TEMOS

Telemedical Emergency Management on Board the International Space Station

Final report

Interdisciplinary Study between Johannes Gutenberg-University Mainz, University Erlangen, International Space University Strasbourg and Russian Society of Telemedicine / Cardiology Research Center Moscow

submitted from
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Executive Summary

Increased human presence in space within the next decades requires clear, scientifically justified guidelines for treatment of medical emergencies on manned orbital platforms. Over the years in the U.S. and Soviet/Russian space programs, several medical problems have arisen, some of them with an impact on mission timeline. Many of these were successfully treated using onboard medical facilities, and perhaps were prevented from becoming more serious. Technical problems on MIR orbital complex and on the International Space Station have highlighted the potential for serious occupational injury to crews living and working in space.

Recommendations and conclusions for the medical management in Russian, US and ESA programs are based on known physiological changes in space, experience with analogous environments, risk analysis (”what if“ scenario), expected available resources and a known level of medical training. No space experience has been accumulated so far and the outcome in real emergency will depend on the specific situation. Up to this date, all deaths of crew members were consequences of sudden catastrophic failures of spacecraft structures or systems, with no time left for corrective actions to be taken. Deviation from nominal health status of crewmembers on board, or during an EVA, were solved either in space, or by required prophylactic de-orbit of crewmembers without Advanced Life Support measures.

With construction and operation of the ISS, the amount of man/hours in space and in extravehicular environment will increase. Interference with spacecraft mechanical or electrical components and irregularities in function of life support systems may result in adverse effect on crew health. Commercialisation of the ISS and possible development of commercial space travel will make selection criteria for crewmembers less strict, resulting in potentially higher incidence of medical problems in flight.

The probability of unfavourable outcomes of the life-threatening conditions, which may occur during the space flight, will be enhanced by the absence on board of space stations of trained medical personnel, capable of providing qualified emergency therapy as well as further patient intensive care. Lack of appropriate medical instrumentation normally required in such situations, must be also considered. Therefore, one of the major tasks in our work was the formulation of recommendations for the development of modern configuration of instrumental, therapeutic, diagnostic and telemedical support on board the ISS.

The report begins with a description of the existing data on physiological and pathophysiological changes in microgravity as well as the existing experience and structures for management of emergencies during the past space flight missions with special focus on cardiovasular and neurovestibular diseases. In the analysis of the present situation on board the ISS the present risk sources on board the ISS and during EVA are discussed. The current diagnostic equipment for medical emergencies and a short description of the de-orbiting scenario are included. A definition of data structure and their management is essential for a successful implementation of telemedical procedures. The appropriate protocols, acquisition and transfer are listed, including a description of the medical and technical data currently available. The project covers the relevant aspects of data management and suggests the further development.

Various urgent conditions, requiring medical care including resuscitation and emergency evacuation, may occur during the stay onboard the ISS, especially in association with Extra Vehicular Activities. The reconstruction and maintenance of the ISS requires that significant portion of work will be performed in outer space. Considering that a real experience with emergency life-support measures in micro- or hypergravity environment is completely lacking and an evacuation of crewmembers from orbital platforms under continuous critical care treatment would present serious logistical problems, it is important to define an appropriate level of medical

care for the most important emergency medical problems. The project investigated the following probable scenarios, which require complex emergency medical assistance :

- Acute myocardial infarction,
- Acute internal bleeding followed by hypovolemic shock,
- Trauma and burns,
- Loss of Orientation due to vestibular neuropathy,
- Complex injuries during EVA due to depressurisation of the space suit and development of life-threatening conditions.

For each scenario, specific recommendations are given. Continuous life support during transport to ground facilities after the de-orbit is considered an integrated portion of the emergency medical treatment.

In the absence of an on-site physicians judgement, telemedicine clearly provides means to assess crew member health status and to make informed decisions regarding appropriate in-flight care, or the need to return to Earth for special treatment. In-flight medical treatment recommendations should be based on the telemedical consultations. The project gives recommendations for system architecture, performance and operational use of telemedical links and devices for both the space and ground segment. The definition of telemedical support architecture was the main objective of the project.

Limited possibility of real training of emergency medical situations in space with a need to make theoretical predictions of a medical outcome, for a de-conditioned crew members were the main reasons for the use of a Human Patient Simulator (HPS) in the project. A cosmonaut model integrating the physiological changes during space flight was developed. The problem of simulation of a typical cosmonaut was solved through a strategy of simulation in separate states of the space mission: pre-flight, launch, orbit entry, short-term flight, long-term flight, EVA and landing. This classification facilitates the use of simulated cosmonauts as a model for training diagnostics, management and therapy of emergency situations, e.g. trauma in each phase of the simulated space flight. The HPS is believed to be a useful tool to be implemented in the future operational space medicine.

The procedures, related to provision of emergency medical care in spaceflight with emphasis on the utilisation of telemedicial link were tested in GCTC (Gagarin Cosmonaut Training Center) in Russia. Experiments were conducted in ground-based mock-ups of the ISS and of the Sojuz descent vehicle, in centrifuges and during parabolic flights. The rationale for improvement of current procedures, based on experiment and on theoretical investigation in Germany and in Russia, is explained. The testing encompassed a simulation of the adapted algorithms in the mock-ups of the ISS and Soyuz TM descent module. Data transfer between different competence centers (Moscow, Mainz, Erlangen) was also tested

The recommendations for medical diagnosis and treatment, considering the special physiological changes in microgravity were integrated in the existing algorithms on the ISS including an integration of the difficult airway management. Furthermore, the optimal equipment of diagnostic and therapeutic tools and for telemedical support, including instruments and medication for critical care treatment, were revised including a recommendation of the optimal scenario for a de-orbit of a critically ill patient.

The recommendations for medical diagnosis and treatment, taking in account the microgravity-specific physiological changes and the spacecraft environment, were added to the existing ISS algorithms. The equipment for diagnostics, therapy and for telemedical support, including instruments and medication for critical care treatment, were revised. and new recommendations for de-orbit of critically ill crew members were issued.

Preface and project backround

Continuous medical care has been identified as one of the highest priorities in future human space exploration by all space agencies. Present experience with emergency treatment of life threatening conditions in space is extremely limited and the level of public knowledge about health problems of space travel is very low. Considering the attention and resources allocated to the International Space Station, any failure to provide an appropriate treatment in real emergency situations will be subject to public scrutiny with possible repercussions on space exploration policy.

This project has been originated after discussions between Russian scientific institutions, involved in the human space flight, the German Aerospace Agency DLR and Mainz medical school in the spring 2000. After preliminary definition of the project scope, an appropriate structure for international cooperation, compliant to DLR funding requirements, has been defined and a proposal was submitted. The rationale for the submission was based on existing tradition of scientific cooperation between German and Russian space establishments. The backbone of the project consists of two essential components. Firstly, there is the long standing Russian experience with maintenance of manned orbital platforms and extensive research database pertinent to space flight. Secondly, the selected German university establishment is known as a centre of excellence in a terrestrial emergency critical care .

Within the project lifetime, several changes in the human space flight occurred, which had to be considered in the scope of our work. It became clear, that the Russian Soyuz TM spacecraft will be the only designated vehicle for emergency crew return in the coming years. After the grounding of the US Space Shuttle fleet, the transportation capacity to the ISS, and the size of the ISS crew have both been significantly reduced. Consequently, there is less capacity available for medical experiments and we focused on practical, rather than experimental aspects of our work, with an aim to implement them into the operational medical support as soon as possible.

The results of this project and the given recommendations are by no means exhaustive. It is believed that they may stimulate an additional cooperative effort between all ISS partners and that they will constitute a starting platform for more extensive research in the future.

Project description

Part I provides a summary of the relevant physiologic changes in different stages of a space mission with focus on cardiovascular and neurovestibular adaptation. The medical indications for mission termination are described including a list of the risk sources on board the spacecraft.
The present situation on the ISS including the current diagnostic equipment and the available resources for cardiopulmonary resuscitation and advance life support are composed in section 3.2. The de-orbiting of a ill crewmember in a re-entry vehicle is also included. The description is based on the Russian and international experience accumulated during flights on different complexes and on the results of ground-based tests.

The current hardware and procedures and their limitation are mentioned in part II. A definition of the data structure and their management are the most important prerequisites for a successful implementation of telemedical procedures. The common protocols for data acquisition and transfer including lists of the medical and technical data currently available are defined. Examples of the current telemedical possibilities are given.
One of the essential tasks of the project was a use of Human Patient Simulator, to obtain experimental results of physiological responses of human organism to sudden health disturbances during various phases of the mission. Results of these experiments, limits of simulation and requirements for integration of HPS into operational medical support are given in the part II.

The results of experimental investigations and the scientific data are scheduled in part III. The experimental design of this study was devided in :

- experiments in microgravity (parabolic flights),
- experiments in hypergravity (centrifuge),
- experiments in ISS and Sojuz mock-up,
- practical training of telemedicine procedures in mock-ups of orbital complexes,
- implementation of Human Patient Simulator, including feasibility testing of new ALS algorithms developed for use in space.

The procedures, related to provision of emergency medical care in spaceflight with emphasis on utilisation of telemedicine link were tested in Russia. Experiments were conducted in ground-based mock-ups of ISS and of Sojuz descent vehicle, in centrifuges and during parabolic flights. The rationale for improvement of current procedures, based on experiment and on theoretical investigation in Germany and in Russia, is explained.

In part IV a data synthesis is accomplished. The recommendations are given for:

- telemedical support for accurate diagnosis and treatment,
- methods of CPR and AALS in space flight,
- optimal equipment of diagnostic and therapeutic, instruments and medication for critical care treatment on board the ISS,
- transfer of critically ill patient from ISS to Sojuz TM spacecraft, de-orbit, landing,
- offers on development of project.

The describtion is based on the Russian and international experience accumulated during flights on different complexes and on the results of ground-based tests.

1 Effects of space environment on the human physiology and performance

In space flight, the human is subjected to a number of factors which may have significant effects on critical functional systems of the human body.

1.1 Physiological changes

The major physiological changes in flight are:

a) Dynamic factors are:

- Microgravity,
- Acceleration.

b) Environmental factors are:

- Altered barometric pressure,
- Changed gas composition of air,
- Temperature and humidity,
- Acoustics,
- Mechanical impacts,
- Ionising radiation,
- Ultraviolet radiation,
- Biological effects,
- Chemical exposure.

c) Psychological factors are:

- Heavy operator's duty,
- Monotony,
- Work in confinement within a small self-relying group.
- Stressful events.

d) Factors attending extravehicular activities:

- Combination of an increased physical activity and psychoemotional stress.

There is no question that microgravity is the key trigger of the physiological shifts developing during space flight.

In microgravity, where the pull of Earth's gravity loses its effect, the human body experiences neither deformation nor mechanical strain.

Consequences of this phenomenon are removal of weight loading on the body, hydrostatic pressure, subsequent shifting of body fluids towards the cranial end and reduction of functional loading of the musculoskeletal apparatus.

Displacement of a portion of blood to the cardiopulmonary region at the initial phase of space flight leads to a short increase in the circulating blood pool.

The above shifts are triggers of a variety of secondary cardiovascular and endocrine reactions.

According to numerous investigations, already at the onset of piloted space flight a redistribution of body fluids results in prompt compensatory reactions and resultant hypohydration, decrease in the central blood pool, intercellular fluid, and more intensive excretion of electrolytes, especially potassium.

These immediate adaptive reactions to microgravity are responsible for the developments that can be qualified as two types of long-term reactions.

Type one is described by activation and straining of the hormonal controls in order to sustain the water-salt and hemodynamic balance.

Type two is described by changes in vessels located a little more distal from the hydrostatically indifferent point due to their lowered functional loading and inhibition of erythropoiesis.

Approximately two months after launch a new level of cardiovascular function comes into sight manifested by readjustment of the cardiac function, further CBP reduction, and relative stabilisation of the venous return to the heart.
Between flight months 4 and 8, blood influx to the heart gets balanced and stabilised, stroke and minute volumes normalised, activity of the renin-angiotensin-aldosterone system (RAAS) enhanced, and renal excretion of the antidiuretic hormone (ADH) and sodium gradually recovered.
At the same time, reduction of the blood plasma volume in the lower body (mainly in the lower extremities) brings about deconditioning of controls of the leg vessels and greater compliance and contractility of the crus veins, inhibition of erythropoiesis and functional erythropenia, and decline in the body tolerance of physical and gravitational loads as the climax of the previous changes.
Absence in microgravity of weight load on the musculoskeletal apparatus leads to unnecessary large muscular efforts and high tone of the anti-gravity muscles, which reasults in changes of the metabolic processes of the musculoskeletal system.
Alterations in the musculoskeletal functions entail a degradation of the ability of the body to deposit potassium in muscular tissue and calcium in bone tissue and consequent loss of these ions until establishment of negative balance.
Below is a brief summarisation with a description of the bodily changes that take place during space flight.

1.1.1 Changes on the onset of space flight (approx. 7 days):

- Subjective developments associated with redistribution of body fluids,
- Modification of sensory interactions and manifestation of sensory conflicts,
- Elevation of dynamic and decrease of static excitability of the vestibular apparatus,
- Space motion sickness,
- Alteration of the motoric coordination.

1.1.2 Changes during long-duration exposure to space flight

Motor system:

- Subatrophy or atrophy and reduction in mass and strength of anti-gravity muscles,
- Change in the proprioceptive sensory inputs and spinal automatism,
- Degradation of motor control efficiency.

Bone system:

- Loss of mineral density in various parts of the lower body skeleton and on the contrary, mineral density gain in the upper body.

Cardiovascular system

- More frequent cardiac arrhythmia,
- Decline in tolerance of orthostatic and physical loads.

Water-salt balance:

- Hypohydration,
- Negative balance of some ions.

Metabolism:

- Negative nitrogen balance and predominance of catabolic processes,
- Change in secretion of a number of hormones,
- Progressing arrest of glucose utilisation during sugar test further into space flight (after months 3-4).

Blood system:

- Functional erythropenie.

Immunity system:

- Inhibition of the cell immunity activity.

Accelerations are responded by a whole complex of reactions varying with vector, magnitude and period of exposure, and the functional status of the human body.
The cardiovascular system is most vulnerable to long-duration linear accelerations. Shifts in the cardiovascular system manifest themselves by local vascular reactions to increased or decreased hydrostatic pressure, e.g. changes in hemodynamics and bioelectrical activity of the heart. The total scheme of the cardiovascular reflex reactions is presented in the following figure.

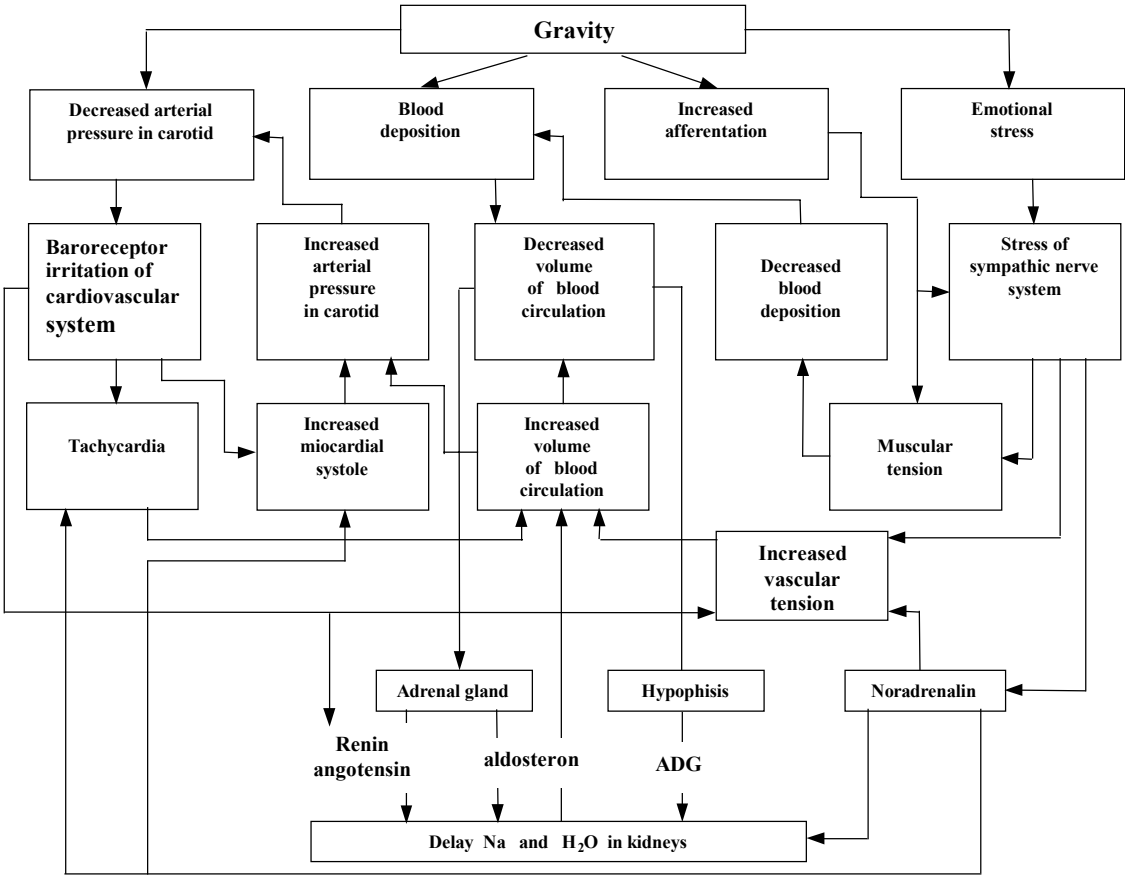


Fig. 1: Reflex and humoral reactions of the cardiovascular system to +G-

G-loads exert very profound influence on every level of the respiratory system and modify breathing mechanics, gas exchange in the lung, arterial hypoxemia and tissue exchange. Regardless of the direction, g-loads will provoke dyspnea, combined with first increase and later on with diminution of the lung volume.
Disorders of external breathing results in an impairment of gas exchange in body tissues. The sequence of the breathing disorders during exposure to linear g-loads is described in the following figure.

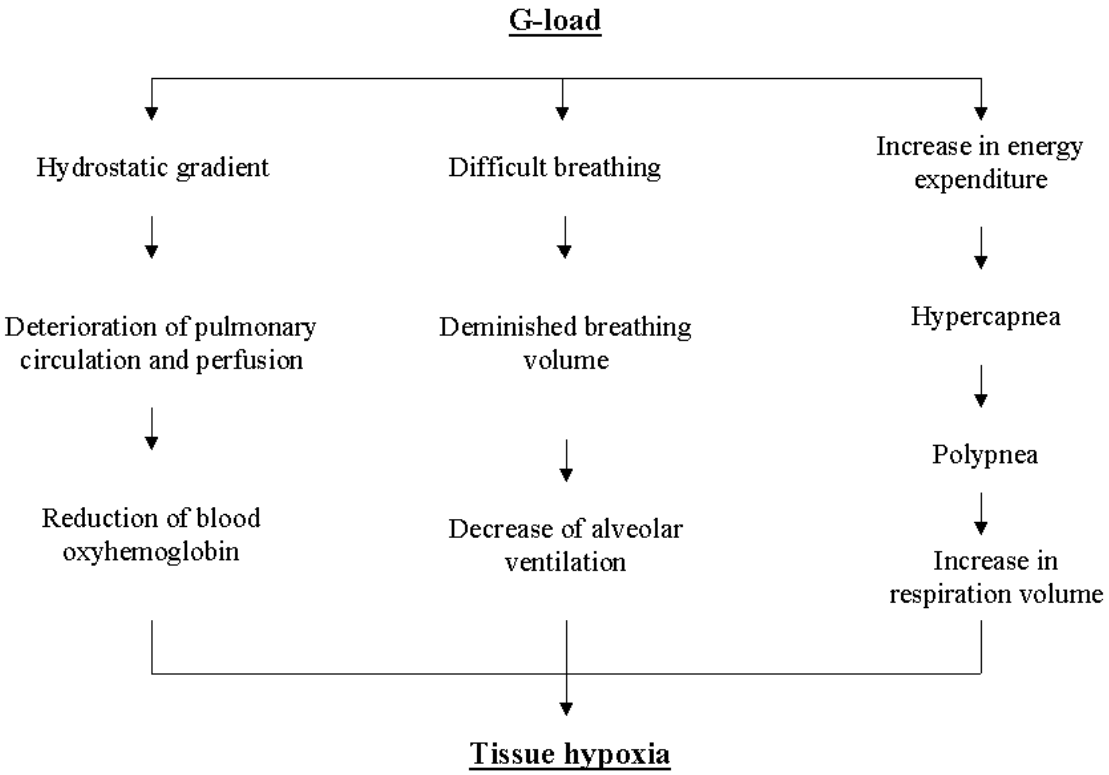


Fig. 2: Breathing disorders due to exposure to g-loads

Shock accelerations can be experienced on the phase of touchdown of the descending module and at the docking procedure of the space vehicles.
Bradycardia, drop of blood pressure and various forms of cardiac disturbances are consequences of shock accelerations.
When analysing the second set of factors affecting the human body, we should accept the fact that environmental factors, if their parameters are kept within admissible values, do not have a negative impact on the health of the space crew.

1.1.3 Cardiovascular dysfunction in manned space flight

Results of examinations of cosmonauts give convincing evidence that the most expressed and clinically significant shifts are cardiovascular, presented as changes in the cardiac function, thus rearranging of the central and regional hemodynamic system. The important place of these shifts due to real and simulated space flight factors was revealed already during initial, relatively short-term space flights.
Further investigations with the use of modern, more informative and precise techniques of the cardiological diagnostics made it apparent that these particular unfavourable shifts of the heart functions and the changes in the circulation are key causes for the worsening of cosmonauts` health during long-term space flights and on the return to the terrestrial gravity. Therefore, purposeful studies of the effects of extreme space flight factors on the changes of the cardiovascular system have been performed in essentially all piloted missions within the programs of crew health

monitoring and medical research. Special focus was placed on the observation of dynamics of the myocardium bioelectrical activity at rest and against functional loading tests and heavy duties that challenged cosmonauts' mental performance, and emotional and physical endurance. Periodic ECG recording was also conducted during 24-hr Holter monitoring and by indication during some other medical investigations.

In the following investigation electrocardiogram was registered in 12 universally accepted leads (3 standard, 3 unipolar and 6 thoracic) and in the DS-lead with the help of multifunctional system GAMMA-01 mounted aboard the space station. Twelve common leads were used to make ECG records at rest and the DS-lead was used during administration of functional tests (LBNP, VEL). In addition, ECG monitoring was performed using ALPHA-06 and BETA-08 on the phases of insertion into orbit, docking to the orbital station, descent, and during operations in open space. Standard methods were applied to interpret and analyse ECG records. In order to analyse changes in the cardiac electrical potential during depolarisation and repolarisation, the so-called integral profile indices were utilised: sum of amplitudes of all QRS waves QRS ($\sum AQRS_{I-III}$, $\sum AQRS_{V1-3}$,$\sum AQRS_{V4-6}$) and T-waves ($\sum AT_{I-III}$, $\sum AT_{V1-3}$,$\sum AT_{V5-6}$) for specific sets of leads. Statistics were performed with Student's t-test.

The work has been primarily done using data about cardiac bioelectrical activity in 62 Russian members of the MIR prime crews who participated in missions up to six months in length, and in 7 US astronauts who participated in 116- to 188-d MIR missions (NASA/ MIR missions 1-7).

One of the characteristic effects of space flight on the human heart is the change in the heart rate (HR) and more severe sine arrhythmia inflight and after flight.

For instance, before launch eight members of the MIR prime crews displayed sine bradycardia with HR at 47-54/min. during functional rest; three cosmonauts of the crew had bradycardia recorded in each session of inflight investigations. Before launch, in 54 cosmonauts heart rate was within the normal range (57 to 80 /min. in different persons). In flight, in 8 cosmonauts HR was found a bit slow; in another 8 cosmonauts HR was not noticeably changed and in the remaining 46 cosmonauts HR grew fast. Hence, 46 out of 62 cosmonauts were characterised by a slight HR acceleration. On the average, in space flights up to six months in duration a statistically significant HR rise ($p< 0.05$) was observed starting from month 1 and persisted throughout the whole period of orbiting. Increase in HR fluctuated within 7-11% of preflight mean value. As a rule, changes were phased and particularly conspicuous on flight months 3, 4 and 6.

