IMPACTS OF NEW ENVIRONMENTAL AND SAFETY REGULATIONS ON URANIUM MINING, MILLING AND WASTE MANAGEMENT IN CHINA

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Abstract

Nuclear power progress has triggered the development and innovation of nuclear fuel industries in China. At present the Chinese government has put more emphasis on industrial readjustment and technical innovation in uranium mining and milling in order to fuel the nuclear power development, satisfy environmental protection and improve economic efficiency of the industry. The current organizations and approval procedure for establishing regulations and the implementation and consequences of the regulations, technical polices and development strategies concerning uranium mining, milling, treatment of waste ores and mill tailings, and reduction of the workers' suffered exposure dose etc. in China are discussed and the economic, health and environmental impacts of the uranium mining and metallurgy with reformation achievement and the introduction of advanced technologies such as the in-situ leaching and heap leaching mining technologies are assessed in this paper.

1. INTRODUCTION

China has devoted to the establishment and development of a complete nuclear fuel cycle (NFC) system, including uranium resource exploration, uranium mining and processing, uranium conversion, fuel manufacture, reactors irradiated fuel reprocessing and REU recycle for over 40 years. Since 1979, China's nuclear industry has changed its emphasis to serve the national economy and people's live, especially nuclear power. Consequently, the working emphasis of China's nuclear fuel cycle industry is also transferred to this aim.

The passed two years were regarded as the crucial years of start-up to the development for China's nuclear power programme. The construction of 4 nuclear power projects with 8 units in total planned for the Ninth Five-Year Plan period, i.e. from 1996 to 2000, has been in full swing. A new nuclear industry system with nuclear power as the leading effort has come into being [1, 2, 7, 8].

Nuclear power progress has triggered the development and innovation of nuclear fuel industries in China. At present the Chinese government has put more emphasis on technical innovation in uranium mining and milling in order to satisfy environmental protection and improve economic efficiency of the industry.

The current organizations and approval procedure for establishing regulations and the implementation and consequences of the regulations, technical polices and development strategies concerning uranium mining, milling, treatment of waste ores and mill tailings, and reduction of the workers' suffered exposure dose etc. in China are discussed and the social-economic, health and environmental impacts of the uranium mining and metallurgy with reformation achievement and the introduction of advanced technologies such as in-situ leaching and heap leaching mining technologies at the turn of the century are assessed in the following.

2. BASIC POLICES CONCERNING THE DEVELOPMENT OF MINING AND MILLING INDUSTRY

Since the middle of 1980s, with the consideration of the domestic condition and reality of nuclear fuel industry, following basic polices have been applied to the development of uranium mining and milling industry in China [1, 8, 9, 12]:

- Principle of peaceful use of nuclear technology for nuclear power programme to set up brand-new modernized and economical uranium mining and milling industrial system to match with nuclear power development;
- Establishment of the progressively new type operation mechanism and group enterprises and joint-stock corporation with every effort to follow the management system of modern enterprises in order to keep abreast with the development of national market economy;
- Combination of open-up and domestic orientation of fuel supply and promotion of international co-operation between China and foreign countries in developing the nuclear power and fuel market in China. Stressing on technical R & D, and meanwhile, introducing, digesting and absorbing foreign advanced techniques aims to improve the equipment and technical level of local mining and milling industry;
- Abiding by the state and international regulations on radiation protection and environmental protection to ensure the safety of uranium mining and milling facilities and personal.

3. PRINCIPLES FOR REGULATION DRAFTING

Uranium exploration, mining, milling and waste management, because of the radioactivity, will cause radioactive exposure dose to mining and milling workers and long-term threat or hazards to public health, safety, and environment if not properly managed. Hence, the industry of uranium mining and milling relates not only to complicated activities in technical and economic fields, but also to social-political issues which are concerned by and sensitive to the general public and various social communities.

In order to ensure the safe management of uranium mining, milling, treatment of waste ores and mill tailings, etc., besides the general principles, the following basic principles have been formulated and followed in drafting the relevant regulations [15].

4. SAFETY FIRST

The basic safety objective of uranium exploration, mining, milling and waste management lies in the appropriate and optimum methodology to be used in uranium mining and milling industry, so that unacceptable hazards to human health and the environment can be avoided at present as well as in the future; the design and operation of any facilities and system or any activities in respect of uranium mining, milling, treatment of waste ores and mill tailings must meet the requirements for radiation and environmental protection, and principles for protecting future generations.

