International Journal of Environmental Sciences
Vol. 6 No. 2 (December, 2020)

ON THE SPACE ACTIVITIES AT THE BAIKONUR COSMODROME AN APPROACH TO AN INTEGRATED ENVIRONMENTAL ASSESSMENT

Lars Carlsen
Awareness Center, Hyldeholm 4, Veddelev, DK, Roskilde, Denmark,
LC@AwarenessCenter.dk

Bulat N. Kenessov, Svetlana Ye. Batyrbekova &
Mikhail K. Nauryzbayev
Center of Physico-Chemical Methods of Investigations and Analysis of
al-Farabi Kazakh National University, 95A, Karassai batyr str, Almaty, Kazakhstan

Abstract: *An integrated environmental assessment of the space activities at the Baikonur Cosmodrome in Kazakhstan is presented applying the DPSIR (Driving forces, Pressures, State, Impacts, Responses) framework. It is verified that both nationally and internationally based driving forces prevail comprising scientific, commercial and economic factors. The main pressures to the environment and thus eventually to man are of chemical nature although also physical pressures are disclosed. Studies based on several field trips and subsequent chemical and biological analyses have disclosed severe alterations of the environment and further suggest an increased level of diseases among residents close to the fall of the separated burned-out rocket stages. The impacts to the environment and thus to humans due to direct or indirect contact with residual rocket fuel and its transformation products have been disclosed and preliminary theoretical studies suggest severe adverse effects from a series of these compounds to environmental species as well as to humans. The paper discusses possible responses to diminish and eventually eliminate the undesired impact to environment and humans by residual rocket fuel and its transformation products.*

Keywords*: DPSIR, Integrated Environmental Assessment, Space activities, Rocket fuel, 1,1-dimethyl hydrazine, Heptyl, Transformation products.*

1. INTRODUCTION

The Baikonur Cosmodrome has over the years been an important site for rocket launching and up to now more than 2 thousand launches of different rocket-carriers was launched from here and today the Baikonur Cosmodrome plays an important role in the building of the International Space Station (ISS). It should be noted that in contrast to other countries Russia, China and Kazakhstan–launch rockets from land based space centers. This potentially exposes both the environment and the population to health problems due to the spread of harmful substances as well as scrap material.

The area northeast of the Baikonur Cosmodrome in Kazakhstan functions as dropping zone for burned-out first stages of the rocket. These dropping zones are found in the river basins of the rivers Nura, Ishim and Irtysh in Kazakhstan and in the river basin of the river Ob in southern Siberia. Major Kazakh cities as Astana and Pavlodar as well as the Russian city Novosibirsk are found within these areas [1].

Although the fall of the burned-out first stages takes place from a height of 50 and 100 km it is accompanied by a spill of unburned rocket fuel in the amount from 0.6 to 4 tons of 1,1-dimethyl hydrazine and about 4 tons of nitrogen oxidants [2]. However, only minor parts, 10-30 kg, eventually reach the ground and subsequently being spread over an area of several square kilometers of land, where it either evaporates and/or penetrates into the soil [2,3]. However, especially by rocket launches during the cold winter season significant higher amounts of the unburned rocket fuel may reach the ground [4].

The Baikonur Cosmodrome territory covers more than 6.700 km^2 and more than 45.000 km^2 of the Karaganda, Akmola, Pavlodar and East Kazakhstan oblasts are subject to the negative influence of 22 fall regions of falling parts of the burned-out rocker-carriers first stages. Initially trajectories and fall places were selected to include only so-called "unproductive" lands, such as poorly inhabited steppe, semi-deserts and deserts areas without taking the fragility and uniqueness of these areas were into account. By their ecological condition the fall areas are referred to as "zones of ecological disaster" and covers more than 7.700.000 km^2 [1] comprising pastures, hayfields and tillages, as well as forests, reservoirs, recreational and protected natural territories and monument of cultural interest. Further, industrial enterprises, cities electric power stations, railways, big rivers and channels located in the vicinity of the fall regions are potentially subject to impact of falling rockets.

The pollution of the Kazakh territories with rocket fuel and the transformation products of the residual fuel is currently being intensively investigated [3,5] disclosing contamination at more than 1000 sites where burned-out rocket stages had dropped more than 20 years ago. Recent studies [3] have demonstrated that some soils are heavily contaminated with the 1,1-dimethyl hydrazine the concentrations ranging up to 1000 mg kg^{-1} dry soil. Hence, the activities at the Baikonur Cosmodrome have over the years have resulted in a significant pollution of various sites in Kazakhstan with the rocket fuel 1,1-dimethyl hydrazine [3,6] as well as a series of transformation products of the primary fuel [5,7,8].

In the present study, we present an attempt towards an integrated environmental assessment with the DPSIR framework [9] as the method of choice.

2. METHODS

The DPSIR (Driving forces, Pressures, State, Impacts, Responses) framework takes into account a chain of past and present situations as well as suggests future activities as responses aiming at improving the environmental health.

2.1 Driving Forces

The driving forces are centered on economic sectors and human activities, i.e. activities in the society that directly or indirectly are causing the pressures on the environment. Roughly speaking the driving forces can be classified as those creating the nuisance and those consuming resources. Thus, in broad terms driving forces comprise population, economy, land use and societal development. More specific examples of driving forces comprise manufacturing and Industry, energy production, transport systems, agricultural activities, fisheries, households and consumers and waste treatment, the list by no means being exhaustive.

