Study on Environmental Risk Assessment and Management Methods for the Recycle of Industrial Solid Waste

Shuo Yang *, Huiting Guo and Xiuteng Wang

Resource and Environmental Branch, China National Institute of Standardization, Beijing 100191, China
Email: yangshuo_1984@126.com

Abstract. Industrial solid waste demonstrates both the resources and pollution attributes when be used as raw materials for production. Hence, it is critical to prevent the industrial solid waste from endangering the human beings and environment when it is recycled, so to balance the resource efficiency and safety. The present study reviewed the development of relevant theories and methods in the relation with environmental risk assessment and management worldwide. The characteristics of industrial solid waste are also taken into consideration. The pollutants in the industrial solid waste are classified as the human-health hazard type and product-quality damaging type depending on whether the pollutant can pose negative effect on human health, and only the human-health hazard type is regarded as the subject for risk assessment and management. Based on the classification and simplification, this study proposed the environmental risk assessment and management methods for the recycle process of the industrial solid. The aluminum extraction from coal fly ash was analyzed and the risk was assessed by applying the “Four-step Method”. The corresponding risk surveillance scheme was developed based on the risk assessment. Both the method developed by the study as well as the case analysis may provide some insight for relevant research.

1. Introduction
The recycle and reutilization of solid waste can realize the purposes of resources saving, environmental protection and economic development at the same time. However, compared with the regular raw material from nature source, the environmental risk of solid waste in the cause of recycle and its potential affect during using can’t be ignored. To secure the safety of environment and human beings, reliable risk assessment and management system must be established.

The Kalundborg industry park is a very typical case. At the beginning of 1970s, the enterprises (for instance, the power plant, refinery, pharmaceutical factory, and etc) in the park tried to collaborate to achieve better waste management and more efficient usage of fresh water. Therefore, they spontaneously formed an “Industrial Symbiosis” system, which consisted of 5 enterprises and the surrounding facilities at first, then more part of the cascade matter and energy flow was incorporated. Among which, the gypsum resulted from the desulfurization of Asnaesvaerket Coal-fired Power Plant was supplied to GyProc Gypsum Materials Company for the production of gypsum board. However, it was found very soon during the conventional analysis that the gypsum from the GyProc Gypsum Materials Company contained a large amount of vanadium, which may endanger the human health. After more thorough investigation, it was found that Asnaesvaerket Coal-fired Power Plant used the fuel containing vanadium. The vanadium migrated and transformed along the Kalundborg Industrial Symbiosis System, which caused the accumulation of heavy metal in the recycled products.

China’s solid waste recycling industry has been developing rapidly in recent years. New solid waste recycling technology has been developed and applied to replace the nature resource for the
production process. However, compared with the rapid technical development, China’s risk management and surveillance work still lags behind. The toxic and harmful substances in the solid waste migrate along the industrial chain, which will cause the potential or actual hazards. For instance, the Zijin Mining Pollution Incident in 2010 and Guangxi Cadmium Pollution Incident in 2012 caused very severe environmental and social impacts. In 2014, more than 1000 environmental criminal cases occurred in China. The lack of risk assessment and management have obstructed future development of the recycle and reutilization of industrial solid waste in China. As a result, the establishment of relevant method and system become more important than ever especially in the context of the ever-worsen environmental and resource crisis in China.

The toxic and harmful substance contained in the solid waste may enter into the recycling process and even exist in the recycling products. The corresponding environmental risks will greatly affect the acceptance of the market and customers over the solid waste recycling products, restricting the development of solid waste recycling industry. Meanwhile, the analysis of environmental risk impact factors of industrial solid waste recycling industry may facilitate preventing from the secondary pollution occurred during the industrial solid waste recycling process, make the industrial solid waste recycling process conform to the standards of relevant environmental regulations, and also safeguard the quality and usage safety of solid waste recycling products.