Distinct sine arrhythmia were also seen more than once upon return of the cosmonauts to the normal 1-g gravity. For example, quite significant HR change was revealed by 24-hr Holter monitoring following the one-year space flight; after landing HR varied within the range of 74-128/ min. in one cosmonaut and 70-178/ min. in the other.

More significant disturbances of the cardiac rhythm like extrasystoles during rest and load can be assumed among typical adverse effects of microgravity on the cardiac function of cosmonauts during and after flights.

Most of the members of the MIR prime crews displayed rare, single monotope extrasystoles which were associated, as a rule, with emotionally or physically demanding events (first hours in microgravity, assembly operations, EVA, functional tests on the bicycle ergometer and the treadmill and others). The greatest number of extrasystoles was counted in extreme situations, during EVA and physical testing on the bicycle ergometer and the treadmill (49% and 39% of the total number, respectively).

It should be noted that in none of the cosmonauts extrasystoles were primary, that is, similar rhythm deviations had been observed at least in one of investigations before flight. However, in 12 out of 60 cosmonauts cardiac rhythm disturbances in flight were more significant than pre flight: in several cases there were frequent single extrasystoles; there were also cases of supraventricular extrasystoles combined with ventricular, as well as occasional paired, group and allorhythmic extrasystoles. Four cosmonauts developed two types of arrhythmia – extrasystole and sine pause (a pause following a normal systole is 180% of the preceding RR-interval). In most cases, maximal

number of arrhythmia (extrasystoles and sine pauses) was registered during EVA. It should be stressed that, as a rule, extrasystoles were observed against good well being; they did not disturb hemodynamics significantly and were qualified as a functional phenomenon engendered by the extracardiac factors.

The advent of single ventricular extrasystoles at rest beginning on flight days 44-45 was also registered in two out of 7 NASA astronauts; their extrasystoles were more distinct on the backdrop of functional tests. For example, on flight day 99 reaction of one astronaut to incremental physical load (IPL) was satisfactory, as in minutes 2 through 5 of recovery from the test 5 sine pauses and 4 periods of apparent sine arrhythmia were displayed. In another astronaut, cardiac rhythm disturbances were quite considerable during implementation of the LBNP test. On flight day 122, relative gain in HR was greater even when compared with data of pre-flight testing when a poor tolerance of the test was discovered: a supraventricular extrasystole was registered at –25 mm Hg; at the end of minute 1 at –30 mm Hg there was a brief (4 sec) period of supraventricular paroxysmal tachycardia with calculated HR of 165 /min. These were accompanied by a drop in end-systolic and pulse blood pressure and an emergence of signs of dilatation of small vertebrobasilar vessels.

One more highly typical manifestation of the adverse effects of microgravity and other extreme space flight factors on the cardiac bioelectrical activity in cosmonauts is alterations of ECG amplitude, which were very significant in several cases.

Among in-flight ECG changes characteristic of the MIR prime crews was instability of components of ventricular repolarisation with broad spontaneous oscillations of amplitude; in three cosmonauts those were augmented by T-wave oscillation. Statistical analysis revealed a regular, statistically significant ($p< 0.05$) decline of T-amplitude that started on month one in flight and was largely diffusive by character with prevalence of changes in the leads reflecting posterolateral potentials in the left ventricle. On the average for 62 cosmonauts, T-amplitude dropped by 30-35% in the standard lead, by 15-30% in V_{1-3}, by 25-40% in V_{4-6} , and by 20-30% in DS as compared with pre-flight mean values. In cosmonauts, who made repeated (two or more) flights this drop of T-amplitude was comparatively more profound.

In three cosmonauts, in addition to T-amplitude decline, distortions in the repolarisation phase included deformed – two-humped – T-wave, flattening and partial or full inversion. These changes were observed in one cosmonaut prior to launch and two cosmonauts in space flight. Variability of the end fragment of the ventricular ECG complex was presented by significant fluctuations of T-wave size, shape and direction, so that the number of leads registered these deviations. Variability range was quite broad: from two-humped, two-phase and inverted T-waves in all leads, including temporary recovery of normal electrocardiogram. One of these cosmonauts made three flights, each time with similar deviations in repolarisation. Aside from T deformation during virtually each IPL test, this cosmonaut exhibited also a skew-ascending ST depression up to 1.9 mm maximum, episodic ST depression with an arch convex upwards. Similar ST changes were registered during EVA, too.

This type of change at the end-ventricular ECG complex was also noticed in the US astronauts who flew missions to MIR; i.e. a T-amplitude depression in the standard and, for the most part, left thoracic leads characteristic of long exposure in microgravity and essentially the same as in the Russian cosmonauts. From the data in figure 1 a distinct T-amplitude depression in all astronauts occured; however, we failed to establish any well-marked dependence of the depth of T-amplitude depression in mission duration (fig. 3).

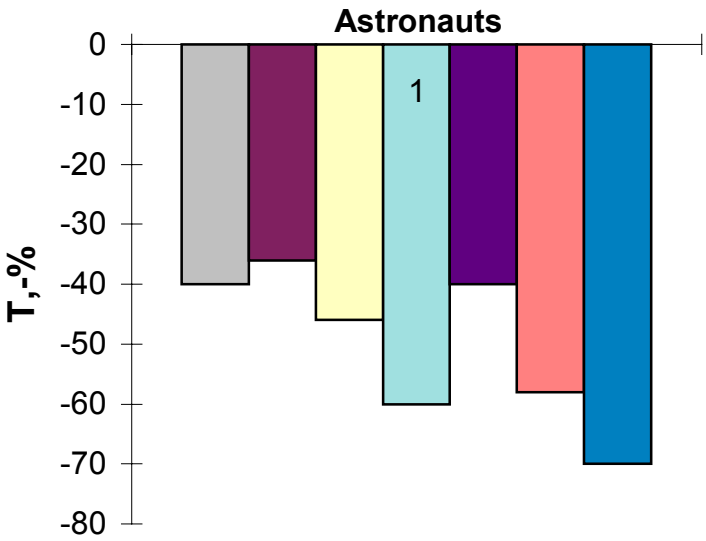


Fig. 3: Maximal changes in T-amplitude in the astronauts on MIR (MIR/NASA missions NASA 1-7) (in % to pre-flight values).

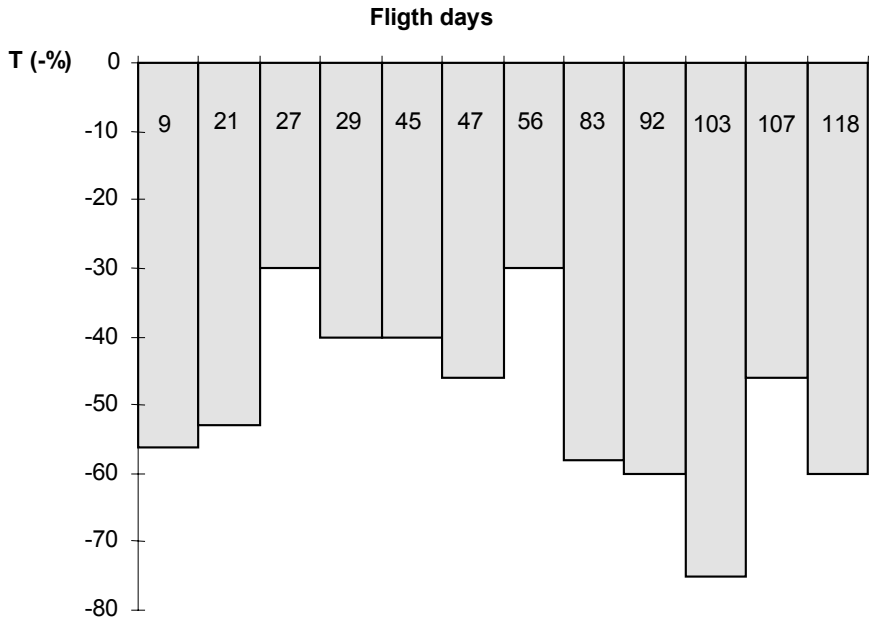
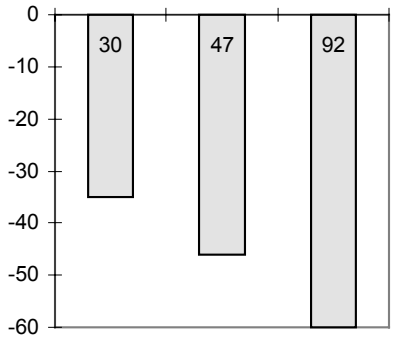


Fig. 4: T-amplitude depression in the NASA astronauts in different periods of space flight (peak values, in %)

It should be emphasised that the time and measure of these changes in ECG were highly individual. For example, one astronaut had the T-amplitude depressed only on flight day 107 and another one was distinguished by a gradual progression toward the end of the mission of depression of the T-amplitude. There was an astronaut whose T-amplitude first went down but then up, so that by the end of his stay in microgravity T-amplitude was even a little bit higher than pre-flight (fig. 5, 6).



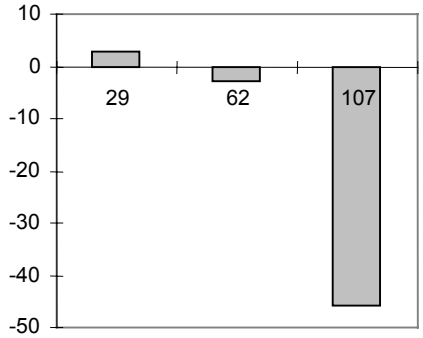


Fig. 5: T-amplitude dynamics in flight (in % relative to baseline data)

Fig. 6: T-amplitude dynamics in flight (in % relative to baseline data)

It is an important fact that after landing ECG recording evidenced very rapid recovery of the parameters in all cases suggesting a functional, reversible character of these shifts.

Hence, changes in the bioelectrical activity of the myocardium during relative physiological rest included, in most of the cases, amplification of pre-flight sine cardiac arrhythmia, appearance of ventricular or supraventricular extrasystoles and, which is characteristic of extended stay in microgravity, distinct T-amplitude depression in the standard and, predominantly, left thoracic leads. We should make the point that T-amplitude depression was not attendant by changes in heart positioning in the thorax or unfavourable (ischemic and other) ECG alterations indicative of disturbance, much less coronary insufficiency.

It was found out that the probability of cardiac dysrhythmia in cosmonauts due to microgravity is determined by the combination of a large number of factors including alteration of the circulation control processes, shifts in the water-electrolyte status, emotional and physical stresses (most often caused by off-nominal events), and individual characteristics of the cardiac function controls.

The above shifts can be triggered by, specifically, adjustment of the cardiac function controls, changes in extracardiac and intracardiac hemodynamics consequent to the micro-g induced blood redistribution, and adaptive metabolic (electrolyte) shifts in the course of extended exposure in microgravity.

The afore named assumption is indirectly confirmed by observations made in cosmonauts (including immediately in flight) and experiments flown in biosatellites according to which microgravity does affect various sides of metabolism, including nitrogen, carbohydrate and lipid metabolism and functional shifts in the neuroendocrine and humoral-electrolyte control systems in the body. These shifts may bring about changes in myocardium metabolism.

These deviations in the cardiac function may also develop in consequence of relative hypokinesia, since cosmonauts have to live under the spatial constraint of small modules for a long period of time. Indirectly, this can be deduced from very similar changes in the ECG end-ventricular complex (analogous forms of cardiac arrhythmia, depressed T-amplitude, mostly in the left thoracic leads in the absence of any significant changes in the T-wave form, concurrent changes in ST, etc.) that we and other investigators used to register in human subjects during extended head-down bed rest which is used in ground-based studies of the combined effects of hypokinesia and headward blood displacement on the cardiac function in humans.

Possible increase of the venous blood return to the upper vessels in cosmonauts and consequent increase in diastolic filling of the cardiac cavities is attested by the data of echocardiography (EchoKG). Specifically, in French astronaut J. L. Cretien changes of the main EchoCG parameters proceeded in phases and included significant increases in end-diastolic (EDV) and stroke volume

(SV) on days 3-4 in space flight (by 13 and 22%, respectively); by flight day 6 these changes gave way to secondary reductions of values lower than before launch. This turn was likely to be associated with adaptive diminuition of the circulating blood volume at the beginning of microgravity.
Investigations during the 237-day MIR mission were started on flight day 30; they also showed decreases in the left EDV and SV (by 14-15 and 9-22%, respectively) in two cosmonauts at rest; on the contrary, in the third cosmonaut of the crew the parameters of blood filling and functioning were approximately 20% higher as compared with pre-flight values. EDV reduction was proportional to the left end-systolic volume ESV reduction, whereas the ejection fraction slightly increased.
It is important that these cited investigations did not report symptoms of disturbed cardiac systoles in the cosmonauts at any point of their missions.
The fact of decreased end-diastolic filling of the left heart was borne out by the data of several other investigators who performed EchoKG in two astronauts during US Space Shuttle missions and 12 Russian MIR cosmonauts in 1998-1999. During 6 day and up to a 6 month stay in microgravity cosmonauts displayed statistically significant EDV diminution (8-13%) but not any material changes in the ejection fraction, one of the basic parameters of the myocardium systolic function. In the opinion of the majority of space medical investigators, this reduction in the end-diastolic filling of the left heart is a result of the adaptive reactions of cosmonauts, the main constituent of which is compensatory CBV reduction.
It should be noticed that the available data about blood shifting headward during early adaptation to microgravity, together with initial transitory increase in the central blood volume, occupy a key position in the concepts describing physiological reactions of the human cardiovascular system to microgravity. The volumoreceptor reflex path involves the neurohumoral control of liquid balance in the body leading to exaggerated urine excretion of fluid and sodium and consequent diminuition of the circulating blood volume – CBV.
Many investigators believe that CBV reduction can be one of the chief causes for functional changes in the cardiovascular system during space flight. According to different authors, CBV during space flights of various duration and HDT can reduce from 8 to 20%. It should be mentioned that CBD was found significantly reduced after short-term flights, too (Degtyarev V.A., 1980).
In ground-based experiments with bed rested subjects CBV changes on the same pattern as in space flight.
During hypokinesia, which is the inevitable attribute of space flight, CBV reduction, particularly of the plasma fraction, is a result of not only a drop of the hydrostatic pressure in vessels and concurrent increase of the central blood volume, but also a considerable decrease of the motor activity. Indirectly, this supposition is supported by the positive effect of physical exercises performed by supine human subjects during clinostatic hypokinesia on maintenance of the amount of intravascular fluids.
As it was noted, reduction in plasma volume occurs on the first day after insertion into orbit leading to respective increases in hematocrit and blood viscosity. This activates the mechanism of maintaining the main constants of circulating blood; as a result, erythrocyte mass decreases and becomes proportional to the blood volume. Erythropoietin in blood serum decreases reducing production of young erythrocytes. Inhibition of erythropoiesis and deposition of iron are also evidenced by increased content of serum ferritonin in plasma. Mean life span of erythrocytes is not significantly altered in space flight. With the lowered erythropoiesis and unchanged life space of erythrocytes, the erythrocyte count gradually decreases and hematocrit regains normal values.
Reduction of erythropoiesis and development of “anemia” in long-term space flight are caused not only by hemoconcentration and dehydration but also by modification of mechanisms of controlling energy balance and tissue metabolism, and alterations in blood forming organs.

The most consistent observations made following space flights above two weeks in duration were decreases in the concentration and mass of hemoglobin and erythrocyte count. Loss of the hemoglobin mass by 12-33% largely occurred during the initial two months of flight. The erythrocyte count in cosmonauts after 96 to 175-d missions was shown to be reduced by 15-21%.
As for morphological changes, according to the data of cosmonaut-physician V.V. Polyakov the most consistent findings were anisocytosis, hypochromia of erythrocytes, singular target-like cells and acanthocytes.
Space experiments with isolated human erythrocytes demonstrated effects of microgravity on intercellular interaction and functioning of cell membranes.
Hence, under certain conditions of space flight, changes in the coagulate and anti-coagulate systems may lead to circulatory disorders in microvessels and even thrombotic lesions.
Aside from the transport function, blood volume has a particularly important role in maintaining adequate filling of the vessels and venous return. These are changes in CBV that initiate a sequence of reflex reactions affecting metabolism and circulation of extravascular fluid and protein in the body. Insufficient CBV can underlie not only degradation of orthostatic stability and physical performance of cosmonauts, but also impact venous return to the heart, diastolic filling of the cardiac cavities and, consequently, intracardiac hemodynamics and tropism of the myocardium.
Despite the functional, reverse character of these shifts, dynamics of the myocardial bioelectrical activity can be considered unfavourable and worthy of notice of investigators. An argument for this thesis is that, as it has been said earlier, frequently enough the in-flight shifts grew in measure on the background of intense mental or physical work, during functional testing by physical exercises and LBNP, and especially in the case of low cardiovascular tolerance of the functional tests. One should bear it in mind that under untoward circumstances (very high neuropsychic and physical stresses during EVA and dynamic flight operations, due to off-nominal events and contingencies, etc.) these shifts may by themselves be the cause for more pervasive changes in hemodynamics and cardiac function. Considering the above, the top lines of the NASA list of the 20 most probable diseases in space flight have been given to cardiac disorders followed up by myocardial infarction.
Diagnostics in cosmonauts of the cardiovascular shifts that may be aggravated under provocative circumstances points to the need to be more aggressive in determining underlying mechanisms and elaborating pathogenically substantiated therapeutic and preventive measures for space crews.
There are specific changes in a cosmonaut's health which, if found during examination or space flight, can serve as a guide for termination of examination or consideration of the issue of aborting space flight.

1.1.4 Physiological changes of the equilibrium

In microgravity the equilibrium is achieved without muscular power. Therefore a diversification of the control strategies takes place. The cosmonaut achieves orientation in microgravity only by his own coordinates and a visual orientation of the ambience. The changes of the visual system lead to a recalibration of vestibular and somatosensoric impulses. In microgravity, due to a loss of information by the otoliths, a decalibration of the vestibular system can be observed. After a latency of a few days the subjective sensation is adapted; a gradual adaptation of the torsional component of the vestibular ocular reflex VOR takes place. The adaptation of the VOR results in the replacement of the otolith function by the somatosensoric system. The exact mechanism of the neuronal adaptation and the level of the adaptation is still under investigation.
The main problem of the astronauts after the return to earth are ascribed to a reduction of the vestibulo spinal reflex. Also, a destabilisation and an asymmetry of the regulation of the torsional eye movement can be observed.

1.1.5 Neurovestibular dysfunction and risk sources in microgravity

1.1.5.1 Space motion sickness

The space motion sickness SMS is described in more than 60% of cosmonauts in microgravity. The main symptoms include instability, anxiousness, vertigo and vegetative symptoms. Diverse pathologic mechanisms are described as cause. Microgravity leads to a fluid shift with variation of intracranial pressure. Also, a modification of the hormonal and neurotransmitter balance was observed. Moreover, a sensoric conflict between the otoliths, the semicircular ear canals, the visus and the kinetic system occurs in microgravity. An interaction of these diverse strategies is suggested to be the cause of the space motion sickness.
Various medication have been used to prevent and treat the SMS. So far the medication with antihistaminics and anticholinergics is favoured. But still, the treatment is ineffective for some treated cosmonauts. Therefore, new medications are under investigation. The treatment with NK1-antagonists, 5-HT1A-agonists and 5-HT2A-agonists are promising. But effective and harmless usage in humans has to be proven.
After the adaptation of various vestibular reflexes to microgravity an orthostatic dysregulation may also result.

1.1.5.2 Neurvestibular risk sources in microgravity

Influence of vestibular pathologies on the mental status

Vestibular pathologies may arise in microgravity and have influence on the mental and physical status of the cosmonaut. These pathologies include the following side effects:

- Problems of orientation with reduction of strength to mental or physical tasks, mainly in cases of transition of the gravity (combined with nystagmus, oscillopsia and dysopia),
- Loss of neuromuscular co-ordination and power (including ataxia, instability),
- Poor orientation in three-dimensional space due to reduction of mental or cognitive performance,
- Autonomic dysfunction due to vestibular diseases,
- Permanent dysfunction of the three-dimensional orientation or equilibrium in microgravity.

Vestibular neuropathy

This disease is characterised by permanent vertigo with an acute onset. The intensity of the vertigo weakens within days. In most cases the vertigo includes a torsional component and vegetative symptoms (i.e. pallor, low blood pressure and nausea). In some patients also hearing loss or tinnitus may occur.
The pathogenesis is still unclear but a viral infection with degeneration of the scarpae ganglion and peripheral neurones is suggested. Signs of a vascular origin could not be proven in histopathological studies as of yet.
In the beginning, the nystagmus may strike to the affected ear (stadium I). In stadium II the nystagmus strikes to the healthy ear due to the loss of the vestibular function in the affected ear. In the interval of days to weeks a central compensation takes place. Therefore after the compensation no nystagmus can be seen any more (stadium III). In stadium IV a recovery of the vestibular system may arise and the nystagmus may strike to the affected ear again.

Acute exacerbation of Ménière disease

The Ménière disease is characterised by a paroxysmal vertigo with sudden onset, strong vegetative symptoms in combination with hearing loss and tinnitus. The symptoms fade away after a period of minutes to hours.

The attacks arise in intervals of days to weeks and may pause over a long period of time (in single cases a pause of many years has been described).

Within the attack a nystagmus which strikes to the affected ear mainly with a rotatoric component appears. A nystagmus to the healthy ear may be followed later on. In case of a Ménière attack the nystagmus can also alternate in both sides.

The Ménière disease is caused by a malfunction of the resorption of the endolymphatic fluid in the endolymphatic sac. Therefore, a rise of the endolymphatic pressure leads to a hydrops and a widening of the endolymphatic space with consecutive pastes**,** deformations or rupture of the membrane. An exchange of endolymphatic and perilymphatic fluid leads to a rise of the potassium concentration in the perilymphatic fluid which lowers the action potential of the peripheral nerves and causes a depolarisation of the cells with consecutive nystagmus to the ear. After a short period a paresis occurs with contralateral nystagmus. This symptom can be observed in most cases.

In the interval of the disease a normal hearing function may exist, with hearing loss at the attack and, a rise of hearing after the attack. The completion of the symptoms (vertigo, tinnitus, and hearing loss) can take up to several years.

Central vestibular disease and non vestibular dysfunction has to demarcate to peripheral vestibular diseases.

The central vestibular vertigo is characterised by a sudden onset with a change of the intensity in time. It may be combined with vegetative symptoms. Most patients complain of lateropulsion, vertigo or unsteadiness of motion.

In some cases a nystagmus with horizontal, vertical, rotatoric or changing component can be diagnosed. But the nystagmus is not obligate. The vertigo includes a feeling of unsteadiness. A combination of dysfunction of co-ordination with ataxia and problems in speaking can also be included.

The non vestibular vertigo can occur in any other disease. In the clinical examination no nystagmus, ataxia or unsteadiness can be diagnosed. The patients mainly complain of orthostatic problems and paraesthesia in the lower limb. Possible causes are diverse and have to be investigated after some time.

1.1.6 Psychological changes in microgravity

The third set includes psychological factors. These factors can have a multifarious effect on the human under the conditions of space flight. For instance, psychic state and emotions of cosmonauts can be upset by intensive and frequently monotonous work, ineffective planning of flight operations, constraints of living in confinement with other members of a small autonomous group, occasional stressful events, awareness of risk and hazard characteristic of space missions, required frequent sleep shifting because of night operations, etc.

As a result of life under the above factors, crew members can develop fatigue, irritability, emotional liability, sleep disorders, degradation of mental performance and motivation to fulfill the mission program, and the so-called somatogenic, for the most part vegetative-vascular, problems.

Considering the fact that psychoemotional factors can stress the cosmonauts' occupation with impact on the main functional formations, including the central nervous and cardiovascular systems, there is reason to believe that an appearance of some pathologies (vegetative-vascular dystonia, hypertensive vascular reactions, etc.) in space flight cannot be excluded. This probability may, undoubtedly, discover latent defects in the pre-flight state of the cardiovascular and neurohumoral systems.

The combination of extreme physical loads and psychoemotional stress as the main factors of the extravehicular activities may also be taken into account. An exposure to these factors may cause tachycardia, various forms of cardiac arrhythmia, and symptoms of hyperventilation.
In summery, the largest contribution of rather diverse cardiovascular disorders in piloted space missions is made by microgravity and the psychological factors. Accelerations, though impacting the function of the cardiovascular system, have less and relatively short effects which are mostly experienced at the active phases of piloted space flight.