In sum driving forces can be regarded as 'needs' for individuals, industry or society.

2.2 Pressures

The impact (pressure) on the environment develops from the human activities that are associated with meeting the above mentioned 'needs' (driving forces). Thus, the pressures are results of production or consumption processes, such as non-sustainable use of resources, changes in land use, and direct and indirect emissions of chemicals, waste, etc to air, water and soil.

2.3 State

The state refers to the environmental and human health as a result of the pressures. Hence, the state comprises a combination the physical, chemical and biological quality of the various environmental compartments, i.e., soil, water and air, as well as their mutual interplay with respect to, e.g., the biodiversity, vegetation water and soil organisms within a specific ecosystem, a specific type of landscape, a given population etc.

2.4 Impacts

The impacts refer to environmental and economic factors. Thus, the possible changes in the physical, chemical or biological states may unambiguously cause impacts on the environmental and human health, e.g., as a result of increasing concentrations of hazardous chemicals in the environment and eventually on both the economic and social performance of society.

Ultimately the impacts focus on changes in the human welfare comprising both physical and mental health as a result in changes in the quality, e.g., state, of the environment. However, also the possible changes in the environmental health due to changes in the physical, chemical and/or biological state may be covered here.

2.5 Responses

The responses comprise *a priori* the reactions by authorities, regulators or society in general to the changes induced through the other element in the DPSIR chain. Thus, responses could comprise both passive and active measures. Hence a passive measure, relating to driving forces could be initiatives, to change people's transport pattern from private cars to public transportation by making zones where private cars are not allowed, whereas an active measure would be an increase of taxes on gasoline to motivate people to use alternative modes of transportation.

Responses related to pressures would be various regulations aiming at a reduction of the emissions of hazardous chemicals to the environment, whereas responses related to state would comprise, e.g., cleaning up or remediation projects of contaminated land.

It is noted that basically all responses are caused by the impact element. Impacts are results of possible changes in driving forces, pressures and/or state. Obviously, if no changes in these element and thus no chances in impacts, imposing responses as the above mentioned can not be argued.

In Figure 1, the complete DPSIR framework is visualized.

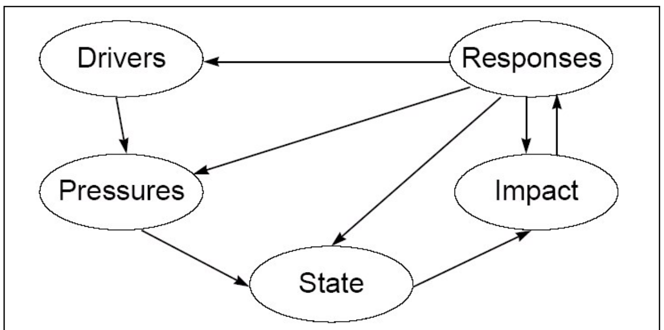

Figure 1: The Interrelation between the Single Elements in the DPSIR Framework (Adopted from [9])

3. RESULS AND DISCUSSION

The DPSIR model as framework for an integrated assessment, in the present case of the space activities at the Baikonur Cosmodrome constitutes an advantageous tool to elucidate the causality of the links between the single elements as illustrated by the arrows in Figure 1.

Obviously the driving forces are the most fundamental in the assessment as these activities are the actual source of the environmental, and thus eventually human health problems and a possible removal of these activities will unambiguously diminish or, in the long run possible eliminate the problems. It should in this context be noted that in some cases it might be difficult to have a clear boundary between, e.g., driving forces and pressures or between state and impacts. However, as will be seen from the following this is only to a minor extent true looking at the actual example of the space activities at the Baikonur Cosmodrome.

3.1 Driving Forces

In relation to the space activities at the Baikonur Cosmodrome 3 major driving forces have been disclosed, 2 of those being directly related to Kazakhstan and 1 related to Russia and the international community.

Space activities are one of the most important and fast growing industries all over the world and one of the largest space centers, i.e., the Baikonur Cosmodrome, is located in Kazakhstan. In 2005 Kazakhstan initiated the State Program "Development of Space Activity" [10].The main objective of the program is to become one of countries being able to launch rockets into the space, which obviously constitute a major driving force. Hence, for development of space activities the Kazakh government allocated KZT11 billion corresponding to ca. m$ 100 for 2009 [11].

Secondly, the current use of the Baikonur Cosmodrome by Russia constitutes a major source of income for Kazakhstan. Thus, the contract between Kazakhstan and Russia about the rent of cosmodrome till 2050 gives Kazakhstan m$115 in addition to further m$50 for the development of Baikonur town [12]. Thus, the financial aspects obviously constitute a second major driving force.

The third major driving force is closely connected to both Russian and international interests. Thus, the Baikonur Cosmodrome provide unique possibilities for launching heavy cargo carriers, like of the Proton type that allow bringing up to 22 tons of cargo into the space [4] and as such constitute one of the sites from which cargo are brought to the International Space Station, ISS [13].

It appears obvious that a removal of the activities constituting the major driving forces will apparently not immediately be an option for reducing or eliminating environmental and thus human health impacts neither in the short nor in the long run. Thus, the negative environmental effects of rocket launchings is increasing as inter-national interest and it is expected that the problems associated with toxic rocket propellants will increase in future years [14].

