Isolation Experiments and Their Role in Risk Mitigation During Pandemics

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Abstract. The human is the most important element of the ecosystem. Due to the fact that the technosphere depends on the human life, the priority is to save the human health and to provide high performance even in stressful situations as it helps to mitigate risks when critical situations arise including at industries. In order to study the human behaviour under stress in more details, we suggest putting humans into the artificial ecosystem where the human is the key element. At this, the decomposition of such complex system is the external environment, the life support system arranges by technical means and the human acts as a loading element. Such approach should be applied to control the condition of the environment surrounding the human and to be able to model various scripts of the environmental effect on humans and vice versa. Such study has shown that human performance and general condition are affected by tiredness, the time spend in isolation, frequency of critical situations. The global situation in 2019-2020 and self-isolation during the pandemics allow expanding this study and evaluating the effect of isolation on the technosphere safety. The result of this work is the well-developed comprehensive human-machine system within which the study is carried out. Recommendations obtained during the calculation experiments are compared with the natural data. On these grounds, conclusions are drawn that allow one to mitigate risks under conditions of isolation.

1. Introduction
The human life depends on the condition of the human environment. Disasters, ecological issues and even industrial critical situations affect human performance and condition and may cause grave health issues [1, 2, 3, 4]. Modern ecosystems become more artificial: air conditioning, water purification and mineralization, recycling of resources. That's why it is very important to study artificial ecological systems and the role of the human in it [5].

For more profound and detailed study of the process, the object or the phenomenon, it is very convenient to reconstruct the environment that may be supported as stable or to set up accurate, controlled aberrations, i.e. to consider isolation under ideal conditions [6]. At this, the object itself is modelled in more details or present in the natural form. Isolation experiments involving humans have different purposes: from testing of various technical systems, e.g., air conditioning or water regeneration systems as well as the human-machine interaction to the study of the human psycho-emotional and psycho-social condition [1, 2, 3, 7, 8, 9, 10, 11].
The studies related to eco-technical systems, artificial ecosystems as well as isolation experiments are often held either in specialized pressurized modules or in submarines, or in isolated areas that allow one to increase the “isolation level” and to carry out a more complete modelling [5, 8, 9, 10, 12, 13]. However, the pandemic danger resulted in the partial isolation of the population allows seeing the studies from a new perspective.

2. Rationale
The social isolation is not a natural human environment [2, 3]. However, such experiments help to study the aspects of technosphere safety within the human factor, to prepare humans for flights, to test life support systems as well as to study psychological aspects of the personality. Although isolation experiments involving humans have different purposes, the human plays a leading role in all of them. Some of such experiments were analysed within this study [5, 8, 9, 10, 12, 13]. It was revealed that in order to do the complete study of the artificial ecosystem where the human is placed for isolation, it is necessary to provide for the drill in cases of emergencies that affect technosphere safety.

It should be noted that it is very complicated from the technical and financial viewpoints to build the complete natural sample of the life support system: such systems are developed in single quantities and expensive [11, 13, 14]. Therefore, within this study it was decided to use virtual imitators of systems included into the complex of the life support system. Imitation modelling was selected to create models of the system as this tool is best suited for the study of complex systems which management involves decision-making under terms of uncertainty [15, 16, 17]. Compared with other methods, such modelling allows considering more alternatives, improving the quality of administrative decisions and giving a more accurate prediction of their consequences.

Specific features of the eco-technical system reviewed herein (whether it is applicable for both general studies and private studies for the aerospace industry) emphasize the unique character of the work.

3. Problem statement
The key specific feature of this research is that the human is considered as a managing element of the system that suggests resilience of the operator and their behaviour in the critical situation. It means that it is the human factor that may affect the risk mitigation in the critical situation and its extension to the disaster.

