and most other Cd compounds, as indicated by its melting point and solubility (Table 1).

Table 1. Physical properties of Cd and Te compounds

| Compound | Molecular Weight | Density (g/cc) | Melting Point ($^oC$) | Solubility (g/100 cc) |
|---|---|---|---|---|
| CdTe | 240 | 6.30 | 1041 | insoluble |
| Cd | 112.40 | 8.64 | 321 | insoluble |
| Cd(OH)2 | 146.41 | 4.79 | 300 | $2.6 \times 10^{-4}$ |
| CdCO3 | 172.41 | 4.26 | 500 | insoluble |
| CdCl2 | 182.32 | 4.06 | 508 | 140 |
| CdSO4 | 208.46 | 4.69 | 1000 | 72 |

| | | | | |
|---|---|---|---|---|
| Te | 127.6 | 6.00 | 449 | insoluble |
| H2Te | 129.6 | 4.49 | -49 | very soluble |
| TeO2 | 159.6 | 5.67 | 733 | insoluble |
| H2TeO3 | 177.6 | 3.05 | 40 | $6.7 \times 10^{-4}$ |
| $H_2TeO_4.2H_2O$ | 229.6 | 3.16 | 136 | soluble |

f. References

1. Handbook of Chemistry and Physics, 60th edition, CRC Press, 1979.
2. Moskowitz P., Bernholc N., Fthenakis V.M., Pardi R., Steinberger H., Thumm W., Environmental, Health and Safety Issues of Cadmium Telluride Photovoltaic Modules, Advances in Solar Energy, Vol. 10, Chapter 4, American Solar Energy Society, Boulder CO, 1990.

## II. Production, Use, Occurrences, and Analysis

a. Production

i. Source and synthesis:

CdTe is formed from the parent compounds, Cd and Te, by either liquid- or gas-phase chemistries.

CdTe is manufactured from pure Cd and Te, both of which are by-products of smelting base metals (i.e., Zn, Cu, and Pb). Tellurium is a by-product of copper refining. Cadmium is generated from smelting zinc ores (~80%), and lead ores (~20%). Cadmium minerals are not found alone in commercially viable deposits. The major cadmium mineral, greenockite (CdS), is associated with sphalerite, (ZnS), present in both zinc and lead ores.

The demand for zinc has increased steadily for decades, driven by economic growth. Therefore, impure cadmium is produced, regardless of its use. Before cadmium production started in the United States in 1907, about 85% of the Cd content of the zinc concentrates was lost in roasting the concentrate, and in the fractional distillation of Zn metal (US Bureau of Mines, Liewellyn, 1994). The feed material for producing cadmium consists of fume and dust, collected as flue dust in baghouses during the pyrometallurgical processing of zinc and of residues from the electrolytic production of zinc (Liewellyn, 1994). When the market does not absorb all the Cd generated by metal smelters/refiners, the residues from which Cd is recovered are either stockpiled for future use, cemented and buried, or disposed of [Plachy, 2000].

ii. Current production and pathway

CdTe is produced in small amounts by the following companies: Asarco, Teck Cominco, Umicore, Amalgamet, Cerac, and 5N Plus. Production is limited and the volumes produced are not published. In 1999, the yearly production of CdTe was estimated to be 29,600 pounds. The ability of the companies to scale-up production is considered excellent (Guilinger, 1999). Asarco now is the main supplier of high-purity CdTe (99.999%) in powder form for the photovoltaic industry. Ojebuoboh (personal communication, 2003) confirmed that Asarco could easily and inexpensively increase production to meet the needs of the photovoltaic markets.

b. Uses

The material is used for solar cells (photovoltaics), detectors, nanoinks, and nanorods. Current use is rather limited, but the emerging applications of CdTe solar cells are very promising. CdTe is one of only three photovoltaic materials that presently are used by PV manufacturers, and is a major candidate for penetrating any large-scale market for photovoltaics. Already, one commercial facility, several universities, and the NREL laboratories are using this compound to develop efficient thin-film-based PV cells and modules. The first start in CdTe PV manufacturing was made in 2003 when First Solar Inc. of Perrysburg, OH, began limited production in its new 25MW/yr facility. This potential for large commercial markets is discussed in Section VI "Rationale for Recommendation…"

c. Occurrence in the Environment

CdTe does not occur normally in the environment. The parent compounds, Cd and Te, are present in nature in the form of sulfur and other salts. Both components are produced as by-products of mining base metals (i.e., Zn, Pb, Cu).

