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The development and regulation of occupational exposure limits in Taiwan

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Abstract

The occupational exposure limits (OELs) in Taiwan was promulgated in 1974 and has been revised five times since then. Many of the OELs were adopted from the most recent ACGIH TLVs and US OSHA PELs. A total of 483 chemicals were listed in the current Taiwan OELs Standard. The procedures of OELs development in Taiwan include the IOSH organized a recommended exposure limits (RELs) Committee to select the target chemicals and to recommend the RELs through literature review based on the health effects in the first stage, then, the CLA put policy needs, economical and technical feasibility into consideration and set up the final OELs at the second stage. A standard operation manual of RELs Committee has been developed. Based on our experience, several issues including the participation of representatives from a comprehensive spectrum, communication/education and training/enforcement, continuous collection of the local exposure data and health hazard information, use of health risk assessment, consideration of economic, and technical feasibility, as well as the globalization and information and experience sharing are critical in developing the appropriate OELs. Three examples including benzene, crystalline silica, and 2-methoxy ethanol are given to demonstrate the operation of system.

Keywords: Occupational exposure limits; Recommended exposure limits; Health risk assessment

1. Introduction

Taiwan's total population was 22.52 millions and a labor force of 10.13 million as of 2003, and 9.68 million workers were paid by specific employers. In the same year, Gross national product (GNP) was US$ 296.2 billion, with per capita GNP reaching US$ 13,167 (DGBAS, 2003). Semiconductor, petrochemical, biotechnology, construction industries, optielectro, steel, metal, paints, and the resin manufacturing are the major industries in Taiwan. Organic solvents, heavy metals, and pesticides were widely used in the country.

The occupational exposure limits (OELs) in Taiwan were first promulgated by the Ministry of Interior in 1974, were then revised in 1981 and in 1985, respectively. After the establishment of the Council of Labor Affairs (CLA, the ministry level of organization in the central government in Taiwan) in 1987, the OELs were further revised in 1995 and 2003, respectively (CLA, 2003). Basically, most of the OELs were adopted directly from the most recent threshold

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limit values (TLVs) recommended by the American Conference for Governmental Industrial Hygienist (ACGIH) and the permissible exposure limits (PELs) of the US Occupational Safety and Health Administration (OSHA). The total number of chemicals listed in the OELs standard was increased from 196 to 479 in 1995, and was further increased to 483 in 2003. In 2001, the Institute of Occupational Safety and Health (IOSH) was requested by the CLA to organize the recommended exposure limits (RELs) Committee to recommend the RELs through literature review. Each year, the RELs Committee proposed RELs for five candidate chemicals to CLA mainly based on human health effects. The CLA then invites representatives from other governmental agencies, scientific organizations, industrial associations, and labor unions and add up the consideration of policy needs, economical, and technical feasibility to set up the final OELs.

2. Procedures of OELs development

The major governmental agencies responsible for the development of OELs are the IOSH and CLA (IOSH is the research institute under the CLA). Other related governmental agencies include the Ministry of Health and the Ministry of Economic Affairs. In addition to the governmental agencies, several scientific organizations such as the Chinese Environmental and Occupational Medicine Association, the Association of Occupational Medicine, ROC, the Chinese Occupational Hygienist Association, and faculties from universities are also joined to contribute their expertise in epidemiology, toxicology, industrial hygiene, and occupational medicine. Among the current 20 RELs committee members, four members are from the governmental agencies, fourteen from scientific organizations, and two from industrial associations. Under the RELs committee, there are three sub-committees to deal with organic, dust/inorganic, and miscellaneous chemicals, as shown in Fig. 1.

A standard operation manual of RELs committee has been established in 2002 (IOSH, 2003). Lists of candidate chemicals were recommended by governmental agencies, scientific organizations, industrial associations, labor unions, and individual citizens. The RELs committee meetings are held in February, May, August, and November each year. Five candidate chemicals are selected each year for intended changes. For each candidate chemical, one specialist is designated to review the updated literatures and prepares a draft document, which is reviewed by two other specialists with different expertise.