3.2 Pressures

The pressures to the environment can immediately be divided into physical and chemical pressures, the latter being subdivided into pressures on the atmospheric, aquatic and terrestrial compartments, respectively. Both types of pressures a related to the launching of the rockets and the subsequent fall of the burned-out first and second stages.

The physical pressures to the environment as associated with the fall of scrap rocket part creating physical changes in the landscape. Thus, the fall of the first stages typically results in craters of ca. 1 m depth and ca. 5 m diameter [4]. However, it should in this context be remembered that special situations, due to unforeseen accident may significantly increase both the physical and the chemical pressures. Hence, following the accident with a Proton-M rocket in Sept. 2007 a crater (epicenter) of 45 m in diameter and 20 m depth was developed [15]. Further scrap parts of the rocket were spread up to 15 km from the epicenter [16].

The chemical pressures are obviously closely connected to the rocket fuel, 1,1-dimethyl hydrazine (UDMH) and the oxidizing agent dinitrogen tetraoxide (N_2O_4), the latter being a problem only in relation to atmospheric dispersion during the launching and to a minor extent during the fall of the burned-out first stage.

Krasnov, Drobzheva and coworkers [17,18,19] attempted to develop a model to describe the atmospheric dispersion following accidental crashes of Proton rockets focusing on the fate of the cloud of UDMH being formed during the explosion. The concentrations of UDMH being several orders of magnitude higher than maximum allowed concentrations (*vide infra*). It was disclosed that the extension of the cloud may be tens of kilometers the value being further increased by dispersive forces. It is should be noted that the model, due to the lack of exact input parameters.

The pressures to the terrestrial and aquatic environment arise following the separation of the first and later the second burned-out stages of the rockets taking place in approx. 50 and 150 km heights, respectively in the case of Proton flights. Heavy rocket carriers like the Proton and the Dnepr rockets use the highly toxic UDMH, also known as heptyl, as fuel and N_2O_4 as oxidizing agent. Following separation and the subsequent fall of first burned-out stage, up to 2 tons (depending of season) of residual UDMH is discharged onto the surface [2,3,4]. As a consequence both the aquatic and the terrestrial environments within the fall regions are thus polluted with the highly toxic UDMH (**1**) [6] as well as with its potentially equally toxic transformation products (2 – 18) (Figure 2) [8].

Especially during the cold winter season the discharge to the environment are high due to a significantly reduced evaporation of UDMH. Under these circumstances especially discharged to, e.g., rivers and water courses appear as problematic as the fall in such cases will not be accompanied by explosions that could diminish the amount of discharged UDMH.

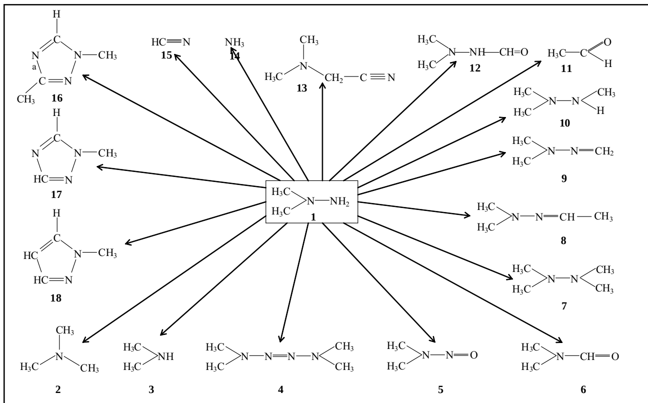

Figure 2: Transformation of 1,1-dimethyl Hydrazine (UDMH) in Soil and Water

As was the case with the above mentioned physical pressure accidents may significantly increase the pressures of all environmental compartments. Thus, the crash of a heavy Dnepr rocket, fueled with 40 tons of UDMH, only 74 seconds after the launch from the Baikonur Cosmodrome in July, 2006 [20,21] and, even worse, the accident with a Proton-M rocket in Sept. 2007 where 218 tons of UDMH was released to the environment [16] accentuates the need for further work in order eventually to reduce, or possibly eliminate the pressures to the environment and thus eventually to the human health of residents within or close to the fall regions as a result of the space activities at the Baikonur Cosmodrome.

It is worthwhile in this connection to point to the fact that such special situations, i.e., big accident leading to increased both physical and chemical pressures typically occur for 3-4% of the launches for the Proton carriers [4]. Some authors state the accident rate as high as close to 10% [22].

3.3. State

Over the years more than 2000 rocket launches have taken place from the Baikonur Cosmodrome and during a more than 40 years period more than 330 launches of rockets of the Proton type of with a success rate of approx. 96% [13].

In Kazakhstan several fall regions have over the years been used for separated of "Proton" rockets. Presently fall regions named 25,15 (ca. 1600 km^2) and 148 (Ca. 1200 km^2) are the preferred sites for landings of the separated burned-out stages of the Proton rockets.

Officially, fall regions are closed regions, but in practice the local population often uses these sites for grassing areas for their livestock. However, these areas appear partially heavily polluted. Thus, recent studies [3] disclosed that within the fall region 25,15, located to the south-west of Zhezkazgan, some spots contains UDMH in concentrations up to 1000 mg/kg.

