THE ASSESSMENT OF MAJOR ACCIDENT RISKS IN TALLINN (ESTONIA)

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One of the tasks of human civilisations is to protect individual members and groups against natural and man-made hazards to a certain extent. Risk is defined as the probability of the disaster related to the consequences. The major hazards and the prevention measures for protecting people in Tallinn (the capital of Estonia) are presented. The value of human life is calculated. The three variable risk calculator is used. The liquid fuel centre and the rail transport of petroleum through the town very near to the dwellings is assessed as very high risk. Three nuclear power stations closest to Estonia (Ignalina, Sosnovy Bor, Loviisa) are at a greater distance than 300 km and in the case of the possible straight direction of wind, the primary cloud of nuclear contamination would reach Tallinn not earlier than an hour and not later than 24 hours if there was leakage at a nuclear power station. So the dangerousness of contamination Tallinn with radioactive particles is assessed as moderate risk.

INTRODUCTION AND THEORETICAL BACKGROUND

The main challenge for risk assessment is the protection of human beings, followed by the protection of environment and property. The value of human life has not been identified by the Estonian researchers, although it has been calculated in industrialized countries and in the EU.

Tallinn (with the population nearly 400,000 people), the capital of Estonia is located in the southern coast of the Gulf of Finland. Tallinn gets its drinking water from the Lake of Ülemiste which is situated very near to the Tallinn Airport and central traffic centre. The water in the Lake is polluted by the combustion products of fuels. Great amounts of toxic chlorine are used by the Purification Centre situated near the lake. The other possible hazards for causing the major accidents in Tallinn are: explosive chemicals used by the enterprises, ionising radiation from near-by nuclear power stations and transport of petroleum by railway through the town. The hazards and solutions for the problems are analysed in the current paper.

The safety management of environmental and occupational hazards predicts involvement of several disciplines and parties: knowledge, risk and health management; managers, health personnel and authorities at national and international (nuclear power stations) level.

In order to perform cost benefit analysis for risk management purposes it is necessary to adopt a benchmark value for the loss of life. One of the tasks of human civilisations is to protect individual members and groups against natural and man-made hazards to a certain extent. The aim of the modern probabilistic approach is to give protection when risks are felt to be high (Jongejan 2005). Risk is defined as the probability of the disaster related to the consequences. As long as the modern approach is not firmly embedded in society, the idea of acceptable risk may be quite suddenly influenced by a single spectacular accident.

Vlek and Stallen (1980) investigated the judgment of risks for individual, societical and industrial activites. Lichtenstein et al. (1978) have called the tendency of people to overestimate the likelihood of rare events and to underestimate the likehood of common events "primary bias", and the tendency to overestimate the likehood of sensational events and to underestimate the likelyhood of prosaic events "secondary bias". Starr (1969) suggested that society tolerates greater risks from technologies that provide greater benefits (more specifically, risks are acceptable in proportion to the third power of benefits) and that risks from voluntary technologies are approximately 1,000 times more acceptable than risks from involuntary technologies.

Von Winterfeldt and Edwards (1984) pointed out on the basis on an examination of 162 technological controversies, that societal debates about the acceptability of technology are, not just debates about the acceptability of fatality risks, put debates concern related to morals, religion, political ideologies, power and psychological well-being. Otway and von Winterfeldt (1982) concluded that efforts to base acceptability judgments exclusively on the magnitude of risks to human life are simplistic and misleading. To provide an extreme example, they point out that the physical risks of a technology could in principle be essentially zero but the technology still be judged unacceptable (and subject to opposition) for other social reasons.

The model for determination of an acceptable level of expenditure that can be justifiably incurred on behalf of the public interest in exchange for a small reduction in the risk of death that results in improved quality for all (Pandey et al., 2003; Delhaye, 2003; Jongejan, 2005), needs the determination of following quantities: LQI (life-quality index), SWTP (societal willingness-to-pay), WTP (individual willingness-to-pay), GDP (gross domestic product per capita) and VoSL (the value of a statistical life).