The first step of developing REL of target chemicals is to determine the health endpoints. The health endpoints including cancer and non-cancer of target chemicals are mainly referenced to the ACGIH TLVs and finally determined in the RELs committee meeting. The classification of carcinogens is also adopted mainly from ACGIH. Dose–response data from human epidemiological studies or volunteer chamber experiment are the first choice of reference. Animal studies and in vitro experimental data are selected when human data are not available or inadequate. Only open or published data were adopted. Since 2002 till now, the Taiwan REL committee has established RELs of 20 chemicals. All the health endpoints and the classification of carcinogens were referenced to ACGIH documents. In addition to ACGIH documents, we collect the recent literatures about human epidemiological and experimental studies to evaluate the dose–response relationship.

The major human effects and target organs, the dose–response relationship of human epidemiological data, and the current OELs world-wide are the major parts included in the draft document. Animal and in vitro data are also included in this document. If there is a discrepancy in the minimum effective dose between cancer and non-cancer health effects, both cancer RELs and non-cancer RELs are proposed simultaneously. The draft document is then reviewed by one of the three sub-committees before submitted to the RELs committee. The review processes are mainly focused on the new evidences since last change and the validity and consistency of human data. If chronic effect on target organs is the main concern, only 8-h time-weighted average (RELs-TWA) is proposed. If acute or irritated health effects are the major concerns, a short term exposure limit (RELs-STEL) or ceiling (RELs-C) is proposed.

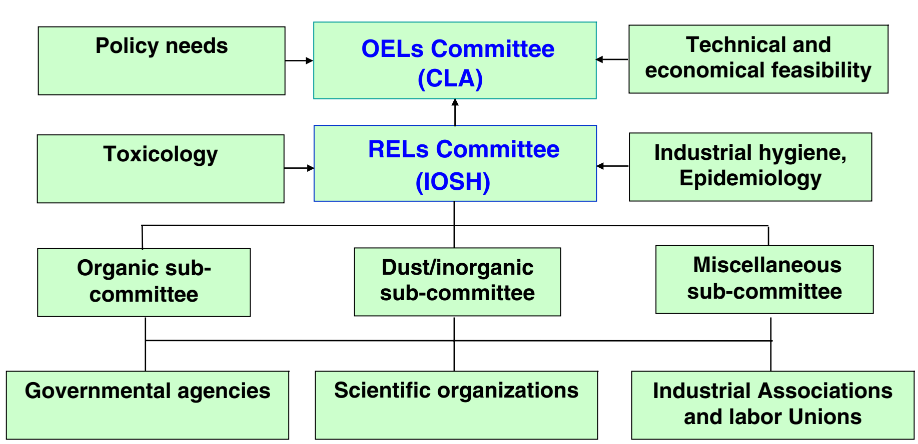

Fig. 1. Organization structure of the OELs committee in Taiwan.

The final RELs of five candidate chemicals proposed in each year are exhibited on the IOSH website as a notice of intended changes and requested for public comments for six months. The CLA put policy needs, economical, and technical feasibility, as well as the comparison of the most updated international standards into consideration and set up the final OELs. The OELs are developed independently within Taiwan (we provide an example of *n*-hexane below), but some chemicals with inadequate information are adapted from existing standards set by other countries.

The national policy in developing the OELs in Taiwan is to provide a better protection of workers' health and also consider the technical and economical feasibility of the domestic enterprises. The criteria of selecting candidate chemicals are mainly based on the popularity of usage or the total consumption, the number of exposed workers, the severity of health effects, and the discrepancy between world-wide OELs and ours. Another criterion that urges revision of OELs is the pressure from the development of a cluster of occupational diseases. One example was the outbreak of *n*-hexane intoxication (Huang et al., 1989, 1991). We found 32 cases of *n*-hexane-induced polyneuropathy in printing and ball manufacturing industries during 1980s. Due to the pressure from the public and based on the exposure level (100 ppm) detected in the workplace of poisoned cases, the most stringent OEL (50 ppm) has been adopted for *n*-hexane even though the US OSHA's PEL for hexane was 500 ppm.