Studies of the UDMH distribution in the soil horizons showed the presence of the latter in depths down to 1.5 m, probably as a result of the high water solubility and migration potential of UDMH [6].

Studies of old fall places (up to 30 years old) disclosed the presence of UDMH, which *a priori* is surprising [6]. However, very low moisture content and possibly diminished microflora may well cause an apparent very high stability of UDMH in these soils.

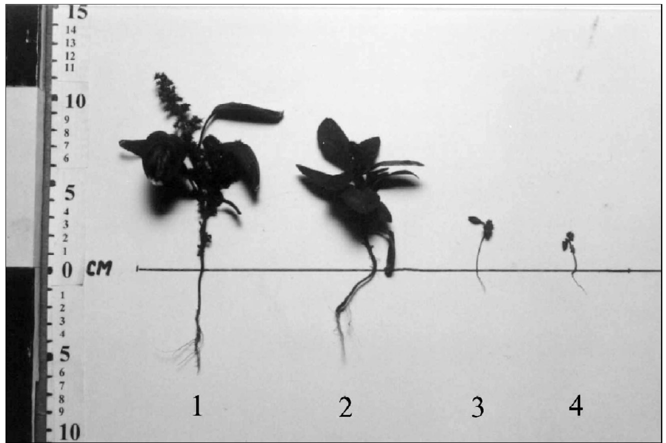

Figure 3: Amaranthus Caudatus L. at Different Concentrations of 1,1-dimethyl Hydrazine: 1- the Reference; 2 – 0.68 mg/kg; 3 – 9.8 mg/kg; 4 – 10.5 mg/kg

3.4 Impacts

The undesired discharge of residual UDMH and the subsequent generation of its transformation products (Figure 2) may obviously cause significantly impact to the environment as well as to the human health.

Obviously, the impact from the falls, like the above discussed pressures, can be divided into a physical and a chemical part. The physical impacts leading to smaller or larger changes in the landscape shall not be further discussed here.

It should be mentioned that potentially the distribution of scrap metal parts in the environment *a priori* constitute a source of metal pollution. However, presently no specific information on this appears available.

The chemical impact on the environment by residual rocket fuel has been disclosed experimentally. Biological studies within the fall regions have disclosed that the flora apparently is affected by the pollution with residual rockets fuel. Thus, decreased growth rate, changes in leaves and plant organs have been noted [3]. Further significant concentration of UDMH, up to 5 mg/kg, in plant tissue have been detected [3]. An illustrative example is given in Figure 3.

In a series of publications the possible environmental impact by UDMH and its transformation products have been studied theoretically applying Quantitative Structure-Activity/Toxicity Relationships (QSAR/QSTR) [6,8].

In a recent study Carlsen *et al.,* [6] presented a preliminary assessment of the potential environmental impact of UDMH as a result of space activities. It was concluded that UDMH especially in dry soils as found in the Kazakh steppe, appear to be persistent due to the lack of biodegradation of the compound. It should be noted that a massive pollution with UDMH may well significantly reduce or even erase the micro flora thus causing the apparent persistency [3].

It has been shown that some abiotic degradation pathways, primarily through oxidative degradations/transformations have been reported [3,6,8] resulting in a variety of degradation/transformation products (cf. Fig.3). In a further elaborate QSAR/QSTR study Carlsen et al. [8] presented a preliminary screening of the potential environmental impact of both UDMH (1) as well as of the secondary pollutants arising from a primary pollution with residual UDMH (2–18).

Here it was shown [8] that both UDMH as well as its transformation products possess a significant migration potential.

Based on their calculations Carlsen et al. [8] concluded that both UDMH as well as the transformation products *a priori* are rapidly biodegraded within weeks in the aerobic environment. It was further found that a series of the studied compounds (1–18) are anaerobically biodegradable. As mentioned above it should be emphasized that a significant primary pollution with 1,1-dimethyl hydrazine may well erase the microbial activity thus prolonging the half lives of the compounds significantly.

It all cases it was found that the compounds (1– 18) have rather high water solubilities up to 1 g/L and correspondingly low octanol-water partitioning coefficients. In agreement with this it could be concluded that none of the studied compounds appear to be bioaccumulating [6,8].

Studies on the possible volatilization of UDMH [6] from water surfaces and from moist soils are not unequivocally conclusive. However, the authors point out that the possibility should not immediately be excluded. On the other hand, it appears clear that due to the high vapor pressure of UDMH may be volatilized from dry soils the resulting air-born concentration subsequently being subject to atmospheric dispersion governed by the atmospheric conditions prevailing locally (Carlsen *et al.,* 2007). Thus, within the borders of the fall region air-born concentrations of UDMH exceed prevailing exposure limits are predicted, whereas only the minimum level risk, MLR value of $2x10^{-4}$ ppm, corresponding to 0.5 $\mu g/m^3$ [23], may be exceeded in significant distance from the fall region [6]. As the transformation products in general exhibit high to medium high vapor pressures [8] these conclusions seems prevailing for these compounds as well. Previous attempts to model the dispersion of UDMH during accidental situations disclosed UDMH clouds of extensions of more than 10 kilometers (*vide supra*) [17].