The life-quality index is calculated as follows (Pandey et al.):

$$LQI = G^q E \qquad (1)$$

where G is the gross domestic product per capita, E is the life expectancy in the country, and q is the ratio of average work to leisure time available to members of society.

Societal willingness-to-pay (by *LQI* method, Jongejan, 2005) is calculated as:

$$SWTP = \frac{VG}{q}\frac{d(E)}{E} \quad (2)$$

where V is the population size; G – gross domestic product per capita; *d(E)* – change in discounted life expectancy averaged over the age-distribution of the national population; E – discounted life expectancy averaged over the age-distribution of the national population.

Considering a society of only one person that is 40 years old and assume that this person has a life expectancy of 72 years – the Estonian life expectancy at birth in 2008 (Life . . . , 2009), the maximum amount of money that would be spent on a risk reducing prospect that would result in an extension of this person's life expectancy with one year according to macro-economic valuation is:

$$WTP = \frac{G}{(1+r)^{72-40}} = \frac{G}{(1+r)^{32}} \quad (3)$$

where r is the discount rate.

According to LQI-methodology, the societal willingness-to-pay per year can also be calculated:

$$SWTP = \frac{G}{qE_i(1+r)^{32}} \quad (4)$$

where E_i is discounted life expectancy of the person (40 years old) under consideration.

The value of a statistical life (VoSL) is determined by following equation (Delhaye 2003):

$$VoSL = \frac{WTP}{change\ in\ risk} \quad (5)$$

THE AIM OF THE STUDY

The aim of the study was to identify the value of human life in Estonia and health risks in the capital of Estonia originating from the great amounts of chlorine used for the purification of water in Tallinn; from other chemicals, possible causers of major accidents; from flammable, explosive gases, used at homes or transported through the town from railway stations to the ports; for the health of inhabitants and environment connected with motor, rail and air transport; of the ports and the airport in the town (very near to the centre); from the nuclear power stations in the neighbouring countries (Ignalina, Sosnovy Bor, Loviisa).

THE METHOD AND MATERIAL

The value of human life was calculated based on the literature (Pandey et al., 2003; Jongejan, 2005) and the statistical data (Estonia GDP, 2009; etc.).

The two variable risk matrix and three variable risk calculator (University, 2003) used in current study for assessment the main risk of major hazards in Tallinn. The data of chemicals and other hazards in Tallinn Water Purification Centre were used. The results of the investigation of the major hazards in Tallinn carried out in Tallinn University of Technology in 2000, were also used (Tint et al., 2003).

SOCIETAL COST-BENEFIT ANALYSIS

The EU data (2002) on the monetary valuation of road fatalities in the Baltic States (Estonia – 630,000; Latvia 534,999; Lithuania 575,000), in Norway – 2,055,000, in the UK – 1,617,000 and in the Netherlands – 1,672,999 can be found in the report from the HEATCO project (Bickel P et al., 2006).

The data differ a lot by countries. For example, in Norway the human's life is assessed 3–4 times higher than in the Baltic states. There are no studies for assessment for the value of human life inside of Estonia.

Basing on the economic and statistical data of Estonia (Economy, 2009; Estonia GDP, 2009; Life, 2009) the overall life expectancy at birth in Estonia in 2007 and 2008 was accordingly 72.3 and 72.56 years; the GDP per capita in Estonia in 2007 and 2008 was: accordingly 15,615 and 16,769 euro.

For calculation the life quality index *LGI* (equition 1) the value of the exponent q has to be settled. The value of q is assessed from 0.15 to 0.2 by different authors (Pandey et al., 2003; Zechhauser, 1973). Using the value of $q = 0.175$, life quality index (*LQI*) in Estonia will be 396 euro.