3. Perspectives in the use of health risk assessment for OEL development in Taiwan

Health risk assessment can be considered as a process to scientifically and systematically integrate information and data feasible for decision-making and is widely accepted by the international scientific communities as a useful tool to set up regulations. In order to harmonize Taiwanese RELs with international standards, a risk assessment approach under the RELs Committee is under establishment as requested by the CLA. By adopting the general framework consisting of hazard identification, dose–response relationship, exposure assessment, and risk characterization, a tentative flow chart shown in Fig. 2 (Wu et al., 2004). In these procedures, default assumptions are very critical to fill the information, data, and/or mechanism gaps and to lay the foundation for hazard identification and selection of an appropriate dose–response model. The potential health effects of concerns include cancer and non-cancer endpoints. If sufficient, epidemiology data is the first choice to be used, and if not, animal data are used to assess cancer risk or reference dose (RfD) for a specific chemical. In the assessment of cancer risk using animal data, malignant and benign tumors will be combined for risk extrapolation from high to low dose (Swenberg et al., 1987). Published data or well-designed studies are preferred than the unpublished. Although several dose–response models have been proposed to calculated cancer slope factor (CSF), the benchmark dose approach is recommended to calculate LED_{10}, and the animal CSF equals to the slope of the linear line connected LED_{10} and the origin (US EPA, 1996). The risk extrapolation across species is based on three quarter power of body weight ratio. The mechanistic data is used to identify the mode of action to reduce uncertainty in species risk extrapolation and to validate the appropriate usage of linearity in high-to-low-dose risk extrapolation. If data is sufficient, pharmacokinetic modeling will be used for route-to-route extrapolation, if not, 50% of absorption efficiency is assumed and used. If non-cancer effects are identified for a chemical, LED_{10} is used to replace the non-observed adverse effect level (NOAEL) in order to exploit the full-range of dose–responses. The uncertainty factor used is 100 with 10 accounting for species differences and the other 10 accounting for the sensitive subpopulation. RELs will be calculated by using the above SCFs or RfDs, given the acceptable cancer risk is 1 in 1000 in workplaces and 8-h exposures per day and 5 days per week of exposure frequency and 30 years of exposure period.

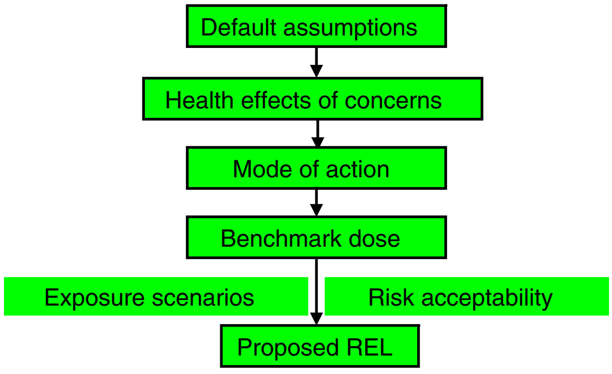

Fig. 2. The proposed procedures of health risk assessment on chemicals in workplaces.

4. Enforcement and communication of OELs

After the RELs are formally adopted as the OELs, the CLA conducts intensive public communication as well as education and training with other governmental agencies, the industrial associations, labor unions, universities, and vocational training centers. The regional and area inspectorates of CLA are the major responsible agencies to enforce the OELs Standard. Violation of this standard result in fine, partial, or complete shut-down of the operations or the whole plant, or even sending the cases to the court.

To more effectively enforce the OELs, several critical national programs including the hazard communication program, globally harmonized system, exposure monitoring program (recommended sampling and analytical methods, certification of sampling personnel, guidelines for sampling strategy), laboratory accreditation program, quality control program for blood lead measurement, respiratory protection program, hearing conservation programs, consultation program, guidelines for the diagnosis of occupational diseases, educational resource centers for safety and health professionals, prevention/compensation/return to work centers for occupational diseases, and nationwide exposure survey have been developed in Taiwan since 1990 (Shih et al., 2004), as shown in Fig. 3.