UDMH appears to be toxic to aquatic species exhibiting chronic toxicity levels below 1 mg/L [6,8]. Concerning the transformation products (cf. Figure 3) it appears that substances with an intact hydrazine structure or hydrazones display a toxicity that indicate that transformation products of these types may contribute to the overall environmental toxicity of residual rocket fuel as these compounds display toxicities comparable or even higher than the toxicity of the primary pollutant [8].

Obviously the actual impact on the environment is depending on the amount of UDMH originally discharged to the environment and subsequently the amount of transformation products being formed. In a recent paper [24], the acceptable environmental loadings to the aquatic and the terrestrial environment of UDMH and its transformation products to the environment have been addressed based on the assumption that the risk characterization ratios, RCR, for the single compounds in no cases should exceed 1 as, roughly speaking, substances displaying RCR, i.e. the ratio between the predicted environmental concentrations, PEC, and the predicted no effect concentration, PNEC, below 1 are regarded being of no immediate concern, whereas in the case of substances with RCR values above 1 a priori are of concern and risk reducing measures are to be brought into force [25]. The estimated maximum loadings for the single compounds are displayed in Table 1 [24].

In agreement with the above, acceptable environmental loadings for the compounds 1, 7, 8, 10 and 12, all possessing hydrazine or hydrazone structures to the aquatic environment appear to be less than 10 kg/year in order to comply with the requirement that the RCR should not exceed 1 at any time or point. For compound 9, also possessing hydrazone structure the acceptable loading is estimated to be 47.2 kg/year. For the remaining 11 substances higher maximum environmental loadings apparently prevails.

Table 1
Acceptable Environmental Loading of UDMH and its Transformation Products (cf. Figure 3) to the Aquatic and Terrestrial Environment, Respectively,

ID	T_{max} *(kg)Aquatic*	T_{max} *(kg)Terrestrial*
1	7.7	1.0
2	136.7	13.5
3	990.6	87.1
4	2324.6	166.1
5	285.4	72.3
6	122641.5	1961.3
7	10.1	2.3
8	7.7	3.6
9	47.2	12.0
10	8.9	1.7
11	4198.1	42.4
12	8.4	0.3
13	279.4	18.6
15	32122.6	576.4
16	3281.8	5128.9
17	6242.6	6015.5
18	1843.0	194.7

For the terrestrial environment the maximum acceptable loadings in general appears to be somewhat lower. Thus, the acceptable loadings for the hydrazine or hydrazone structure containing compounds 1, 7, 8, 10 and 12 are estimated to be less than 10 kg/year, whereas for compounds 2, 9, 11 and 13 acceptable loadings apparently are somewhere between 10 and 50 kg/year For the remaining 8 compounds somewhat higher loadings apparently prevails.

Taking in account the actual discharge of residual UDMH to the aquatic and terrestrial environment (*vide supra*) it appears immediately highly likely that the acceptable environmental loading for the more toxic compounds may be exceeded following the falls of the burned-out first stages of the rocket carriers.

Turning to the possible impacts on human health, recent studies from the Karaganda and Kyzyl-Orda oblasts are available. It was disclosed that the population within these two oblasts displays a statistically significant higher rate of diseases than normal average [26]. Further, studies of human health impact were conducted within the Altai region where the burned-out second stages of the Proton carriers fall. It was disclosed that the population, in comparison with the population in non-affected regions, have a higher level of deceases of digestive system [27]. Although not proved, this can potentially be ascribed to the environmental pollution with residual UDMH.

In the study by Carlsen *et al.*, [6] a preliminary assessment of the potential human health impact of UDMH was presented. Hence, on this study and by comparison to available experimental data it was concluded that UDMH should be considered carcinogenic, mutagenic, convulsant, teratogenic and embryotoxic in addition to the general toxic characteristics including respiratory effects, nausea, vomiting, neurological effects, pulmonary edema, liver injury etc. [6 and references therein].

Carlsen *et al.* [28] further reported on a QSAR/QSTR approach to the potential human health impacts as a result of environmental discharge of UDMH and subsequently its transformation products.

The studies revealed that the compounds apparently all are readily bioavailable a significant part of the substances being found as the free species in the systemic circulation. As the compounds apparently do not to undergo significant 1st pass metabolism [28] accordingly concluded that the compounds may move freely throughout the body and perpetrate its biological effects.

Apart from N-nitroso dimethylamine none of the compounds (1–18) studied are predicted to exhibit any significant acute toxicity [28]. However, several adverse organ specific human health effects are predicted including damages on the blood, cardiovascular and gastrointestinal systems as well as in the kidney, liver and lungs (Table 2). Further several of the compounds are predicted to exhibit high probabilities for being carcinogenic, mutagenic, teratogenics and/or embryotoxic (Table 3).

A subsequent ranking of the compounds applying partial order ranking methodologies [29,30] disclosed the seven compounds that on a cumulative basis should receive the major attention to be 5 = 4 > 10 > 8 > 1 > 12 > 9 [28].

3.5 Responses

The immediate response would be to invoke the precautionary principle [31 and references therein]. In a German suggestion for an extension of the DPSIR principle [32] it was suggested that the precautionary principle should be invoked thus tricking responses directly acting on the driving forces and/or the pressures (Figure 4).