d. Analysis (Exposure Monitoring)

Little information has been published from monitoring employee's exposures to CdTe during the manufacturing of photovoltaic cells. CdTe exposure currently is measured as total cadmium. The OSHA Cadmium Standard, 29CFR§1910.1027 mandates, among other requirements, medically monitoring employees when they are exposed at, or above, the OSHA 8-hour time-weighted average permissible exposure limit for cadmium of 5 $\mu g/m^3$ for 30 days or more per year. Bohland and Smigielski (2000) reported their results in preventing environmental exposures to cadmium compounds during the manufacture of CdTe PV modules at Solar Cells Inc., which is currently First Solar Inc. Industrial-hygiene data for manufacturing activities are presented, and engineering controls discussed. The findings from monitoring over a period of ten years are detailed, and comparisons made to Cd concentrations in the blood and urine of long-term employees and smokers. Seven hundred monitoring tests for blood cadmium, urine cadmium, and $\beta_2$-microglobulin excretion were done on First Solar workers to track biological responses to occupational cadmium exposures. The data from these tests, supported by industrial-hygiene air sampling data, demonstrate that there was no significant occupationally related cadmium exposure to workers in this facility.

Information gathered through personal communication with personnel in other manufacturing facilities shows no detectable levels of cadmium exposure during a maintenance operation (CdTe physical-vapor-deposition system and CdTe oven overhaul), daily operations in physical-vapor-deposition, and sandblasting cadmium- target operations. However, area samples taken in line with the exhaust flow during the maintenance of a CdTe physical-vapor-deposition system were 0.03 $mg/m^3$ Cd. Initial wipe samples taken in deposition and sample preparation laboratories ranged from below detection to 0.59 mg, but later dropped below detectable levels after good housekeeping procedures were established. Wipe samples in a physical-vapor- deposition laboratory ranged from 1.7 – 92 $\mu g$. Personal samples were collected from the sandblasting/buffing operation, laser-scribing room, and chemical treatment room of a thin film CdTe module facility. All results were below the current OSHA action level of 2.5 $\mu g/m^3$ for Cd. Area samples found non-detectable levels of cadmium within and outside the cell

production area (e.g., secretary's desk, lunch room, module chemical treatment room center of work area, analytical laboratory, and laser room). Wipe samples ranged from a low of 0.0038 mg (secretary's desk) to a high of 2.4 mg within the work area. Unadjusted urine cadmium levels ranged from 0.2 – 0.9 mg/L.

e. References


1. Krinitsyn P. G., Study of the conditions of CdTe Crystal growth, Chemistry for Sustainable Development, 8, 167-170, 2000.
2. Bohland J. and Smigielski K., First Solar's CdTe module manufacturing experience; environmental, health and safety results, Proceedings of the 28th IEEE Photovoltaic Specialists Conference, Anchorage, AK, September 2000.
3. Plachy J. Cadmium, Session 17, U.S. Geological Survey Minerals Yearbook-2001.
4. Guilinger J., Assessment of Critical Thin Film Resources; Cadmium Telluride, RAF-9-29609, May 1999.