The change in life expectancy averaged over the age-distribution of the national population dE (years 2008–2007) = 0.26 years; the change in gross domestic product dG (years 2008–2007) = 1,154 euro. For the risk reduction of 1×10^{-6}, the increase in life expectancy dE/E is possible to calculate: $dE/E = 3.6 \times 10^{-5}$; the individual willingness-to-pay $WTP =$ 3.34 euro/year (equition 3) if the discount rate $r = 0$; using the real discount rate in Estonia (Economy, 2009): $r = 5$, the willingness-to-pay WTP will be 0.700 euro/year. The influence of discount rate to WTP is discribed by Pandey (2003).

To avoid the risk (1×10^{-6}) over a population of one million people, *SWTP* (equition 2) was subsequently calculated as 0.700 million euro/year.

The value of statistical life in Estonia VoSL (equition 5) can be inferred as money per unit reduction of death, which is equal to 0.7 euro/10^{-6} = 0.7 million euro.

DESCRIPTION OF MAJOR ACCIDENT HAZARDS IN TALLINN

THE LEGISLATION CONCERNING THE MANAGEMENT OF MAJOR HAZARDS IN ESTONIA

The regulation "Methods for risk analysis of towns and counties" was adopted by the Ministry of Internal Affairs in 2001. The regulation has the following chapters:

(1) Organization of work for carrying out risk analysis in towns and other communities
(2) The content of risk analysis

(3) Collecting the information
(4) Identification of possible accidents
(5) Assessment of the probability of possible accidents
(6) Determination of the risk category
(7) Arrangement of prevention.

The risk connected with the use of chemicals by the workers is regulated by the Chemical Act (1998). The terms as risk, probability, consequence, risk analysis, risk sources, risk classes, objects in danger, accident, and initial event are presented in "EVS-EN 1050:2000 – Safety of machinery. Principles for risk assessment". In this standard also the question of reliability is dealt with (the reliability of safety functions), but no risk criteria are presented.

INDUSTRIAL SOURCES OF POSSIBLE MAJOR ACCIDENTS

The supervision of potentially dangerous techniques and industrial processes at enterprises and other institutions is carried out by the Technical Inspectorate of Estonia (allocated to the Ministry of Economic Affairs and Communications). The function of the Inspectorate is to reduce to a minimum the risk of accidents causing pollution of the surroundings and injuries to people. It is the duty of the Inspectorate to follow general trends of technical development and to co-ordinate basic and in-service training programmes at relevant training centres.

Activities in the field of technical safety, covered by the EU directives, are directed to ensuring the highest possible standards of safety and security for: pressure equipment and vessels, lighting equipment, gas appliances and piping, chemical processing devices, and machinery.

The activities of the Technical Inspectorate in the field of safety supervision of mineral extraction are exercised over: underground and opencast mineral extraction; borehole drilling technology for geological exploration; the manufacture and treatment of explosive substances for civilian purposes; market surveillance and the treatment of pyrotechnic products.

According to the regulation based on the Chemical Act, the category A (the most hazardous substances used) includes in Tallinn two enterprises: Tallinn Water Ltd. and Estonian Propane Ltd. Tallinn Water handles 16 tonnes of chlorine at the same time. The enterprises (firms) on the B level are ScanTrans Ltd. (motor oil, heavy motor oil), Dekoil Ltd. (motor oil, black oil) and Stevedores Ltd. (ammonia and ammonium nitrate).

The C category in Tallinn consists of 110 firms (petrol stations, hospitals with their oxygen reserve etc.).

The greatest hazards for Tallinn are Estonian Propane Ltd., where 600 tonnes of liquid gas is dealt with, and also transport of petroleum products by railway through the town from the railway station in the east of Tallinn to the ports in the north and west side of the town. A hundred tanks, each of them containing 60 tonnes of black oil, can stand simultaneously in town 20 metres from wooden buildings.

THE HAZARD OF THE POLLUTION OF DRINKING WATER IN TALLINN

Tallinn gets most of its water from Lake Ülemiste (this supply is ca 80,000 m^3/h). In 1927 a Water Purification Centre (WPC) was built to the Lake. At the beginning the water was purified only with chlorine. In addition, inhabitants of Tallinn get water from wells (9,000 m^3/h). The inhabitants use ca 77% of the Lake Ülemiste water, the rest is used by enterprises.