As mentioned above, it is obvious that responses comprising elimination of the driving forces and thus the subsequent pressures apparently will not

Table 2
Predicted Probabilities for the Compounds to Exhibit Positive Ames Test and Adverse Organ Specific Health Effects (Carlsen *et al.*, 2009b). (na denotes that Calculated Values are not Available)

		Probability for adverse health effects[b]					
No	*Probability for positive Ames test*[a]	*Blood*	*Cardio-vascular*	*Gastro-intestinal*	*Kidney*	*Liver*	*Lungs*
1	0.899 IC	0.57	0.40	0.65 T	0.28	0.48 T	0.34 T
2	0.266 N	0.44	0.34	0.80	0.20	0.18	0.27
3	0.258 N	0.20	0.31	0.26	0.11	0.20 T	0.20
4	1.000	0.79	0.07	0.92	0.57	0.85	0.74
5	0.999 P	0.76	0.06	0.97	0.75 T	0.93 T	0.71 T
6	0.367 N	0.27	0.12	0.65	0.14	0.05	0.40
7	0.631	0.52	0.33	0.83	0.19	0.10	0.17 T
8	0.864	0.63	0.06	0.84	0.31	0.05	0.75
9	0.848	0.32	0.08	0.90	0.42	0.07	0.72
10	0.757	0.53	0.64	0.66	0.14	0.29 T	0.29 T
11	0.327 N	0.19	0.08	0.25	0.09	0.04 T	0.04 T
12	0.840	0.48	0.14	0.71	0.15	0.28	0.42
13	0.219	0.47	0.21	0.89	0.18	0.12	0.47
15	0.137 N	0.10	0.08	0.81	0.09	0.05	0.27
16	0.187	0.14	0.02	0.46	0.03	0.06	0.04
17	0.102	0.12	0.02	0.46	0.07	0.02	0.05
18	0.193	0.08	0.02	0.36	0.04	0.02	0.05

[a] P, N, IC denote positive, negative and inconclusive experimental results
[b] T denotes that tumors have been found in experimental studies

Table 3
Predictions of Selected Biological Activities[a] (Carlsen *et al.*, 2009b)

No	*Carcinogenic*	*Mutagenic*	*Teratogenic*	*Embryotoxic*
1	0.955 (0.002)	0.762 (0.006)	0.689 (0.031)	0.672 (0.016)
2	0.619 (0.001)	NE	NE	0.527 (0.043)
3	NE	NE	0.563 (0.062)	NE
4	0.894 (0.003)	0.792 (0.005)	0.946 (0.006)	0.816 (0.007)
5	0.980 (0.001)	0.969 (0.002)	0.952 (0.005)	0.866 (0.005)
6	0.951 (0.002)	NE	0.614 (0.048)	0.795 (0.009)
7	0.827 (0.006)	0.539 (0.010)	0.698 (0.030)	0.604 (0.026)
8	0.980 (0.002)	NE	NE	NE
9	0.683 (0.012)	NE	NE	NE
10	0.923 (0.006)	0.619 (0.007)	0.811 (0.012)	0.681 (0.015)
11	0.628 (0.011)	NE	NE	NE
12	0.897 (0.003)	0.524 (0.011)	0.530 (0.072)	NE
13	NE	NE	NE	NE
15	NE	NE	NE	NE
16	NE	NE	NE	NE
17	NE	NE	NE	NE
18	NE	NE	NE	NE

[a] Values given are the calculated probability for the compounds to exhibit the effect (only values above 0.5 is given). Values in parentheses are the calculated probabilities for the compounds for not exhibiting the effect.
NE indicates that if the compound exhibit the effect the probability will be below 0.5.

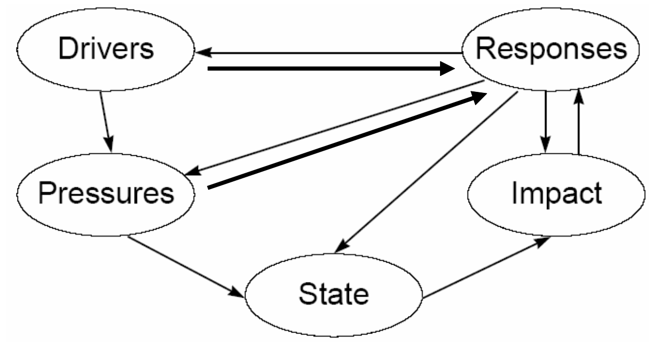

Figure 4: The Interrelation between the Single Elements in the DPSIR Framework Including the Interactions Based on the Precautionary Principle (Adopted from [32])

constitute an option, even though with reference to the precautionary principle [32] this obviously would be the primary choice. Thus, it appears appropriate to look for suitable responses to "states" and "impacts", respectively.

With reference to the above sections the responses to "states" and "impacts" eventually securing environmental and human health should in the short run comprise:

- Development of appropriate remediation and/or clean-up strategies
- Recommendations to residents close to fall regions with respect to precautions to be taken in order to avoid accidental contact, directly or indirectly, with the pollutants.

However, it is clear that a scientifically more comprehensive background for this is necessary. In order to achieve this, we suggest further responses to comprise:

- Setting up appropriate environmental and human health monitoring systems.
- Development of appropriate analytical methods for selected compounds (cf. [8,28]) complying with the monitoring system.
- Performance of appropriate experimental toxicological studied on selected transformation products (cf. [8,28]).
- Development of appropriate predictive tools for the environmental and human health impact such as geographical information systems (GIS) possibly in combination with ranking techniques like partial order ranking tools.