The solid waste contains many kinds of toxic and harmful substances, while the environmental risks can be affected by the total amount, chemical form as well as the mitigation of these pollutants. For the environmental risk assessment & control of such a complex system, this study adopts the analytic hierarchy process to classify the pollutants depending on whether the they endanger the human health. The human hazard category refers to the substance kind that may cause the direct harm to the human health, for instance, the radionuclide that may impose the death, disability, disease and other impacts upon human body, organic and inorganic pollutants, strong acid and alkaline substances, heavy metal element, and etc. The quality damaging category, on the hand, mainly includes any substance that may not or indirectly affect human health but may lead to the quality problems of products, such as, the chlorine and sulfur contained in the concrete that will accelerating the metallic corrosion and shortening the lifespan of materials. For the quality damaging category substances, the quality standards of relative products may be directly adopted, which simplifies the complexity of risk assessment and control works.

For environment risks, this study selects its narrow sense definition, mainly due to the following reasons: firstly, for the subject of study, namely, bulk industrial solid waste recycling, the human hazard category pollutants shall be the major subject of environmental risk control during the industrial solid waste recycling process. For both the recycling process and products, human beings are not only the participant of recycling process, but also the user of recycling products. Therefore, the direct impact subjects of such pollutants are both human beings. Secondly, the human reaction against external environment is predictable, especially in medicine and toxicology, where a large number of cases and information are accumulated. Therefore, it is possible to establish the much more reliable risk assessment and control methods. Thirdly, great differences exist in the natural environment, while the pollution or risk bearing capacity of natural environment is jointly determined by many factors (such as geography, climate, biodiversity, and etc). Therefore, it is difficult to form the generally applicable risk assessment and control mechanism. As a result, this study finally simplifies the environmental risk assessment of industrial solid waste recycling as the human health impact evaluation works of the specific sort of pollutant contained in the evaluation subject, as per the analytic hierarchy process.
2. Study Method

The relevant study regarding the human health impact evaluation has already become very mature, almost developing the methodology that describes the adverse human health effects resulted from exposure to the environmental hazard factors. The basic evaluation process flow is as shown in Figure 2, mainly including the source term analysis, hazard identification, dose-response assessment, exposure assessment and risk characterization. The risk control will be carried out on the basis of evaluation results [1].

![Figure 2. Process Flow of Human Health Impact Evaluation](image)

Figure 1. Analytic Hierarchy Process of Pollutant Impact during the Industrial Solid Waste Recycling Process

The environmental risk assessment carried out in this study is mainly against the solid waste recycling process. Prior to the occurrence of risk incidents, it will prepare the surveillance and response plan of risk factors as per the actual conditions of the subject. Due to the variable features of industrial solid waste, there are different recycling technologies accordingly. Therefore, it is very difficult to develop a universal recycling process risk control process, while it is required to prepare the targeted environmental risk control plan in combination with the specific conditions. Based on the “Four-step Method” and combined with the features of solid waste recycling, this study provides the general idea of preparing the environmental risk control plan against the industrial solid waste recycling environment.
1) Risk Factor Identification
This study takes the substance that is harmful to human body as the subject of risk surveillance, while the identification of such substances may refer to Catalogue of Hazardous Chemicals, Standard for Pollution Control on Hazardous Waste Storage, Standard for Pollution Control on the Security Landfill Site for Hazardous Wastes, Standard for Pollution Control on Co-processing of Solid Wastes in Cement Kiln, and other laws, regulations and standards. Meanwhile, it is required to take the substances featured in the carcinogenicity, acute toxicity, skin corrosion/irritation, serious eye damage/eye irritation, respiratory or skin sensitization, germ cell mutagenicity, reproductive toxicity and aspiration hazard, as the subjects of risk surveillance and response. When determining the subject of risk surveillance, it is also required to consider the existence method and features of toxic element. Generally, more attention shall be paid to the unstable and easily released substances (as shown in Table 1).

| Existence Features of Toxic Elements | Hazard/Attention Degree |
|-------------------------------------|-------------------------|
| Volatile (e.g. Hg)                  | ★★★                    |
| Less volatile, but reactive (e.g. Cr)| ★★                     |
| Less volatile & reactive (e.g. Cu)  | ★                      |