5. ECONOMY

This principle is subject to the following conditions:

(a) The feasibility in technique and economy must be considered when the specific objectives and requirements of each process in uranium exploration, mining, milling and waste management are determined;
(b) For the regulation and standardization of a specific process in uranium exploration, mining, milling and waste management, both its economic rationality and the comprehensive economic rationality in the whole uranium mining and milling industry shall be considered. Although there are some difficulties in this cost-benefit analysis, in any case, it is important to define this principle; and
(c) Taking into account the technical and social factors, the ALARA principle has to be implemented to keep the individual and the collective dose lower than the specific limits.

Adopting international and foreign state-of-the-arts regulations according to national conditions

It is a common principle to be followed in various projects of uranium exploration, mining, milling and waste management. Firstly, it is easily accepted by the circles of the sociality if the international and foreign general principles and limits on safety & environmental protection in this field are incorporated into Chinese regulations and standards. Secondly, the implementation of this principle will facilitate the international co-operation.

Organization and approval procedure

The current organizations and approval procedure for establishing the regulations and standards of uranium exploration, mining, milling and waste management in China are shown in Figure 1, which is consistent with the uranium mining and milling industry system approved by the authorities concerned.

CNNC - China National Nuclear Corporation

The CNNC directly under the State Council is a national extra-large industrial conglomerate and undertakes the tasks of production, management, scientific research, development and construction in nuclear industry, including:

(a) the exploration, assessment, exploitation and extraction of nation wide radioactive mineral resources;
(b) empowered by the State, examination, registration and licensing of qualification certificates for radioactive geology survey and exploitation;
(c) designated by the State, authorizing and issuing professional regulations and standard in uranium exploration, mining, milling and waste management. etc.

GBGE, CNNC - The General Bureau of Geological Exploration of CNNC

The GBGE, CNNC is in charge of prospecting and exploration of uranium resources. It has established bureaux of geologic exploration in east, central-south, northwest, south, northeast and southwest of China and the Beijing Research Institute of Uranium Geology.