## III. Toxicology

a. Human data, case reports, and epidemiological studies
There are no human data on CdTe

b. Experimental animal information
Currently, there is limited information on animal- and human-toxicity for CdTe, the only papers available being those published by Harris et al. (1994), and Morgan et al. (1995 and 1997). Harris et al., conducted a 28-day ingestion study that evaluated the systemic- and reproductive-effects of CdTe on male and female Sprague Dawley rats; CdTe had no adverse effects at dosages of 100, 250, 500, or 1000 mg/kg/day. Morgan's work examined the pulmonary toxicity of CdTe in rats 72 hours and 28 days after intratracheal instillation. These studies showed that instillation of 12, 25, 50, or 100 mg/kg CdTe produced toxic effects in the rats' lungs. There were increases in lung weight, in the total number of cells in the bronchoalveolar lavage fluid, and in lactate dehydrogenase activity. At the high doses (i.e., 50 and 100 mg/kg) the rats died. In summary, the ingestion studies showed no significant deleterious effects, whereas the inhalation studies demonstrated the compound's toxicity. These are studies of short-term effects; no information exists on long-term toxic effects and the bioavailability of the compound through inhalation.
The abstracts of these articles are shown below.

Environ Res 1995 Oct;71(1):16-24

**Acute pulmonary toxicity of copper gallium diselenide, copper indium diselenide, and cadmium telluride intratracheally instilled into rats.**

Morgan DL, Shines CJ, Jeter SP, Wilson RE, Elwell MP, Price HC, Moskowitz PD., National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina 27709, USA.

Acute toxicity studies were conducted on copper gallium diselenide (CGS), copper indium diselenide (CIS), and cadmium telluride (CT), three novel compounds used in the photovoltaic and semiconductor industries. Female Sprague-Dawley rats (six rats/dose) were administered 0,

12, 25, 50, or 100 mg/kg body wt of CGS, CIS, or CT by intratracheal instillation. At 72 hr after treatment, body weight gain was significantly decreased in the 100 mg/kg CIS group and in all CT dose groups. Lung weights were increased in most chemical-treated rats, with CT causing the greatest increase. Total numbers of cells in bronchoalveolar lavage fluid (BALF) were significantly increased in treated rats and were greatest in the 100 mg/kg CIS group. Differential cell counts of BALF demonstrated a marked decrease in the percentage of alveolar macrophages and an increase in the percentage of polymorphonuclear leukocytes in all dose groups of all three chemicals. Slight to moderate increases in lactate dehydrogenase activity were observed in BALF from CGS- and CIS-treated rats; marked increases were observed in CT-treated rats. BALF protein was significantly increased in rats treated with CIS and CT. Microscopic examination revealed lymphoid hyperplasia in lungs of rats treated with all three chemicals. CT caused necrosis of the terminal bronchiolar epithelium and epithelium of the alveolar duct region with inflammation, prominent fibrin exudates, and type II cell hyperplasia. CGS and CIS also caused intraalveolar inflammation and type II cell hyperplasia, but did not cause the necrosis and fibrin exudate observed in lungs of CT-treated rats. Based on changes in lung weight, BALF indices, and histopathology, CT was the most toxic for the lung; CIS had intermediate toxicity and CGS was the least toxic. The solubilities of CGS and CIS were relatively low and similar at both pH levels and do not readily explain the observed differences in pulmonary toxicity. The solubility of CdTe was considerably greater than that of CGS and CIS and likely contributed to the greater toxicity of this compound.

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Toxicol Appl Pharmacol 1997 Dec;147(2):399-410

**Comparative pulmonary absorption, distribution, and toxicity of copper gallium diselenide, copper indium diselenide, and cadmium telluride in Sprague-Dawley rats.**

Morgan DL, Shines CJ, Jeter SP, Blazka ME, Elwell MR, Wilson RE, Ward SM, Price HC, Moskowitz PD., National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina 27709, USA.