1.2 Indications for termination of the mission

1.2.1 Medical indications for termination of an investigation (physical test)

1) In case of subject's request, regardless of the objective data,

2) In case of the assistant's request, regardless of the objective data and

3) In case of subjective information including:
   - assistant's observation of changed colour of subject's skin (paleness, cyanosis, sharp hyperaemia) and profuse perspiration,
   - subject's complaints of:
     • retrosternal pain with typical irradiation or atypical pain syndrome in the thorax,
     • sensation of asphyxia, severe dyspnea ,
     • asthenia, vertigo, loss of equilibrium, nausea, headache, profuse perspiration,
     • deep fatigue, pain in M. gastrocnemius or any other feeling of discomfort.

4) Objective information:
   - age-specific submaximal HR equivalent to approx. 85% of maximal value determined from formula: HR max = 220-age x 0.85,
   - acute hypertensive reaction (BP elevation up to 220/120 mm Hg and more),
   - no BP rise or BP drop by 5-10 mm Hg below baseline value or value measured at the previous increment, decrease of PAP, diastolic pressure rise above 120 mm Hg,
   - Changes in ECG:
     • ST depression for more than 1 cm from initial level on the ischemic pattern: horizontal, slackening (sickle-shaped), trough-shaped, skew-descending and skew-ascending lasting longer than 0.08 s from connection point "j" and with the depth of 2 mm and more (or with QX/QT > 50%),
     • ST rise more than one cm above initial level,
     • frequent (more than 1:10 in 5 minutes) extrasystoles or high gradation extrasystoles, paroxysmal dysrhythmia, blockades,
     • reduction of the R voltage by more than 30% of initial value,
     • 2-3 mm increase in R voltage in consequence of reciprocal changes caused by ischemia of the opposite wall or appearance of transitory asynergy in the ischemic region,
     • a transitory pathological Q-wave and deepening and extension of existent (cicatricial) Q-wave.

Isolated T inversion or reversion are not considered by most of the authors termination criterion; however, their appearance is alarming for these changes foreshadow seizure of stenocardia or ischemic segment depression.

1.2.2 Medical criteria for flight abortion

1. A life threatening disease or a threatening of a permanent disability of a crewmember in future,
2. Disease that has not been fully cured in flight with the available medical agents and renders further implementation of the mission program impossible,
3. Progressive degradation of tolerance of the physical tests which denies recovery with the help of available therapeutic and prophylactic treatment, rendering further implementation of the mission program impossible,
4. Epidemic prognosis or clinical symptoms of an outburst of a highly contagious infectious disease that cannot be treated etiotropically, threaten of a disability and risks of complications associated with disturbed functions of body organs and systems,
5. Objective information about residential contamination of the environment and life support systems (anthropotechnical niches) by highly virulent or toxic bacterial and mold strains that cannot be removed in the presence of humans,
6. Mental problems that can threaten the health of the sick crewmember and/or other crewmembers, deny recovery with the help of available therapeutic and prophylactic treatment, rendering further implementation of the mission program impossible.

1.2.3 Technical and environmental criteria for flight abortion

1. Aggravation of radiation conditions, i.e. prediction of radiation exposure beyond the maximal admissible limit for the equivalent dose (Russian standard GOST 256-15-215-85) established for missions of a specified duration,
2. Microclimate deviations:
   - Unrecoverable oxygen partial pressure drop up to 140 mm Hg (time of human exposure is determined by the nomogram); exposure to $p0_2$ at 120 mm Hg cannot be longer than 1.5 hours,
   - Rise of oxygen partial pressure up to 350 mm Hg persisting for 2 weeks,
   - Unrecoverable rise of carbon dioxide partial pressure up to 20 mm Hg persisting more than 3 hours,
   - Air temperature rise above 33 ^{o} C persisting 3 days (with consideration of medical data and crew self-evaluation),
   - Air temperature drop in habitable compartments below 15 ^{o} C persisting 3 days (in the absence of environmental clothing) and tending downward (with consideration of medical data and crew self-evaluation),
   - Off-nominal conditions when the totality of toxic compounds (gaseous and aerosols) reach maximal admissible values established for contingency (protocol N 057--13/257-82).
   - Unrecoverable violation of acoustics limits set in Russian standard GOST V 24159-80 which, based upon operational medical monitoring data, poses a direct threat to crew health and renders further implementation of the mission program impossible,
3. Sources of information for decision making about flight abort
   - Speech and TV communication sessions,
   - Data of medical telemetry data analysis,
   - Data of environmental monitoring and calculations and predictions of the Radiation Safety Service.

1.3 Analysis of present situation on the ISS

A malfunction of the following variables may lead to a risk source in microgravity:

- Technical,
- Microclimate (LSS failure),
- Microbiological,
- Radiation,
- EVA (spacesuit LSS failure, no physiological telemetry and decompression sickness).

1.3.1 Risk sources of emergency situations on board spacecraft

Risk sources on board the spacecraft include:

- Technical problems,
- Microclimate (LSS failure) problems,
- Impossibility of medical care until crew returns.

Diseases of the peripheral vestibular system may lead to an emergency situation in microgravity mainly due to disorientation and vertigo and are therefore described in detail:

1.3.2 Risks during Extravehicular Activities (EVA)

Risk sources during EVA include:

- Technical problems,
- Changes of environment parameters (failure of life support system),
- Impossibility of medical care until crew returns on board the ISS.

Because decompression sickness (DCS), a major potential hazard of EVA, will have a profound influence on the development of any mission, a discussion of some possible emergencies is appropriate. Its prevention is among the foremost health maintenance challenges facing EVA operations for space station and orbital construction.

DCS is caused by the evolution of nitrogen (N2) bubbles in the tissue, induced by a state of tissue N2 super saturation relative to the ambient pressure. Conditions for this arise in the relatively low pressure environment of the EVA spacesuit compared to the space station pressure of 101.3 kPa (14,7 psi, or sea level equivalent pressure) or during accidental loss of pressure in the space suit. Current technology limits suit pressure to a level much lower than the sea level equivalent, primarily due to mobility constraints. It is during and after the transition to this lower pressure environment that the requirements for relative super saturation are met. As there is a considerable lag before tissue N2 equilibrates with ambient pressure, initial tissue N2 tension can easily exceed ambient pressure. The greater this margin, the more likely is the development of some manifestation of DCS.

The N2 tissue ratio (TR) is defined as tissue N2 tension/ambient pressure post-decompression. Theoretically, when transitioning to a lower pressure, any time this ratio exceeds 1.0 a state of super saturation exists, along with the potential to form bubbles. In practice symptoms of DCS were rarely seen unless this ratio exceeded 1,58. The bubbles can occur in nearly all parts of the body and lead to a direct (blockage of arteries) or indirect (edema in veins or of the interstitial tissue) barrier of the perfusion. Symptoms resulting from the evolution of N2 bubbles in tissue include localised limb and joint pain, known as type I DCS or "the bends", and the less common but more severe, vestibular, neurological and pulmonary damage, known as type II DCS. It has since been shown that many factors work to affect the tissue ratio at which DCS may occur.

Among other factors that contribute to the risk of DCS is duration of exposure to the lower pressure. It is well known that the greater the duration of exposure to lower relative pressure, the

greater the likelihood of DCS. The mean duration of Shuttle EVA so far is approximately 5 hours like the Mir EVA experience, and EVA in the 6-8 hour range are envisioned for the space station. Similar EVA duration would be expected for most orbital construction endeavors.
The effect of physical exercise during and after exposure increasing the incidence of DCS is well recognised. Presumably, resulting muscular tensile forces and micro vascular collapse provide a milieu more conducive to micro bubble nuclei generation and subsequent bubble growth in tissue. EVA operations will primarily involve moderate exercise levels for extended periods, especially during space station construction. The effect of physical exercise on DCS incidence continues to be of great concern.
Recent prior exposure to low relative pressure is also a risk factor for the development of DCS. It is generally accepted that reexposure to altitude within a few hours of a previous flight is associated with an increased incidence of DCS. The role of reexposure on consecutive days, however, is less clear, and this is a pertinent question with regard to EVA. Determining the optimal interval between EVA will be crucial, both for scheduled and unforeseen operations, and will vary with several factors.
Increasing age, obesity, female gender, and decreased ambient temperature are also thought to increase the risk of DCS although their contribution to the incidence is minor compared with the previously discussed factors. The dehydrated state is generally held to predispose to DCS, both in aviators and scuba divers, but this, too is a comparatively soft risk factor. It must be considered, however, because fluid status changes predictably in the weightless environment. What role fluid status will play in DCS during EVA is yet unclear. Individual variability may also play a role.
The mainstay of DCS treatment on-orbit is commensurate with its earthbound requirements-fluids and hyperbaric oxygen, with degree and duration of pressurisation dependent on severity of symptoms. If refractory symptoms or type II DCS or air embolism occur, de-orbit and landing need to be performed. For advanced phase space station operations, an onsite hyperbaric chamber is necessary. This will facilitate standard DCS treatment protocols utilised in diving and aviation medicine.
DCS I
The decompression sickness type I contains symptoms of tiredness and pain in the muscles and joints.
DCS II
The decompression sickness type II includes an affection of the lungs, the equilibrium and the central nervous system. The symptoms arise usually within the first six hours after exposure.
Due to intralybyrinthine bubbles or bubbles in inner ear vessels damage of the inner ear may result. Mainly microfissurs of inner ear structure are postulated as the reason. The symptoms include vertigo with directed nystagmus, tinnitus and sensorineural hearing loss. In case of DCS II while EVA loss of orientation in combination with vertigo may lead to an acute life threatening situation because the cosmonaut may not be able to return onboard the ISS on his own. An immediate reduction of the intracranial and perilymphatic pressure is mandatory including a bed rest. A surgical exploration is indicated in case the symptoms persist or worsen within 5 to 10 days.
Neurological symptoms of the spinal cord or peripheral nerves include a wide spectrum. A severe symptom occurs when partial or total myelopathy of the thoracic part of the spinal cord arises. The patients complain of paraesthesia in the lower limb and extremities, narrowness of thorax, pain in the back, muscular dysfunction of the extremities and loss of control of the bladder and anus. In the neurological examination a monoparesis or paraparesis together with sensory dysfunction appears. The neurological examination may be asymptomatic. In the spinal cord haemorrhagic infarction, edema, axonal degeneration or demyelination can occur.
The cerebral DCS can occur alone or in combination with the other symptoms. The symptoms may include confusion, cephalgia, ataxia, somnolence, visual dysfunction. In the examination a hemiparesis, dysphasia, hemianopsia, ataxia or other focal sign may be seen. A reduction of mental function can persist or increase. Other pathological signs can mimic the spinal DCS.

The symptoms of the pulmonal DCS include dyspnea, tachypnea, cough and cardiac pain. In severe cases the symptoms of a complete lung embolism, lung edema or ARDS may occur.
The cardiovascular symptoms are retrosternal pain, angina pectoris and severe arrhythmia in combination with cardiac ischemia or myocardial infarction. Ischemias may also occur in other organs, i. e. in the spleen or the GIT.
In the case of DCS shock a generalised formation of bubbles with consecutive damage of the endothelium takes place. It may lead to a disseminated intravascular coagulopathia with shock.
The differentiation between arterial gas embolism and DCS can be impossible in some cases. In some cases, also a combination of these both may occur.
The treatment of the arterial gas embolism is orientated on the ALS algorithm with assisted or artificial respiration with oxygen, rehydration and early recompression.

Trauma to the inner ear as a consequence of atmospheric pressure alteration is a relatively uncommon entity. However, it can be problematic for individuals working underwater, such as divers, submariners, and bridge builders, as well as those working at high altitudes, such as pilots (Kennedy, 1974; Lundgren, 1965) or individuals in artificial environments like astronauts and cosmonauts. Inner ear dysfunction can be produced by rapidly changing air pressure, as in atmospheric barotrauma; by elevated or asymmetric middle ear pressure, as in alternobaric trauma; or by bubble formation within the Labyrinth or its blood supply as in the case of inner ear decompression sickness and isobaric gas counter diffusion sickness. It should be recognised that during flying and especially during diving in deep water, visual and proprioceptive cues are less effective. These environments place an inordinate premium on vestibular input. Therefore, acute vestibular dysfunction leading to disequilibrium, disorientation, nausea, and vomiting can be devastating in such a setting. The same is true for EVA.
Extremes of pressure or abrupt changes in middle ear pressure are capable of damaging middle ear or inner ear structures. The latter is reflected by auditory and vestibular dysfunction. As opposed to alternobaric trauma, barotraumatic injury is frequently long lasting or permanent. Hearing loss and tinnitus are universal complaints, whereas vertigo tends to be less common (30%) and is rarely the sole complaint.
Barotrauma to the inner ear is suffered most frequently by divers, both scuba and breath holding. However, it has also been described during forceful sneezing with a closed mouth and nostrils.
A number of mechanisms have been proposed. All are based on a sudden pressure differential transmitted into the inner ear. Perhaps the most commonly cited theories are the "explosive and implosive" ones.
The implosive theory states that, as a consequence of increased middle ear pressure, the round window or oval window is displaced into the Labyrinth and can rupture into the inner ear. The explosive theory states that the increased intracranial pressure is transferred into the inner ear, resulting in an outward rupture of the round or oval window into the middle ear.
Atmospheric IEBT results in damage of varying degrees to the inner ear. Labyrinthine concussion, intralabyrinthine membrane tears, or damage to receptor structures, as seen in blast trauma, are reported. At its extreme there may be associated oval and, perhaps more likely, round window fistulas. The associated hearing loss varies but typically demonstrates an isolated deficit in the 4 to 8 kHz range. Total deafness has been noted.
A severe complication is the pulmonal barotrauma. A forced change of pressure while or after EVA in combination with dysfunction of lung diffusion can lead to pulmonal symptoms in barotrauma. An extension of the lung tissue can result in a rupture of the lung with consecutive emphysema of the mediastinum, pneumothorax, pneumopericard or rupture of the alveolar membrane with arterial gas embolism.
In case of rupture of the lung tissue patients complain of retrosternal pain, change of the voice or sensation of the globe. In the examination a crepitation of the skin on the neck and thorax including cardiovascular symptoms with tachypnea, hypotension, cyanosis and shock may occur.

When dyspnea, tachypnea and cyanosis are diagnosed, the possibility of a pneumothorax should be kept in mind. In this case, a hypersonoric percussion can be found.
The arterial gas embolism is a severe disease, though embolism may spread all over the body including embolism of the cardiac vessels and arteries of the central nervous system. In this case patients complain of cardiovascular and neurological symptoms.

1.3.3 Current diagnostic equipment and data interpretation methods

The following table describes the medical control parameters on short flights on the ISS:

Examination type	quiescent state	CF/+4-8 Gx	CF/+3-5 Gz	passive postural	Pressure chamber on height 5000 m	bicycle ergometer	Interruptable	schedule 1	schedule 2	vestibular	hemodynamic	orbital injection	deorbiting	quiescent state	active orthostatic	passive postural
biochemical blood analysis	■													■		
clinical blood analysis	■													■		
Urine analysis, clinical and biochemical	■													■		
electrocardiogram - 12 leads	■					■								■		
electrocardiogram - 3 stand. leads				■	■											■
electrocardiogram - D-S lead							■					■	■			
electrocardiogram (Nebu)		■	■					■	■							
heart rate on pulse										■					■	
arterial pressure		■	■	■	■	■	■								■	■
electroencephalography	■															
ultrasonic examination of internal	■													■		
Echocardiography dopplercardiography	■													■		
rheoencephalography	■			■							■			■		■
tetrapolar rheography	■													■		
Examination of external respiration function	■													■		
pneumography		■	■				■	■	■	■		■	■			

Comment:
покой – Research in quiescent state.
ЦФ - (CF) Centrifuge
4-8 Gx - effect of accelerate in the line of breast-back (value 4-8 units)
3-5 Gx - effect of accelerate in the line of head-pelvis (value 3-5 units)
ППП- (PPT) passive postural test
БК- 5000 м – lifting in pressure chamber on height 5000 м
ГЛ – hydrolaboratory (EVA operation execution)
ВЭ - bicycle ergometer
ПКУК – interrupted accumulation of acceleration (Кориолиса)
График 1 – (schedule 1) rotation on centrifuge according to schedule of orbital injection of spaceship

График 2 - (schedule 2) rotation on centrifuge according to schedule of spaceship landing
МК-5 – (Medical Control -5) exercise tolerance test on bicycle ergometer
ОДНТ – negative pressure on lower half of body
ВКД - EVA
АОП – active orthostatic sign
Вестибул тренир.- vestibular training
Тренировка в ГЛ - training in hydrolaboratory
Трен. Гемодин - hemodynamic training

Tab. 1: Standard parameter of the medical control on short flights on the ISS

Parameters of "Neurolab" (cosmonauts examination during the flight)

The complex should provide a registration, amplification, pre-processing of the following physiological signals:

Electrocardiogram lead:
- ECG lead DS,
- ECG1 lead I,
- ECG2 lead II,

2 electro-oculogram lead:
- EOG1 horizontal lead,
- EOG2 vertical lead on the right eye,

Electroencephalogram lead:
- EEG - FZ,
- EEG - CZ,
- EEG - PZ,
- EEG - F3-C3,
- EEG - C3-P3,
- EEG - F4- C4,
- EEG - C4- P4,

Electromyogram:
- EMG - forearm of right hand,
- EMG M. trapecius,

Pneumogram abdominal,
Pulse wave of right hand little finger,
Skin temperature of right hand little finger,
Body temperature (right axillary region),
Electrical resistance of skin:
- right hand little finger,
- frontal region of head (forehead),

Blood pressure (BP) tachyoscillographic of left hand cuff:
- BP of right hand fourth finger cuff,

Impedance cardiogram (with 3 electrode).

The complex should provide registration of the following parameters of an environment:
- Atmospheric pressure in range from 300 up to 1000 mm Hg with an error no more than ±1 mm Hg,
- Temperatures of an environment in range from 10 up to 40 C with an error no more than 1,
- Relative humidity (RH) in range from 20 up to 100 % with an error no more than 5 %.

The complex should provide registration of the speech information:

- With use of necklace microphone (ларингофона) РЕЧЬ-1 (speech-1),
- With use of the microphone РЕЧЬ-2 (speech-2).

The complex should provide registration of signals going from operating handles РУД and РУО (delivery РКК ENERGY):
For the handle of РУД:

- (-X) - acceleration at a starting of object,
- (+X) - acceleration at braking of object,
- (-Y) - acceleration at moving of object downwards,
- (+Y) - acceleration at moving of object upwards,
- (-Z) - acceleration at moving of object to the right,
- (+Z) - acceleration at moving of object to the left.

For the handle РУО:

- (-Uy) - angular velocity of a turn of object to the right,
- (+Uy) - angular velocity of a turn of object to the left,
- (-Uz) - angular velocity of a turn of object upwards,
- (+Uz) - angular velocity of a turn of object downwards,
- (-Ux) - angular velocity of a turn of object clockwise,
- (+Ux) - angular velocity of a turn of object counter-clockwise

The complex should provide registration of signals going from control panels "Homeostat - M", "Homeostat - C",

- U1, U2, U3 - level of a signal on an output of control handles of control panels "Homeostat - M", "Homeostat - C",
- X1, X2, X3 - level of a signal on an input of indicators of control panels "Homeostat - M", "Homeostat - C",
- Kc - coefficient of complexity of the solution of a problem,
- IDP1, IDP2, IDP3 - identifiers of control panels.

1.3.4 Available resources for cardiopulmonary resuscitation and advanced life support

The RSP provides the following functions:

- Low-flow 100% Oxygen to conscious person,
- Manual ventilation via Ambu bag (ALSP),
- Automatic ventilation for unconscious person.

Volume	337 ft^3 (.0095 m^3)
Dimensions	(4"x12.5"x3.5")
Mass	7.61 lbs. (3.45 kg.)
Power Requirements	None
Power Source	N/A
Fluid/Gas Description (with design pressures)	Gaseous O_2
First Available Flight	5A.1 (but not functional until 7A when USOS O_2 arrives)
Stowed/Deployed Location	CHeCS Rack Locker
Maximum Expected Operating Pressures	Regulator: 120 psi Supply Hose: 120 psi Control Module: 65 psi Control Module Supply Hose: 65 psi Patient Valve (Demand Valve): 43 psi Patient Valve Control Hose: 43 psi Patient Valve Supply Hose: 43 psi

RSP Components:

- Regulator: decreases nominal ISS supply pressure of 120 psi to 50 psi for use with the control module and provides low flow oxygen at approximate ambient pressure,
- Control Module: responsible for the timing and volume of gas delivered to the patient during automatic ventilation,
- Patient Valve: interface between control module and patient endotracheal tube for automatic ventilation,
- Supply Hose (8' 10"): connects to ISS O_2 bus (any O_2 source: CHeCS Rack, PBA, Shuttle Middeck),
- Extension Hose: used as an extension between patient valve and endotracheal Tube.

Tab. 2: RSP components

Advanced Life Support Pack (ALSP)

The ALSP stores medical instruments and supplies to support specific Advanced Cardiac Life Support (ACLS) and Basic Trauma Life Support (BTLS) protocols. It allows a Crew Medical Officer (CMO) to locate and utilise a collection of emergency medical instruments and supplies for the initial care and stabilisation of a critically ill/injured crewmember. This hardware is deployed during a medical incident aboard ISS or can be used during rescue transport operations. The ALSP separates the contents into organised identifiable kits according to the supported physiological functions. The ALSP provides for transport and restraint of stored items during ISS operations.

Fig. 7: ALS pack

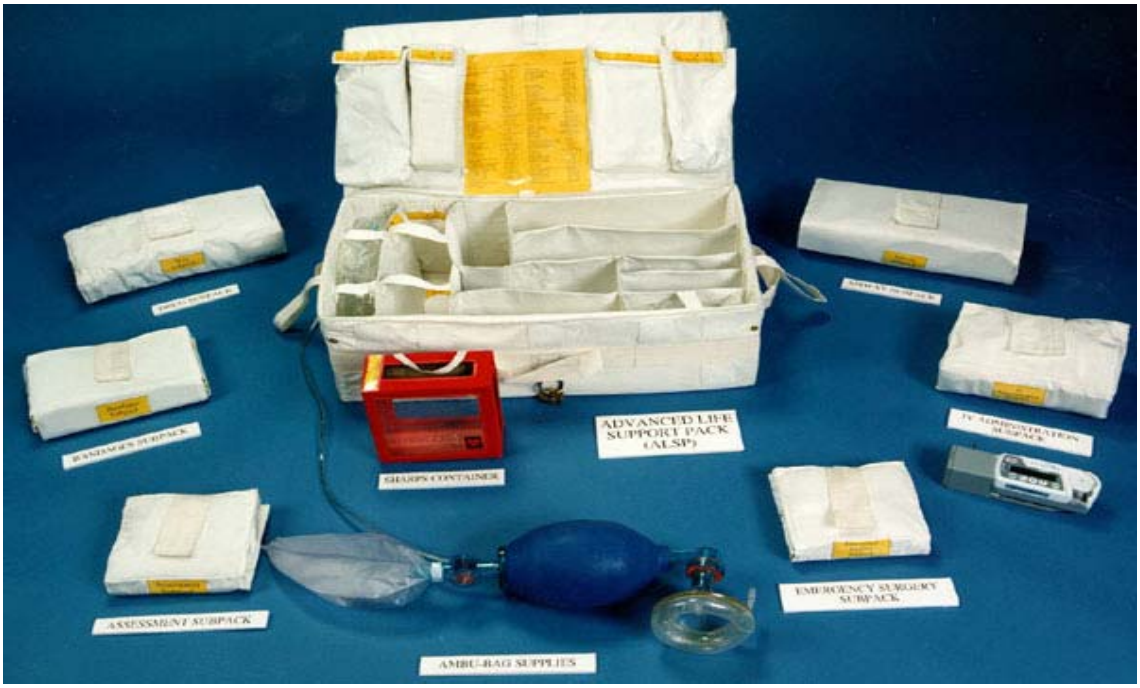


Fig. 8: ALS pack

Volume	1.66ft^3 (0.04689m^3)
Mass	36.0lbs (16.34kg)
Dimensions	26.0" x 14.0" x 8.0"
Power Requirements	None
Power Source	None
Battery Description	N/A
Fluid/Gas Description	N/A
First Available Flight	2A.2
Stowed/Deployed Location	Before arrival of CHeCS rack: SM (exact location unknown) After Flight 5A.1: CHeCS Rack Stowage Locker: LAB1D4_D2

ALSP components

- Subpacks,
- Airway Subpack,
- Assessment Subpack,
- Drug Subpack,
- Bandages Subpack,
- Emergency Surgery Subpack,
- IV Administration Subpack.

