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## THE IMPACT OF WASTE INCINERATION ON HUMAN BEINGS AND THE ENVIRONMENT

### ODDZIAŁYWANIE SPALARNI ODPADÓW NA LUDZI I ŚRODOWISKO

**Abstract:** The article discusses issues related to the impact of incineration on human health and the environment. The aim of the work is to make a broad overview of the existing literature in this area. The problem was described in the literature based on a number of waste incineration plants studies in both Europe and all around the world. Subjects analyzed in the literature were risks at workplace, both administrative ones and directly related to the process of thermal treatment of waste. These risks result among others from the atmospheric emissions of many pollutants, including most of all polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, heavy metals and some volatile organic compounds. The results of these studies will be an important argument in the discussion on the possible risks to humans and the environment posed by waste incineration plants and the expediency of building waste incinerators in Poland.

**Keywords:** waste incineration, waste-to energy, environmental impact, occupational safety and health

### Introduction

Polish integration with the European Union requires us to adapt to the legal requirements in almost every area of the economy. The integration process was started long before the Polish accession to the European Union, and formally ended at the moment of accession in 2004, although the implementation of new directives into Polish law is a continuous process. An area where there are still significant differences between the EU countries and Poland as well as the greatest time lag is environmental protection, in particular waste management.

At present we are in the process of remodeling the entire waste management system, which results from the need to meet the European requirements. Despite the fact that, according to Eurostat, a statistical Pole produces much less municipal waste than an average citizen of the EU (respectively Poland - 300 kg/year/inhabitant, European Union - 500 kg/year/inhabitant) - there is still a lot of work for us in this regard. Up till now in Poland in fact the only method of dealing with waste has been landfilling. We are obliged to change this situation by obtaining the appropriate level of recovery, recycling and by

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reducing waste generation. Reduction of the waste landfill is inseparably connected with the necessity of its thermal treatment, in particular the waste which can neither be recovered nor recycled. Thermal processing is also a method of energy recovery from generated waste, which is one of the measures of waste handling according to Directive 2008/98/EC [1].

Plans to build waste incineration plants are accompanied by a huge public controversy, protests, usually not supported by rational arguments. The purpose of this paper is to review the existing literature on currently operating waste incineration facilities in Europe and in the world, with special emphasis on the impact of studied facilities on the people employed in them and the people living in the immediate surroundings as well as the impact on the environment. In this article, based on our extensive review of the literature, we presented the actual impact of a waste incineration process and accompanying atmospheric emissions of harmful agents on people and the environment in the vicinity of the investment.

### Hazards associated with the process of waste incineration

Pollutants generated in waste incineration plants, as by-products of the thermal process, are the main argument for opponents of the construction of these facilities. These are mainly heavy metals: dioxins (polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans - PCDD/Fs), polycyclic aromatic hydrocarbons, polychlorinated biphenyls and various volatile organic compounds.

Table 1 shows a summary of the main chemical pollutants in the context of their effects on human health. Particular attention was paid to the carcinogenic effects of these chemicals.

Table 1  
Basic chemical hazards in waste incineration plants and their health consequences.  
Own study based on [2] and [9]

Threat	Place of accumulation in the organism	Expected health impacts	Proven probability of occurrence in humans
Cadmium	Liver, kidneys	Adverse effects on the lungs and kidneys and possible lung, prostate cancer	sufficient
Chromium	Liver, spleen, bone marrow (only Cr(III), Cr(VI) is not accumulated)	Skin inflammation, lung cancer	sufficient
Nickel	Liver, kidneys, bones, lungs	Increased risk of lung and nose cancer, frequent allergic reactions	sufficient
Lead	Whole organism	Cancer of lungs, urinary bladder, kidneys, gastrointestinal tract	insufficient
Dioxins (PCDD/Fs)	Adipose tissue, milk	Chloracne, changes in metabolism, negative impact on the reproductive abilities, increased risk of cancer	no data
Polycyclic aromatic hydrocarbons (PAHs)	Adipose tissue, milk	Cancer of lungs, skin, urinary bladder	no data

Carcinogenesis is one of possible consequences of exposure to the substances listed in the table. According to the report of the Institute for Environment and Health in 1997 [3] it

has been found, that although there is no significant increase in the incidence of cancer in people working in incineration plants or living in their vicinity in relation to the general population they are exposed, however, to higher levels of these pollutants. The authors of the report did not exclude that the study might not be sensitive enough to detect existing side-effects of exposure to listed chemical substances. The later publication of the Carcinogeny Commission in 2000 includes a similar conclusion: "Any potential cancer risk resulting from residence near municipal solid waste incineration plants are extremely low and probably unmeasurable even using the most modern epidemiological techniques" [4].