According to the exposure assessment regulations in Taiwan, all the exposure data for compliance purpose must be collected by certified sampling personnel and accredited industrial hygiene laboratories. Each year the IOSH conducted its own nationwide exposure surveys for 3–5 target chemicals suggested by the RELs committee, the CLA, and the labor inspection authorities. In the mean time, the IOSH also collected and analyzed the exposure data from enterprises, labor inspection authorities (more than 80,000 samples a year), and local universities and research institutions to establish the national exposure data bank. The exposure data bank were allowed us to evaluate the overall compliance of OELs. The CLA chose the high exposure industries and enterprises as the high priority for emphasis inspection program, according to the IOSH's recommendation. The IOSH, on the other hand, also provided consultation assistance and conducted the follow-up surveys to evaluate the effectiveness of improvement, to examine the compliance of current OELs, and to examine the benefits for recommending more stringent RELs. Taking 1,3-butadiene for example, CLA reduced the OEL from 1000 to 10 ppm in 1995, and plans to further reduce to 5 ppm in 2006 based on the IOSH's nationwide follow-up exposure survey data. Other examples of enforcement of OELs include lead and dimethyl formamide (DMF). The mean airborne lead concentration and the proportion of high blood lead workers in three high risk lead industries (lead acid battery, PVC stabilizer, and lead oxide manufacturing industries) declined 25 and 34%, respectively, within two years of consultation assistance. The mean airborne exposure levels of DMF reduced 42% and the mean urinary *N*-methyl formamide, the major metabolite of DMF, reduced 69% in synthetic leather manufacturing industry after one year of consultation assistance. Each year, the compliance officers themselves collected 1000 personal samples to check up the quality of exposure data conducted by enterprises in the emphasis inspection program. Therefore, the compliance of OELs has become an important indicator of effectiveness of our national consultation program.

5. Example of OEL development

5.1. OEL of benzene

Our current OEL of benzene is 5 ppm with STEL of 10 ppm. Benzene was listed in candidate chemicals of intended change in 2003. The Taiwan REL committee reviewed three studies of Pliofilm cohort established by US NIOSH (Crump, 1994; Paxton et al., 1994; Schnatter et al., 1996) for leukemogenesis. Since the SMRs for leukemia in Pliofilm workers were 6.93 ($p < 0.01$), 4.87($p < 0.05$), and 2.80 ($p > 0.05$), respectively, in >50–500 ppm-years groups of these three studies, the committee concluded that exposure to current OEL of 5 ppm for a working lifetime, equivalent to 225 ppm-years, results in an unacceptable risk of leukemia. The Committee also agreed the result from Crump (ACGIH, 2001) that a relative risk of 1.5 for benzene exposure at 45 ppm-years, equivalent to 1 ppm for a working lifetime, is still unacceptable. The Taiwan REL Committee adopted ACGIH and proposed REL of 0.5 ppm based on the Schnatter's study which used ppm-years dose metric and indicated that at a TWA of 0.5 ppm benzene, the odds of death from leukemia due to occupational benzene exposure would be indistinguishable from the odds of death from leukemia for a worker who is not exposed to benzene. Our nationwide survey conducted in petrochemical industry also showed that 0.5 ppm seemed to be technically and economically feasible in Taiwan. At the same time, we have also developed the biological monitoring methods for urinary SPMA and t, t-MA measurement for workers exposed to benzene (Liao PC et al., 2002, Lin LC et al., 2004).

5.2. OEL of crystalline silica

Although some literatures have pointed out that lung cancer is associated with occupational exposure to crystal-

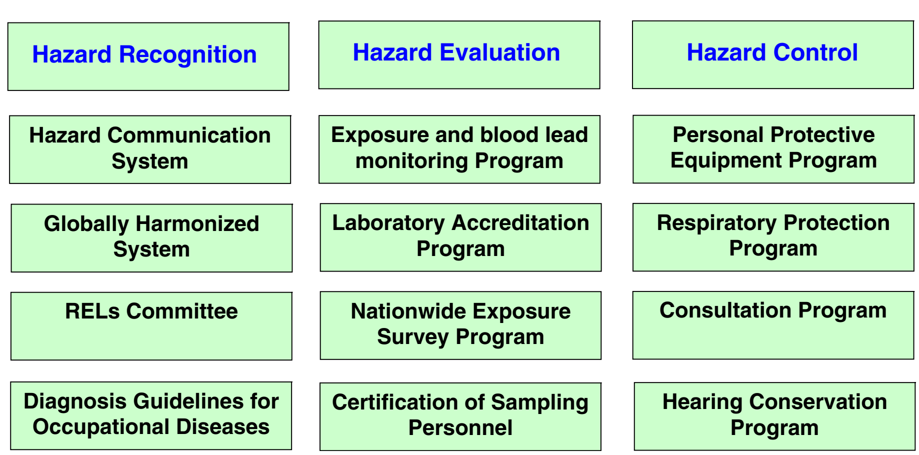

Fig. 3. A schematic diagram of the national occupational hygiene programs in Taiwan.

line silica (ATS, 1997; IARC, 1987), our OELs committee determined to choose the silicosis as the major concerned health endpoint. Using the US OSHA's permissible exposure limits (PELs) of crystalline silica as the reference, the OELs committee conducted an in-depth literatures review in 1995 and 2003.