Copper gallium diselenide (CGS), copper indium diselenide (CIS), and cadmium telluride (CdTe) are novel compounds used in the photovoltaic and semiconductor industries. This study was conducted to characterize the relative toxicities of these compounds and to evaluate the pulmonary absorption and distribution after intratracheal instillation. Female Sprague-Dawley rats were administered a single equimolar dose (70 mM) of CGS (21 mg/kg), CIS (24 mg/kg), CdTe (17 mg/kg), or saline by intratracheal instillation. Bronchoalveolar lavage fluid (BALF) protein, fibronectin, inflammatory cells, lung hydroxyproline, and tissue distribution were measured 1, 3, 7, 14, and 28 days after instillation. Relative lung weights were significantly increased in CIS- and CdTe-treated rats at most time points. Inflammatory lesions in the lungs consisting of an influx of macrophages, lymphocytes, and PMNs were most severe in CdTe-treated rats, intermediate in CIS-treated rats, and minimal in rats receiving CGS. Hyperplasia of alveolar type 2 cells was present in CIS- and CdTe-treated rats and was greatest in CdTe-treated rats. Pulmonary interstitial fibrosis was observed in CdTe-treated rats at all time points. All three compounds caused marked increases in total BALF cell numbers, with the greatest increase observed in CIS-treated rats. BALF protein, fibronectin, and lung hydroxyproline were significantly increased in all treated animals and were highest in CdTe-treated animals. There was no apparent pulmonary absorption or tissue distribution of CGS. Indium levels increased in extrapulmonary tissues of CIS-treated rats, although Cu and Se levels remained unchanged. CdTe was absorbed from the lung to a greater extent than CGS and CIS. Cd and Te levels

decreased in the lung and increased in extrapulmonary tissues. Of these compounds CdTe presents the greatest potential health risk because it causes severe pulmonary inflammation and fibrosis and because it is readily absorbed from the lung may potentially cause extrapulmonary toxicity.

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Toxicologist 1994 Mar;14(1):267 (Abstract # 581)

**The general and reproductive toxicity of the photovoltaic material cadmium telluride (CdTe).**

Harris MW, Chapin RE, Haskins EA, Allen JD, Wilson RE, Ward SM, Davis BJ, Collins BJ, Lockhart AC, Moskowitz PD.

Photovoltaic modules are solid state devices that turn sunlight directly into electricity. CdTe may replace silicon in these devices to improve device performance. Before this material is used, it's important to understand its overall toxicity, especially because of existing concerns for other Cd compounds. These studies were designed to address these concerns. A modified 28 d. test of Harris et al (FAAT: 19:186, '92) was used with 10 SD rats/sex/dose. A pilot dose-range-finding study found hematology, clin chem, and body/organ weight effects at the lowest level (100 mg/kg/d); main study doses were set at 10, 30, and 100 mg CdTe/kg/d, p.o. in 0.5% methylcellulose. Food consumption was variably decreased (less than or equal to 18%) at 30 and 100 mg/kg. All dosed males gained less weight; the high dose group lost 23 gr (3.7% body wt). Relative kidney weight was increased; male liver and spleen wts and all reproductive indices (fertility, sperm #, motility) were unchanged. CdTe did not alter the number of live implants, resorptions or corpora lutea in females treated before/during/after cohabiting with treated males, although body wt gain was inhibited by CdTe (less than or equal to 50%). Another group of females was dosed GD 6-15 only, and delivered their litters; all were killed pnd4. There was a dose-related decrease in dam body wt in all CdTe groups (on pnd1, less than or equal to 15%), with no change in the number of live pups delivered, postnatal deaths or pup wt at or after birth. These data show that, despite effects on body wt gain, this duration of CdTe dosing had no detectable effects on male or female rat reproduction.

c. *In vitro* and other short-term tests
   There are no reports of *in vitro* and other short-term tests in the literature. Also, there are no pharmacokinetic data on CdTe.

d. Comparative Toxicity of CdTe Precursors
   When little information is available on a compound, such as CdTe, the parent compound is regarded as a surrogate and toxicity is inferred from those data. Of the parent compounds, cadmium and tellurium, cadmium is considered more toxic and is currently regulated by the Occupational Safety and Health Administration (OSHA) under 29CFR§1910.1027-Cadmium. It is considered a lung carcinogen and is known to cause long-term injury both to the kidneys and bones. The acute health effects from inhaling cadmium include pneumonitis, pulmonary edema, and death. Regardless of the route of adsorption, approximately one half to one third of the body burden of cadmium is found in the kidneys, with the highest concentration in the renal cortex. Even if cadmium is stored in another compartment, it can be transported from there to the kidney where it causes renal damage. Therefore, OSHA considers all cadmium compounds to be toxic, and

includes cadmium telluride in the standard. The Tenth Report on Carcinogens (2002) lists several studies indicating that that cadmium and cadmium compounds are human carcinogens. Although it is stated that "a variety of soluble and insoluble cadmium compounds" were used in the cited animal studies, only cadmium chloride is explicitly named. Cadmium chloride is water soluble and volatile, whereas cadmium telluride is insoluble and has a high sublimation temperature.