Although harmful effects of heavy metals on a human organism and the natural environment seems to be obvious and undeniably confirmed by years of research and experiences, there is still no certainty about the health effects of other substances discussed above - dioxins and polycyclic aromatic hydrocarbons. In the scientific community it is hard to find clear statements and conclusions based on research results, especially those dioxins are emitted during all thermal processes such as: energy production, industrial production, road transport and incineration processes in the municipal sector. There are also natural sources of dioxin emissions - forest fires, volcanic eruptions, electrical discharges. Public concern as well as non-governmental organizations, which proclaim the opinions about undoubted dangers of dioxin and polycyclic aromatic hydrocarbons usually without reference to a specific source, do not help either. In contrast to them Cole et al maintains in his work [5] that the classification of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) by the IARC as a carcinogen of Group I is incorrect and that test results do not indicate a carcinogenic effect of this compound on humans in small or high doses.

On the other hand, according to the available literature, it is an undisputed fact that polycyclic aromatic hydrocarbons (PAHs) have carcinogenic properties, and 4 of them are classified by IARC as carcinogens of class I. Particularly dangerous is benzo(a)pyrene, for which there is verified evidence of carcinogenicity in relation to the human body.

In addition to chemical hazards in waste incineration plants there should also be mentioned physical hazards - such as noise and hot microclimate.

Noise, apart from the basic and obvious effects such as: hindering communication, causing distraction at work, increasing the risk of accident and causing discomfort in people exposed to it. The adverse effect of noise on the human body is complex, since it involves direct action: on middle and inner ear and indirect action: on nervous system and psyche as well as the reflex effects on the functioning of other organs. This factor accelerates fatigue, adversely affects the entire body and, above all, can result in damage and even loss of hearing. Indirect effects of damage to the hearing organ among others include: noises in the ears, a feeling of fullness. They can be permanent or reversible. Irreversible effect of noise is the result of partial or total loss of hearing caused by noise impact over many years. The consequence of the partial loss of hearing due to harmful effects of noise are significant disturbances in the assessment of the volume of sound, loss of ability to distinguish pitch and limited ability to determine the direction of sounds [5].

The consequences of the impact of noise on humans include also other than hearing reactions of the body. These include: changes in the cardiovascular system - hypertension, increased heart rate, changes in the gastrointestinal tract - excessive secretion of gastric juice, the tendency to develop gastric ulcer disease, changes in the carbohydrate, fat and

protein metabolism - a decrease in blood glucose level, a hormonal disorder - stress reactions, quantitative changes in hormones [5].

Working in a hot microclimate requires from the human body an extra effort to maintain thermal equilibrium. For this purpose, the body produces and secretes an increased amount of sweat, which requires heat dissipation by the blood flow to the skin that is cooler than the internal tissue. Hot microclimate has a significant impact on the well-being of working people and their efficiency [6].

The situation of having to work in hot microclimate is called the body heat stress. It causes skin vasodilation, increased sweating and thus the loss of water and mineral salts, the increase in body temperature and heart rate increase. All these irregularities in the functioning of the body lead to illnesses such as heat exhaustion, heat cramps, heat syncope and heat stroke [7].

Another group includes biological hazards which, according to the definition in the Regulation of the Minister of Health [8], are "harmful biological agents which may cause infection, allergy or toxicity and include:

- 1) cellular microorganisms, including genetically modified;
- 2) cell-free units capable of replication or of transferring genetic material, including genetically modified;
- 3) cell cultures;
- 4) human endoparasites".

The above-mentioned regulation mentions work in waste management plants, which undoubtedly includes waste incineration plants, as belonging to works which expose workers to biological agents [8].

These physical and biological hazards do not raise many social controversies, especially as they relate primarily to the staff of these facilities. They, however, can not be ignored, because incineration plants are not self-serviced installations and the health of people working there deserves the same attention and protection as the health of local residents.