2) Migration & Transformation Analysis and Risk Control Strategy of Toxic Elements
During the solid waste recycling process, both the quality and quantity of the toxic elements may change along with the process. Their migration & transformation may be analyzed depending on the inlet, outlet and accumulation along with the production process. The specific risk surveillance and control strategy can be adopted accordingly (as shown in Table 2).

| Migration & Transformation Methods of Toxic Elements | Risk Control Strategy |
|------------------------------------------------------|-----------------------|
| With the main inlet, main outlet and accumulation point | Quality surveillance of key raw materials, operating condition surveillance of key points, and quality surveillance and risk assessment of key products or byproducts |
| With the main inlet & main outlet, but without the accumulation point | Quality surveillance of key raw materials, and quality surveillance and risk assessment of key products or byproducts |
| With the main inlet and accumulation point, but without main outlet | Quality surveillance & risk assessment of key raw materials, operating condition surveillance of key points, and quality surveillance and risk assessment of key products or byproducts |
| With the main inlet, but without the main outlet and accumulation point | Quality surveillance of key raw materials, and quality surveillance and risk assessment of key products or byproducts |
| Without the main inlet, but with the main outlet and accumulation point | Quality surveillance of raw materials, operating condition surveillance of key points, and quality surveillance and risk assessment of key products or byproducts |
| Without the main inlet and accumulation point, but with the main outlet | Quality surveillance of raw materials, and quality surveillance and risk assessment of key products or byproducts |
3) Determination of Reference Dose

Based on the migration & transformation analysis of toxic elements, it is required to judge the likely exposure manner, mainly including the oral ingestion and inhalation ingestion, while the relevant dose limit may be determined with reference to the “Integrated Risk Information System” (hereinafter referred to as “IRIS”) and other medical and toxicological study results.

e) Development of the Risk Surveillance Plan

The risk surveillance plan of the industrial solid waste recycling shall include but not be limited to five parts, namely, technical process flow introduction, risk element identification, risk element migration & transformation analysis, reference dose and surveillance & control measures, as shown in Table 3.

| Table 3. Composition of Risk Surveillance Plan along with the Solid Waste Recycling Process |
|---------------------------------------------------------------|
| Technical Process Flow                                        |
| ➢ Basic information introduction of raw materials,            |
|    auxiliary materials and products;                         |
| ➢ Module partition of key links                              |
| …… Name, contents and existence methods (raw materials,      |
|    auxiliary materials…) of risk elements;                   |
| ➢ Human health impacts (lethal, carcinogenic, pathogenic…)   |
| ➢ Judgment basis (laws & regulations, standards and literature…) |
| …… Element flow and substance flow analysis of recycling     |
|    process                                                   |
| Risk Element Migration & Transformation Analysis             |
| ➢ Environmental risk source, destination, and enrichment     |
|    trend analysis                                            |
| ➢ Determination of risk surveillance key points               |
| …… Analysis of risk element exposure means (oral ingestion   |
|    or inhalation ingestion)                                  |
| Determination of Reference Dose                              |
| ➢ The actual exposure dose detection results (If any)         |
| ➢ Reference dose (RFD and RCF limits, and data source)        |
| …… Setting of key risk surveillance point                     |
| Risk Surveillance Technology                                 |
| ➢ Risk control & separation technology                       |
| ➢ Risk response measures                                     |
| ……                                                           |