4. CONCLUSIONS AND OUTLOOK

The present paper presents an integrated environmental assessment of the space activities at the Baikonur Cosmodrome in Kazakhstan applying the DPSIR (Driving forces, Pressures, State, Impacts, Responses) framework, the eventual objective to formulate a series of responses that both in the short and in the long run will secure the environmental health of the areas as well as the human health of residents living within or close to the fall regions of the separated burned-out rocket stages.

It is concluded that although *a priori* the most effective responses would be a reduction or even stopping of the activities, at least until further scientific information has been achieved, this will in practice not be a operational option. Hence, we suggested a series of appropriate responses including development of remediation technologies, recommendations to residents, setting up monitoring systems, development of analytical techniques, conduction of toxicological studies and developing appropriate predictive tools.

Based on the preliminary studies on the possible environmental impact [6,8,24] we strongly suggest that further attention should be given to the products containing hydrazine structure, i.e., tri- and tetramethyl hydrazine and 1-fomyl 2,2-dimethyl hydrazine as well as to the hydrazones of formaldehyde and acetaldehyde.

In relation to the potential human health impact [28] the same compounds obviously need further attention in addition to the tetramethyl tetrazene (4) and the N-nitroso dimethyl amine (5).

Finally, it should be remembered that a series of other cosmodromes for land-based rockets launches and thus fall places are located in Kazakhstan, Russia and China. However, at least in Kazakhstan and Russia the majority of activities in these facilities are of military nature and as such only very limited information is available. Nevertheless, it can be expected that these activities lead to similar environmental and human health impacts as those from the Baikonur activities but they are not as such part of the present study.

Acknowledgements

The authors are grateful to ISTC (International Science & Technology Center) for financial support through the projects K-451.2 and K-1482, respectively.

Further the authors are grateful to the National Environmental Research Institute at Aarhus University, Denmark for making the OML Multi model for studying atmospheric dispersion available.

References

UNDP, Environment and Development Nexus in Kazakhstan. Publication in Support of the Millennium

Development Goals. Goal 7: Ensure Environmental Sustainability. UNDPKAZ 06, 2006.

Nauryzbaev, M. K., Batyrbekova, S. E, Tassibekov, Kh. S., Kenessov, B.N., Vorozheikin, A.P., Proskuryakov, Yu.V. (2005), Ecological Problems of Central Asia Resulting from Space Rocket Debris, In: History and Society in Central and Inner Asia, Toronto Studies in Central and Inner Asia, No. 7, Asian Institute, University of Toronto, Toronto, 327-349.

System Analysis of Environmental Objects in the Territories of Kazakhstan, which Suffered Negative Influence Through Baikonur Space Port Activity, Final Technical Report of ISTC K451.2, Center of Physical-Chemical Methods of Analysis, al-Farabi Kazakh National University in Almaty, Kazakhstan 2006.

Adushkin, V. V, Kozlov, C. I., Petrov, A. V. (2000), Ecological Problems and Risks of Rocket-space Techniques Impacts on Environment, Ankil, Moscow.

Development of Effective Methods of Analysis of Environmental Objects Contaminated with Rocket Fuel Components and Creation of a Scheme of High-Sensitive Biosensor Module for the Presence of Mutagens, 1st Quarterly Technical Report of ISTC K-1482, Center of Physical-Chemical Methods of Analysis, al-Farabi Kazakh National University in Almaty, Kazakhstan, 2008.

Carlsen, L., Kenesova, O. A., Batyrbekova, S. E. (2007), A Preliminary Assessment of the Potential Environmental and Human Health Impact of Unsymmetrical Dimethylhydrazine as a Result of Space Activities, *Chemosphere*, 67, 1108-1116.

Kenessov, B., Batyrbekova, S., Nauryzbayev, M., Bekbassov, T., Alimzhanova, M., Carlsen, L. (2008), Gas Chromatography with Mass-Spectrometric Detection for Determination of 1-Methyl-1H-1,2,4-Triazole in Soils Affected by Rocket Fuel Spills in Central Kazakhstan, Chromatographia, 67, 421-424

Carlsen, L., Kenessov, B., Batyrbekova, S.Ye. (2008), A QSAR/QSTR Study on the Environmental Health Impact by the Rocket Fuel 1,1-dimethyl hydrazine and its Transformation Products, Environ. Health Insights, 2008:1, 11-20 (available online: *http://la-press.com/article.php?article_id=913) (accessed Oct. 2008).*

Kristensen, P. (2004), The DPSIR Framework, Paper Presented at the 27-29 September 2004 Workshop on a Comprehensive/Detailed Assessment of the Vulnerability of Water Resources to Environmental Change in Africa Using River Basin Approach. UNEP Headquarters, Nairobi, Kenya.

http://enviro.lclark.edu:8002/servlet/SBReadResourceServlet?rid=1145949501662_742777852_522 (accessed Oct. 2008).