Tab. 3: ALSP components

Additional Subcomponents

- IV Infusion Pump,
- Intravenous Fluid (IVF) - 4.5L,
- Sharps Container,
- Ambu Bag and Mask,
- Automatic Blood Pressure Cuff (ABPC),
- Stethoscope,
- Blood Pressure Cuff,
- Ziplock Bags.

Airway Subpack

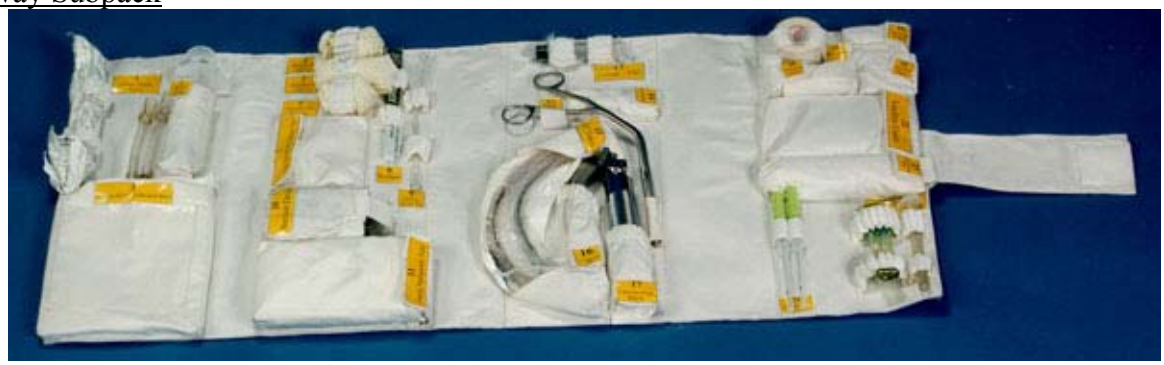


Fig. 9: Airway Subpack

Contents:

endotracheal Tube with stylet	Surgical Gloves
Chest Drain	Catheters (14G)
Laryngoscope	Xylocaine Jelly Lubricant
Magill Forceps	Nasal Airway
nasogastric Tube	Oral Airway
Proventil Inhaler	Suction Device + Accessories
Syringe (10cc)	Tracheostomy Tube
Tape	Vaseline Gauze
Povidone-Iodine Swabs	Alcohol Wipes
Scalpel	Curved Scissors

Tab. 4: Airway subpack components

Assessment Subpack

Fig. 10: Assessment Subpack

Contents:

Oral Disposable Thermometer	Penlight
Pulse Oximeter	Pulse Oximeter Transducers
Tongue Depressors	

Tab. 5: Assessment subpack components

Drug Subpack

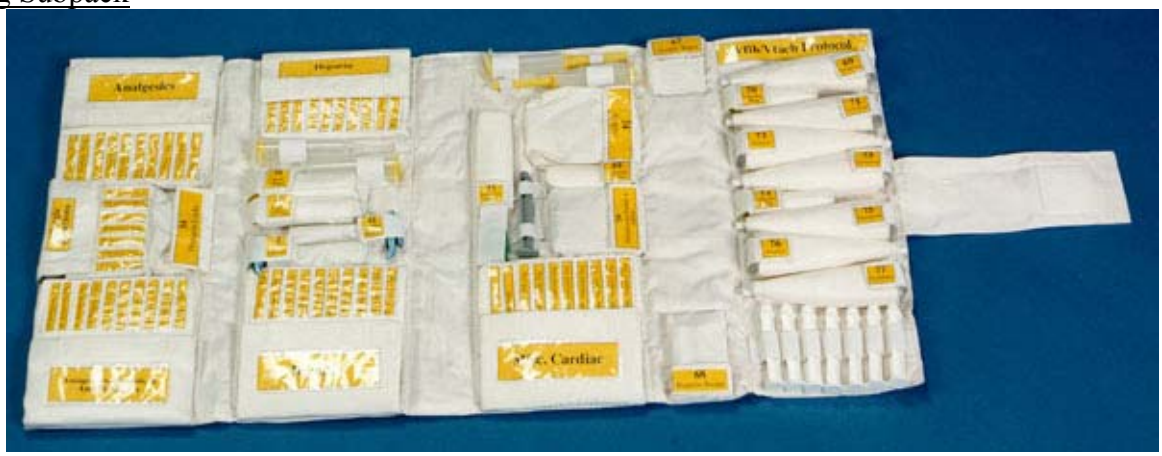


Fig. 11: Drug Subpack

Contents:

Adenocard	Atropine
Diphenhydramine (Benadryl)	Bretylium
Meperidine (Demerol)	Phenytoin (Dilantin)
Dopamine	Epinephrine 1:1000
Epinephrine 1:10,000	Haldol
Dexamethasone (Hexadrol)	Inderal (oral)
Furosemide (Lasix)	Lidocaine (cardiac)
Morphine Sulfate	Narcan
Nitroglycerin (transdermal)	Nitroglycerin (oral)
Romazicon	Tubex injector
Diazepam (Valium)	Verapamil

Tab. 6: Drug subpack components

Bandages Subpack

Fig. 12: Bandages Subpack

Contents:

Gauze Pads	Cotton Balls
Cotton Swabs	Kerlix Dressing
Kling Dressing	Telfa Pads
Tegaderm Dressing	

Tab. 7: Bandages subpack components

Emergency Surgery Subpack

Fig. 13: Emergency surgery subpack

Contents:

Surgical Instruments Assembly:	Surgical Gloves
Needle Driver	Scalpels
Forceps	Bandage Scissors
Hemostats	Sterile Drape
Sutures	Steri-Strips
Tape	Povidone-Iodine Swabs
Benzoin Swabs	

Tab. 8: Emergency surgery subpack components

IV Administration Subpack

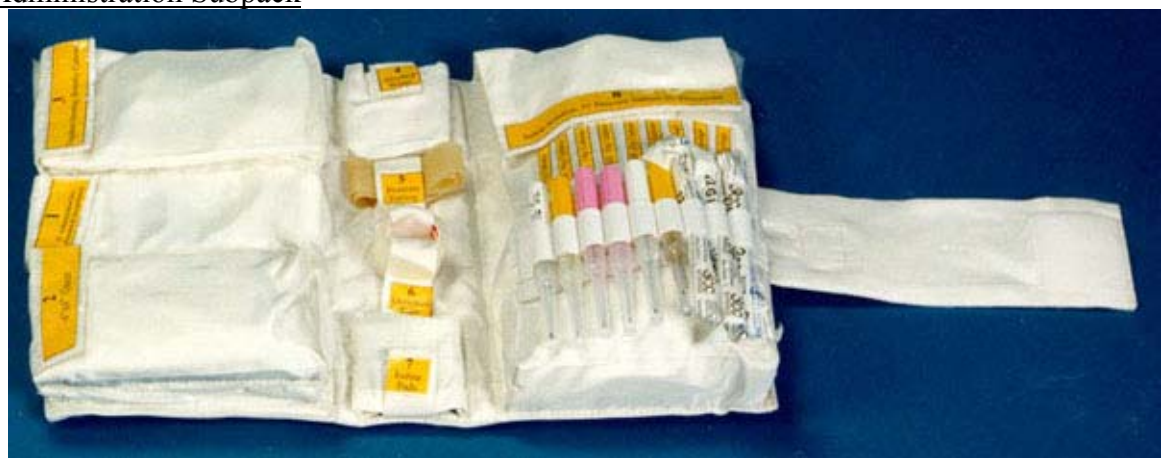


Fig. 14: IV administration subpack

Contents:

Butterfly Needles	Iodine Pads
IV Administration sets (non-powered and powered)	IV Flowmeter
IV Intracatheters (16G, 18G, 20G)	Tourniquet
Saline (500ml)	Pressure Infusor
Syringes (3cc, 20cc)	Y-type Catheters
Lever Lock Cannulas	

Tab. 9: IV administration subpack components

Additional subcomponents

IV Infusion Pump

The IV Infusion Pump provides powered continuous infusion of IVF, saline, in a microgravity environment.

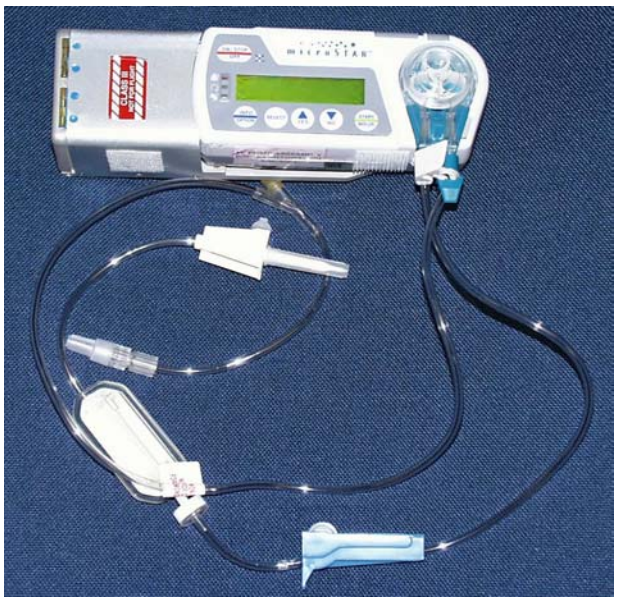


Fig. 15: IV Infusion Pump

Volume	59mm X 53mm X 205mm
Mass	0.65kg (including batteries)
Power Requirements	Battery pack composed of 9V batteries
Power Source	Primary battery pack
Battery Description	9V lithium, 4 required for nominal operation
Fluid/Gas Description	N/A
Stowed/Deployed Location	(within kit): ALSP
Measurement Parameters/ Analysis Capabilities	Operating Ranges: The IV infusion pump power supply shall provide no less than 10 hours of continuous flow at a rate of 125ml/min Nominal Values of Parameters: KVO rate: 0.9ml/hr Accuracy: +/-5%

Tab. 10: IV infusion pump components

Automatic Blood Pressure Cuff (ABPC)

The ABPC will be used by the CMO in taking automatic BP and HR readings. HR and BP are determined within 1 minute of manual activation by oscillometric technique. The ABPC includes a redundant pressure transducer to prevent over inflation of the cuff.

Fig. 16: IV Automatic Blood Pressure Cuff (ABPC)

Volume	Not Available
Mass	Not Available
Power Requirements	Battery: 1.5V
Battery Power	1.5V
Power Source	Battery
Battery Description	Each is 1.5V; four are required to operate the APBC. All are alkaline, size AA.
Fluid/Gas Description	N/A
Stowed/Deployed Location	ALSP-4 (within kit)
Measurement Parameters/ Analysis Capabilities:	BP: 20mmHg - 280mmHg HR: 40bpm - 200bpm (beats per minute)
Accuracy	BP: +/- 3mmHg or 2% whichever is greater for BP HR: +/-5%

Tab. 11: Automatic blood pressure components

Crew Interfaces for Operation

For using the iv. infusion pump the crew will have push-button controls to turn the device on and off and to adjust infusion rate and the volume to be infused.

The crew will activate the ABPC by push-button control to turn the unit on/off, activate a test cycle, recall previous data stored in memory, and adjust the maximum pressure values.

Consumables Description

(4) lithium 9V batteries, (4) 1.5 V alkaline AA batteries. Additional batteries will be carried in HASP until resupply of ALSP.

Resupply Schedule

The entire ALSP is resupplied once every 18 months or at the first available opportunity. However, the Drug Subpack is resupplied once every 6 months.

Batteries are intended to last until the entire ALSP is replaced.

Data Capabilities

The IV infusion pump displays data on a LCD screen. Data regarding the volume infused, volume remaining, and the current infusion rate is stored in internal memory until next use of the instrument.

The ABPC data is displayed on a LCD screen. Data recorded from the previous device activation is only stored in internal memory and accessed via the “Memory” button.

Refurnishment / Maintenance Schedule

No in-flight repair will be performed. Defective components will be replaced as needed. Any necessary maintenance will be performed during ground refurbishment.

Existing algorithm on board ISS

The existing algorithms are described in the attached file "algorithms on board the ISS", including a detailed medication list about the current drugs on board and their side effects.

The following existing algorithms for the ISS are mentioned in the attachment:

- Diagnostic algorithms:
    - RSP set-up algorithm,
    - Diagnosis-rhythm diagrams,
- Myocardial infarction algorithm,
- Tachycardia algorithm:
    - Synchronised cardioversion algorithm,
    - Bradycardia algorithm,
- Asytole algorithm,
- Pulseless electrical activity algorithm,
- Post resuscitation algorithm,
- Breathing difficulty algorithm,
- Crycothyrotomy algorithm:
    - CPR algorithm,
    - Nasal and oral airway,
    - Suction device,
    - Tracheal intubation,
    - Motion sickness,
    - Nausea and vomiting,
    - Pain relief,
- Injections algorithm,
- Shock algorithm,
- Burns algorithm,
- Vertigo algorithm,
- Barotrauma and DCS/ Bends.

1.3.5 De-orbiting of ill crewmember in re-entry vehicle

The return vehicle must be available in contingency situations that will require the crew to abandon the station immediately, to assure the return of the crew if the regular transport spacecraft are not available and to guarantee an emergency de-orbit of at least one de-conditioned, critically ill patient and one de-conditioned attendant. In order to meet these criteria, RV must be attached permanently to the station. Other options, like redundant spacecraft in higher orbit or dedicated rescue mission, initiated from the ground, are not feasible. However, the attachment to the station presents a single-point failure situation, when access to the vehicle becomes blocked.

At the beginning of the year 2004, Sojuz TM is the only operational spacecraft, for the crew transport to and from the ISS. It will also remain the primary rescue craft, permanently attached to the station and consequently be the designated spacecraft for the transport of sick crewmembers. The current options for an emergency de-orbit are analysed here; modifications of Sojuz landing module, the medical constraints and the suggested modifications are covered in parts 2 and 3.

The real experience with de-orbit of a crewmember under continuous intensive medical treatment is completely absent in both Russian and US programs. The probability of serious medical complications or of a total failure to render an effective medical help during de-orbiting is very high. Risk analysis for different medical scenarios, was briefly investigated in the framework of the project and is mentioned in parts 2 and 3.

Landing sites selection

Appropriate landing site for a spacecraft with critically ill crewmember on board can be selected according to the following criteria:

- Availability due to orbital parameters,
- Accessibility and environment,
- On site availability of medical resources,
- Possibility of a fast transfer into tertiary facility under continuous treatment.

With Sojuz TM re-entry profiles, the landing sites are generally in spacecraft's orbital plane and within a pre-defined down-range. Active aerodynamic and power control of the descending vehicle increases the cross-range.

Logistic support in medical contingency consists of:

- Stabilisation phase on board the spacecraft,
- Activation and relocation of recovery forces,
- Transfer into re-entry vehicle and waiting in orbit,
- Re-entry and landing,
- Recovery and transfer into definitive facility.

The second and the third item are the important variables. Transportation between different facilities is the most risky phase of the treatment in any environment and must be kept short. Orbital waiting time in the rescue vehicle must be reduced to an absolute minimum, especially if small spacecraft are used.

The following categories of landing sites are available:

Designated airport

This has been used only by Space Shuttle on continental USA territory. Additional sites as backup for emergency landing are theoretically available on all other continents except Antarctica, but were never practically used. Conditions for medical support and patient transport after landing are good; delay in preparation of recovery forces is minimal and medical treatment can be continued without significant delays after landing.

Practical availability is low; it is limited by number of orbits within the cross-range of the selected landing site and by the availability of Shuttle orbiter at the space platform. Dedicated Space Shuttle mission to return critically ill crewmembers from the station is theoretically possible, but not practicable because of unacceptable delay.

Designated area – land

This has been used by USSR – Russia since the beginning of human space flight. For geographical, logistic and political reasons, the primary landing area is within the flat continental landmass of Kazachstan or Russia. Landing outside the designated range is possible, with claimed accuracy within one kilometre. Availability of ground support and delay in relocation of recovery team are the main constraints in case of non-nominal landing with patient on board. Use of additional designated sites with support structure, located on other continents, e.g. western USA or Australia, would be theoretically possible; it could be a suitable option for fast evacuation from space stations.

Landing impact forces of Sojuz TM are reduced, by use of retro-rockets before touchdown, to values, which can be tolerated by critical care patient without adverse affects. Once on the ground, the spacecraft is stable; the position can be changed to facilitate the extraction of the patient through the hatch

Recovery team, including all medical specialists is transported by aircraft and helicopter to the anticipated landing site. Temporary medical facility, consisting of inflatable fabric structure is deployed on site. Medical treatment, at the level comparable to secondary centre, can be provided immediately after recovery and continue aboard helicopter and aircraft en route to the final facility.

Designated area – water

This option was not used since termination of Apollo programme. Sojuz TM is also equipped for landing on water surface, but this option was never intentionally used. Although selection of landing sites is theoretically greater and accuracy is not as paramount, this option has several disadvantages.

Extraction of the patient takes place in an unstable spacecraft position, especially at rough sea. The absence of solid platform around the spacecraft will limit the number of assisting personnel and extrication devices. Hoisting into the helicopter for transfer to the ship deck is mandatory. Continuous critical care under these conditions is very difficult access to the patient is limited. Potential exposure of medical devices to seawater may result in equipment failure.

In case of landing site overshoot, the delay between splashdown and recovery may result in status deterioration of the ill crewmember and can provoke seasickness of the attendant. In case of forced egress and delayed recovery, transfer of the patient into the survival raft is not practicable. The range of the SAR helicopters and availability of ships with other supporting equipment are important constraints on landing accuracy.

Random site

Sojuz TM has theoretical capability of re-entry during ascending and descending node of each orbit. "Landing anywhere" option was presented as one of major design advantages of the earlier proposed Crew Return Vehicle.

Except in case of catastrophic failure at the station with subsequent impossibility to maintain orbital autonomy of the descent vehicle, this option shall never be used with critical patient on board and is questionable even with healthy crew. Logistic difficulties with recovery, especially at sea, are obvious.

About 27% of Earth surface are dry land. With orbital inclination of 51 degrees, accessible surface will be reduced to around 20%. Approximately 40% of it is densely populated, or rugged, not readily accessible, and lacking any usable infrastructure. Equatorial rainforests, deserts, mountains and inland bodies of water will present substantial risk. This leaves about 12% of Earth surface suitable for an emergency landing with a good chance of efficient recovery and functioning ground support operations. Climatic extremes and current weather conditions at the landing site, daytime and possible political problems with entry into the territory and crew recovery must be considered.

Medical requirements

Spacecraft size and performance should be determined by operational and engineering aspects rather than medical requirements. It is easier to adapt existing and proven vehicle design to specific medical situation, rather than building new spacecraft around the hypothetical patient.

Cost-benefit analysis of rescue missions and dedicated vehicles development versus potential crewmembers' loss of life or sustained damage should be made and compared with situation in analogous terrestrial environments with high occupational risk. The suggestions for Sojuz TM modifications are given in the subsequent sections.

G-loads

The nominal re-entry profile of Sojuz TM spacecraft is shown in the following table:

operation	height	time, T	accelerate forces
turning on control engine (ДУ)	386 Km	To	0
separating	375 Km	To +25 min 35 sec	0
separating	102 Km	To + 28 min 32 sec	0

peak of accelerative forces	41,6 Km	To +34 min 27 sec	3,8 g
startup basic system of parachute (ОСП)	10,7 Km	To +36 min 48 sec	1,2 g
Separation front thermal protection (ЛТЗ)	-	To +37 min 20 sec	0
reconnection basic system of parachute (ОСП)	-	To + 40 min 48 sec	0
turning on soft landing engine (ДМП)	1 m	To +51 min 48 sec	1g

Table 12: Time versus G-forces for a nominal Sojuz TM spacecraft landing.

Other re- entry G-loads for existing spacecraft are approximately up to 17 min + and 1,5 Gz (Space Shuttle) and up to 8-9 + Gx for ballistic re-entry of Sojuz TM capsule. Typical peak during nominal landing of Sojuz TM is just under + 4 Gx. Effects of sustained acceleration on hemodynamics are discussed in the section "physiologic changes." It is obvious, that any patient's exposure to acceleration above + 2 G should be in x axis to minimise adverse effects. No consensus exists yet about maximal permissible forces for patients but Sojuz-type loads would be generally acceptable. Apparently, it is possible to change Sojuz entry trajectory to further reduce g-loads.

Effect of g-forced on attendant's manual performance and on existing and proposed medical devices is described in the part 2. If a patient is transported with an operational life support equipment, the need for a manual intervention during high g- profiles is very limited.

The most significant hemodynamics changes are found during rapid transition between +/- G forces. Such profiles are typical for civilian aerobatics environment and are normally not found in space flight, but their investigation might be valuable in further space cardiology research. Limits and duration of impact acceleration forces are still being discussed. Design reference values with patient on board are +/-10 G x, +/- 5 G y, +/- 5 G z, all for 0,2 sec.

Animal experiments have been performed to evaluate effect of blood loss on G forces tolerance. Sustained acceleration with + 3,3 Gx and + 8 Gx , corresponding roughly to nominal and ballistic re-entry profiles, with 20% and 40% blood loss were compared. As expected, higher G produced greater influence, but the loss of blood was the more important factor. Similar study was performed with toxic-induced lung injury; the G effect on respiratory function was transient and the lover G profile would be clearly preferable. No results of similar experiments on humans have been found. These experimental results must be interpreted carefully in the real critical care situation.

Firstly, it is expected that circulating volume will be replaced by electrolyte solutions and O2 transport capacity of blood enhanced by O2 application. Secondly, any patient with severe damage to lung parenchyma or with chest trauma shall be intubated and artificially ventilated.

Thirdly, continuous pharmacological support with vasoactive substances can be provided to partly compensate for adverse effect during dynamic phases of flight. Continuity of critical care treatment during re-entry and instant reaction to changes in vital parameters is essential.

The current de-orbit procedures require person which is conscious, has stable hemodynamics, and spontaneous airway protection, is capable of wearing the space-suit, capable of active ingress into the spacecraft and survives re-entry without intervention. Typical critical care patient doesn't fulfil this criteria; the solutions to this problem are discussed in the subsequent chapters.

2 Data structure and Management, Telemedicine Transmission and Simulation

2.1 Data structure/ compatibility

Regular evaluation of crew health during the space flight, medical prediction, therapeutic consultation and control are functional duties of the ground medical operators who rely primarily on data downlinked from GAMMA-1M, bicycle ergometer VB-3, Chibis used for health checks inside the space station, and BETA-08 outside the vehicle the for medical monitoring of EVA crews.

The results of medical investigations are reported to the crew surgeon during compasses and downlinked in the batch mode.

Regular health checks are aimed at collecting medical information necessary for a qualified evaluation of crew health and physical fitness.

To certify cosmonauts and astronauts for operation Egress, the medical information obtained at rest and during functional tests is analysed.

Special importance is attributed to medical monitoring on the phases of insertion, docking of the Sojuz vehicles, of Egress operations, LBNP training sessions, and descent in Sojuz.

The health monitoring program includes:

- health evaluation every 30 days,
- medical check prior to EVA,
- EVA monitoring,
- post-EVA check,
- fitness evaluation every 30 days,
- medical examination before return to Earth (2 weeks before landing).

Health evaluation every 30 days consists of physical examination of all crew members by a medical expert with entries made in relevant questionnaires, 12-lead EcG, clinical laboratory investigations, i.e. blood biochemistry (REFLOTRON-4), hematocrit count determination and urine analysis (UROLUX).

Results of the laboratory investigations are downlinked in the batch mode or during communication passes.

Anthropometric measurements, i.e. body mass and crus circumference determinations, are also performed. Results are reported in compasses.

The Pre-EVA medical check includes evaluation of physical performance and strength of the arm muscles, and filling out the abridged Questionnaire. On the EVA day, the ECG is recorded, BP measured, body mass determined and urine biochemistry analysed.