3. Case Study: Aluminum extraction from Coal Fly Ash

3.1. Technical Process Flow

The recycling of aluminum extraction from coal fly ash is a typical solid waste recycling industrial chain, which can properly absorb the solid waste from the power plant, namely, coal fly ash to make the aluminum oxide product, by using the soda lime sintering-dominant new technology, while the process flow is as shown in figure 3. Among which, at the pre-desilication section, the adjusting coal fly ash coming from the thermal power plant will react with the pre-adjusting circulating mother liquor (with the major component of NaOH), carrying out the primary separation of aluminum & silicon. Thus, the desiliconized coal fly ash will be obtained after washing the pre-desiliconized coal fly ash. At the sintering section, the desiliconized coal fly ash will be mixed with other raw materials (such as limestone, anthracite, and etc) and then be added with the appropriate carbon recycling mother liquor for adjusting, which will produce the raw slurry. Then, the raw slurry will enter into the ignition kiln.
where the bitumite is added to carry out under high temperature to generate the clinker. At the dissolution section, ignition clinker will have the dissolution reaction with the adjusting dissolution liquid, achieving the secondary separation of aluminum & silicon. After multi-washing of the slag phase, the silicon-calcium slag will be produced. The silicon-calcium slag may be used to make the cement & building materials and etc. After the decomposition process (inclusive of carbonation and seed precipitation), the aluminum hydroxide and decomposition mother liquor will be produced from the dissolved pregnant liquor. At the active calcium preparation section, the refined desilication liquor resulted from the pre-desilication will react with the calcium hydroxide to prepare the active calcium silicate.

![Figure 3. Process Flow of Aluminum Extraction from Coal Fly Ash](image)

### 3.2. Risk Element Identification

As shown from the process flow of aluminum extraction from coal fly ash, it is found that the major factor that may cause the impacts upon human health in this industrial chain is heavy metal. As per the requirements of Standard for Pollution Control on Hazardous Waste Storage (GB18597-2001), Standard for Pollution Control on the Security Landfill Site for Hazardous Wastes (GB18598-2001) and Standard for Pollution Control on Co-processing of Solid Wastes in Cement Kiln (GB 30485-2013), and the heavy metal average value of raw materials and cement clinker, this study determines the environmental risk threshold of heavy metal in silicon-calcium slag, and screens the heavy metal element that needs special attention in the industrial chain of aluminum extraction from coal fly ash.

#### Table 4. Coal Fly Ash Environmental Risk Element Analysis

| Element | Average Content ppm | Threshold ppm | Relative Distance % |
|---------|---------------------|---------------|---------------------|
| Cr      | 90.4                | 66            | 36.97               |
| Mn      | 210.37              | 95.1          | 121.21              |
| Pb      | 80.26               | 51            | 96.78               |
| Zn      | 89.13               | 44.5          | 100.29              |

#### Table 5. Silicon-Calcium Slag Environmental Risk Element Analysis

| Element         | Average Content ppm | Threshold ppm | Relative Distance % |
|-----------------|---------------------|---------------|---------------------|
| Cr              | 143.92              | 66            | 118.06              |
| Mn              | 235.22              | 95.1          | 147.32              |
| Pb              | 70.55               | 51            | 119.25              |
| Zn              | 88.58               | 44.5          | 99.06               |
As per the average content of heavy metal elements of coal fly ash and silicon-calcium slag, it is found that the average contents of four heavy metal elements, namely, Cr, Mn, Pb & Zn exceed the relevant standards and regulated thresholds. Among which, Pb & Cr have the significant negative impact upon the human health. Meanwhile, with the ongoing production process, significant enrichment of Cr occurs to the silicon-calcium slag, while the content of Pb is greatly reduced, which means that it is likely to be released to the external environment. Therefore, this study takes Cr and Pb as the focus of environmental risk surveillance, and separately researches their dose-response and migration & transformation process.

3.3. Dose-Response of Pb & Cr

In order to support the implementation of environmental risk assessment, US Environmental Protection Agency establishes the “Integrated Risk Information System” (hereinafter referred to as “IRIS”), and also includes the pathology study data of 500 plus common toxic elements and chemical compound into the database. The hazard degrees of all sorts of toxic substances are demonstrated in the form of Reference Dose (hereinafter referred to as “RFD”), while it represents the Acceptable Daily Dose (hereinafter referred to as “ADI”), with the unit of mg/kg-day. When the human body’s exposure dose of a certain toxic substance exceeds the RFD, it is thought that there is the risk of human health damage. The calculation equation of its quantification coefficient Harzard Quotient (hereinafter referred to as “HQ”) is as shown below:

$$HQ = \frac{\text{Actual Daily Exposure (mg/kg–day)}}{\text{RFD}} \quad (1)$$

In IRIS system, the human health impacts of all sorts of element and chemical compound fall into three categories, namely, oral type, inhalation type and carcinogenicity type. The dose-response information of lead and its compounds recorded in IRIS is as shown in Figure 4.