Akorda, The Decree of the President of Kazakhstan. About the Development of Space Activities in the Republic of Kazakhstan, 2005. *http://www.akorda.kz/www/www_akorda_kz.nsf/BF9128A751A461F6462572340019E5EA/$FILE*/О%20развитии%20космической%20деятельности%20в%20Республике%20Казахстан%20на*%202005.doc (accessed Oct. 2008).*

Kazakhstan Today, for Development of Cosmos Activity in 2009 it is Allocated KZT11 billion, 2008. *http://eng.gazeta.kz/art.asp?aid=117523* (accessed Oct. 2008)

Pavlodar, Legislation of Kazakhstan on-line. Contract of Rent of Baikonur Cosmodrome between Government of the Republic of Kazakhstan and the Government of the Russian Federation, 1994. *http://www.pavlodar.com/zakon/?dok=03238&all=all* (accessed Oct. 2008)

Wikipedia, Proton Rocket, 2008. *http://en.wikipedia.org/wiki/Proton_rocket* (accessed Oct. 2008).

Nature, Rockets in Russia's Back yard, 1995, 433, issue 7022, 91.

Nakanune, Around the Crater from the Fall of "Proton-M" Sample Take of a Ground and Search for Fragments. The PHOTO, 2007. *http://www.nakanune.ru/news/2007/09/07/292923* (accessed Oct. 2008).

Nakanune, In the Moment of "Proton" Fall, Fuel Tanks Contained 218 tons of heptyl, 2007. *http://www.nakanune.ru/news/2007/09/06/292745* (accessed Oct. 2008).

Drobzheva, Ya.V., Krasnov, V. M., Suimenbayev, B. T. (2003), A Problem of Prediction of the Place of Fall of Sprayed Rocket Fuel Components during Accidental Situation, The Bulletin of KazNU. Chemical Series, 31/3, 110-114

Krasnov, V. M., Suimenbayev, B. T. (2006), Evolution of Dimethylhydrazine Drops in Cloud Formed during Explosion of Rocket-carrier. Proceedings of Natl. Academy of Science of the Republic of Kazakhstan, Physico-mathematical Series, 4, 79-84.

Drobzheva, Ya.V., Krasnov, V.M. (2006), Evolution of Toxic Cloud Formed during Explosion of Rocket-carrier. Proceedings of Natl. Academy of Science of the Republic of Kazakhstan, Physico-mathematical Series, 4, 74-79.

Eurasia Daily, Moscow and Astana at Odds Over Russian Rocket Crash, 2006. *http://jamestown.org/edm/article.php?article_id=2371363* (Accessed Oct. 2008).

Gazeta, Heptyl Concentrations on "Dnepr" Crash Site by far above Norm–Ministry of Emergency, 2006. *http://eng.gazeta.kz/art.asp?aid=78496* (accessed Oct. 2008).

Semenov, V., Argutinsky, D., Yakshin, Yu., Kozyrev, A., Medvedeva, Yu., Orbital kompleks "Mir" 1986-2001, Rosaviakosmos, Moscow, 2001.

ATSDR, Toxicological Profiles for Hydrazines, U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, Public Health Service, Agency for Toxic Substances and Disease Registry, 1997. *http://www.atsdr.cdc.gov/toxprofiles/tp100.pdf* (Accessed Oct. 2008).

Carlsen, L., Kenessov, B., Batyrbekova, S.Ye. (2009), An Assessment of Acceptable Environmental Loadings of

1,1-dimethyl Hydrazine and its Transformation Products, Submitted for Publication.

Denehurst, Chemical Safety Report (CSR), Denehurst Safety Ltd, 2008. *http://www.denehurst.co.uk/id28.html* (accessed Oct. 2008).

Belonog, A. A., Zhubatov, Zh. K., Kozlovskiy, V. A., Mukhatedzhanov, E.K., Murzanova, R. S., Bariyeva, B.Sh., Magomadov, A.M. (2007), Sanitaric-hygienic Characteristics and Human Health Condition in Population Aggregates Lying Close to Territories Affected by Activity of "Baikonur" Cosmodrome. The Bulletin of KazNU. Chemical Series, 49/5, 22-25.

Meshkov, N. A., Valtseva, Ye. A., Ivanov, S. I. (2008), Human Health Conditions in Territories Located Close to Fall Regions of Rocket-carriers Separating Parts, International Ecological Forum "Environment and Human Health", Saint-Petersburg, 120-121.

Carlsen, L., Kenessov, B., Batyrbekova, S.Ye. (2009), A QSAR/QSTR Study on the Human Health Impact by the Rocket Fuel 1,1-dimethyl Hydrazine and its Transformation Products, Submitted for publication.

Brüggemann, R., Carlsen, L., Eds. (2006), Partial Order in Environmental Sciences and Chemistry, Springer, Berlin.

Carlsen, L. (2008), Hierarchical Partial Order Ranking, *Environ.Pollut.*, 155, 247-253.

Hansen, S. F., Carlsen, L., Tickner, J. A. (2007), Chemicals Regulation and Precaution: Does REACH Really Incorporate the Precautionary Principle, *Environ. Sci. Pol.*, 10, 395-404.

Helcom, DPSIR Reporting Scheme, HELCOM MONAS 4/2002, Document 5/4, 2002

http://sea.helcom.fi:15037/dps/docs/documents/Monitoring%20and%20Assessment%20Group%20(MONAS)/MONAS%204,%202002/5-4.pdf (accessed Oct. 2008).