Within this study, it was necessary to make the imitator of real life support systems, modelling existence of the human in isolation (in the pressure compartment) while simulating specific features of the external environment and the atmosphere and the option for set-up and the drill of critical case scripts. The modelled system consists of the finite number of elements involved into the energetic and the mass exchange. The system has the element describing the human (the ideal human model). At this, the human is isolated under the bio-medical supervision and the human-machine interface is developed in accordance to Anokhin's theory [18]. Interaction between all of these components is shown in Figure 1 where the COMPLEX is the combination of life support systems and models of environmental elements (this element synthesizes and processes signals, is self-regulated) and the HUMAN is the element consisting of the system's operator and the block of assessment and control over its activities.

![Figure 1](image_url). Interaction between elements of the system.
4. Theory
The artificial ecological system under this study is the eco-technical system where the human:
- determines the purpose of creation and operation laws of the system;
- determines biomedical, physiological and technical requirements to individual systems;
- is the main source of metabolic recycled products and the main consumer of produced environmental components as well as the source of the disturbing effect during operation of individual systems [19].

The eco-technical system within the space of conditions (i.e., ordered combinations of external and internal parameter values determining processes of technological flow transformation) may be determined as a function $C$:

$$C = C(|C|, \overline{C}, \underline{C}).$$ (1)

where $|C|$ is the structure of the system (time-invariant fixation of links between individual parts), including into the array of related structures; $\overline{C}$ is the operational law of the system determined according to the purpose of its creation $C$.

The initial decomposition of the eco-technical system suggests isolation within the integral system some structures where metabolic products are transformed into initial environmental components - the integrated life support system (the system $S$) and the external environment (the system $E$) taking into account all external and internal links determining the operational law of the system $C$ [6, 19]:

$$S = S(|S|, \overline{S});$$ (2)
$$E = E(|E|, \overline{E}, \underline{E}).$$ (3)

However, operational laws of systems $S$ and $E$ may be generally considered as interactions of their construct states resulting into establishment of new construct states

$$\Delta \tau \left\{\left[(|S|, \overline{S}), (|E|, \overline{E})\right] \rightarrow \left[(|S|', \overline{S}'), (|E|', \overline{E}')\right]\right\}.$$ (4)

where $\Delta \tau$ is the considered time interval.

The array of the system's parameters reflects its internal content, that is the structure and operational principles. Characteristics of the system are its external features important for interaction with other systems. The content of characteristics is determined depending on the studied features of the system. Characteristics of the system are operationally dependent on its parameters. [6, 18, 19].

The technological structure of the life support system is based on real, including flight and perspective airborne systems and includes: the system for water regeneration from the atmospheric condensate; the system for water regeneration from urine; the oxygen generation system; the perchlorate-based solid fuel oxygen generator; the system for purification of the atmosphere from harmful substances; the system for purification of the atmosphere from the carbon dioxide; the carbon dioxide concentration system; the carbon dioxide recycling system; the oxygen filling system for balloons to provide for the extravehicular activity; the pressurization and depressurization system; the energy supply system; the thermal conditioning system [6].

Interaction between systems is built upon laws of physics preserving the weight and energy balance. Verification was made by comparison of the obtained environmental data with the data of isolation experiments as well as with the data of life support systems at space stations [8, 13, 14, 20, 21, 22, 23, 24]. Imitational modelling was selected as the method to create the complex [15, 16] and NI LabView software was used for the software implementation as it provides for making the software operated in the real time mode and having a lot of options for visualization and integration with the natural equipment.

5. Practical relevance
The human, the environment, the life support system and the construction of inhabited sites form the artificial ecological system that is essentially comprehensive, integral, open under flows of weight, energy and information. Interaction of the operator with this system enables assessment of the human
activity and system operation as atmospheric parameters are indicators of the work quality [13, 25, 26].

Critical case scripts under consideration have 2 categories: the ones requiring replacement of the equipment with the expired shelf life (e.g., applicable to gas balloons or socket blocks) as well as situations requiring extra attention and development of the logical algorithm of actions to remove the issue (e.g., modelled by the sample in the pressurized module determined according to the drop in pressure and the gas environment condition).

