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Assessment of the health effects of indium compounds in experimental animals

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Indium is an essential rare metal primarily obtained as a by-product of zinc refining. One of the most common forms of indium is indium tin oxide (ITO), a sintered material containing 90% indium oxide and 10% tin oxide. Until the mid-1990s, only limited data on the toxicity of indium was available from experimental animals, and no information existed regarding its health effects in humans. Therefore, indium was considered a safe metal, and little attention has been paid to the risks of handling indium in the workplace. However, in 2001, a fatal case of occupational exposure to ITO was reported in Japan, sparking widespread awareness of indium toxicity [1]. This incident, caused by indium inhalation, triggered a series of epidemiological studies on workers handling indium. These studies confirmed that exposure to ITO and indium compounds, such as indium oxide and indium hydroxide, which are mainly used in the ITO manufacturing process, can lead to lung damage [2]. Although a causal relationship between human exposure to insoluble indium compounds and the development of interstitial pneumonia and emphysema has been verified, their effects on organs other than the lungs have not yet been reported. The human health effects of indium-containing semiconductors and solar cell materials remain poorly understood. Furthermore, epidemiological studies on workers exposed to indium have reported a small number of lung cancer cases; however, no clear association between indium exposure and lung cancer development has been observed [3].

Animal experiments have been conducted to evaluate the toxicity of various indium compounds [4]. The available data indicate that indium compounds, such as ITO, indium arsenide (InAs), indium phosphide (InP), copper indium gallium, and diselenium (CIGS) solar cells are toxic to the lungs of experimental animals upon inhalation. In addition to lung damage, ITO nanoparticles are shown to cause kidney damage, whereas InAs, InP, and ITO are linked to testicular damage. Furthermore, compelling evidence has demonstrated the carcinogenic potential of InP in long-term inhalation studies with rats and mice, and similar findings have been observed in ITO-treated rats. InAs is also suspected to be carcinogenic in hamsters instilled intratracheaslly. Based on the results of these animal experiments, the International Agency for Research on Cancer (IARC), a cancer agency of the World Health Organization (WHO), classified InP as probably carcinogenic to humans (Group 2A) and ITO as possibly carcinogenic to humans (Group 2B). This table summarizes the known carcinogenicity and organ damage caused by insoluble indium compounds in humans and experimental animals.

As shown in the table 1, almost all insoluble indium compounds have been found to cause lung damage in animal studies. Although the lung damage potential caused by ITO and indium compounds used in the manufacturing process is well understood in humans, the health effects of indium-containing semiconductors and solar materials on humans remain unclear. As animal experiments have indicated that insoluble indium compounds can cause pulmonary carcinogenicity and damage to organs other than the lungs, it is important to pay more attention to human exposure to insoluble indium compounds and take effective measures to prevent such exposure.

References

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[2] K. Omae *et al,* Occup. Health Rev. **36**, 50-76 (2023)
[3] M. Nakano *et al,* J. Occup. Health. **61**, doi:10.1002/1348-9585.12050 (2019)
[4] A. Tanaka, J. Occup. Health. **67**, doi.org/10.1093/JOCCUH/uiaf007 (2025)

Table 1 Toxicity and carcinogenicity due to respiratory exposure to insoluble indium compounds.

Indium compounds		ITO grinding particles	ITO nano particles	In_2O_3	$In(OH)_3$	In (metal)	InP	InAs	CIGS
Humans									
Toxicity	Lung	+		+	+	+			
Carcinogenicity	Lung	±							
Animals									
Toxicity	Lung	+	+	+	+		+	+	+
	Kidney		+						
	Testis	±					+	+	
Carcinogenicity	Lung	+					+	±	

+: Toxic or carcinogenic to organs, ±: Possibly toxic or carcinogenic to organs
ITO, Indium-tin oxide; In_2O_3, Indium oxide; $In(OH)_3$, Indium hydroxide; In, Indium; InP, Indium phosphide; InAs, Indium arsenide ; CIGS, Copper indium gallium diselenide