During rulemaking in April 1991, the Dry Color Manufacturers Association (DCMA) submitted studies to support the position that cadmium pigments are less soluble and less bioavailable, and thus, less toxic to the kidney than other cadmium in other compounds (OSHA, 2003). From their studies, it appears that insoluble respirable cadmium compounds are less able to enter the blood stream than the soluble ones. However, OSHA maintained that while less cadmium enters the blood, more is retained in the lungs. The OSHA accordingly ruled that respirable insoluble compounds probably contribute significantly to damaging the lungs, and, therefore, there is no reason for differentiating between soluble and insoluble respirable cadmium. However, OSHA accepted the differential effects of soluble vs. insoluble Cd compounds in the ingestion pathway. This discussion centered on differentiating the toxicity of CdS from the known effects of the more soluble CdO. In the absence of data that indicate only relatively insoluble forms of cadmium sulfide will be present, OSHA did not separate one cadmium compound from others for regulatory purposes. OSHA believes that they must err on the side of workers' health and considers that mixtures of relatively more and less soluble forms will be present at one time or another in the workplace.

There is limited information on the toxicity of tellurium compounds. Tellurium is metabolized to dimethyl telluride that is responsible for the characteristic garlic odor of the breath in chronically exposed persons; it may persist for up to 3 months after exposure is over. The compound is excreted in urine, sweat, and expired air. Tellurium accumulates in the liver, kidney, and spleen. Prenatal exposure to tellurium in laboratory animals produced reproductive lesions, such as hydrocephaly in rats, and behavioral effects in rabbits. There are no reports at present of serious occupational illness from exposure to tellurium or its compounds. Tellurium currently is regulated by OSHA as a threshold-based contaminant. The 8-hr PEL of workplace standard of 0.1 $mg/m^3$ was set to avoid systemic poisoning.

e. References

1. Harris, M.W. *et al.* 1994a. The general and reproductive toxicity of the photovoltaic material cadmium telluride, presented at the Society of Toxicology 1994 Annual Meeting, Dallas, Texas, 13-17 March 1994; *Toxicologist* 14(1): 1020, 1994.
2. Morgan, D.L., C.J. Shines, S.P. Jeter, R.E. Wilson, M.P. Elwell, H.C. Price and P.D. Moskowitz. Acute pulmonary toxicity of copper gallium diselenide, copper

indium diselenide, and cadmium telluride intratracheally instilled into rats, *Environmental Research 71*: 16-24, 1995.

3. Morgan, D.L., C.J. Shines, S.P. Jeter, M. Blazka, M.R. Elwell, R.E. Wilson, S.M. Ward, H.C. Price and P.D. Moskowitz. Comparative pulmonary absorption, distribution and toxicity of copper gallium diselenide, copper indium diselenide, and cadmium telluride in Sprague-Dawley rats, Toxicol. Appl. Pharmacol., 147, 39-410, 1997.
4. Tenth Report on Carcinogens, Cadmium and Cadmium Compounds, , Dept. of Health and Human Services, National Toxicology Program, December 2002, http://ehp.niehs.nih.gov/roc/tenth/profiles/s028cadm.pdf
5. OSHA, Cadmium Regulations (Preambles to final rules), U.S. Department of Labor, April 11, 2003. http://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=PREAMBLES&p_toc_level=1&p_keyvalue=Cadmium

## IV. Disposition and Structure-activity Relationships

No published information was found on disposition and structure-activity relationships.

## V. Ongoing Toxicological and Environmental Studies

No toxicology studies are planned within the Department of Energy (DOE), its subcontractors, or the private sector.