Chlorine represents a hazard for the environment and people (the amount of liquid chlorine in storage is 8–16 tonnes). In the case of an emergency situation chlorine evaporates, forming gas cloud heavier than air that would be a hazard for the workers of WPC and inhabitants (1,800 houses nearer that 1.5 km from WPC). The WPC has high-level measurement equipment for detecting chlorine gas flows. A plan for the elimination of accidents with chlorine is being worked out with the co-operation with Tallinn Rescue Department.

Nowadays the WPC (since 1997) also uses ozone besides chlorine for water purification. The use of ozone has improved the quality of drinking water. Ozone is a very toxic substance, but unstable. The substance is produced from the outdoor air using a high-voltage field. The concentration of ozone is continuously determined by the measurement equipment. If the concentration of ozone gets higher than the limit concentration (0.2 mg/m^3), the emergency signalization system will turn on. The workers are provided with personal protective equipment. Unlike chlorine, ozone is decomposed very quickly and does not represent a danger for the population outside the WPC. Ozone is able to disintegrate almost all toxic and biologically heavily decomposed substances (pesticides, phenols, aircraft fuel, the bacteria and protozoa). The most effective is the use of ozone together with hydrogen peroxide. If there were any restrictions for Tallinn inhabitant's water supply from Lake Ülemiste, the needs could be covered with the supply from wells, in some cases water has to be delivered by trucks.

HAZARDS ORIGINATING FROM HANDLING OF LIQUID FUELS AND CHEMICALS TRANSPORTED THROUGH TALLINN

Liquid fuels have to be considered the greatest hazard in Tallinn. Propane and butane are very flammable and can explode. Estonian Propane Ltd. is the enterprise where liquid propane, butane and their mixture are bought, sold and stored and gas cylinders are filled and transported. The development of emergency plans in Estonian Propane Ltd. is in the initial stage. The total amount of liquid fuels in the Estonian Propane Ltd. was 3900 tonnes in 2006. About 140 tank liquid fuel reservoirs contains 11 earth-level steel reservoirs with a capacity of 50 m^3, 4 earth-level steel reservoirs of 100 m^3 and 4 underground reservoirs of 4.2 m^3. All the reservoirs are interconnected and the work pressure is up to 16 bars. The filling of gas cylinders is carried out in a separate room. In 2006, 2340 tonnes of liquid fuel was pumped to gas cylinders. The same amount went to motor fuel reservoirs. Different kinds of accidents (gas in the air of the workroom etc.) are possible. Risk analysis and presentation of a plan for the prevention of accidents to Tallinn Rescue Department is badly needed.

The spectrum of chemicals carried through Tallinn is not exactly known. Chemical Act in Estonia was adopted in 1998. Chemicals Dealing Centre and Chemical Safety Commission have been established. Chemicals Dealing Centre has not yet all the information on chemicals transported through Tallinn, particularly on those handled in ports. Occupational Health and Safety Act (from 1999) and Chemical Act (from 1998) declare the necessity of risk analysis at workplace. The identification of chemicals, and exposure limits for the hazards in the work environment are determined. The regulations based on the Chemical Act list dangerous substances, procedures for the identification, classification, packaging and labelling of dangerous substances, procedures for recording dangerous chemicals in high-risk enterprises, the procedure for the export and import of banned and severely restricted chemicals, procedures for the export and import of banned and severely restricted chemicals, procedures for the preparation and submission of data sheets, safety reports and emergency plans in enterprises liable to be affected by a major accident, limitation of using detergents hazardous to the population and environment, restrictions on the use of dangerous substances.