The experiment included several stages of the study [13]:
- preparation experiments and testing in order to accumulate the data;
- the two-week isolation;
- 105 days of isolation;
- 520 days of isolation.

The experiment involved three groups of specifically selected persons. Each group worked according to its own schedule that included the routine work with the system (monitoring, mode switching) as well as the planned drill of case scripts. Moreover, tasks were assigned outside the schedule. The time of response to requests, their processing rate were documented into the outgoing protocol. Moreover, external surveillance of the operator's activity was done to have the option for fixation of the external human condition: focus, precision, correctness of the system's use. The specialized device integrated into the PC mouse was used for the experiment. It helped to calculate the blood pressure, HR, heart rhythm strips [4, 7].

The following analyses were conducted:
- ergonomics of the system used by operators;
- human condition in stress and rest terms;
- effectiveness of the operator's actions during the drill of critical case scripts;
- the relation of the working quality to the complexity of the task.

During the stage of preparation the data for the drill of critical case scripts was accumulated by volunteers outside isolation. These data were reflected in calculation of the average time for removal of each critical situation that the operator faces. Furthermore, based upon the average time and the time of the operator's work, it was calculated how effectively they worked. The two-week isolation was aimed to analyse ergonomics of the system and to carry out its technical maintenance. 105- and 520-day experiments helped to remove more than 150 planned critical situations in addition to technical works and removal of the situation outside the schedule. The scope of works was similar for each party of the experiment. Performance was assessed using the special device, and the comparative analysis was also one. Thus, the circular diagram in Figure 2 shows options of low performance (outside the circle) and the optimal performance (proximity to the inner circle) as well as other measurements.

![Figure 2. Performance assessment data.](image-url)
As exemplified by seven critical case scripts (Figure 3), it can be seen how performance values were varied for 6 operators (most benchmark cases were selected).

![Figure 3. General performance values.](image)

The graphs show limiting points when performance is high as well as points of the operator’s critical condition when the human is stressed out or experiences tiredness. As the performance rate was used that was obtained in the group outside isolation, performance of the group inside isolation very rarely increases up to the maximum value.

The Figure 4 shows relation of performance to the time for removal of issues.

![Figure 4. Relation of performance to the script processing rate.](image)

Thus, as performance drops, the time for critical case script processing increases. To boost up performance and focus, operators were recommended to follow their daily cycle charts, rotate sleep and rest modes, to strictly follow guidelines for removal of critical situations and to familiarize themselves in advance with all technical documents about systems. To do consequent technical maintenance while working with the complex and to study protocols of daily changes in environmental parameters.

The obtained data help to assess safety of the human operator’s activity according to the flight test principle [13, 25]. It is $P_{\text{safety}} > 0.995$.

6. Conclusions
The study data were used to study the human behaviour during isolation in the artificial ecosystem. The issues of safety and relation of performance and the response to critical situations to the stress were considered in more details.

The following results were obtained:
- The complex was designed that combines the extended model of the artificial ecosystem (the life support system, environment parameters and the human part);
- Experimental methods were developed and the obtained data were analysed;
- The ergonomic analysis of interaction with the complex was made on the basis of the query of participants in preparation and two-week experiments. Afterwards, their recommendations were taken into account for improvement of the complex.
- The information base of expertise was formed upon results of the experiment.
- The data obtained as a result of experiments during and outside isolation confirmed the negative effect of isolation for humans.

The following recommendations were developed:
- For ergonomic improvements of the system: to improve visualization of critical situations;
- For the use of the complex: the complex may be integrated with natural samples of life support systems and environmental controllers that may be applied for approbation of new designs as well as for testing of controllers etc.;
- For the work with the human operator: the complex is transferred for the use by the Moscow Aviation Institute to carry out laboratory works by students of the aerospace faculty (methods are under development) and may also be used for training of the flight crew;
- For the study of human performance and resilience: experiments helped to develop recommendations concerning preservation of high performance and focus during treatment of case scripts that may be applied to isolation in the pandemic circumstances.

7. References

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