To more accurately monitor the exposures of respirable crystalline silica, three new size-selective samplers have been developed (Chen et al., 1998, 1999a; Tsai et al., 1999a). Our studies demonstrated that the data reported in literature using the traditional cyclones could underestimate workers' exposures due to the low loading capacity and shift of penetration curves of cyclones (Chen CC et al., 1999b, 1999c; Tsai et al., 1999b). To collect the occupational exposure data in Taiwan, nationwide exposure surveys and investigation of contents of crystalline silica in industrial raw materials have been executed for high risk operations such as incinerator demolitions, foundry, and construction workplaces. The OEL of silica was mainly determined based on the exposures and risk of silicosis, as well as the technical and economical feasibilities.

Since epidemiologic studies (Hughes, 1995; Rice and Stayner, 1995; Steenland and Brown, 1995; US EPA, 1996) have suggested that cumulative exposure estimates represent the best available source of information for characterizing the dose–response relationship in occupational cohort, we adopted the Muir model (Muir et al., 1989) to estimate the risk of silicosis based on the quartz contents of respirable dust and the exposure concentration. Taking the high risk incinerator demolition workers for example, the mean exposure of respirable crystalline silica is 0.2–1.0 mg/m^3, and the estimated risk of silicosis for a 45-year working lifetime is $0.18 \times 10^{-3} - 53.57 \times 10^{-3}$, which are highly overrate 1×10^{-3} exposure risk suggested by the US OSHA. Although some recent epidemiologic studies suggested that the current OEL of respirable crystalline silica (0.1 mg/m^3) be revised (Hnizdo and Sluis-Cremer, 1993; Kreiss and Zhen, 1996; Steenland and Brown, 1995), the OELs committee in Taiwan still decided to keep the current OEL unchanged due to the consideration of economical impact and technical feasibility for small business. The current OELs of mineral dusts are listed in Table 1. Assuming the protection factor of respirator is 10, the risk of silicosis can be effectively reduced to less than 1×10^{-3}. Therefore, workers in high risk operations have been more stringently requested to wear respirators, install better engineering control, and conduct good occupational health program to reduce the silica exposure.

5.3. OEL of 2-methoxy ethanol (2-ME)

2-ME has been widely used in the copper laminate circuit board manufacturing industry in Taiwan. Animal studies and human intoxication cases revealed that the exposure to 2-ME might cause adverse health effects through inhalation, dermal absorption, and ingestion (Larese et al., 1992; Nagano et al., 1984; Welch et al., 1988; Wickramaratne, 1986). However, human data on occupational exposures was very limited. The schematic diagram of research of 2-ME was shown in Fig. 4.

Table 1
OELs[a] of mineral dusts in Taiwan (revised in 1995)

Types	Dusts	OELs	
		Respirable dust	Total dust
Type I	Mineral dusts with free $SiO_2 \geqslant 10\%$	$10\ mg/m^3/(\%SiO_2 + 2)$	$30\ mg/m^3/(\%SiO_2 + 2)$
Type II	Mineral dusts with free $SiO_2 < 10\%$	$1\ mg/m^3$	$4\ mg/m^3$
Type III	Asbestos[b,c]	$1\ f/cm^3$	
Type IV	Nuisance dusts	$5\ mg/m^3$	$10\ mg/m^3$

[a] All refer to the 8-h time-weighted average.
[b] mean fibers with length longer than 5 μm and the aspect ratio (length to diameter ratio) larger than 3.
[c] The current OEL apply to all forms of asbestos, however, the RELs committee is planning to examine whether or not we need to set up different OELs for different form of asbestos.