HAZARDS FROM ROAD, AIR, SEA AND RAIL TRANSPORT

The main possible consequences of transport accidents are: loss of human lives, leakage from trailers containing dangerous substances, fires, explosions, pollution of the sea, earth, the air of towns and other settlements. As the industrial activities have diminished in Tallinn in recent years the main danger comes from petrol stations, boiler houses and liquid gas transport. The safety of petrol stations has not been investigated (they are often owned by foreigners). The Estonian regulation "Transport of dangerous goods on roads" (2009) was worked out on the basis of international rules (ADR). In the case of very dangerous substances (explosives, very toxic chemicals, and radioactive substances) the way for transport through Estonia and the capital has to be harmonized with the Estonian Rescue Board. The serious motor accidents are investigated by the Estonian Transport Policy Department. The number of victims in road accidents in Estonia has diminished in 2008 (Table 1), but too brave young male drivers, much too high speed for driving in bad weather conditions, accidents with pedestrians (among them with children) are still problems in traffic in Tallinn and all over Estonia.

Also the leakage of transport vehicles is highly possible, followed by environmental contamination, fires and explosions. Transportation of dangerous goods by road is regulated by legislation, but there are no rules for rail transport.

Tallinn Airport is situated very close to Lake Ülemiste from where inhabitants of Tallinn get their drinking water. The probability that a plane would fall into the lake is once in 40 years (The risk, 2001). The probability of a plane falling directly on the Chlorine Department in the territory of Tallinn Purification Centre is lower. Another hazard from the Airport is the contamination of the water of Lake Ülemiste with fuel pollutants as planes fly over the lake every day. This hazard is very small as ozone used for the purification of the water is very effective substance for the decomposition of fuel pollutants. The transport of dangerous substances by plane is restricted by the regulations of the Estonian Civil Aviation Administration.

The main goods transported by the sea (from and to the ports of Estonia) are petroleum, petroleum products and liquid gas (58% of all). Most of them go through 17 larger ports of Tallinn. For example, Tallinn Muuga Port has a reservoir for petroleum products with the capacity of 622,600 m^3. The probability that if there was large petroleum pollution in Paljassaare port (Tallinn) groundwater would be polluted is high, as groundwater is near the surface there. Estonian Maritime Administration regulates the transport of goods by the sea. Besides the *Estonia ship* catastrophe in 1994, the main accidents in sea transport for Estonia have until now been fires on ships.

The greatest problem for Tallinn is railway transport of goods through the town. By Railway Act (1999) the security zone in towns is 30 metres, outside of the

Table 1. Road transport fatal accidents n Estonia, 2002–2008 (Road safety, 2009)

Year	Fatal accidents on roads	Fatal accidents/ 10,000 inhabitants
2000	204	1.49
2001	199	1.46
2002	223	1.64
2003	164	1.21
2004	170	1.26
2005	169	1.25
2006	204	1.52
2007	196	1.46
2008	132	1.01

Table 2. Two variable risk matrix: definition of consequences (University of Melbourne, 2003)

Security level	Health and safety	Natural environment
V	Multiple fatalities, or significant irreversible effects to >50 persons	Very serious, long-term environment impairment of ecosystem functions
IV	Single fatality and/or severe irreversible disability (30%) to one or more persons	Very serious, long-term environment impairment of ecosystem functions
III	Moderate irreversible disability or impairment (30%) to one or more persons	Serious medium term environmental effects
II	Objective but reversible disability requiring hospitalization	Moderate, short-term effect, but not affecting ecosystem functions
I	No medical treatment required	Minor effects on biological physical environment

Table 3. Two variable risk matrix: definition and likelihood

Level	Descriptor	Descriptor	Indicative Frequency (expected to occur)
A	Almost certain	The event will occur on an annual basis	Once a year or more frequently
B	Likely	The event has occurred several times or more in your career	Once every three years
C	Possible	The event might occur once in your career	Once every ten years
D	Unlikely	The does occur somewhere from time to time	Once every thirty years
E	Rare	Heard of something like the occurring elsewhere	Once every 100 years

Table 4. Two variable risk matrix: consequnces and risk levels

	Consequences labels				
Likelihood Label	I	II	III	IV	V
A	Medium	High	High	Very high	Very high
B	Medium	Medium	High	High	Very high
C	Low	Medium	High	High	High
D	Low	Low	Medium	Medium	High
E	Low	Low	Medium	Medium	High