EVA monitoring includes recording of the ECG, pneumogram, and main spacesuit functional parameters.

The purpose of the post-EVA check has to inspect and examine extremities and integument for traumatic injuries made in EVA, body mass determination and urine biochemistry.

Fitness evaluation every 30 days is based on the results of functional testing by sub maximal loads on the bicycle ergometer and treadmill.

Medical examination before the return to Earth includes physical examination of all crew members, 12-lead ECG, clinical laboratory investigations of blood and urine, and fitness and orthostatic stability testing.

The schematic of ISS RS telemedicine data reception, processing and communication to users is shown in fig. 21.

2.2 Data structure and transfer protocols from existing telemedical equipment

Data downlink facilities on ISS and at MCC-M

The telemetric system BITS2-12 has been installed in the vehicle to collect and downlink data from equipment. Data transfer from ISS to MCC-M is executed only during downlink sessions and communications passes.

Outside the coverage of ground tracking stations telemetry and medical information, as well as spacesuit parameters, are filed in the memory unit to be down linked in the communication zones.

To provide telemetric link between crews on ISS RS and MCC-M, a system has been designed with the capabilities to collect, process, store, display, and distribute medical and maintenance information; the system is composed of the dedicated information centre at MCC-M (IVK MK/MNE) and terminals of the Medical Operations team (GMO GOGU).

The system enables the GMO GOGU personnel to evaluate current cosmonauts' health state immediately during compasses on the basis of physiological data down linked and displayed at the medical terminals.

Preliminary processed data and maintenance data are transferred by IVK MK/MNE to the terminals of the IBMP (TsUMOKO) radiation personnel.

Analysis of the results of radiation measurements is performed with account of the ISS Service module ballistics and attitude.

Telemedicine data storage and display at MCC-M

IVK MK/MNE hard- and software provide for tackling the following:

- Reception of data of health monitoring, medical payloads, and maintenance data integrated in the digital batch streams,
- Processing of the whole bulk of information in real time,
- Mounting and updating of short- (up to 10 days) and long-term (for the whole of the ISS RS operation) archives and databases of all types of processed health monitoring and maintenance information acquired during pre-flight training, in and post flight,
- Mounting and updating of the short- and long-term archives and databases of biomedical payloads data,
- multi-user access to the health monitoring and medical payloads archives and data bases with constraints to specific user categories (public, official use only, confidential etc.) to prevent unauthorised access,
- filing and transfer of the IVK processed health monitoring and medical payloads data (digital and graphic, electronic and hard copies),
- Type of information transfer in the IVK monitors (screens),
- Telemedicine data display at the personal working station,
- specialist and hard copies, as in graphic analog format (all parameters) and in the digital-alphabetic format.

Graphic data representation

Current MCC-M software allows graphic data representation in formats with the next characteristics:

- varying number of tracks (6 maximum),
- number of parameters on a track – 1-2,
- varying track width,
- varying graphic advance velocity,
- temporal scale is digitised in minutes and seconds (min., s),

Graphic files contain the following reference information:

- Moscow time of graphic onset (hr., min., s),
- Temporal scale interval (s),
- Indices of measured parameters,
- Graphic advance velocity (mm/s),
- mode (real time and delayed),
- Special formats.

To assess microclimate and radiation parameters in the ISS RS compartments, GMO GOGU personnel on duty use information provided by the MCC-M informational centre (IBK).
Analog-digital information is supplied in text and graphic files.
Below is the list of biomedical investigations data which are downlinked to MCC-Moscow within the batch streams and subjected to real-time automated processing in a dedicated medical monitoring and research information centre at MCC-M. Results of processing are then transferred, also in real time, to users' terminals for display and filing.

Experiment MBI-5 "Cardio-LBNP" – Comprehensive studies of the dynamics of the main cardiac function parameters and central and local circulation in cosmonauts at rest and during LBNP in flight.
Purpose. Evaluation of the human body functional potential in space flight is aimed at delving into adaptation processes at different periods in microgravity with consideration for specifics of a mission phase.
Achievement criterion: The experiment needs to be performed with the participation of at least 10 cosmonauts.
Objectives: The acquisition of new data from functional testing of cosmonauts on long-duration missions in order to perform comprehensive evaluation of adaptation and studies of processes underlying the adaptive reactions on various levels of circulation.
Equipment required for the experiment: orbital system GAMMA 1M.
Records of parameters made under the experimental protocol are downlinked within the batch streams, processed in real-time in a dedicated medical monitoring and research information centre at MCC-M, and transferred to the GMO GOGU terminals also in real time.

Experiment RBO-1 "Prognosis" – Development of a method for quick and effective prediction of radiation dose to the IS RS crew.
Purpose. Mounting a database to be used in development of a method for short-term forecasting influences of charged particles and dose rate from space radiation in- and outside the space station.
Results of previous investigations. Compared were readings of dosimeters R-16 on Mir and the ISS. The ISS Radiation Database has been build up by the following increments 1 and 2 and is now being replenished by radiation measurements during increment 5.
Objectives: Real-time collection of data from the orbital radiation monitoring dosimeters.
Test verification and an upgrade of methods of predicting radiation environment in the space station compartments and on external surfaces.
The experiment involves equipment of the orbital radiation monitoring system; namely these are the switch and power unit, pulse analyser, R-16 and DB-8 -type dosimeters.
Data for the experiment are downlinked via the orbital BITS 2-12 transmission link during each communication pass. Data are preliminary processed at IVK and transferred to the IBMP radiation personnel together with maintenance data.
Radiation measurement data are analysed with consideration for ISS RS ballistics and attitude.

Experiment MO-1 – Investigation of the resting bioelectrical activity of the heart
The experiment is scheduled every 30±3 days. It is performed in the Service module using GAMMA 1M, kit GAMMA, and wet wipes SLG.

No physical exercise is required for the investigation. Experimental sessions are assisted by a GMO operator at MCC-M who gets GAMMA 1M data in real time (5-6 minutes of compass are allotted to downlink data from one cosmonaut).

Experiment MO-4 – Evaluation of orthostatic stability during LBNP.
The experiment begins after 60 days in flight; it is conducted no earlier than 1.5 hrs. after meals but before exercises. Experimental sessions are performed in the Service module with the use of LBNP pneumo-vacuum suit Chibis, GAMMA 2M, kit GAMMA-1, and wet wipes SLG.
Each session takes one hour of the subject and one hour of the operator time. The test session is assisted by a GMO operator at MCC-M who gets GAMMA 1M data in real time (minimum 15 min. of compass are required for one investigation).

Experiment MO-5 – Cardiovascular investigations during the graded physical test on the bicycle ergometer.
Test sessions are performed each month and 5 to 7 days before pre-planned EVA 1.5 hrs after meals but before exercises. Experimental sessions are performed in the Service module with the use of GAMMA iM, bicycle ergometer VB-3, kit GAMMA-1, and wet wipes SLG.
Each session takes 50 minutes of the subject and 50 minutes of the operator time. The test session is assisted by a GMO operator at MCC-M who gets GAMMA 1M data in real time (12-15 min. of compass are required for one investigation).

Experiment MO-6 – Evaluation of the arm muscle strength on the bicycle ergometer.
The test is administered by crewmembers assigned for EVA in the Orlan spacesuit 10-12 days prior to egress at 1.5 hrs after meals but before exercises. Test sessions are performed in the Service module with the use of GAMMA 1M, bicycle ergometer VB-3, kit GAMMA-1, and wet wipes SLG.
Each session takes 30 minutes of the subject and 30 minutes of the operator time. The test session is assisted by a GMO operator at MCC-M who gets GAMMA 1M data in real time (8-10 min. of compass are required for one investigation).

Experiment MO-12 – Investigation of the cardiac bioelectrical activity in the orthogonal leads
Test sessions are performed in the Service module with the use of GAMMA 1M, PKO-ECG-orth. No physical exercise is required for investigation. At least 30 minutes should pass after meal. Each session takes 30 minutes of the subject and 30 minutes of the operator time. The test session is assisted by a GMO operator at MCC-M who gets GAMMA 1M data in real time (5-6 min. of compass are required for investigation of one subject).

Experiment "Morning examination on the EVA day"
Only participants in EVA donned in the Orlan spacesuit are examined. The test session is performed with the use of Orlan system BETA 08 and a tensoplus-sphygmometer. Each session takes 15 minutes of the EVA crew and is assisted by a GMO operator at MCC-M who gets BETA 08 in real time (minimum 5 minutes of compass).

2.3 Present structure and protocol of telemedical data transfer

This section deals with the principles underlying the Protocol of communication of different telemetry data (analog, digital, encryption parameters, medical data, etc.) between remote Telemetry Information Centres. The Protocol has been developed on the basis of CCSDS recommendations with consideration of the MCC-M experience in data distribution internally among subsystems of the dedicated information centre (IVK), and data communication to external users. Especially productive was the interface established between MCC-M and MCC-H to

communicate various telemetry information on the MIR/ SHUTTLE program and the current ISS program.

2.3.1 Data downlink from the ISS with GAMMA-1M

Purpose: Determination of the bioelectrical activity of the cosmonaut's heart during relative rest
Measured parameters:

- electrocardiogram in the DS-lead (ECG_{DS}),
- electrocardiogram in three standard leads (ECG – I, II, III),
- electrocardiogram in six thoracic leads (ECG – V1… – V6),
- radial artery sphygmogram (SG_{rad}),
- femoral artery sphygmogram (SG_{fem}),
- crus artery sphygmogram (SG_{crus}),
- temporal pulsogram (TPG),
- venoarterial pulsogram (VAP),
- kinetocardiogram of the right and left thorax (KCGr, KCGl),
- tacho-oscillogram to be used in BP determination (TO,TK),
- cuff pressure signals to be used in BP determination (PS),
- Kedrov's rheogram (RPGarm-arm**p**),
- bimastoidal rheogram (RPG_{bm}),
- frontomastoidal rheogram (RPG_{fm}),
- RPG rheograms (liver, lung, crus, forearm),
- BP range of measurement: 40 to 240 mm Hg.

Records of 6 parameters (depending on the selected program) of one cosmonaut are downlinked simultaneously from the ISS RS Service module.

2.3.2 Data downlink during EVA with BEAT 08

For medical monitoring during EVA the Beta 08 system has been integrated.
Measured parameters:

- electrocardiogram in the DS-lead (ECG_{DS}),
- pneumogram (PG),
- body (parotid) temperature (BT).

Body temperature measuring range: 33 to 39°C.
ECG, PG and BT records from each cosmonaut are downlinked from the ISS RS Service module.
Data of scheduled health monitoring are:

- GAMMA 1M (data from one crew member),
- ECG (simultaneous record of 6 out of 12 parameters depending on the selected program),
- REG – rheoencephalogram,
- RPG – (REG and RPG, 4 parameters simultaneously),
- BP,
- Pressure signal (PS),
- VB-3 performance data,
- Pedal shaft running rate,
- Loading value,
- Chibis performance data,
- Pressure gradient.

2.3.3 Data downlinked from the Sojuz-TM vehicle with ALPHA-11 system

- ECG,
- PG,
- Seismocardiogram (SCG),
- Data of medical monitoring of EVA crew downlinked from BETA 08,
- EKG,
- PG,
- BT,
- Spacesuit performance data,
- Gas pressure in mm Hg,
- Carbon dioxide concentration in %,
- Carbon dioxide difference at the absorber inlet and outlet in %,
- Temperature difference at water-filled suit inlet and outlet in °C,
- Temperature of the water-filled suit inlet in °C,
- Gas expenditure in l/min,
- Main tank oxygen pressure in atm,
- Backup tank oxygen pressure in atm,
- Suit battery voltage in V.

2.4 Testing the existing videoconference channel with the Russian Telemedicine Society Centre

The principle structure of information exchange includes data communication and establishment of videocon communication between participants in the Project. Videocons will be conducted in the one-point mode at IBMP and MCC-M and in the multi-point mode at the Gutenberg University in Mainz and RAT.

Videocon Interface protocols

The classic videocon structure connects terminals through the ISDN lines (digital network with integrated services). Utilisation of the ISDN channels and other networks and lines with assured communication quality (V.35, E1/T1 and others) is regulated by a series of H.320 recommendations developed by the ITU-T Telecommunication Standardisation Sector. Recently, greater footing has been gained by videocons using IP-networks, equally locally, regionally and globally distributed (standard H.323). By and large, it can be said that today virtually any digital communication channel with sufficient bandwidth can be used for the arrangement of videocons.

At present, videocons are conducted through communication lines with the bandwidth from 64 kbit/s to 512 Kbit/s (ISDN) and from 1-1.5 Mbit/s (IP networks). However, we should remember that acceptable video quality can be achieved at about 200 kbit/s, whereas a high-quality image in good systems is achieved at about 300 Kbit/s and higher.

There is the opinion that IP-systems require a broader bandwidth. Indeed, because of some specifics of information communication within the networks with commutation of packets (adding of headings, RTCP service packets etc.) the bandwidth needs to be extended by 20-30%. Experience shows that quality of videocons conducted through three BRI-channels (384 Kbit/s) or an IP-channel with the bandwidth of about 500 Kbit/s is approximately the same. Leading manufacturers of videocon systems have long ago started production of multiprotocol (H.320/H.323) systems operating very well in IP and ISDN networks simultaneously.

Experience also shows that frequently it is easier to utilise IP channels than ISDN. Therefore, when considering a specific case, preference is often given to IP-systems.

Hence, to conduct videocons between participants in the Project it is expedient to use H.323 protocols, which substantially simplifies the communication design presented.

Data communicated in telemetric packets with the structure illustrated in fig. 17.

Headers		Packet Data
Primary header	Secondary Header	Packet Data

Fig. 17: Telemetric packets

Telemetry Packet contains the following fields:

- Primary Header in the CCSDS structure; two lower bytes of the header contain Packet width in bytes without consideration for the heading length,
- Secondary header,
- Packet Data,
- Primary header with the data identifying,
- Source, e.g. orbital telemetry system,
- sequence of packet transfer,
- Packet length,
- Secondary header contains additional data including,
- Delivery time
- Data type.

Depending on type of the data, the Packet Data field may be absent. The Packet Data field is absent in communication of opening and closing messages, in empty bits computers exchange after connection without exchange of meaningful data etc. All elements in a telemetry data packet have a direct or network-generated bytes order. Figure 18 shows the sequence of data exchange in a communication session.

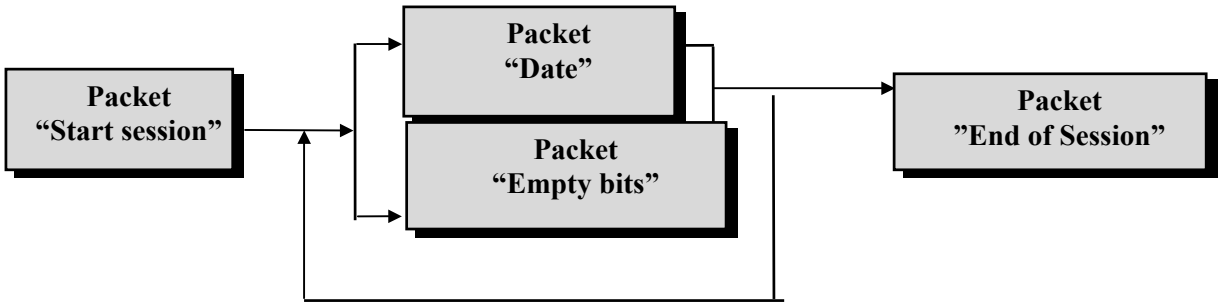


Fig. 18: Data packets

The “Start session” packet initiates and the “End of session” closes the communication session. After communication initiation, either “Data” packets with telemetry data or “Empty bits” packets can be sent if no data have prepared

We shall consider the process of space downlink. Since each telemetry packet has a primary and secondary header with information about packet length, type of data and index of orbital telemetry system, different data can be downlinked in one session. The type of data characterises the structure of downlinked information. The packet length allows separation of data of one packet from data of another. If the type of data is the same, the packets can be differentiated by the index

of an orbital telemetry system. This is the way of multiplexing from different orbital telemetry systems.
Four parameters are essential for assembly of telemetry packets for a given orbital telemetry system.
One is Type of data in the Secondary header which identifies the structure of records of the variable length for one and several meanings of telemetry parameters. Each partner can define the structure of records to be communicated by specification of the type of data.
Two other parameters are Type of meaning and Status in the Record header and are used to identify various regular structures in telemetry data.
The fourth parameter is Parameter index in the Record header which is a universal key to data records; the key can help interpret random data.
This ensures flexibility in telemetry packet assembly.

Structure of the Packet Data field with records of the variable length
Structure of the Packet Data field (fig. 18) to be downlinked is shown in fig. 19.

Record No. 1	Records No. 2	. . .	Record No. N

Fig. 19: Structure of packet fields

Each record has a variable length. Two types of records are the following: a one-value record and a record of array of parameter values. The second type can be used specifically to downlink medical data arrays. One Packet Data field can contain both types of record.
Within the structure of record of either one parameter or data array the next fields can be identified:

- Parameter index,
- Type of value,
- Parameter state,
- Status,
- Dimension index,
- Record data time,
- Record data length,
- Record data.

Seven fields from the top determine the fixed structure and make the Record header; the last field in the list contains downlinked data and has a variable length.
Two types of records are distinguished by content of the Record Data field:

- type-1 record is associated with the field containing one value and
- type-2 is associated with the field containing an array of values.

Type-1 record is recognized by symbol 1 in the most significant bit in the Status field and type-2 record – by symbol 0 in this field.

Value type determines a method of interpreting one value or an array in the Record Data field. Admissible Value types are presented in the table below:

N	Type of value	Interpretation of type of value		Content
		One value record	Array record	
1	void = 0	yes	yes	Value in the Record data is interpreted as a random bit sequence; length in bytes is defined in the Record Data length field
2	byte = 1	yes	yes	8-bit integer without sign
3	short = 2	yes	yes	16-bit integer
4	int = 3	yes	yes	32-bit integer
5	long = 4	yes	yes	64-bit integer
6	float = 5	yes	yes	32-bit real number
7	double = 6	yes	yes	64-bit real number
8	code = 7	yes	no	Code value ($1 <= L_{code} <= 64$)

Tab. 13: Code value and code length

As it has been said, the Status field is intended for communication of a scalar or vector value. This field is also used to define the necessity to show time prior to each value communicated in a one-type array, sampling rate, etc.

At present, MCC-M supplies results of telemedicine data processing to the internal (Medical ops team, GMO GOGU) and external (IMBP) users.

Telemedicine and maintenance data are communicated to GMO GOGU in real time and on completion of communication passages via the local network using FTP for a data communication interface between MCC-M and IBMP

MCC-M and TsUMOKO communicate through sluice server MCC-M and FTP-server, respectively:

- MCC-M transfers information in the delayed (post-compass) move mode,
- The information can be communicated from TsMOKO any time,
- Exchange servers of MCC-M and TsUMOKO are configured with symmetric catalogue structures: folder OUT for output files and folder IN for input files
- The MCC-M sluice server receives information as new data becomes available at the dedicated information centre
- Information is communicated to the TsUMOKO FTP-server following a respective request.

The three-year experience in this technology of data exchange between MCC-M and TsUMOKO permits a positive conclusion concerning the selected interface.

At the same time, MCC-M is taking efforts in preparation for providing telemedicine data using the Web-technology.

2.5 Point-To-Point/ P2P link (Moscow-Mainz-Erlangen), safety and security

Data protection is one of the most critical aspects of establishing a system for telemetric data exchange. In a broad sense, data protection is interpreted as protection from distortion during:

- long-term storage nodes (servers),
- all phases of processing,
- transportation.

Typically, the problem of data protection from distortion is overcome through the use of the next methods:

- selection of reliable equipment,
- data duplication at different phases of processing,
- selection of adequate DBOS, archives, DB maintenance program,
- selection of adequate common software (DBOS, etc.),
- verification of specialized software,
- selection of technologies for data protection against unauthorized access (UA) on the phases of data processing, presentation and storage, and exchange between participants in the project.

The above issues will be a subject in the following parts of this project.

At the present phase, data protection is facilitated by existing national standards regulating associated processes (GOST and Requirements of the State Technical Board). GOST and the Requirements are used as guidelines by developers of hard- and software compatible with different operation platforms and DBOS (WINDOWS, UNIX etc.).

The choice of a hard- and software system for data protection from distortion during videocons or data communication is governed by the following factors:

- type of operation platform,
- type of computer,
- interfaces of communication and on-line equipment,
- traffic capacity of communication channels.

This can be done in two ways:

- using an IP communication network with data protection consistent with GOST,
- using appropriate cryptoprotection hard- and software systems ShIP, COMFAX etc.

This project is planned to employ three digital IP data communication networks (attachment 2):

- COMCOR network for data exchange between Russian participants
- COMCOR, ROSTELECOM and DeutscheTelecom networks for data exchange between participants in the project and the Guttenberg University (Germany).

The COMCOR digital network has been granted a class G data protection certificate. ROSTELECOM and DeutscheTelecom do not have certificates. With this in view, the following provisions will be made to protect data from distortion:

On phase one of the Project data protection will be limited by the means existing in the IP networks and data exchange protocols.

On the second phase, a protocol will be developed to protect data from distortion at all stages of processing, presentation, storage and communication of telemedicine information that will be mandatory for all participants in the Project.

The protocol will contain proposals of hard- and software, approaches to networking participants in the Project to establish videocon communication among Project participants, permanent service maintenance of hard- and software of participants in the Project, anti-UA protection, and utilization of available or development of new data protection of hard- and software (cryptoprotection, etc.).

2.6 Protection of videocon communication (cryptographic systems IP-safe-pro)

The document proposes cryptographic information protection IPSafe-PRO (encoding, sim-protection, inter-network filtering) to be used to conduct protected IP-based videoconferences.
Confidentiality of information exchanged during videoconferences can be secure with the use of proposed cryptographic hard- and software IPSafe-PRO.
The cryptographic system IPSafe-PRO has been designed for virtual private IP-networks (VPN). It is a cryptographic sluice (IP router with the functions of a inter-network filter) that ensures information confidentiality by building ESP (Encapsulated Security Payload, RFC 2406) protected tunnels out of a set of IPSec specs.
Standard IPSafe-PRO is a device with two FreeBSD-controlled Ethernet interfaces housed in an IBM PC compatible book-size computer (fig.1). As an option, interface plates to support standards G.703, G.704, V.35, RS-232 can be built in.

Fig. 20: IPSafe-PRO

IPSafe-PRO uses certified cryptonuleus (FreeBSD controlled SKZI version CRYPTO-COM 3.0) управлением ОС FreeBSD).
IPSafe-PRO protects confidential information exchange between remote clients of an information system utilizing IP-networks (fig.20).
The device is mounted as a static router at the inlet of a local network (LN) or a network segment (fig. 20, IPSafe-PRO 1, 3, 5) and functions as an IP-router and filter and cryptographic protector of in- and outgoing IP-packets. The device can be integrated with the network in the communication mode based on the PPP protocol (fig. 20, IPSafe-PRO 2, 4).
Within the network, IPSafe-PRO works immediately with IP packets and is absolutely transparent for end user.