## **Study of the effects of incineration on the neighborhood**

Studies on the effects of dioxins (PCDD/Fs) for residents in impact areas of waste incineration plants were carried out in recent years in Belgium, France, Portugal and Italy. The authors of papers focused on the existence of the health effects of dioxin emissions to the atmosphere. The works relate to the incineration plants built in the 70s, 80s and 90s, dioxin emissions in that period was not monitored but the level of emissions was roughly estimated for the needs of the carried out simulations (Table 2).

The results of the study are not conclusive, although most of the presented conclusions indicate a clear impact of dioxins on the deterioration of the health condition of the tested population. It should, however, be taken into consideration that the studied facilities were old which were built to meet the demands of a much less restrictive law, tailored to meet less demanding standards of emissions to the atmosphere. These plants over time were modernized and adapted to more and more stringent regulatory requirements or were closed, however, considering the fact that the accumulation of harmful substances in the environment, despite the reduction of emissions to the atmosphere, dioxins accumulated

during the years of releasing them to the environment could affect for a long time and could freely migrate and be absorbed by people on many levels.

Table 2  
Comparison of the area, purpose and scope of research, results and conclusions on the impact of incineration plants on the environment obtained by different authors

Area and aim of the study	Range of research	Emission level (applicable emission standards)	Test results	Conclusions
[10] Neerlandquarter, Belgium; 2 waste incinerators opened in the 70-ties and 80-ties, Research carried out due to complaints of residents about numerous health problems.	Risk assessment based on chemical, toxicological research and modeling of dioxins propagation and calculating their content in the soil, food and water; The level of exposure converted to equivalent 2,3,7,8-TCDD; Blood samples were taken from 24 children (10-12 years old) from the test area and from the control group.	Estimated: from 18.9 g TEQ/year in 1980 up to 3.1 g TEQ/year in 1997.	Soil contamination does not correspond to the substance spreading model. Cytogenetic studies do not show statistically significant differences between the test and control groups.	Incinerators are not the only source of tested pathogens. Children living in the area in question do not receive high doses of genotoxic substances. Living in the exposed area does not result in an increased health risk.
[11] Surroundings of 16 waste incineration plants in four administrative units in France; the aim of the study was to assess the impact of long-term exposure to dioxins in the population living near a waste incineration plant.	The relationship between the incidence of cancer and exposure to 2,3,7,8-TCDD, using national cancer registries, 25 000 000 people over the age of 14 annually were examined, in 1990-1999, about 135 000 cases of cancer were found.	Estimated content in soil in the years 1972-1984: 0.003-0.097 $\mu\text{g}/\text{m}^2/\text{year}$ .	There is a positive relationship between the exposure to dioxins in the 70' and 80' and the incidence of various types of cancer in the years 1990-1999, the demonstrated exposure is greater for women than for men, although it occurs in both sexes.	Studies are related to the previous situation and do not depict the current problems; studies do not take into account individual factors such as place of residence, occupational exposure, dietary habits.
[12] Part of the province of Venice (about half of its population), Italy; aim of the study is an assessment of the risk of sarcoma in relation to environmental pollution by dioxins emitted from waste incinerators.	The relationship between the incidence of sarcoma and exposure to dioxins emitted from waste incinerators, there were used data from the years 1990-1996 included in the local registry of cancer; 186 out of 205 cases of sarcoma were selected in patients meeting the criterion of residence in the study area, for each patient three control samples were taken.	Estimated emission level to the atmosphere in the years 1961-1996: from $3.0 \cdot 10^{-7}$ , increased to $1.7 \cdot 10^{-6}$ (year 1973), and then was falling from 1984 to $1.0 \cdot 10^{-7}$ in 1988.	Studies show a significant increase in risk of sarcoma associated with both the level and length of exposure to dioxins, the risk is far greater for women.	The results confirm the carcinogenic effect of dioxins on humans, the results confirm the thesis about the effects of exposure to dioxins on the incidence of sarcoma in the general population, with small concentration of these pollutants and long-term exposure.