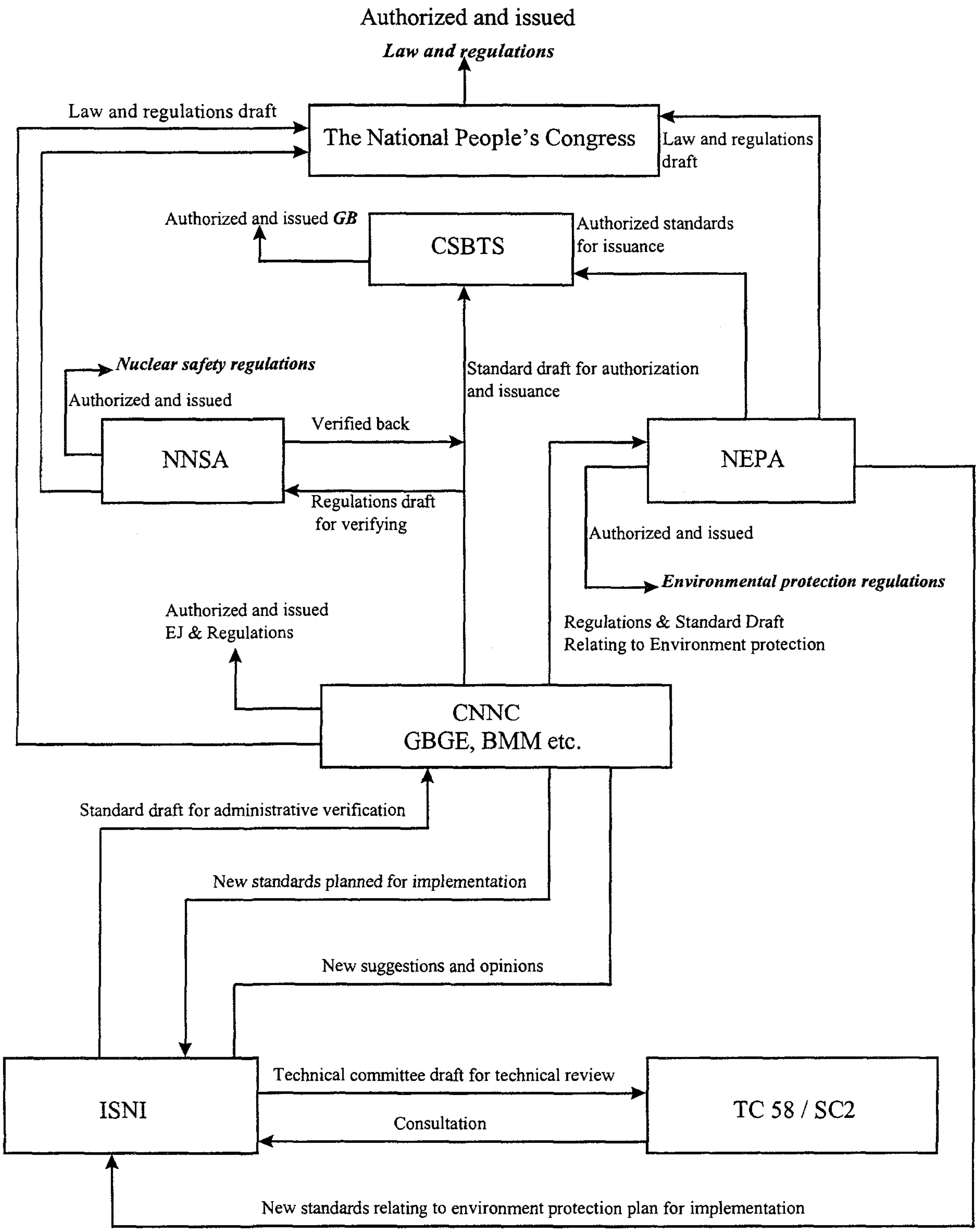

FIG. 1. Procedure for establishing the regulations and standards of uranium exploration, mining, milling and waste management in China.

BMM, CNNC - The Bureau of Mining and Metallurgy of CNNC

The BMM, CNNC possesses dozens of enterprises and institutions, covering uranium mines, ore radiometric sorting plants, mills and some institutes. It has been engaged in exploitation and production of uranium compounds, such as ADU, AUC, UO_2, U_3O_8 etc.

NNSA - National Nuclear Safety Administration

The NNSA, as a functional institution under the State Council, is responsible for managing the national nuclear safety and performs unified management and supervision of the nation wide safety issue in peaceful uses of nuclear energy and nuclear techniques, and enacts the principles, policies and regulations applied to nuclear safety.

NEPA - National Environmental Protection Agency
CSBTS - China State Bureau of Technical Supervision
ISNI - Institute for Standardization of Nuclear Industry
TC 58/SC 2 - The National Technical Committee for Standardization of Nuclear Energy/Subcommittee for Radiation Protection
EJ - Nuclear Professional Standard of the People's Republic of China
GB - National Standard of the People's Republic of China
CSTIND - the Commission of Science, Technology and Industry for National Defence

Status of the regulations

A comparatively integrated and applicable system associated with regulations/standards on uranium exploration, mining, milling and waste management has begun to take shape. It embodies the experience in uranium mining & milling industry over the past 30 years in China, and reflects the generally accepted international regulations and advanced experience on uranium mining, milling, treatment of waste ores and mill tailings, etc.

Some typical environmental and safety regulations regarding uranium mining, milling and waste management are as follows:

(1) Environmental Protection Law of the People's Republic of China (promulgated by Order No.22 of the President of the People's Republic of China, 1989)
(2) Regulations for radioactive protection (GB 8703-88)
(3) Regulations for the safe management of wastes from the mining and milling of uranium and thorium ores (GB14585-93)
(4) Normalized limits of radioactive effluent discharges for nuclear fuel cycle facilities (GB 13695-92)
(5) Regulations for design of tailing storage of uranium mining (EJ725-93)
(6) Inspection and surveillance for safe operation of tailing storage of uranium mining (EJ794-93)
(7) Technical rules for safe management of waste from the mining and milling of uranium and thorium ores (EJ/T 683-92)
(8) Regulations for environmental management of decommissioning of uranium mining facilities (GB14586-93)

Now the competent authorities are paying much more attention to industrial structure regulation, advanced movement mechanism and technical innovation in uranium mining and milling in order to fuel the nuclear power development, satisfy environmental protection and improve economic efficiency of the industry.

6. IMPACTS OF THE REGULATIONS

Uranium mining and milling industry in China, through readjustment and reform over the past ten years, has experienced great changes, considerable progress achieved. Up to now, historical readjustment tasks have been fulfilled, the main achievements are as follows:

6.1. Keeping the rational level of the production

The uranium production as readjusted shall serve primarily the needs of nuclear power development, and the policy of "self-reliance of natural uranium" shall be implemented. Uranium production capacity has been kept at a rational level to meet the requirement of nuclear fuel in recent nuclear power development. The quality criteria of uranium products can be applied also in the production of nuclear power-grade uranium dioxide, resulting from readjusting the whole process through research and development, as compared to those exclusively supporting military purposes; and professional standards have been formulated.

Following the export of natural uranium from China, two national standards, i.e. Uranium Concentrates and Ammonium Uranyl Tricarbonate were issued in 1988 so as to comply with the request in forms and quality standards of uranium products during normal trade activities in world uranium market.