![Figure 4. Dose-Response Information of Lead and its Compounds](image)

| Category (section)               | Assessment Available? | Last Revised   |
|---------------------------------|-----------------------|----------------|
| Oral RfD (I.A.)                 | qualitative discussion| 07/08/2004     |
| Inhalation RfC (I.B.)           | not evaluated         |                |
| Carcinogenicity Assessment (I.I.)| yes                   | 09/26/1988     |

The lead and its chemical compounds have the impacts upon human bodies, such as neurotoxicity, developmental retardation, hypertension, hearing impairment, affecting the hemoglobin synthesis, causing the male reproductive damage and etc. However, different from other elements, lead does not have the significant toxicity symptoms over human impacts. Therefore, the quantitative RfD value is not given in the relevant studies. However, lead and its compounds may have the carcinogenicity effects. The animal test results show that the ingestion of some variable solubility lead salt via the food and subcutaneous manner may lead to the tumor. The lead carcinogenicity data are still not perfect. Although there are some toxicologic studies on the workers of lead smelter and battery plant, the very significant direct connection between lead and carcinogenicity is still not found.

The dose-response information of Cr recorded in IRIS is as shown in Figure 5.
Chromium III has very little harmful impact upon human body, while the industrial poisoning report is not found. However, Chromium III mainly has the chronic toxicity impact upon human body. It may invade the human body through the digestive tract, respiratory tract, skin and mucosa, and is mainly accumulated in the liver, kidney and endocrine gland of human body. If entering into human body via the respiratory tract, Chromium III is prone to be accumulated in the lung. Chromium III has the strong oxidation function. Therefore, generally, the chronic intoxication will begin with the local damage and then gradually becomes incurable. When invading the human body via the respiratory tract, it may begin to invade the respiratory tract, causing the rhinitis, pharyngitis, laryngitis and bronchitis. The animal test dominates. For the oral ingestion, Hexavalent chromium RFD is 3E-3mg/kg-day. For the inhalation ingestion, the foggy hexavalent chromium RFC is 8E-6mg/m³, while the granular hexavalent chromium RFC is 1E-4mg/m³. For the inhalation ingestion, the lung cancer may be resulted. Mancuso has tracked the health conditions of 332 chrome exposure workers. Among the 283 death cases, there are 66 nos. of lung cancer patients (accounting for 23.3% of death number and 64.7% of cancer number). Therefore, it is believed that the chrome has the significant carcinogenicity effects.

3.4. Pb & Cr Migration & Transformation during the Aluminum Extraction from Coal Flying Ash

The heavy metal elements in the industrial chain of aluminum extraction from coal flying ash that exceeds the standard threshold and has the enrichment or discharge include the Pb and Cr. Among which, the exposure of Pb is through oral ingestion, while the exposure of Cr can be both oral ingestion and inhalation ingestion. Therefore, it is required to analyze the migration & transformation rules of Pb and Cr during the process of aluminum extraction from coal flying ash, while the corresponding risk control measures shall be taken.

1) Migration & Transformation of Pb

The Pb contents in the raw materials, output and emissions during the process flow of aluminum extraction from coal flying ash are as shown in Table 6.
Table 6. Mass Balance Calculation of Pb during the Process Flow of Aluminum Extraction from Coal Flying Ash