Area and aim of the study	Range of research	Emission level (applicable emission standards)	Test results	Conclusions
<p>[13] Area of the city Besancon, France, in total about 65 km<sup>2</sup>, waste incineration plant opened in 1971 is located at a distance of 4 km from the city center; aim of the work is to determine routes of dioxins absorption and the relationship between the exposure to low levels of dioxins and the incidence of non-Hodgkin's lymphoma.</p>	<p>The incidence of non-Hodgkin's lymphoma in the years 1980-1995; control group was selected, model of average concentration of dioxins at ground level in the study area, using data on dioxin emissions in 1999, restoration of previous data was not possible, the data were compared with the incidence of detected cases of non-Hodgkin's lymphoma on the modeled area.</p>	<p>Model: 0.001-0.0016 pg/m<sup>3</sup> Measurements: 16.3 ng I-TEQ/m<sup>3</sup> in waste gases in 1997</p>	<p>Studies show statistically significant increase in the risk of non-Hodgkin's lymphoma in a group of people living in the area of the highest concentration of dioxins; This risk is 2, 3 times higher than in the group living in areas with the lowest concentration of dioxins.</p>	<p>The results confirm the thesis of an increased risk of developing non-Hodgkin's lymphoma among people living in the area of waste incineration plants.</p>
<p>[14] Portugal, waste incineration plants around the city of Lisbon and on the island of Madeira.</p>	<p>Measurement of the content of dioxins in human milk in two areas with significantly different levels of pollution, research was conducted on 181 volunteers, over the years 1999 to 2003; The test may not be representative - the studies involved only women of working age who were breastfeeding.</p>	<p>Content of PCDD/F in milk: average: 10.6 TEQ pg/g of fat for the area of Lisbon, 6.5 TEQ pg/g for Madeira; the median - 10.6 TEQ pg/g for the area of Lisbon, 5.8 TEQ pg/g for Madeira.</p>	<p>Average and median values are almost identical for the test group and the control group in both areas; Statistical differences can be seen when comparing the two studied areas - for women from the area of Lisbon, content of PCDD/F in milk is higher than in women on Madeira.</p>	<p>The results indicate no relationship between the residence near waste incineration plants and elevated levels of PCDD / F in milk. There was noted increased levels of PCDD/F in women who live in more polluted (Lisbon) and increased level of PCDD/F along with the age of volunteers, which is connected with the accumulation of pollutants in the body for years of exposure.</p>

## Study of the effects of incineration on employees

There were also conducted studies of the impact of the same substances on the health of people working in waste incineration plants. These studies were not limited only to the impact of dioxins on human health, there were taken into account also heavy metals, volatile organic compounds. Biological agents, dust or noise in waste incineration plants and their impact on the health of workers were described only in a small number of research works. The assessment of the hazards for people working in these plants was above all based on blood and urine tests, but also on the general health examination, conducted personal surveys on lifestyle, dietary habits, ailments associated with the work, if such were

observed. The purpose of the comparison of works was primarily the identification of hazards existing in the work environment, assessment of risk associated with them, estimated at various workplaces: administrative and technical or workers - directly connected with the process of waste incineration. An important element of the conducted research was of course health consequences of human exposure to the identified hazards present in the workplace - their reversible and permanent effects, intensity, incidence of observed health effects.

The test results show that it is difficult to tell clearly how big impact on the health of employees has working in exposure to occupational hazards occurring in waste incineration plants. The authors of the Finnish publication on the incineration of municipal waste in Turku indicate that the restructuring of the incineration plant, monitoring the types of waste that go into the combustion chamber and the use of appropriate protection for employees makes it possible to protect people both inside and outside the plant against adverse factors related to the operation of the incineration plant [22]. However, unlike other works, this publication also contains information on biological agents, presence of dust, bioaerosols, endotoxins, noise level. It indicates the specific personal protective equipment to be used by employees in the places, where permissible levels of harmful factors can be exceeded, it does not indicate hazards caused by most frequently mentioned chemicals.