6.2. New enterprises, new movement mechanism

Several mines and mills were closed down or stopped production because of resources exhausted and less social-economical efficiency while three new joint enterprises of uranium mining and milling were put into operation around 1990s, i.e. Yining Mine (Xinjiang), Lantian Mine (Shannxi) and Benxi (Liaoning). Thus, appropriate production level can be kept for uranium industry to meet the growth of uranium demand by the end of this century, and also distribution of production optimized to improve the quality of the uranium mining and milling enterprises as a whole.

Yining Mine is the first enterprise in China specialized in in-situ leaching process, the production amounting to 100 t U in 1996. In China, Lantian Mine is the first to use surface heap-leaching process and underground-blasting in-situ heap-leaching process in uranium mining. Benxi Mine, which was put into production in 1996, uses full-hydraulic rock bench drill and carry-scraper in mining, and it is the first to use the strong acid-curing and ferric-trickle heap-leaching process in commercial production. The latest findings of research and development in mining and milling technologies developed in recent years in China are used in these three plants.

At the same time, a series of administrative reform measures, such as adopting new personal engagement regime, new project contract system and regulations about non-operating assets stripped to local government or community etc., are implemented in construction and management of the mines, technical and economic indexes greatly raised as compared with those in other old mines and mills.

Though the production capacity of each mine and mill enterprise is not so large, their experience plays an important role as a demonstration engineering in construction of new uranium mining and milling enterprises as well as renewal and reconstruction of the existing mines and mills in the future.

6.3. Renewal and reconstruction of the conventional mines and mills

Renewal and reconstruction have been carried out extensively in the conventional uranium mines and mills proceeding with production so as to speed up their technical progress and improve their social-economic efficiency.

During the reconstruction of milling plants in Hengyang Uranium Mill, Fuzhou Uranium Mine and Renhua Uranium Mine, technology and equipment newly-developed in China have been adopted, linking-up in integrated milling process as a whole improved, planning of intermediate products changed, work flow simplified, and consistency with mining capacity in mines strengthened, which have made the aims met in energy-saving, material consumption reduction and economic-benefit improvement. The key equipment and facilities which have been put into production after successful research and development include 5421-type radiometric sorter, high-efficient thickener, horizontal belt filter, low-layer fluidized-bed scrubbing column, full counter-current multi-layer mixer-settler, fluidized-bed precipitator, etc.

Breakthrough progress in testing and production relating to uranium mining by using in-situ leaching process have been achieved successively in Yunnan and Xinjiang Provinces. Soon after large-scale commercial application of heap-leaching technology succeeded in Ganzhou Mine (Jiangxi), this process in deferent modes, as tested and disseminated now in many other mines, have been employed satisfactorily in production. At the same time, a complete heap-leaching process suitable to local mines has been found out. Now, uranium products produced by using in-situ leaching and heap-leaching processes account for about 60% of the annual production.

While adjusting uranium production capacity and raising production efficiency, the staff members and workers associated with uranium production have been appraised and reduced in number, and non-uranium products and industries developed by laid-off persons using surplus facilities. The personnel working in uranium production was reduced to 8,500 in 1996 compared to 45,000 in 1984. The all-personnel average labor productivity of uranium mines and mills is six times of that in early 1980s. In uranium industry, 26,000 persons were shifted to other trades, and another 10,000 persons moved to other departments over the past 10 years.

As a matter of fact, developing non-uranium production and stripping non-operating assets to local community in the conventional mines and mills also ensures the steady adjustment of uranium production, lightens the burden of uranium-oriented enterprises. Meanwhile, price of products can be competitive in world market through deepening reform, strengthening management, strictly business accounting, raising labor productivity, and reducing cost constantly.

6.4. Developing the uranium extraction and purification techniques applicable to China

There are four principal types of uranium deposits in the known uranium resources in China. Those that are in volcanic rock (20%), in granite (36%), in sandstone (21%) and in carbonaceous-siliceous-pelitic rock (15%) [11, 13]. In view of different types of uranium ores existing in China, processes have been adopted in production to develop uranium extraction and purification techniques suitable to China [6, 13, 16].

6.4.1. Treatment of volcanic-rock uranium ore by using synergistic Eluex process

The synergistic Eluex process was used to recover uranium from dilute ore-sludge adsorption by D2EHPA+TRPO (dialkylphosphorus extractants + neutral phosphorus extractants) instead of TFA. The application of D2EHPA+TRPO synergistic extractant effectively restrains Mo and iron being extracted, the product purity thus ensured. In addition, the uranium loading capacity of the organic phase of synergistic Eluex system is higher than that of the trifatty amine system, the extraction efficiency hence raised. This process is particularly applicable to China and with wide suitability is advantageous both in treating low-grade ore to ensure high purity of product, and in making full use of reflux to reduce the discharge volume of waste water, which gains good economic returns and social benefits.