|               | Heavy Metal Flow Maximum (g/h) | Heavy Metal Flow Minimum (g/h) | Percentage Content of Heavy Metal % |
|---------------|-------------------------------|-------------------------------|------------------------------------|
| **Input**     |                               |                               |                                    |
| Coal Flying Ash| 5839.79                       | 5297.96                       | 51.18%–61.28%                      |
| Limestone     | 1759.77                       | 1148.81                       | 11.17%–18.33%                      |
| Bitumite 21.3%| 2499.87                       | 1914.69                       | 18.58%–26.12%                      |
| Water         | 0.00                          | 0.00                          | 0.00%                              |
| Calcium Hydroxide| 314.74                      | 272.03                       | 2.51%–3.49%                        |
| Anthracite 16.5%| 478.67                       | 353.62                       | 3.28%–5.25%                        |
| **Output**    |                               |                               |                                    |
| Silicon-Calcium Slag| 6448.99                  | 5175.64                       | 53.81%–62.66%                      |
| Calcium Silicate| 1554.09                      | 1254.06                       | 11.84%–16.68%                      |
| Smoke         | 2759.46                       | 2486.23                       | 23.41%–29.69%                      |
| Aluminum Oxide| 103.55                        | 129.87                        | 0.95%–1.43%                        |

During the process of industrial chain of aluminum extraction from coal flying ash, the heavy metal Pb mainly comes from the coal flying ash, while the main outlet is silicon-calcium slag and two accumulation points exist in this process. The more heavy metal content is brought in by the coal flying ash, the higher the heavy metal concentration is contained in the silicon-calcium slag, and the larger the heavy metal environmental risk would become. Therefore, it is required to monitor the heavy metal Pb in the coal flying ash and silicon-calcium slag, to prevent from their impacts upon the environment. The migration law of heavy metal Pb is relatively general, while the major migration and transformation working procedure is pre-desilication, adjusting sintering and dissolution. Among which, the enrichment phenomenon occurs to the adjusting sintering section, while the heavy metal Pb flow in the ignition clinker is the largest among all the mass flow, and the heavy metal environmental risk is also much higher. Therefore, it is required to monitor the Pb at the sintering section, so as to reduce the environmental risk. Meanwhile, the enrichment phenomenon also occurs at the causticizing evaporation operating conditions of Pb. The Pb content in the recycling NaOH mother liquor is gradually accumulated over time, which may have a certain impact upon the production system. Therefore, it is required to monitor and control the Pb element in the recycling NaOH mother liquor and operating conditions of causticizing evaporation section. The Pb at the sintering section mainly comes from the desiliconized coal flying ash (48%–60%), and partially comes from the bitumite, anthracite and limestone. After the sintering process, 65%–75% Pb enters into the ignition clinker and 30% enters into the smoke. At the dissolution section, most Pb (>90%) in the ignition clinker enters into the silicon-calcium slag. Other Pb in the raw materials enter into the calcium silicate and smoke, while partial Pb is recycling in the system together with the NaOH mother liquor.

2) Migration & Transformation of Cr

The Cr contents in the raw materials, output and emissions during the process flow of aluminum extraction from coal flying ash are as shown in Table 7.
Table 7. Mass Balance Calculation of Cr during the Process Flow of Aluminum Extraction from Coal Flying Ash

|                  | Heavy Metal Flow Maximum (g/h) | Heavy Metal Flow Minimum (g/h) | Flow Percentage of Heavy Metal% |
|------------------|--------------------------------|--------------------------------|---------------------------------|
| **Input**        |                                |                                |                                 |
| Coal Flying Ash  | 5231.65                        | 4911.14                        | 45.03%~51.50%                   |
| Limestone        | 2786.91                        | 2273.86                        | 21.22%~26.92%                   |
| Water            | 0.00                           | 0.00                           | 0.00%                           |
| Bitumite 21.3%   | 2135.67                        | 1682.59                        | 15.62%~20.75%                   |
| Calcium          | 119.73                         | 103.66                         | 0.92%~1.22%                     |
| Hydroxide        | 119.73                         | 103.66                         | 0.92%~1.22%                     |
| Anthracite 16.5% | 952.87                         | 866.46                         | 7.78%~9.60%                     |
| **Output**       |                                |                                |                                 |
| Silicon-Calcium  | 5992.23                        | 5573.59                        | 54.63%~60.96%                   |
| Slag             |                                |                                |                                 |
| Calcium Silicate | 1279.65                        | 1021.11                        | 9.85%~13.23%                    |
| Smoke            | 3237.15                        | 2735.28                        | 27.03%~32.66%                   |
| Aluminum Hydroxide | 111.52                    | 81.26                          | 0.77%~1.18%                     |