The DOE supports work that is underway at Brookhaven National Laboratory to assess the potential hazards of emissions from CdTe photovoltaic modules when exposed to fire.

## VI. Rationale for Recommendation and Suggested Studies

We believe that CdTe is an excellent candidate compound for NTP to consider for future long-term testing for the following reasons:

1) CdTe is a very promising material for large-scale generation of photovoltaic energy that will reduce air pollution and our dependence on imported oil. PV central- and distributed-electricity generation would enhance our homeland energy independence and security;
2) Using CdTe in photovoltaics is a viable method of minimizing environmental pollution from cadmium waste and emissions during the refining of zinc and lead;
3) There are very limited toxicological data on CdTe, and, in view of its commercial potential, such information is much needed.

These issues are elaborated below:

1) <u>CdTe, a Promising Photovoltaics Material</u>
Photovoltaic-energy technologies have made significant strides lately. From 1997 through 2002, annual worldwide production of photovoltaic cells and modules increased

by 35% per year, growing from about 126 MW in 1997 to 540 MW in 2002 (Figure 1). The DOE's Solar Technologies Program along with the PV industry project that, with new and improved technologies, photovoltaics production would sustain a 25% per year growth for 20 to 30 more years. The DOE's five-yr plan and the U.S. Photovoltaic Industry Roadmap state that PV electricity generation in the United States is a vast new energy frontier and that "…the domestic market will provide up to 15% (about 3,200 MW) of the new US peak electricity generating capacity expected to be required in 2020. Cumulative U.S. PV shipments will be about 36 GW at this time (US PV Industry Roadmap, 2001)."

CdTe is one of only three photovoltaic materials that are currently used by PV manufacturers, and is a major candidate for satisfying these implementation scales (Zweibel, 1999; Kazmerski et al, 2003). Presently, one commercial facility, several universities, and the NREL's laboratories are using this compound in developing efficient thin-film-based PV cells and modules. First Solar Inc., Perrysburg, OH made the first start on commercial CdTe PV production in 2003 by opening up a limited test production in their new 25MW/yr facility.

In addition, CdTe is today's choice of nanorod material for developing new nanotechnology-based solar (PV) devices at the University of California at Berkeley. These nano-PV devices potentially will match the performance of expensive silicon solar-cells, and they could be painted on surfaces (including cloths). In addition, CdTe nanoparticles are at the focal center of materials research in electronic-, catalytic-, and electro-optical-applications at the Max Planck Institute of Colloids and Interfaces in Germany. These projected uses are important in medicine, industry, and astrophysics.

e. References


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2. Photovoltaics: Energy for the New Millennium, The National 2000-2004 Photovoltaics Program Plan, US Department of Energy, US Department of Energy, January 2000.
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4. Photon magazine http://www.photon-magazine.com/
5. PV News magazine, Paul Maycock, editor, 22(2), Feb. 2003
6. Zweibel K., Solar Energy Materials and Solar Cells (1999), vol. 59, pp 1-18.
7. Malsch I., Thin Films Seek a Solar Future, The Industrial Physicist, April/May 2003, pp. 16-19.
8. Kazmerski L. and Surek T., Power from the Sun, spie's oemagazine, April 2003, pp. 24-27.
9. Kazmerski L., Surek T. and Zweibel K., Letter to S. A. Masten in support of CdTe nomination to NTP, April, 3, 2003.

2) CdTe PV is a meaningful option to minimize environmental pollution

As discussed in section II, cadmium production uses the emissions and waste from the production of zinc, lead, steel, and iron. Before cadmium production started in the United States, 85% of the Cd content of the zinc ores was discharged into the environment (Liewellyn, 1994). Even today, when the market does not absorb all the Cd generated by metal smelters/refiners, the residues from which Cd is recovered are stockpiled for future use, cemented and buried, or disposed of [Plachy, 2000]. Therefore, **Cd can either be put to beneficial uses, or released into the environment**. This argument is supported with data from reports from the US Bureau of Mines (Liewellyn, 1994; Plachy, 2000), and also from the results of the The Rhine Basin multi-national study, probably the largest application of Systems Analysis on Industrial Metabolism. The study explored scenarios of banning Cd products in the five countries comprising the Rhine region, and concluded that such products cannot be banned without making provisions for safer uses of cadmium. The study concludes that " ***One possible option would be to allow the production and use of Cd-containing products with inherently low availability for leaching.*** *The other option, depositing the Cd-containing wastes in safely contained landfills, has other risks*".(Stigliani & Anderberg, 1994).