6.4.2. Treatment of granite-type uranium ore by using clarification extraction process

The granite-type uranium ore is characterized by high grade of uranium, fast sedimentation of ore sands, severe resin wearing, unsuitable for ore-sludge adsorption extraction process. The successful development of highly-efficient polyacrylamide (PAA) flocculant and highly-selective tertiary amine extractant creates a favourable condition for industrial application of clarification extraction process. Prevention of emulsification during extraction is an important prerequisite for realizing the clarification extraction process. Industrial production shows that treatment of uranium ore of this type by using the clarification extraction process is the best way to gain satisfactory technical and economical indexes, and the total uranium recovery ratio can be over 93%.

6.4.3. Treatment of carbonaceous-siliceous-pelitic uranium ore with alkaline extraction process

The hydro-thermal altered carbonaceous-siliceous-pelitic uranium ore bearing high carbonate constituent can hardly be treated with acid process. A process has been successfully developed, which can directly extract and recover uranium from alkaline leaching solution by using quaternary ammonium, instead of direct precipitation process with NaOH or alkali ion exchange process, and this technology has already been applied in commercial production. In the meantime, recycling of alkaline solution creates favourable conditions to improve the utilization ratio of alkali. Through alkali thickening and reverting, the remaining solution after extraction partially returns for countercurrent scrubbing operation with the alkali reverting ratio of 72%, so that the production cost can be reduced considerably. Good technical and social-economical indexes have been achieved during production through correctly solving the problems, step by step, such as organic phase poisoning in organic and sulphide extraction by using quaternary ammonium, and quaternary ammonium loss controlled within the range of 40-50 mg/l. The process features simplicity, stable operation and high-quality products.

6.4.4. Development of in-situ leaching technology to treat sedimentary sandstone uranium ore

In sedimentary sandstone uranium deposit, the cause of formation, associated mineral elements in uranium lodging state and country rock characteristics are very complicated. Sandstone, clay rock, limestone and organogenic rock are the primary constituents in sedimentary rock. The country rock is closely related to the geo-chemical behaviour of uranium mineral formation, and different types of the country rocks are different in oxidation - reduction characteristics. The in-situ leaching technology has been applied in commercial mining of friable sandstone uranium deposit in Xinjiang. The study is being speeded up, which covers in-situ leaching technology of mineral deposits under different geological conditions, in-situ leaching area control, and underground water restoration [3, 4, 14].

According to recent statistics, over 10% of uranium resources are suitable for utilization of in-situ leaching technology. It is a common understanding that the principal advantage of in-situ leaching mining over conventional mining are financial, there are several others such as less energy intensive, low labor intensity per unit of product and less surface disturbance and pollution etc. Therefore, great effort is being made in developing in-situ leaching technology to realize the target that the production of uranium mining by using in-situ leaching accounts for over 30% of total uranium output in China in the near future.

6.5. Emphasizing the environmental protection and restoration technologies development

During the development of uranium extraction and purification techniques, effort is also being made on the study of environmental protection and restoration technologies such as volume reducing and modifying of neutralized sludge from acid waste treatment of uranium ore heap leaching [18], technologies for treating the pollution of the waste ores and mill tailings and installations decommissioning of uranium mining and metallurgy [17, 19], and technologies involving uranium extraction from uranium-bearing lignite, i.e. uranium extraction and recovery using ore sludge in large orifice-plate pulse column from acid-leaching ore sludge with uranium-bearing coal ashes etc.

6.6. Forwarding to an environmentally acceptable and harmless industry

According to the administrative laws and regulations, efficient ways must be adopted to treat the waste ores and mill tailings with radioactive elements produced during the production of uranium mining and metallurgy. Further improvement on hygienic and environmental protection would facilitate uranium mining and milling operations to be transformed into an environmentally acceptable and harmless industry. The following steps are being taken in the industry [3, 5, 10, 19]: discharge volume of radioactive effluents from uranium mines and mills should be strictly brought under control, and relevant control and management programme drawn out on the basis of optimized analysis; in uranium mining and milling, environmental monitoring system should be improved, and monitoring scheme and QC system be optimized; more effective measures should be taken to reduce the occupational exposure to workers in mines and mills, and surrounding local residents. It is stressed that transportation of radioactive materials and storage of solid radioactive waste follow the relevant laws and regulations.

The mining and milling industry in China is progressing to an environmentally acceptable and harmless industry.

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