13.6.5 Environmental Concerns

One of the environmental issues related to the materials in Cu(InGa)Se_2 modules is the availability of less common elements. The content of the critical materials in grams per kW_P has been calculated assuming 12% module efficiency and the result is compared with the amount refined annually in Table 13.6 [216]. The fourth column expresses how much module power could be obtained from the amount refined annually and the last column shows a similar calculation based on the reserves of the various elements. Owing to uncertainties in estimates of reserves, or maximum resources, Table 13.6 just gives an indication of where, and at what level, potential problems in material supply may occur. It is clear that In is the potential bottleneck as regards primary material supply.

$CuInSe_2$ toxicity has been studied by administering it to rats [217]. Even at high doses negligible effects were detected. A lowest observed adverse effect level (LOAEL) of 8.3 μg/kg/day for humans was derived from these studies.

The other substances that constitute Cu(InGa)Se_2 modules are largely nontoxic except for Cd. Many aspects of its use in PV manufacturing have been studied by Fthenakis and Moskowitz [218]. Chemical bath deposition of CdS is the process step that presents the greatest health concerns due to the use of Cd, thiourea, and the generation of waste solutions. In electrodeposition of CdTe, which also is a wet process using Cd precursors, it was found that the greatest health hazards from Cd are from dust generated during feedstock preparation and from fine particles near the baths [218]. Biological monitoring at a process station showed that exposures can be maintained at a level that presents no risk to workers. Thiourea is a toxic and carcinogenic substance that also presents an exposure risk. Rinse water and dilute solutions of acids and Cd-compounds can be treated by a two-stage precipitation/ion exchange process. The Cd can be removed, and recycled, down to 1 to 10 ppb levels [218].

Most Cu(InGa)Se_2 processes use elemental Se, but the forms that are handled are solid shots or pellets that give off very little dust that could be inhaled. Elemental Se is considered to have a relatively low biological activity, but many compounds are very

Table 13.6 Critical materials in Cu(InGa)Se_2 modules with respect to primary supply (After Andersson B, Azar C, Holmberg J, Karlsson S, *Energy* **5**, 407–411 (1998) [216])

Element	Material content [g/kW_P]	Amount refined [kton/y]	Amount refined/ content [GW_P/y]	Reserves/ content [TW_P]
Mo	42	110	2600	130
Cu	17	9000	529 000	30 000
In	23	0.13	5.7	0.1
Ga	5	0.06	12	2.2
Se	43	2	46	1.9
Cd	1.6	20	12 500	330
Zn	37	7400	200 000	4100