Table 3  
Comparison of the area, purpose and scope of research, results, and conclusions on the impact of incineration plants on the health of workers obtained by different authors

Area of study	Scope of research	Tested workplaces	Results	Conclusions
[15] Japan, three and six municipal waste incineration plants	Exposure to dust containing dioxins (dioxins concentration in the dust), test of concentration of dioxins in blood and plasma.	Works performed periodically, <i>eg</i> cleaning of cooling towers, electrostatic precipitators and fabric filters. Permanent works: weighing the waste, operating cranes among others.	Depending on the type of works, average 1.7 pg TEQ/m <sup>3</sup> to 81 000 pg TEQ/m <sup>3</sup> in dust. Average from 46 pg TEQ/g of fat to 346 pg TEQ/g of fat in blood. Average 23 to 35 pg TEQ/g of fat in plasma.	Special attention should be paid to employees who have contact with slag and dust, as the concentration of dioxins in their blood were highest. Concentrations of dioxins in plasma were comparable to concentrations in the control group.
[16] Germany, study in two municipal waste incineration plants - old and new	Study of concentration of 10 major PCDD and PCDFs in blood, in a group of employees of the old and new incineration plants and in the control group, the concentration of 10 major PCDD and PCDF in slag and dust from the old incinerator.	Locksmiths, who are most exposed to the inhalation of dust from waste incineration.	Average TEQ (ppt, fat): old incineration plant: 24.3-66.1 including locksmiths: 38.5-66.1 new incineration plant: 20.5-63.5 control group: 17.3-76.4.	There are no significant differences in exposure between workers of the new incineration plant and the control group, in comparison with the control group in the employees of the old incineration plant there was a significant increase in the concentration of octaCDD, hexaCDF, heptaCDF and the total concentration of PCDD and PCDF.

Area of study	Scope of research	Tested workplaces	Results	Conclusions
[17] Taiwan, temporary workers in four different waste incineration plants	The concentration of PCDD and PCDF in the plasma of temporary workers, carrying out cleaning and maintenance works on the area of different incineration plants, before and after one month's work in the incineration plant.	Workers cleaning and repairing equipment in the area of furnaces, waste gas cleaning devices.	Before starting work: 15.7 and 24.1 pg TEQ/g of fat After one month: 19.6 and 27.5 pg TEQ/g of fat.	The level of the tested substances was significantly higher after than before starting work, especially in those working in exposure to dust, there was no difference in concentration between the workers and management staff, higher concentration of the substance has been observed in persons engaged in this type of work earlier than those working in the plant for the first time.
[18] Taiwan, three municipal waste incineration plants opened in the 90s	Study of PCDD and PCDF concentrations in the air and in blood of randomly selected employees of the incineration plant.	Air measurement - 4 points in each incineration plant; Workers for blood tests were chosen randomly, from different jobs, both workers and administrative staff.	The geometric mean of concentration in blood: 14.6 15.8 and 19.1 pg TEQ/g of fat in subsequent incineration plants; Average concentrations in the air: 0.008-3.01 pg/m <sup>3</sup> .	The results showed no correlation between the time of employment and the concentration of PCDD/F in the blood of workers, there was no correlation between time spent in individual departments of the plants and the level of tested substances in the blood.
[19] Spain, hazardous waste incineration plant opened in 1999	Plasma tests: HCB, PCBs, PCDD, PCDF Urine tests: DCPS, TCPs, PCP, 1-HP and Cd, Cr, Ni, V. Tests of the content of Be, Mn, Hg and Pb in blood; study carried out in two consecutive years of incineration plant operation.	Employees divided into three groups: plant workers, laboratory staff and administrative staff.	Level of PCDD/F in plasma calculated as I-TEQ pg /g of fat): Year 1999 - 26.7 Year 2000 - 16.9 Year 2001 - 10.0 Year 2002 - 10.3	There were no differences between the concentrations of the tested substances in the workers of the incineration plant compared with a group not exposed to these pollutants, no differences were noted in the concentration of tested pollutants between individual professional groups in the plant.
[20] France, two municipal waste incineration plants	Examination of lung function by means of a spirometer in workers exposed to airborne pollutants, during the annual periodic examination, for the next three years; the study of air samples for the presence of airborne pollutants.	Employees of the incineration plant excluding white collar workers.	Vital capacity of lungs (average respectively in the first and third year): Group I: test: 97.8%, control: 99.4% Group III: test: 95.6%, control: 97.0%	No relationship was noted between exposure to airborne pollutants and changes in lung function in workers of incineration plant; there was observed a slight weakening of lung function, which may suggest the presence of obstructive lung disease, but this is not confirmed. There are no significant differences in the test results between the test group and the control group.