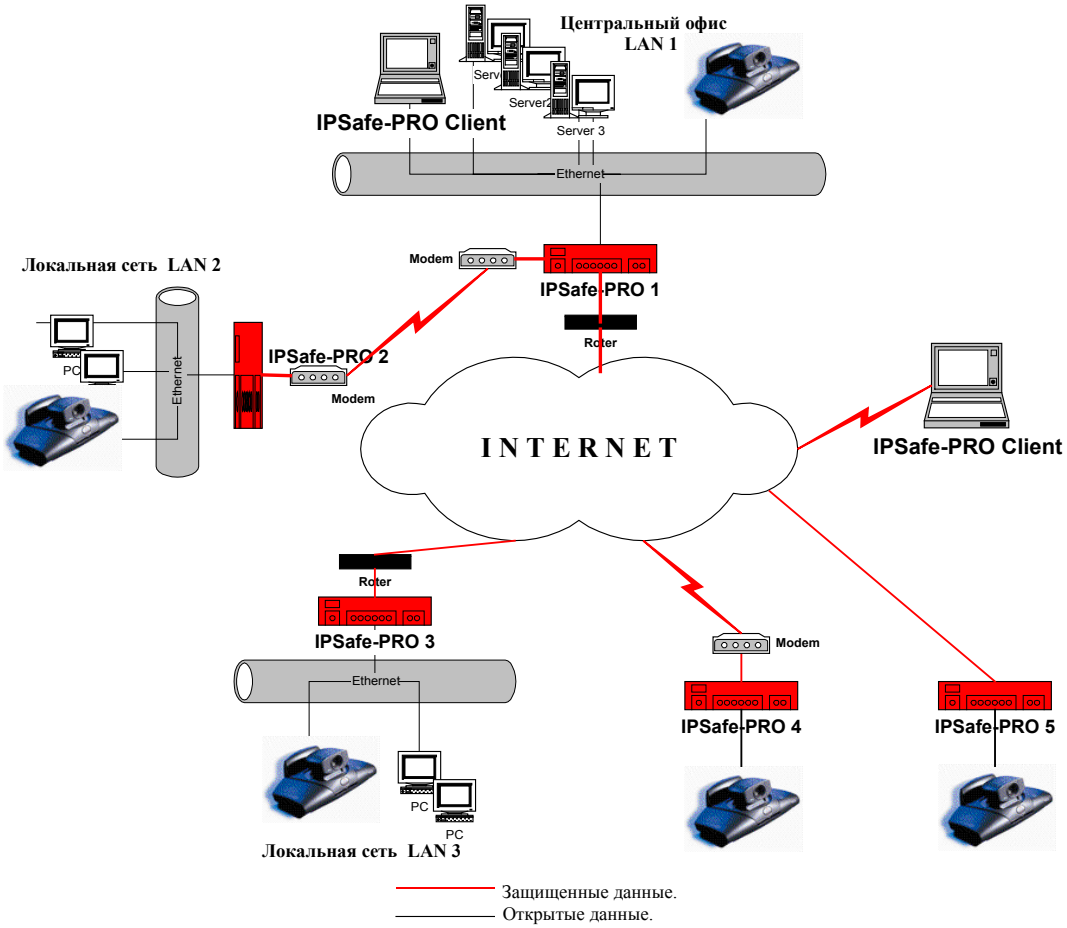


Fig.21: IPSafe-PRO-protected VPN

In combination with Russian and international cryptographic standards, ESP application in the IPSafe-PRO systems renders the following safety services:

- confidentiality of data transfer and processing,
- data integrity,
- authentification of data source,
- hiding of the topology of protected systems and its segments,
- protection from traffic analysis.

Confidentiality is achieved by encoding useful data, and authentification and integrity are ensured by computation of a cryptographic control sum. Topology protection and protection from traffic analysis are executed with the help of the ESP tunnel mode, the essence of which is substitution of true IP addresses of the data source and user and optional introduction of a random number of additional symbols (up to 255) during encoding.

IPSafe-PRO is based on a symmetric key system. Keys are kept and distributed within the protection contexts that unambiguously identify the following:

- the pair of devices connected with a protected tunnel,
- data transfer direction,
- cryptographic protocols and algorithms,
- working keys,
- network interfaces.

In addition to the primary IP-traffic protection function, IPSafe-PRO also has, though limited, functions of a static router and inter-network filtering: protection against puffing, IP-packets filtration by addresses (host address, network number, range of IP addresses), ports (for TCP and

UDP), protocols. etc. With these, the device can be used to protect the local network against unauthorized access and network attacks.
Control of the cryptorouters and distribution of key information can be both centralized and decentralized (combined mode is also possible).
In the centralized mode, formation and distribution of keys are performed either directly by one of the IPSafe-PRO components, or at the administrator's working place supplied with cryptographic program module IPSafe-PRO Client operated by MS Windows 2000.
Module IPSafe-PRO Client allows the cryptosystem administrator at his working place to adjust any cryptorouter in the protected mode. Moreover, the administrator can control the network being at home by connecting to IPSafe-PRO via the Internet in the dial-up mode.
Built in the Windows 2000 network architecture on the level of ndis.sys driver, IPSafe-PRO Client intersects and supports cryptographic processing of IP-packets transported between network protocols and adapters. IPSafe-PRO Client can be installed in client's Notebook or PC as a network server which does not require reconfiguration of applications software. This program module is compatible with IPSafe-PRO protocols and cryptoalgorithms and is intended for driving protection tunnels to interface remote working stations and IPSafe-PRO-protected network resources or the IPSafe-PRO systems directly.
The IPSafe-PRO Client uses certified cryptonucleus Crypto-COM 3.0 of the Russian Federal Agency of Governmental Communication and Information (FAPSI).
In cooperation with experts of NvisionGroup, field testing was performed to assess protective efficiency of IPSafe-PRO in videoconference by the next criteria:
compatibility of cryptorouters with the equipment used in videoconferences (monitoring of network segments to detect losses and delays in IP-packets transfer)
videoconference quality (comparison of video images with and without cryptorouters).
The following modes of videoconference sessions were tested:

- "point-point" (between each pair of videocon terminals),
- multipoint speaker imaging mode,
- multipoint "permanent presence" mode.

For each of the modes, the quality of communication sessions was evaluated with the videocon equipment operating in the next three combinations:

- w/o cryptorouters,
- with cryptorouters but w/o encoding,
- with cryptorouters in the design condition of encoding (GOST 28147-89).

Communication was maintained at the following velocities:

- 128 Kb/s, 384 Kb/s and 768 Kb/s in the "point-point" and multipoint speaker imaging modes
- 128 Kb/s, 384 Kb/s, 1536 Kb/s in the multipoint "permanent presence" mode.

The network monitoring test did not detect any instances of loss or significant delay of packet transfer. Comparison of video images and audio signals attested the absence of quality degradation as a result of activation of IPSafe-PRO cryptorouters.
Hence, these tests showed that information can be protected with the use of the IPSafe-PRO cryptorouters in integration with videocon networks.
The hot backup system is a valuable IPSafe-PRO option. The backup system consists of a pair of constantly mutually testing IPSafe-PROs, one of which is the lead and the other is the backup. In case the lead fails, the backup will automatically take on control, send a respective message to the administrator and start functioning as the lead. As a result, the network sustains operations; network serviceability in the event of failure of one device takes less than 10 seconds.
IPSafe-PRO hot backup has a particular meaning for protecting multipoint videocons conducted through the MCU server as it enhances significant fault-tolerance of the system.

Main characteristics of the IPSafe-PRO system are:

- Tunneling on the basis of the ESP protocol of the family of IPSec recommendations,
- Support of Russian and international cryptographic encoding and deencoding algorithms:
  - GOST 28147-89, RC5, 3DES, DES,
  - GOST R 34.11-94, SHA-1, MD5,
- Inter-network filtering – translation of addresses, anti-puffing protection, IP-packets filtration by addresses, protocols and applications,
- Simultaneous support of both protected and open connections,
- Support of the PPP protocol for asynchronous interaction via usual phone lines,
- NTP (Network Time Protocol) support,
- Hardware (FreeBSD-operated) and software (Windows 2000-operated) implementations,
- Hot backup mode (FreeBSD-operated hardware and the Ethernet interfaces),
- Options of centralized and decentralized administration and key distribution without use of additional hard- and software,
- Data processing velocity – up to 100 Mbps (depending on deencoding algorithm and processor manufacturer),
- FAPSI certified cryptonucleus (Crypto-Com. 3.0).

Crypto-Com 3.0 is a low-level library of cryptographic transformations awarded a FASPI information safety certificate (classes KC-1 and KC-2). The library is open for experts in applied cryptography and is used as a certified cryptonucleus of high-level cryptographic libraries, information protection programs, and hard/software products by Signal-COM (including as a part of IPSafe-PRO and IPSafe-PRO Client).

The Crypto-Com 3.0 library implements Russian cryptographic encoding standards (GOST 28147-89), ETsP (GOST R 34.10-94), and hash-function computation (GOST R 34.11-94); the library has been developed for Intel x86 computers and is compatible with operating systems MS DOS, MS Windows 2000/NT/ME/95/98, SCO Unix, Linux, FreeBSD, HP-UX, and Solaris.

FAPSI certificates № СФ/124-0476 and № СФ/124-0477 issued on June 10, 2001 were given to Crypto-Com 3.0 compatible with MS Windows 2000/NT/95/98 and MS DOS. In view of the positive certification test results, it is anticipated that FASPI will issue a certificate which will permit the protection of information with Crypto-Com 3.0 compatible with operating systems SCO Unix, Linux, FreeBSD, HP-UX, and Solaris.

Summary of the main IPSafe-PRO characteristics

Characteristic	**IPSafe-PRO**
Certification	FAPSI certificate for cryptonucleus Crypto-Com 3.0
Operating system	FreeBSD Windows 2000
protection implementation level	Network
Russian cryptographic standards	GOST 28147-89, GOST R 34.11-94
International cryptographic algorithms	RC5, 3DES, DES, SHA-1, MD5
Protocols used in VPN development	IPSec (ESP)
Protected configurations	Inter-network and intra-network interfaces, remote access

Client's segment	«IPSafe-PRO Client» for Windows 2000
Asynchronous access support	According to PPP (for FreeBSD-controlled hardware systems)
Support of additional interfaces	G.703, G.704, V.35, RS-232 etc. (for FreeBSD-controlled hardware systems)
Hot backup	For FreeBSD-controlled hardware systems with Ethernet interfaces
Type of key system	Symmetric
Administration and key information distribution	Centralized and decentralized with the use of in-built units
Packets filtration	On the network/transport levels
Logging	Making entries in the logbook
Protection from unauthorized access to administration	Hardware keys eToken and hardlock (for Windows 2000)
Overheads to support tunnels	60 bytes per an IP-packet
Maximal traffic capacity (as specified by manufacturer)	100 Mb/s (Pentium 700)
Interfacing with VPN of other manufacturers	ESP is requirement

Tab. 14: Table network protection 1

COST OF THE INFORMATION PROTECTION HARD- AND SOFTWARE

This section gives prices for network protection means utilizing FAPSI certified Crypto-Com 3.0
Prices in US$ with value added tax included

Name of product or service	Price, $	Note
Cryptographic system IPSafe-PRO. Configuration #1.	1,400	Standard implementation – Desktop or Book-size PC
Cryptographic system IPSafe-PRO. Configuration #2.	2,950	Commercial computer (to match a standard 19" rack. Height: 2U).
Hot backup subsystem	400	For configurations #1 and #2.
Software system IPSafe-PRO Client.	See table 3	Price of one system is determined by the overall size of purchase
Additional products and services		
Adjustment and assembly of one IPSafe-PRO set	200	In accordance with client's request
Adjustment and assembly of one IPSafe-PRO Client	30	In accordance with client's request
IPSafe-PRO training	200	At client's request. Price in the table does not include visit of specialist and travel expenses
Annual service maintenance	10% (no less than $30) a month	At client's request on completion of warranty period, to be paid quarterly.

Tab. 15: Network protection 2

Total number of purchased IPSafe-PRO Client	Up to 10	Up to 25	Up to 50	Up to 100	Up to 250	Up to 251
Price of system IPSafe-PRO Client, $	120	110	100	90	80	70

Tab. 16: Network protection 3

Notes:
1. Warranty period is one year since delivery.
2. Any cryptographic system IPSafe-PRO can be used as the Center of Network Administration.

Requirements to channels' traffic capacity to support videocons on the IP protocol (protected mode)

1. Traffic capacity: 784 Kb/s - 1 Mb/s.
Active use of the communication channel should be minimized (communication of big files, generation of database inquiries, etc.) at the time of a videocon session.
Proposed composition of the videocon equipment:
   1. Polycom View Station SP 384 (point-point videocon),
   2. Polycom View Station FX (point-point and multipoint videocons).

2.7 Date structures/compatibility concerning Human Patient Simulator (HPS)

In this chapter we describe the approach for the modelling of cosmonauts on a patient simulator. In the case of the TEMOS project we used a full-scale simulator HPS (human patient simulator) produced by METI.
This simulator uses a physiological model for a representation of the human physiology on a computer controlled patient mannequin. The simulated organism consists of a cardiovascular, a respiratory, and a pharmacological model together with renal and hepatic functions. All these separate models interact with each other and allow a realistic simulation of physiological characteristics of a human body.
These simulators are mostly used in education and training of medical staff or students. The utilisation of full scale simulators in medicine allowed to translate the concept of Crew Resource Management from aviation into the medical context and they allow training of critical situations in a safe environment. The reproducibility of such situations allows training of both technical skills, training of medical abilities, and non technical skills such as communications between trainees and performance of teams.
Additionally, these simulators can be used for the development and the evaluation of safe and ergonomically well designed work environments.
The physiological models of METI's HPS can be accessed through a programming interface and it allows the manipulation of the existing baseline physiologic models. This can be done through changing of the physiological parameters that define the physiological models. The parameters mostly consist of medically interpretable physiological concepts which in many cases coincide with parameters that are used in medicine for the description of the human organism. E.g. for the adaptation of the baseline cardiovascular model to a certain type of patient, it is possible to change the cardiac contractility, the systemic vascular resistance or the venous capacity.

Programming a simulator through physiological concepts has two consequences. On the one hand, a deep knowledge of the physiological changes of the organism that is to be simulated in comparison to the baseline organism is required; on the other hand, this type of programming a priori only allows the simulation of typical organisms with certain physiological characteristics. This means that e.g. the simulation of an organism with a right heart failure will principally produce the same symptoms as a real patient with this problem, but a real coincidence of the produced symptoms and the exact same behaviour cannot be guaranteed. We call this "Educational Simulation" as the possibility of simulation of general and typical characteristics of physiology is sufficient for training and education in medicine.
In the context of the project to model the physiology of cosmonauts on the HPS this has the following consequence: The goal is to consult a patient simulator for the simulation and teleconsultation of critical situations in space. This means that the organism of a real cosmonaut at the time of being in the orbit needs to be represented at a patient simulator and future reactions of the real organism needs to be predictable through a patient simulator. We call this type of simulation "Concrete Simulation". Concrete Simulations are not directly possible on simulators that work through the paradigm of Educational Simulation.
To solve this problem we followed two approaches:
„bottom up" – Representation of cosmonauts by Educational Simulation to obtain simulated organisms that correspond to cosmonauts before, during and after a space mission (see 1.3.2).
„top down" – Representation of cosmonauts on the patient simulator by physiological concepts that were obtained by analysis of data of a specific cosmonaut.

2.8 Definition of Joint Protocol/Standards (HPS-real data)

The translation of measured physiological data (symptoms) of a cosmonaut into a description of the underlying physiological mechanisms that can be used to program the simulator is not a trivial task.
Symptoms, e.g. a discrete value for blood pressure, cannot be interpreted without the knowledge of the context of the state of the whole organism. Discrete values can be classified as "normal" or "pathologically changed" only after understanding the context.
In the case of cosmonauts, such a physiological context of discrete symptoms can be achieved by two components:
Cosmonauts represent a strongly selected and homogeneous group of human organisms. During training the candidates have to pass several medical examinations, which guarantee the behaviour of important organ functions in different situations in certain limits. This gives reason to assume that in certain limits statements on the behaviour of the organisms of cosmonauts as a whole can be also applied on individual cosmonauts.
Differences or statements on the grade of differences of the individual cosmonaut to the average of all the considered cosmonauts can be achieved through the analysis of physiological data of cosmonauts. For this analysis, statistical methods like data-mining methods can be considered. These methods require a big mass of raw data about each cosmonaut in all representative phases in test, training, and flight.
During the course of the project we noticed that data in the required quality and amount are not collected for the individual cosmonaut and thus are not available. This means that a "top-down" approach for the Concrete Simulation cannot be realised in the near future. Examples for the data supplied can be found in 3.3.4.

2.9 Development of software structure for data implementation into HPS

The approach of Educational Simulation of cosmonauts can be realised.
The problem of simulation of a typical cosmonaut was solved through a strategy of simulation in separate states of the space mission. The states were defined as phases before, during, and after a

space flight with constant impacts on the organisms or constant physiological changes. For each of these phases the changes on the simulated organism were implemented on the basis of the same baseline physiology.
In this approach the adaptations and changes of the organisms in the transition from phase to phase were not considered, since sufficient information on the specific mechanisms were not available.
For the realisation of an Educational Simulation of cosmonauts we considered the following phases: Pre-flight, Launch, Orbit-entry, Short-term flight, Long-term flight, EVA and Landing.
In each phase the known changes on the cardiovascular functions, the respiratory apparatus and the other organs, such as liver and kidneys, were realised on the simulator according to the statements found in literature (according to chapter 3.1.1).
Examples of physiologic data generated by the simulated patient in different phases of the space flight:

	Prelaunch	Launch	Orbit entry	in-flight	landing
Weight	70	70	70	68	68
BP_{sys}	124	142	130	120	85
BP_{dia}	80	100	80	80	65
MAP	99	118	102	95	76
HR	69	99	71	80	96
CO	7.7	10	8.4	7.6	5.5
CVP	4-10	9-14	13-16	0-4	-2 - +2
SaO_2	98	97	97	97	97
PAP_{sys}	27-32	37-42	37-42	18-28	11-16
PAP_{dia}	9-15	22-28	15-23	6-10	1-7
PaO_2	97	90	92	88	90
$PaCO_2$	39.5	39	37	36.7	35.9
pH	7.44	7.45	7.46	7.46	7.47
TV	800	400			
RR	11	15	13	13	11

Tab. 17: Examples of physiologic data generated by the simulated patient in different phases of the space flight

In each phase the simulated cosmonaut is controlled by the same physiologic changes as a real cosmonaut as far as they are reported in literature. We can assume – within the range of accuracy

of the underlying models – that the simulated organism will produce principally the same behaviour as a real cosmonaut also when pathological impacts change the organism.
This facilitates the use of simulated cosmonauts as a model for training for diagnosis, management and therapy of emergency situations, e.g. a trauma in each phase of the simulated space flight.

2.10 Simulationg of the physiological changes in microgravity on the HPS

The first model, the pre-launch cosmonaut, is a thirty year-old healthy man in well trained condition with good lung function. (functional residual capacity of 3 l). The next model is the cosmonaut during launch. It is a modified pre-launch model. The launch is an enormous stress situation. Another factor is the effect of hypergravity induced by acceleration. According to this extreme situation we chose to increase the epinephrine concentration. Due to the physical pressure on the thorax we decreased FRC and the compliance.
The physiological changes during orbit entry, caused by microgravity, are the most dramatic. Changes according to blood and abdominal shift were performed. Absence of gravity moves the abdominal organs towards the lung and therefore compress it. In addition, a large blood volume shifts from the leg veins to upper body. To simulate these changes, we decreased chest and lung compliance and added 500 ml of intravascular volume. The venous return was increased, which simulates the faster blood return to heart. PVC were added to normal sinusrhythm. The baseline model for designing the in-flight cosmonaut was the orbit entry patient. The changes here have been observed during several short-term flights up to 14 days.
In this period changes in blood pressure lead to a weaker heart response. We also reduced the plasma volume according to the negative fluid balance and to a fluid shift from plasma to extravascular space.
Due to the loss of fluid and muscle mass, we reduced the body mass.
Early changes after landing are caused by the returning of gravity and are nearly as strong as they are at orbit entry. The fast normalisation of venous return and capacity causes a reverse blood shift from upper body into the legs. Therefore we set venous return to normal and increased venous capacity.
The result is a functional hypovolemia, which is equalised by oral intake of fluid before launch. Lung parameters are set to normal too.
We evaluated our modified algorithms, as recommended in Phase 4, on these simulated cosmonaut models.

Fig. 22: Simulator control unit

Fig. 23: Simulator rack

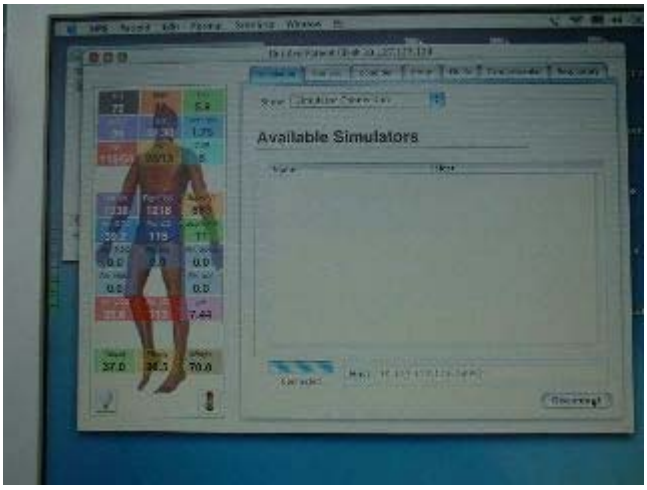


Fig. 24: Simulator control interface

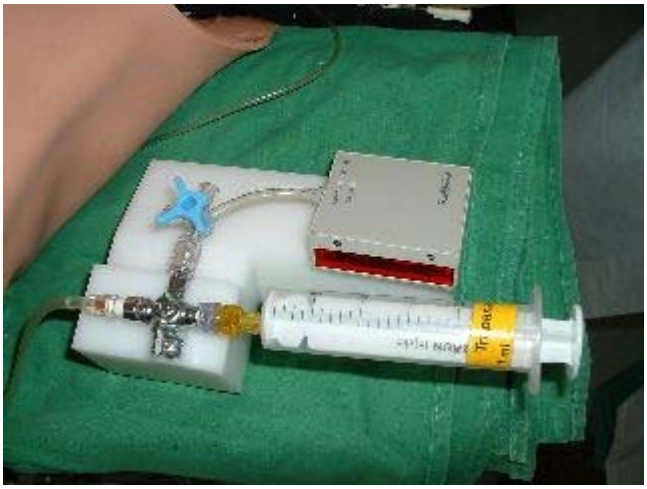


Fig. 25: Drug appliance unit

Fig. 26: Selection of simulated vital parameters

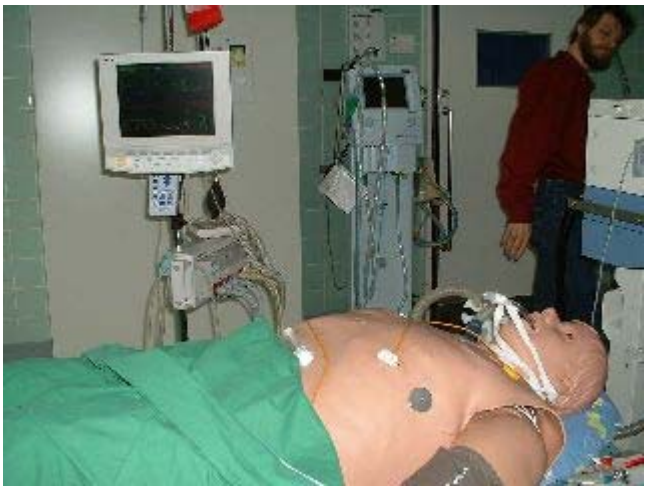


Fig. 27: Simulator model

Fig. 28 a+b: Practical training on simulator mannequin

2.11 Samples of signal and time series

The Russian side provided us with time-series of raw-ECG data, tables with heart rates and screen shots of ECG anomalies. In total, examples of data of about 10 cosmonauts in different phases of training and space missions were communicated. Difficulties in the analysis of the data were mainly imposed by two factors:

On the one hand only a few data for each cosmonaut was collected, e.g. heart rate and blood pressure. Other parameters like etCO2 or SpO2 were not measured at all.

On the other hand, data were not collected in sufficient density: Only in special situations like ergometer training or EVA data were collected. Often there were no data available in other phases of the mission. When the data was collected the intervals between each time of measurement was too big.