The availability of CdTe PV modules for leaching and emitting gases is inherently low. . No other current applications have such environmentally friendly characteristics. The largest present-day use of Cd is in rechargeable NiCd batteries; these are composed of Cd and Cd(OH)2, both of which are less stable than CdTe based on their solubilities, melting points, and boiling points.

In addition, the thin CdTe/CdS layers (typically only 2 microns thick) are encapsulated between sheets of glass or plastic. Current CdTe modules pass the EPA's Toxicity Characteristic Leaching Procedure (TCLP) test, designed to assess the potential for long-term leaching of products disposed in landfills (Cunningham, 1999). Unless the module is very finely ground, dust particles cannot be generated. CdTe has a vapor pressure of zero at ambient conditions. Accordingly, it is impossible for any vapors or dust to be generated when PV modules are used under normal conditions.

Therefore, using Cd in CdTe PV may be a satisfactory solution to the pending problem of finding environmentally friendly uses of cadmium.

References:

Cunningham D., Discussion about TCLP protocols, in proceeding of Photovoltaics and the Environment 1998, Technical Report BNL-52557, February 1999, Brookhaven National Laboratory, Upton, NY 11973.

Liewellyn T.O., Cadmium (Materials Flow), Bureau of Mines, Information Circular 9380, 1994.

Plachy J. Cadmium, Session 17, U.S. Geological Survey Minerals Yearbook-2001.

Stigliani & Anderberg, Chapter 7, Industrial Metabolism, The United Nations University, 1994.

3) Limited toxicological data on CdTe /Protection of workers and the public

Due to the scaling-up of PV production, there will be an increased potential for both occupational and non-occupational exposures. Furthermore, there is a marked lack of information on the toxicity of this compound. We do not know anything about the pharmacokinetics of CdTe. While we can assume that CdTe acts similarly to other cadmium compounds, it would be invaluable to test the validity of this assumption. Short-term animal

studies showed no toxic effects via the ingestion pathway, whereas inhalation-simulating studies demonstrated detrimental effects on the lungs. No comparisons have been made of CdTe's toxic effects via inhalation to those of Cd, nor are there any long-term studies on CdTe.

In the absence of toxicological data, OSHA does not separate one cadmium compound from others for regulatory purposes, and the well-established effects of Cd carcinogenicity are assumed also to pertain for CdTe. Such an assumption introduces inherent constraints in using CdTe for very promising solar cell- and nanomaterial-applications.