Area of study	Scope of research	Tested workplaces	Results	Conclusions
[21] France, two municipal waste incineration plants, one of them also for medical waste	The questionnaire specifying dietary habits, lifestyle, physical examination conducted by one doctor, tests of lead levels in blood, liver enzyme test, spirometry test.	Employees were divided due to the scope of duties, with the exception of administrative staff.	Vital capacity of lungs of individual groups of employees (in [%]): Group: control: 98.9±12.0 Crane operators: 102.3±15.6 Furnace operators: 95.4±11.8 Service staff: 94.8±18.6	Significantly more symptoms of irritation of skin and mucous membranes in a group working in the incineration plant than in the control group, in the exposed group higher incidence of cough; People in the test group showed lower respiratory performance than the control group, there was confirmed a convergence between lower respiratory performance and length of employment in the incineration plant. Incineration plant workers reported more accidental events and benefit from longer sick leaves than those in the control group.

The factors on which most research focus are the chemicals released as a by-product of the combustion reaction, mainly dioxins and heavy metals. Dioxins cause the greatest concern, their impact on human health and life is least known, least sure are effects of these factors on health and life and their quantities present in the environment needed to elicit these effects. Most of the authors point to the need for further observations in the directions indicated by them, because achievements to date do not solve the issue of health risk to workers of the incineration plants, they may be only a guideline indicating the type of problems faced at present and in future by workers exposed to those harmful factors.

## Conclusion

Investing in the construction of waste incineration plants in Poland has a specific goal, apart from the need to meet the legal requirements under the threat of financial penalties from the European Community. Such a change in the entire waste management system is guided by the need to improve the quality of the environment or at least a desire for non-deterioration of its condition. An important issue is if, by changing the present method of dealing with waste, some harmful for environment substances are replaced by other equally adverse, if side effects of the already functioning system are smaller or greater than those of the system that needs to be implemented. For example, by analyzing changes in the waste management system in New York [23] it was stated that living near a landfill causes more than 5 times higher risk of developing cancer and other serious diseases than living in the area of a waste incineration plant. However, this problem can not be solved theorizing, research carried out so far in foreign facilities does not allow for an unambiguous transfer of conclusions to the current situation. Therefore, there is a justified need for a reliable, systematic research in the existing waste incineration plants in our country. So far in Poland there was no motivation to conduct studies in this field, now they are motivated by the health of workers, local residents and the condition of natural environment. It is necessary

to determine whether the current regulations are a sufficient protection against potentially harmful effects of waste incineration plants for workers and people living in the immediate surroundings. The results of the research can serve as a key argument in the debate on the expediency of the construction of waste incineration plants in Poland and the discussion of possible risks that these plants pose to people and the environment.

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## ODDZIAŁYWANIE SPALARNI ODPADÓW NA LUDZI I ŚRODOWISKO

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**Abstrakt:** Poruszono tematykę związaną z oddziaływaniem spalarni odpadów na zdrowie osób w nich zatrudnionych oraz środowisko naturalne. Celem pracy jest dokonanie szerokiego przeglądu istniejącego piśmiennictwa w tym zakresie. Dokonano go, korzystając z licznych, opisanych w literaturze, wyników badań wykonanych w wielu spalarniach odpadów zarówno w Europie, jak i na świecie. W analizowanych pracach poruszano tematykę zagrożeń na stanowiskach pracy, zarówno administracyjnych, jak również bezpośrednio związanych z procesem termicznego przetwarzania odpadów. Zagrożenia te wynikają między innymi z emisji do atmosfery wielu zanieczyszczeń, w tym przede wszystkim polichlorowanych dibenzo-p-dioksyn i polichlorowanych dibenzofuranów, metali ciężkich oraz niektórych lotnych związków organicznych. Wyniki badań stanowiąc będą istotny argument w dyskusji na ewentualnymi zagrożeniami dla ludzi i środowiska stwarzanymi przez spalarnie odpadów i celowości ich budowy w Polsce.

**Słowa kluczowe:** spalanie odpadów, odzysk energii z odpadów, oddziaływanie na środowisko, bezpieczeństwo przemysłowe i higiena pracy