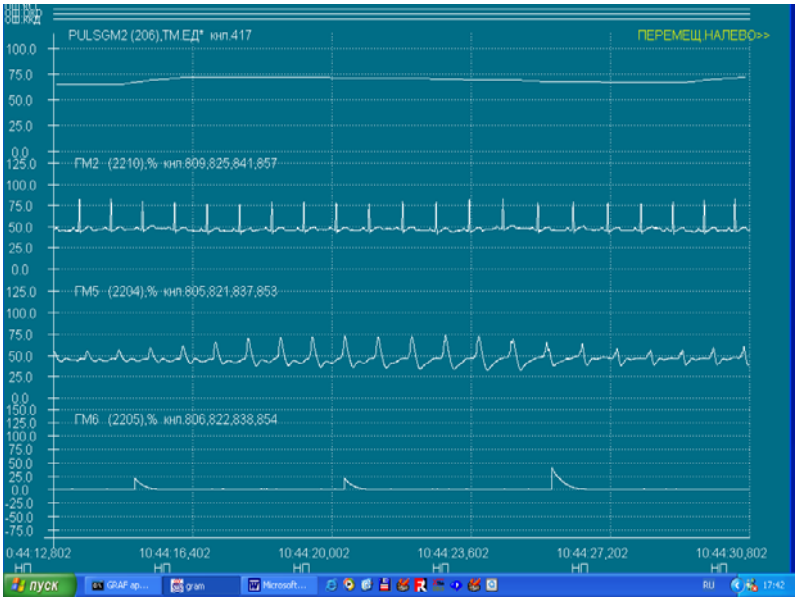


Fig. 29: Example of ECG screenshot

Cosmonaut	MN							
Age [years]	44							
number of previous flights	2							
body weight [Kg]	86							
Flight Phase	flight							
day	31							
test	N5 - Test with graduated exercise on bicycle ergometer							
mode	Time/min	HR [bpm]	BPsys [mmHg]	BPdia [mmHg]	Extrasystoles [%]	g-load	Graph.EKG	Graph.Bp
background mode	-1	71	112	74		none	5_104_MN__fon	
loading 125 WT	1	100			1	none	5_104_MN_125_1	
	2	105				none		
	3	106	135	60		none		
150WT	1	112				none	5_104_MN_150	
	2	114			1	none	5_104_MN_150_2	
	3	117	147	52	1	none		5_104_MN_150_3
175WT	1	124			1	none	5_104_MN_175	
	2	126				none		
	3	128	172	50		none		5_104_MN_175_3
rehabilitation mode	1	100	180	60	1	none	5_104_MN_rehab	
	2	76			2	none	5_104_MN_rehab_2	
	3					none		
	4					none		
	5					none		

Tab. 18: Example of numerical data

2.12 Data exchange protocol/ matrix definition

For the programming of cosmonauts according to the "top-down" approach historical and real time data needs to be transmitted.

Historical data was transmitted by email as Microsoft Excel files. Therefore we have developed a form as a minimal dataset. For each cosmonaut one file was transmitted. In this file datasets of the cosmonaut in the different phases of test, training and flight – as available – were represented as a separate table in the excel file. The minimal dataset consists, besides physiological parameters, also of data of environmental aspects of the space craft or space station as well as personal data of the cosmonaut. The structure of such a dataset can be considered as the baseline relation for a database that stores cosmonaut data.

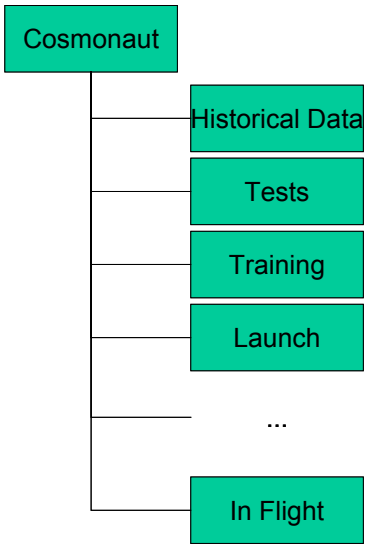


Fig. 30: Baseline data structure

The tables of the dataset can be extended according to the availability of further information. The transmission of data as a Microsoft Excel file allows a wide level of compatibility with most database systems on the one hand, and between the Russian and German side on the other hand. Transmission by email is well suited for historical and non real-time data.

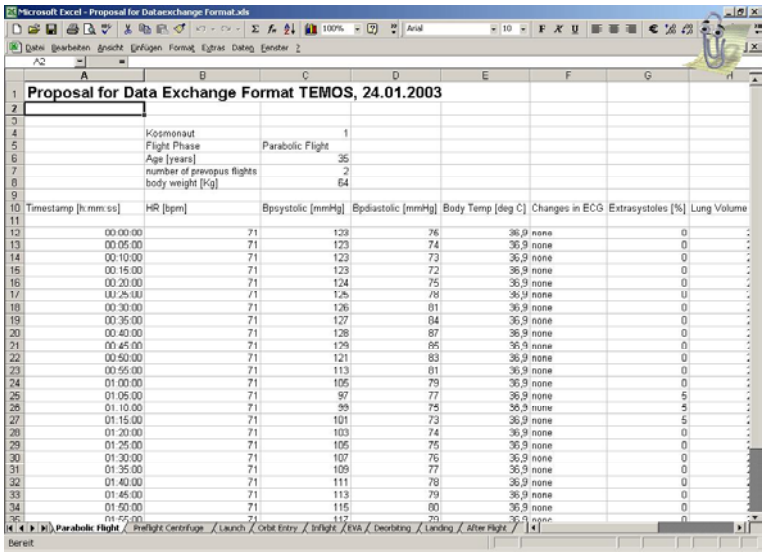


Fig. 31: Example of data transmission form

Once data is supplied in this form in sufficient detail, analysis of the characteristics of each cosmonaut can be done through the means of the above mentioned methods. This will help to get a better understanding of the underlying physiological mechanisms in each cosmonaut.

2.13 Operational requirements for telemedical data evaluation

For telemedical consultations a real-time data transmission is required. The neccesities for the real time data transmission can be oriented on the parameters that a physician can achieve in emergency situations in the terrestrial context for first response measures. Through these parameters it can be decided how severely a patient is injured and what steps from the stabilisation up to the evacuation of the cosmonaut can be introduced.
This data can be transmitted via video conference.
We distinguish between three different sets of data in reference to the medical interpretability and the representation of data.

1. Basic data to evaluate the condition of a patient
    a. Continuously transmitted: ECG, SaO2
    b. Discretely transmitted: NIBP
    c. On demand: Radio communication for medical history and specific questions – this requirement can alternatively be realized through a text-based communication interface.
2. Extended Data from the point of view of intensive care medicine
    a. Continuously transmitted: CO_2
    b. Discretely transmitted: $etCO_2$, respiratory rate, tidal volume. In the case of mechanical ventilation: Peak pressure, Mean pressure, Ventilation mode, inspiratory oxygen fraction.
3. Data with environmental constraints:
    a. Discrete data on ambient pressure, ambient temperature, radiation, partial pressure of oxygen and carbondioxide,
    b. On demand: Video communication for further explanations and visual inspections from ground control.

2.14 Utilisation and limits of telemedicine in critical medical situations

In the event of the appearance of a medical case in orbit, Medical ops personnel, due to the specifics of diagnostic methods, have to tackle the following problems:

- absence of personal contact between doctor and patient,
- medical information acquisition only through the phone and telemetry channels,
- use of the experimental equipment in diagnostics and medical monitoring,
- impossibility of real-time data communication via the available communication lines.

Acute disorders in the functioning of the body systems and diseases can be diagnosed more accurately by a physician within the space crew with the help of computer-assisted or video recording specialised instrumentation data of which are downlinked via the digital or video channels.
In case of a disease or trauma, high-rate communication of video information (images of integument, mucous membranes, joint, muscles, superficial veins, posture etc.) will be particularly helpful.
The history of medical care in piloted missions has several instances of using the telemedical capabilities to diagnose various diseases and damages in cosmonauts.

The establishment of steady digital channels for video exchange within the MCC-orbit-MCC-medical centre loop and ISS configuration with telemedicine diagnostics systems will significantly enhance the capabilities for diagnostics, medical prevention and assistance. These technologies will also open up an opportunity for crew members to be consulted by narrow medical specialities at clinical centres of the international partners in long-duration manned space projects.
The network technology of downlinking video and audio information makes it possible to diagnose health problems in space crew using modern clinical methods and associated space-adapted portable devices. Traditional methods, e.g. X-ray, endoscopy, echography and others can be also adapted for space flight conditions. Real-time downlink of images (broadcast and local television with visual field magnification) potentiates complementing of the current in-flight health monitoring system with advanced methods of investigations already in the near future. Namely, these methods are:

- visual evaluation of integument, visible mucous membranes, external organs, rhinopharynx, the mouth, form of the joint, muscles, superficial veins, and posture,
- diagnostic endoscopy (otoscopy, ophthalmoscopy, inspection of the fauces, rectoscopy),
- X-raying with a miniature unit,
- Evaluation of the myocardium functioning with echocardiography,
- Investigation of local hemodynamics: cerebral (examination of the eyegrounds), microcirculatory (capillaroscopy of the nail matrix, conjunctival biomicroscopy),
- Clinical blood analysis with blood smear scopy.

In case of emergencies all nominal telemetrical equipment have to be adapted by technical and organisational aspects:
1. The connection between ISS and MCC-Moscow should be by protected gateway server:
In emergency scenarios a bi-directional connection cannot be assumed nor waited for. But a maximum release of the data capacity has to be guaranteed including an integration of diverse modalities like a video signal.
In case of a deorbiting scenario in the Sojuz capsule a reduced communication has to be considered.
The telemetrical equipment must be easy in use and always available. It should not only be used for routine protocol onboard the ISS but also for set-up and educational purposes. A complete integration or an integration in parts of the tested telemetrical equipment onboard the Sojuz capsule should be also desired.

2. Gateway server to ground control system, video conference system and the Russian medical support team
The main part of the telemetrical information is provided in raw format. These data are not provided for medical, bioelectrical nor video data analysis. The preparation of these data for telemetrical transfer is provided at the MCC by a technical and medical team. In emergency scenario an online access of these data cannot be guaranteed. A possible solution might be the transfer of unselected and unprepared data via telemetrical integration of the on-screen information by the ground control centre.

3. Communication of Russian and European partners
A fast telemetrical connection of variable partners should be organised in case of emergencies. Next to the standard Internet connection an optimisation of the videoconference connection itself should be achieved. Therefore several competence centres should be connected via fast access to the medical and technical data. The Russian IMBP, including the patient specific templates of the

HPS should perform the co-ordination of the information and the results of the biomedical support of the cosmonauts onboard the ISS. A loss of information should be considered in the discussion, especially for treatment advise.

An integration of all telemetrical connection should be achieved via a data bank server but cannot be guaranteed in emergencies. An ftp server could provide a technical solution of an online access to the raw data of the ISS and the prepared data of the MCC. Also, an adaptation to the latest generation of telemetrical equipment could lead to a better integration and access to these data by competitive centres.

Limitations for the use of HPS for telemedical consultations in critical situations:

The main limitation is the use of educational models in the HPS system. This causes the simulation to be somewhat similar to real physiology, but there is no guarantee that the models actually react like a real human body in every situation.

In the context for space medicine the description of the characteristic cosmonaut's physiology as a whole in the available literature suits well to programming the educational model and we already described how we adopted the models to space conditions. But through this approach still no simulation of the individual cosmonaut is possible.

There would still be no proof if the models react accurately in an unforeseen situation even if perfect conditions were available:

- The bottom-up approach as described in 3.3.8 is feasible.
- All data for the enhancement of the knowledge of the physiology of each individual cosmonaut to calibrate the models through data-mining methods is accessible.
- We have a method to tweak the educational models to actually simulate each individual cosmonaut.

There's a lack of knowledge of physiology of the individual cosmonaut in space. This could be overcome through more enhanced monitoring methods (e.g. SpO2, etCO2, continuous HR, BP, invasive pressures) and further investigations in still poorly described phases of the flight (e.g. EVA, long-term stays, deorbit).

The argument that cosmonauts form a rather homogenous group of human physiologies and reasons of continuity may help to argue against these limitations.

The second limitation is the time needed to start and initialise the simulator and to set-up the medical case. This can only be done parallely to the diagnosis of the medical crisis on board and the question is if there is enough time to do so. In complicated situations where procedures for the rescue of the patient and therapies have to be invented, the simulator could be of use (see recommendations), but in critical situations with a very limited timeframe for reaction the usage of the simulator is probably too slow.

3 Results of Experimental Investigation and Scientific Data

3.1 Experimental investigation in microgravity

3.1.1 ALS procedures in microgravity

The research was conducted by the plane ИЛ-76МДК equipped for flights on parabola (Parabolic flight of Kepler). During flights 10 parabolas (modes of short-term microgravity) of 20 seconds were used for our experiment (fig. 32). Medical research was conducted by two 43 years old physicians with previous experience in parabolic flights.

Before realisation of the research these physicans were trained in methods of intubation on a special mannequin. During flights following manipulations were executed:

- lavage of fauces and larynx with the help of a swab (fig. 33) and aspiration of the gastric content (fig. 34),
- insertion of a plastic air duct in the fauces (fig. 35),
- respiration with the help of an Ambu bag (fig. 36),
- intubation with the help of LMA-Fastrach Endotracheal Tube (ETT) followed by respiration with the Ambu bag (fig. 37),
- intubation with direct laryngoscopy and followed by pulmonary ventilation (fig. 38);
- nasotracheal intubation followed by pulmonary ventilation.

Before flight the mannequin was fastened on the surface of a table (simulating a table at the ISS) with the help of "Velcro". In flight during short-term weightlessness doctors were not fastened.

Two flights were executed. The first flight was terminated before the planed schedule, after 3 parabolas. In the second flight 7 parabolas were executed.

Both methods of intubation were conducted twice, each in the time of microgravity proceeding during 15-20 sec.

During one fragment of microgravitation (20 sec) the indirect cardiac massage (fig. 39) with artificial pulmonary ventilation (fig. 40) in a combination 60 to 5 is conducted.