Table 5a. Three variable risk calculator

Consequence	C	Exposure	E	Likelihood	L
Catastrophe	100	Continuously	10	Almost certain	0
Disaster	50	Frequently	6	Likely	6
Very serious	25	Occasionally	3	Unusual but possible	3
Serious	15	Infrequent	2	Remotely possible	1
Important	5	Rare	1	Conceivable	0.5
Noticeable	1	Very rare	0.5	Practically impossible	0.1

Table 5b. Risk score = CxExL

Risk score	Risk rating
>600	Very high
300–599	High
90–299	Moderate
<90	Low

town – 50 metres. In Tallinn, houses are often situated in this zone. No regulation for transporting dangerous goods by railway has been adopted yet.

HAZARDS FROM NUCLEAR POWER STATIONS

Three nuclear power stations closest to Estonia (Ignalina, Sosnovy Bor, Loviisa) are at a greater distance than

Table 6. Risk levels of more dangerous activities in Tallinn

Risk level by two variable risk matrix					Risk level by three variable risk calculator			
Activity	Security level	Likelyhood level	Consequences level	Risk level	C	E	L	Risk score
Industry	III	B	III	High	25	1	3	75 Low
Water purification centre	III	D	I	Medium	15	2	3	90 Moderate
Liquid fuel centre	IV	C	IV	High	50	3	3	450 High
Rail transport through the town	V	B	V	Very high	50	2	3	300 High
Neighbouring nuclear power stations	V	C	II	Medium	25	3	3	125 Moderate

300 km and the possible direction of wind has to be considered, so the primary cloud of nuclear contamination would reach Tallinn not earlier than an hour and not later than 24 hours if there was leakage at a nuclear power station. The fall of the radioactive substances on the ground depends on the processes in the atmospheric air layers above the ground. Their reaching the ground depends mostly on the fallouts. Depending on the rainfalls the major part of the radioactive substances would fall on the ground and only the inert gases would go further. From this it is obvious why the distribution of radioactive pollution cannot be very strictly predicted although the movement of the radioactive cloud is. The final assessment of the danger from the nuclear power stations could be carried out only on the basis of measurements of the total level and nature of radioactive pollution near the nuclear power station itself. The nuclear contamination of the secondary cloud is rather small.

The hazards of ionising radiation in Estonia are regulated by the Radiation Act (1977). The measurements of beta, gamma and alpha illumination are carried out by the Radiation Protection Centre (established in 1997). On the basis of these measurements it is possible to assess the real danger for the population, the necessity for personal protective equipment and how large the contamination will be, even if the strict measurement results are not known yet. Near the Sosnovy Bor station Finnish and Swedish radiation pick-off stations are arranged besides the Russian measurement centres.

The measurements to assess the nuclear contamination of milk and drinking water are carried out by the Health Protection Inspectorate (HPI) of Estonia. The examination of food and water microbiology is carried out by the accredited laboratories of HPI.

CONCLUSIONS ON RISK ANALYSIS IN TALLINN TOWN

Risk assessment was carried out according to the method worked out in the University of Melbourne (2003). The two variable (Table 2–4) and three variable risk calculator (Table 5a, 5b) are possible to use for assessment of major hazards. The assessment of risk level previously presented hazards on humans; environment and property are presented in Table 6.

Using the two variable risk matrix, the greatest risk (very high) represents the transport of fuels and chemicals with railway through Tallinn town. The problem has been discussed for a long time (also in press), but in the crisis economic situation it is improbable that immediate actions are foreseen. Using the three variable risk calculator, both liquid fuel centre and rail transport through the town represent the same level of risk: high.

The value of human life is increasing in Estonia with the increase of the quality of life. There is a space yet to gain the developed European countries. The research work in prevention of major hazards has to be improved. The new projects in Tallinn University of Technology (Institute of Chemical Engineering) are planned.

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