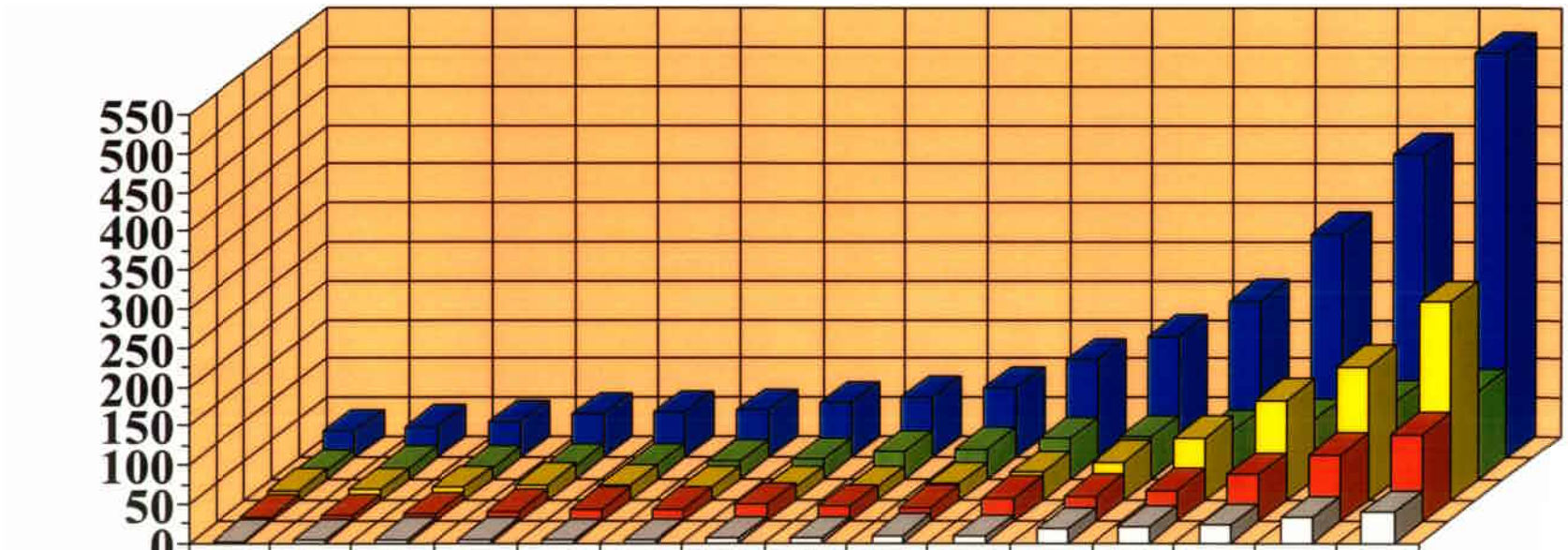
If the pharmacokinetics and toxic effects of CdTe can be demonstrated experimentally, the implication may be that populations exposed to CdTe will be evaluated differently than those exposed to other cadmium compounds. Should the effects of CdTe be less severe than those attributed to Cd, then the barriers for using it in large-scale environmentally beneficial applications could be lifted. However, if they are as severe as those of Cd, then the industry and the public should take notice and implement adequate precautions.

To resolve these questions, long-term ingestion and inhalation testing would be required, as well as the elucidation of the pharmacokinetics of CdTe deposition, distribution, metabolism, and elimination. The inhalation pathway applies primarily to potential exposures during the manufacturing of solar cells, whereas the ingestion pathway applies to exposures after decommissioning them, and during the use and disposal of surfaces (e.g., cloths) painted with nano-particles of CdTe.

In view of the expected widespread applications with such extensive human interfaces, a definitive toxicological study of CdTe's long-term exposure effects becomes a necessity.

Figure 1.

# World PV Cell/Module Production (1988-2002) (in Megawatts)




| | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rest of World | 3 | 4 | 4.7 | 5 | 4.6 | 4.4 | 5.6 | 6.35 | 9.75 | 9.4 | 18.7 | 20.5 | 23.42 | 32.6 | 40.7 |
| Europe | 6.7 | 7.9 | 10.2 | 13.4 | 16.4 | 16.55 | 21.7 | 20.1 | 18.8 | 30.4 | 33.5 | 40 | 60.66 | 86.38 | 112.05 |
| Japan | 12.8 | 14.2 | 16.8 | 19.9 | 18.8 | 16.7 | 16.5 | 16.4 | 21.2 | 35 | 49 | 80 | 128.6 | 171.22 | 254.5 |
| United States | 11.1 | 14.1 | 14.8 | 17.1 | 18.1 | 22.44 | 25.64 | 34.75 | 38.85 | 51 | 53.7 | 60.8 | 74.97 | 100.03 | 112.9 |
| Total | 33.6 | 40.2 | 46.5 | 55.4 | 57.9 | 60.09 | 69.44 | 77.6 | 88.6 | 125.8 | 154.9 | 201.3 | 287.65 | 390.23 | 520.15 |

**From PV News, Paul Maycock, editor; yearly February editions.**

ATTACHEMENT

# COPIES OF REFERENCES

In the order they are cited