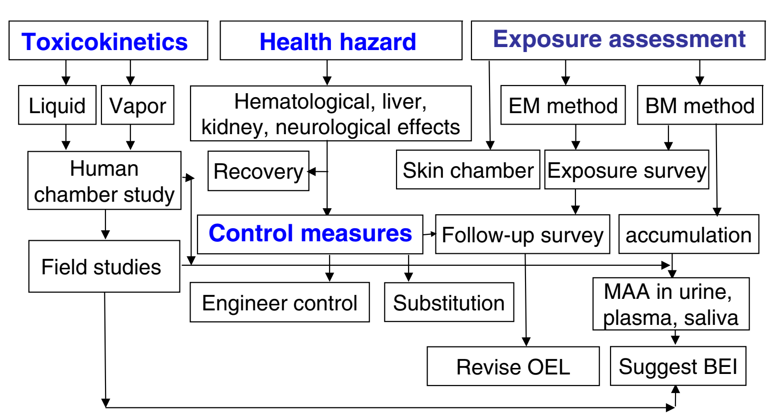

Fig. 4. A schematic diagram of 2-ME research.

Environmental and biological monitoring methods, and a new patented exposure chamber to measure the skin uptake dose of 2-ME vapor have been successfully developed (Shih et al., 1999a, 2000a,b, 2001a). Both our field studies and volunteer chamber experiments have demonstrated that the dermal absorption of vaporous or liquid phases of 2-ME was the major exposure route (Chang et al., 2004, Shih et al., 2000c). 2-methxoy acetic acid (MAA), the major and toxic metabolite of 2-ME, has been demonstrated to be a good biomarker to reflect the occupational exposure of 2-ME (Shih et al., 1999b, 2001b). Hematological manifestations were observed to be the most sensitive health effect of 2-ME (Loh et al., 2004, Shih et al., 2000d), and shortly after a reduction of exposure, the effects could quickly get recovered and the internal dose (urinary MAA) also reduced concomitantly (Shih et al., 2003). After the improvement of working condition, less than 5% of the 8-h personal samples were higher than 5 ppm. Field studies also has shown wearing impermeable rubber gloves during high-risk tasks effectively reduced the skin exposures (Chang et al., 2004). Based on the findings from longitudinal nationwide exposure surveys, CLA OEL Committee decided to lower down the OEL of 2-ME from 25 to 5 ppm with a skin notation. At the same time, IOSH also proposed a biological exposure index of 47 mg urinary MAA/g creatinine collected at Friday post-shift corresponding to a weekly mean exposure of 5 ppm to 2-ME (Shih et al., 1999b). Our human chamber exposure studies and field studies have found significant differences in metabolic pathways between humans and animals (Shih et al., 2000c). Special cautions should be paid for extrapolating animal data to humans. The completeness of a series of 2-ME studies provided not only better protection of workers' health through reduction of exposure with a more technically and economically feasible way but also a better scientific basis for occupational health regulation setting of 2-ME.

6. Conclusion

The OELs development system in Taiwan has been established over the years. Based on our experience, the following issues are critical in developing the appropriate OELs:

1. Participation of representatives from a comprehensive spectrum, including industrial association, labors, academics, governmental agencies, and individual citizens.
2. Communication, education and training, and enforcement.
3. Continuous collection of the exposure data and the most updated health hazard information.
4. Potential use of health risk assessment for the development of OELs.
5. In addition to the health protection, policy needs, and economic and technical feasibility should also be carefully considered.
6. Globalization and information and experience sharing.

In addition to the above issues, our suggestions to further improve the current system in developing OELs include the transparency of legislation, international research cooperation, and sharing of exposure assessment strategies, models, and data. Adequate good quality of exposure data is always critical for occupational epidemiological studies and developing the OELs. The cost for traditional sampling and analytical methods is relatively too high, and the performance of samplers was relatively poor. New size-selective samplers and personal denuders for simultaneously separate sampling of aerosols and gases (or vapors) are needed to improve the performance of exposure assessment. We also need new and less expensive equipment to accurately evaluate the personal exposure time activity patterns in micro-environments, peak exposures, and variation of exposures (within/between days, within-between workers etc.), as well as the cumulative personal exposure doses. In addition to the airborne exposures, the development of methodology in the establishment of internal dose and biological exposure indices should also be considered for some high skin permeable organic solvents.

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