During the whole process of industrial chain of aluminum extraction from coal flying ash, the heavy metal Cr mainly comes from the coal flying ash, while the main outlet is silicon-calcium slag and two accumulation points exist in this process. The heavy metal Cr is mainly taken out by the silicon-calcium slag, while the environmental risk is mainly concentrated on the silicon-calcium slag and smoke. The higher the heavy metal concentration is contained in the silicon-calcium slag, and the larger the heavy metal environmental risk becomes. Therefore, it is required to monitor the heavy metal Cr in the silicon-calcium slag, to prevent from the occurrence of risks. Meanwhile, the Cr in the smoke may cause the direct harm to the human body through the inhalation process. Therefore, it is also the key subject of risk control. The major migration and transformation working procedure of heavy metal Cr is pre-desilication, adjusting sintering, dissolution and causticizing evaporation. Among which, the enrichment phenomenon occurs to the causticizing evaporation section. The Cr in this section respectively comes from the calcium silicate filter liquor, calcium hydroxide and carbon evaporation raw liquor. Among which, the Cr in the calcium silicate filter liquor is about 35.17%~54.30% of total input amount. After passing through the causticizing evaporation process, almost all the Cr will enter into the NaOH recycling mother liquor. Together with the continuously recycling of NaOH mother liquor, Cr will also be accumulated. Therefore, it is required to take risk control measures over the Cr in NaOH.

4. Environmental Risk Control Measures
Based on the study of Pb & Cr migration & transformation during the production process, this study confirms the key links, subjects, heavy metal element category, potential exposure means and reference dose of environmental risk surveillance (as shown in Table 8).
Table 8. Environmental Risk Surveillance & Limits of Aluminum Extraction from Coal Flying Ash

| Key Links            | Subjects            | Elements | Potential Exposure Means          | Reference Dose |
|----------------------|---------------------|----------|-----------------------------------|----------------|
| Pre-desilication     | Coal Flying Ash     | Pb & Cr  | Oral ingestion after dissolution | Cr(VI): RFD=3E-3mg/kg-day |
|                      | (Main inlet of Pb/Cr) |          | Inhalation ingestion of dust      | RCF=1E-4mg/m³ |
| Adjusting Sintering  | Ignition clinker    | Pb       | Oral ingestion after dissolution  | Pb: cannot be detected |
| (Pb Enrichment)      | Smoke               |          | Inhalation ingestion              |                 |
| Dissolution          | Silicon-calcium     | Pb & Cr  | Oral ingestion after dissolution  |                 |
|                      | slag (Main outlet   |          |                                  |                 |
|                      | of Pb/Cr)           |          |                                  |                 |
| Causticizing Evaporation | Recycling NaOH   | Cr       | Oral ingestion                   |                 |
| (Cr Enrichment)      | mother liquor       |          |                                  |                 |

For the aluminum extraction from coal flying ash, special attention shall be paid to prevent from the heavy metal entering into human body via the inhalation ingestion of dust, smoke and others during the production process. Meanwhile, the anti-dissolution measures shall be taken during the storage of silicon-calcium slag and coal flying ash. Due to the definite carcinogenicity effect of Cr, it is required to be taken as the key subject of risk surveillance. Especially, when the Cr in the recycling NaOH mother liquor is accumulated to a certain level, it shall be substituted, while it is also required to properly handle the old liquor.

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6. Reference
[1] USEPA. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). 2004.
[2] Yang W, Lang Y H, Bai J, et al. Quantitative Evaluation of Carcinogenic and Non-carcinogenic Potential for PAHs in Coastal Wetland Soils of China. Ecological Engineering, 2015, 74: 117-124.