Fig. 32: Plane ИЛ-76МДК

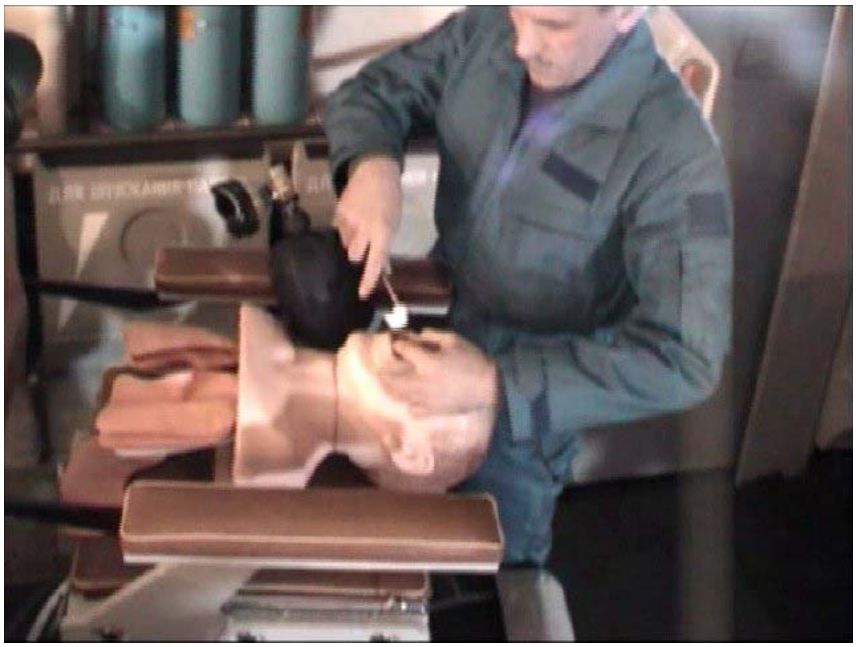


Fig. 33: Lavage of the fauces and larynx

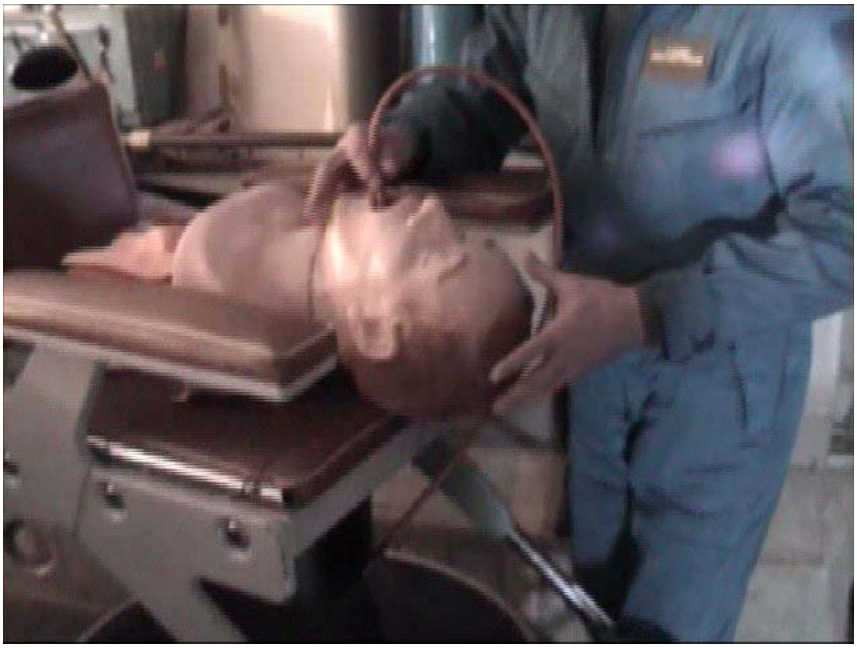


Fig. 34: Aspiration of gastric content airways

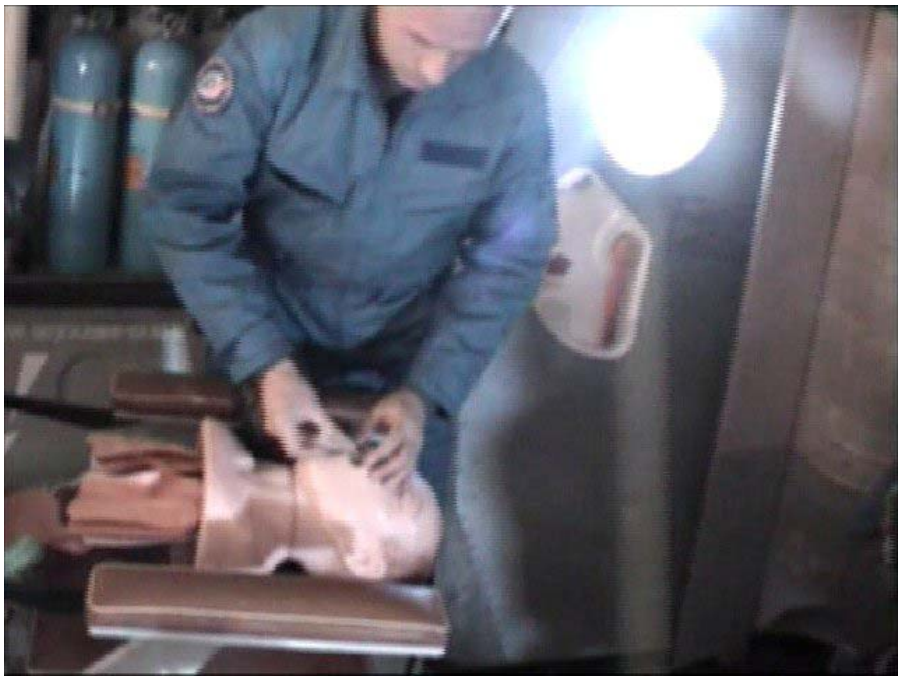


Fig. 35: Insertion of a plastic air duct in the mouth

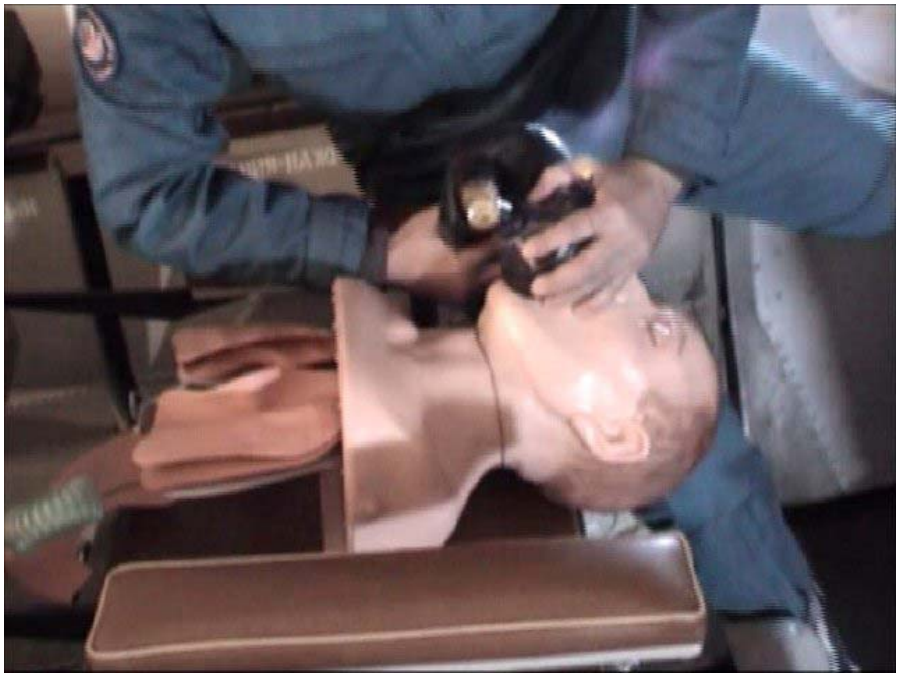


Fig. 36: Respiration with the help of Ambu bag

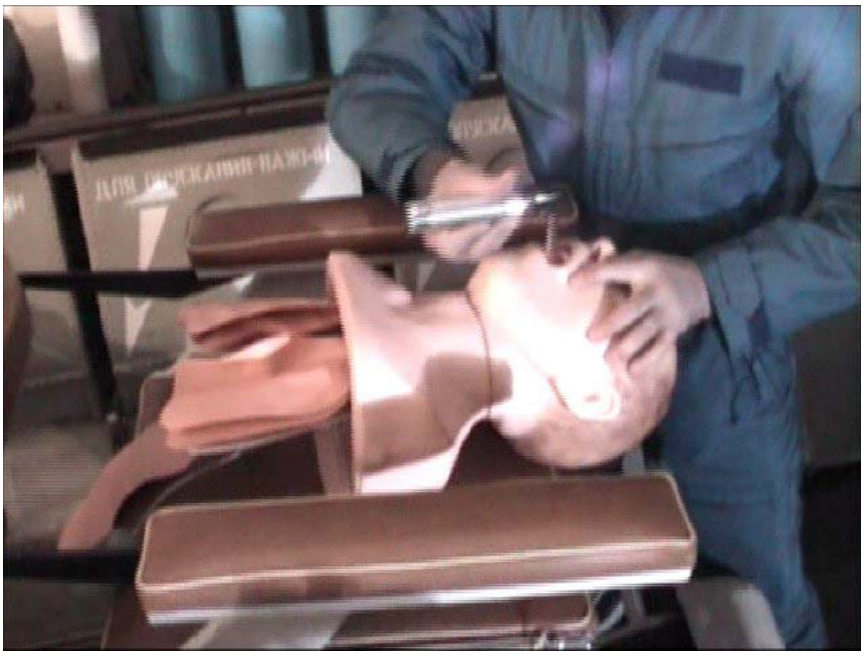


Fig. 37: Intubation of trachea with the help of direct laryngoscopy

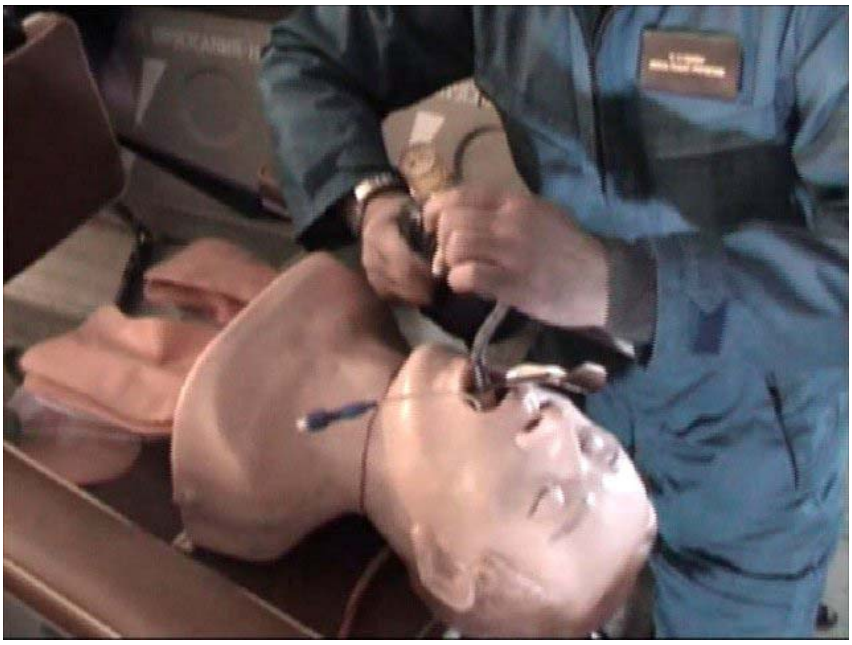


Fig. 38: Pulmonary ventilation

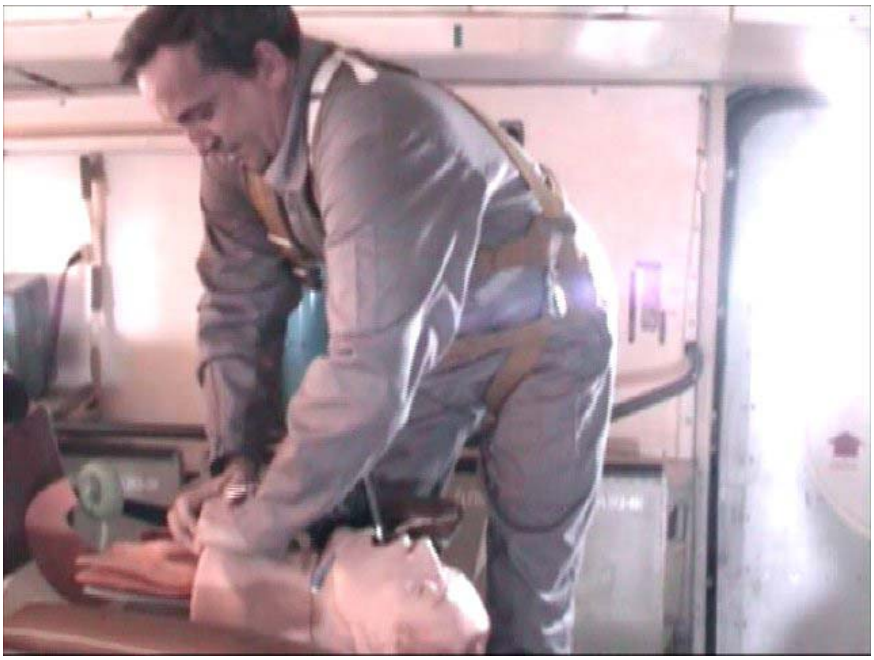


Fig. 39: Indirect cardiac massage

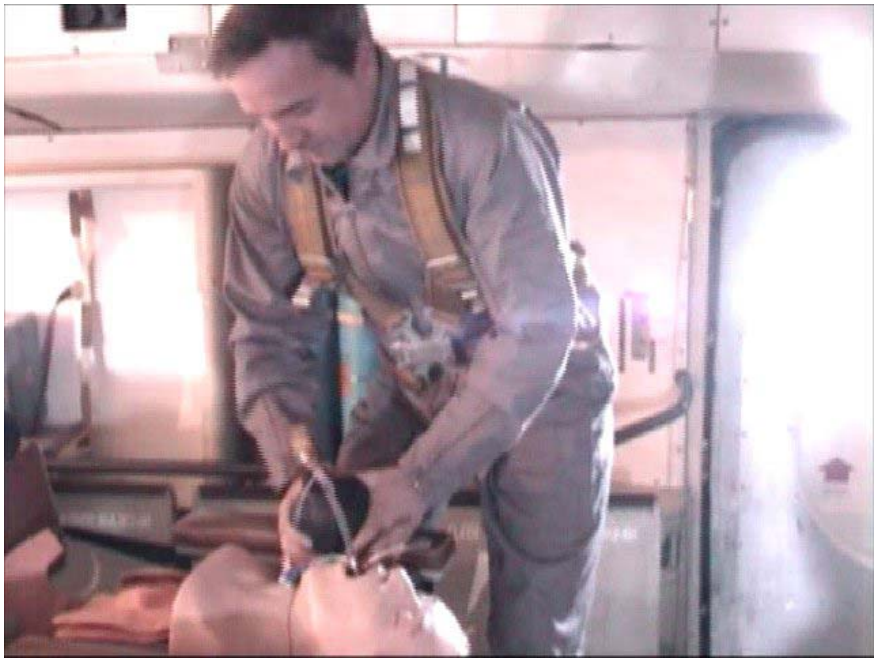


Fig. 40: Artificial pulmonary ventilation

3.1.2 Airway management during parabolic-flight

The medical equipment for an emergency and the medical skills of the crew were tested in the condition of 1g and during simulated microgravity. The first phase investigators are trained in the methods of the tracheal intubation with use of a special mannequin on the ground. Four investigators participated in the experiment. Two were doctors (fig. 42) of intensive care (anaesthesiologist) and two were untrained persons (fig. 41, 43).
The second phase includes the intubation during parabolic flight. The experiment in microgravity starts and ends with reducing the gravity (nearly 15-20 seconds for each attempt).
The following devices were tested on two manequins:

1. endotracheal tube (ETT) 8,0mm,
2. standard laryngeal mask airway (LMA) size 5,
3. intubation box included a laryngoscope size 3, a syringe 20ml and an Ambu bag.

3.1.2.1 Experiments on the ground

The intubation was conducted by direct laryngoscopy. A special maneqin was intubated by airway tube "Portex" № 8 type, with cuff. The correct position of the tube was controlled by observing the filling of the lungs .
Each investigator had 5 attempts, in which the intubation time was fixed for each. The readout of time began from the moment of the first contact with the manequin and was finished by the first inhalation, which was made by a Ambu bag. The mean time of successful intubation was then determined for every investigator.

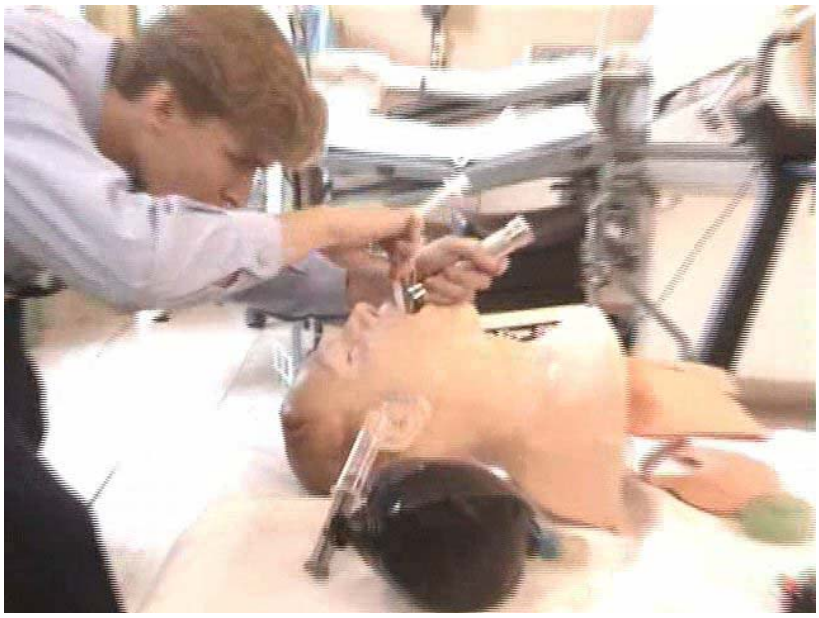


Fig. 41: Intubation on the ground of unskilled person

Intubation with endotracheal tube

Experts in resuscitation could execute attempts successfully (fig. 42). The untrained persons had some successful and some failed attempts (fig. 41, 43).

doctors investigators	Intubation time, sec					
	Attempt 1	Attempt 2	Attempt 3	Attempt 4	Attempt 5	mean time of successful intubation
1	14	24	14	13	14	15,8
2	fail	fail	44	28	25	32,3
3)	fail	23	29	fail	25	28,3
4	14	17	14	12	13	14

Tab. 19: Intubation of trachea with the help of Endotracheal Tube (ETT)

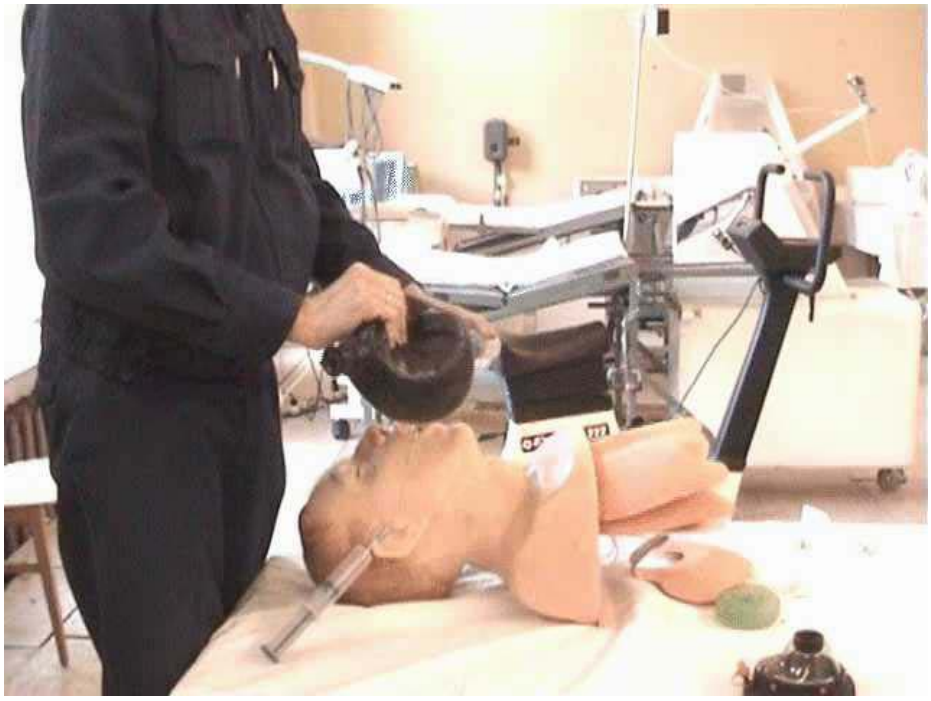


Fig. 42: Succesful intubation

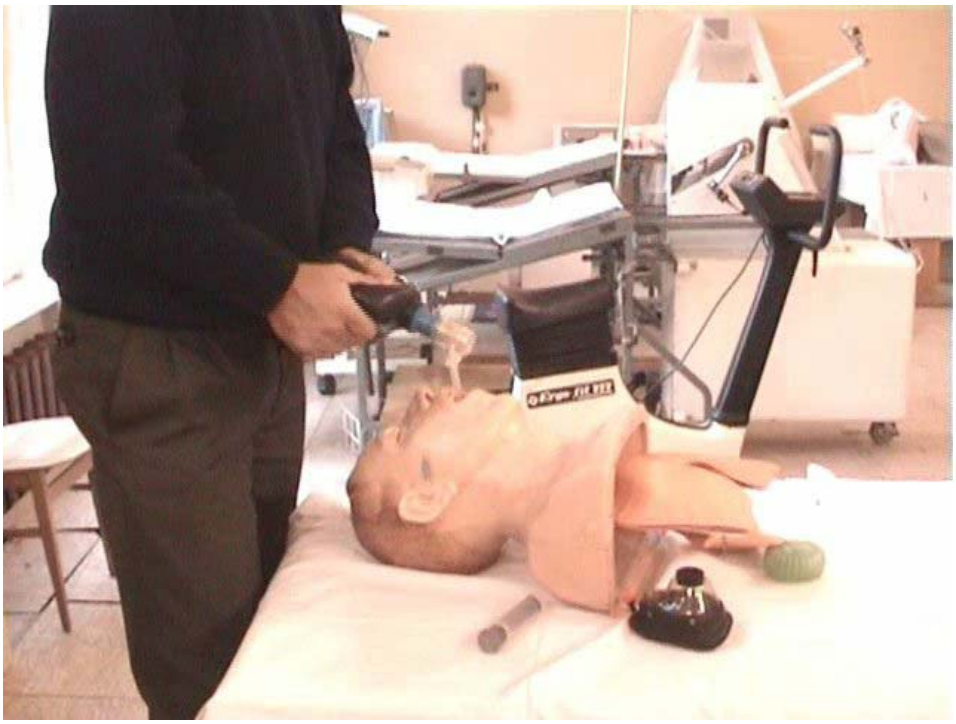


Fig. 43: Failed intubation

Intubation with LMA

Intubation of the trachea with the help of LMA was conducted by two doctor (expert in resuscitation) and two untrained persons.

Up to five successful attempts have made: 21, 24, 17, 19, 18 sec (average 19,8s).

All attempts of untrained investigators were unsuccessful in parabolic flights (prospective - 30 sec, in fact - max 20 sec).

3.1.2.2 Parabolic flight

The intubation of the trachea was conducted in microgravity (only orotracheal and nasotracheal methods) with endotracheal tube № 8 by direct laryngoscopy within 15-20 sec.:

1. orotracheal method

doctors investigators	Intubation time, sec				
	Attempt 1	Attempt 2	Attempt 3	Attempt 4	Attempt 5
2	fail	fail	fail	fail	fail
3	fail	fail	fail	fail	fail

Tab. 20: orotracheal method

2. nasotracheal method

doctors investigators	Intubation time, sec				
	Attempt 1	Attempt 2	Attempt 3	Attempt 4	Attempt 5
2	fail	> 30	fail	> 30	> 30
3	fail	fail	> 30	fail	> 30

Tab. 21: nasotracheal method.

3.1.2.3 *Conclusions*

As a result of the experimental investigation of critical care in microgravity all planned methods of intubation including the lavage of the fauces and the mouth under use of a footoperated aspirator were realised to practice the skills.
During research (in the time of 10 parabolas) the realisation of the planned actions despite the short duration of microgravity (20 sec) on each parabola was possible, and also an average level of the preparation of the doctors whose experimental research was executed.
During the execution of the planned research on 10 parabolas the realisation of various ways of intubation, a lavage of the tracheobronchial tree, an artificial pulmonary ventilation and an indirect heart massage in the condition of microgravity were experimentally proved. The videomaterials of the techniques used for intubation are shown on the attached video files.
The conducted research confirms a possibility of tracheal intubation and the realisation of artificial pulmonary ventilation in conditions of a microgravity in a limitated time of 15-20 sec.
The necessity of the careful training program of the crew members lies compulsory the in pre-flight period. In flight and between flight periods the maintenance of emergency skills is necessary rendering help to the patient.
On the first phase the training of two investigators not possessing intubation technique (according to the required program (ETT, COPA, LMA, ILMA) was conducted. The insertion time changed from 20 up to 35 sec for well-skilled and nearly 90 sec for non-skilled investigators.
The endotracheal tube position was verified with auscultation of various lungs parts and adequacy to thorax excursion.
On the second phase the greatest difficulty represented was intubation with LMA.
This intubation type was replaced in part of the cases by naso-thorax intubation.
As a result of these experiments the intubation is executable in all versions. However, it needs methodical training of cosmonauts in intubation skills in the pre-flight period (on manequins and in clinical conditions), and also periodic training of them during flight for supporting these skills.
During one microgravity fragment (under 20 sec) the indirect massage of the heart with mechanical lung ventilation in the combination 60 to 5 is conducted.

It may be assumed that a repetition of the experiments conducted in parabola flights is inexpedient because of the time limit in microgravity (15-20 sec).

3.2 Experimental simulation of de-orbit G-loads with special focus on medical care

3.2.1 Experimental investigation of simulated de-orbit of crewmember under continuous critical care treatment

Test evaluation of the feasibility to give emergency medical care to serious patients in the course of return from the AS orbit in the Sojuz vehicle was carried out by simulating g-loads on the centrifuge with three-mode gimbals suspension TsF-18 (fig. 44, 45, 46).

To accommodate and restrain the investigator and the mannequin, the centrifuge was outfitted with two standard chairs designed for the Sojuz descent vehicle. Software was developed to control the centrifugation g-loads within the averaged nominal and sparing values impacting crews during return from the AS orbit in Sojuz DV. Profiles of the averaged nominal and sparing g-loads during descent are presented in fig. 47 and fig. 48.

For a more credible simulation of the medical care procedures in spacesuits, the centrifuge was enhanced by adding a spacesuit ventilation control system.

The concept of medical attendance during the action of g-loads in the descent process in Sojuz was based on the following assumptions: the scope of medical procedures to aid serious patients due to the conditions and limited mobility of cosmonauts will be very small; therefore, priority should be given to the scenario according to which the emergency medical care is given while in microgravity on the station and in the Sojuz living module till relative stabilisation of the main physiological functions; after that, the patient (mannequin) is to be taken to the DM couch where theoretically, the occlusion cuff can be placed to measure blood pressure and heart rate, tracheal intubation can be performed, the Ambu mask and bag used, and the dropper with iv. physiological solution and medicines can be installed (if these procedures have not been done earlier) before the g-loads. During g-loads, the surgeon conducts visual observation of the patient, palpates the common carotid artery, periodically measures blood pressure and heart rate, manipulates the Ambu bag, and makes iv. injections (via the intravenous fluid administration set).

The experimental evaluation of the feasibility of emergency medical care with the use of the mannequin involved 3 investigators, each of whom was tested in the context of the concept to fulfil health diagnostics and perform procedures of the emergency medical care on a background of averaged nominal and sparing g-loads characteristic of the descent from orbit. In addition, one of the surgeons was to perform these procedures donned in the non-pressurised ventilated safety suit Sokol.

Centrifuge view

Fig. 22

Fig. 44: TsF 18 centrifuge in the Gagarin GCTC, Russia

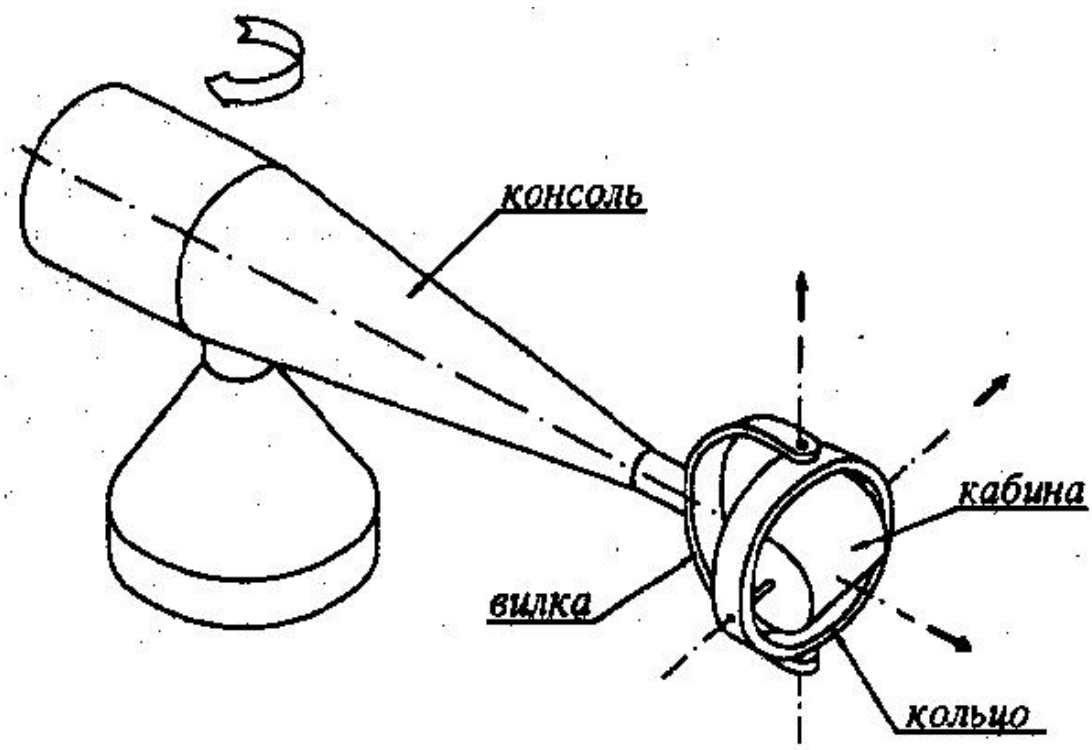


Fig. 45: Schematic view of TsF-18 centrifuge with three-mode gimbals suspension

Fig. 46: Centrifuge cabin

In the course of the project a cardiologic emergency with resucitation procedures in deorbiting conditions is simulated. Therefore, the interior has been modified to accommodate two crewmember in the Launch and Re-entry Suit and parts of the medical equipment, currently available on board the ISS. In the deorbiting procedure was performed with two different persons. Also, the application of medication was tested. Due to the restricted freedom of movement the resucitation procedures and manipulations were limited.

Fig. 47: Restricted freedom of movement in simulated deorbiting

Fig. 48: Respiration in simulated deorbiting

The profiles of the averaged nominal g-loads during the re-entry of Soyuz TM descent modules and the re-entry profiles, simulated for the TEMOS project on the TsF 18 centrifuge are given in the following graphs and tables. Note the difference between the initial and the final G loads; in the simulation scenario: +1G/ 1+G, in the real de-orbit: 0G/ +1G

operation	height	time, T	accelerative forces
turning on control engine (ДУ)	386 Km	To	0
separating	375 Km	To +25 min 35 sec	0
separating	102 Km	To + 28 min 32 sec	0
peak of accelerative forces	41,6 Km	To +34 min 27 sec	3,8 g
startup basic system of parachute (ОСП)	10,7 Km	To +36 min 48 sec	1,2 g
Separation front thermal protection (ЛТЗ)	-	To +37 min 20 sec	0
reconnection basic system of parachute (ОСП)	-	To + 40 min 48 sec	0
turning on soft landing engine (ДМП)	1 m	To +51 min 48 sec	1g

Tab. 22: Nominal re-entry profile of Sojuz spacecraft

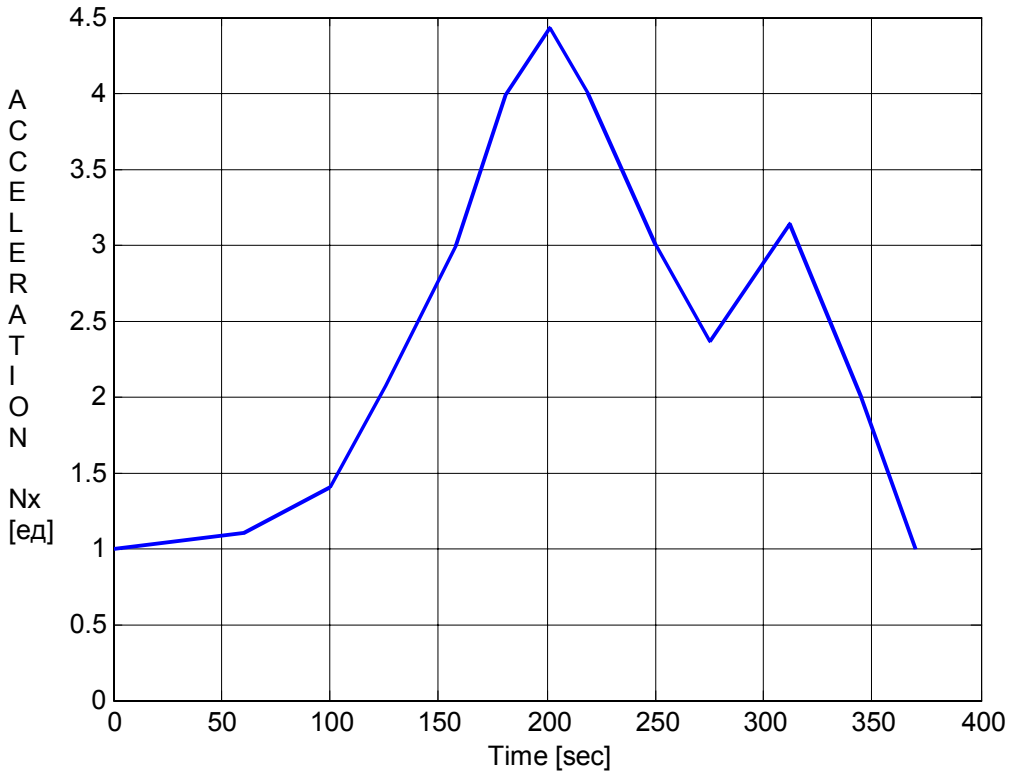


Fig. 49: Nominal re-entry simulation in the centrifuge

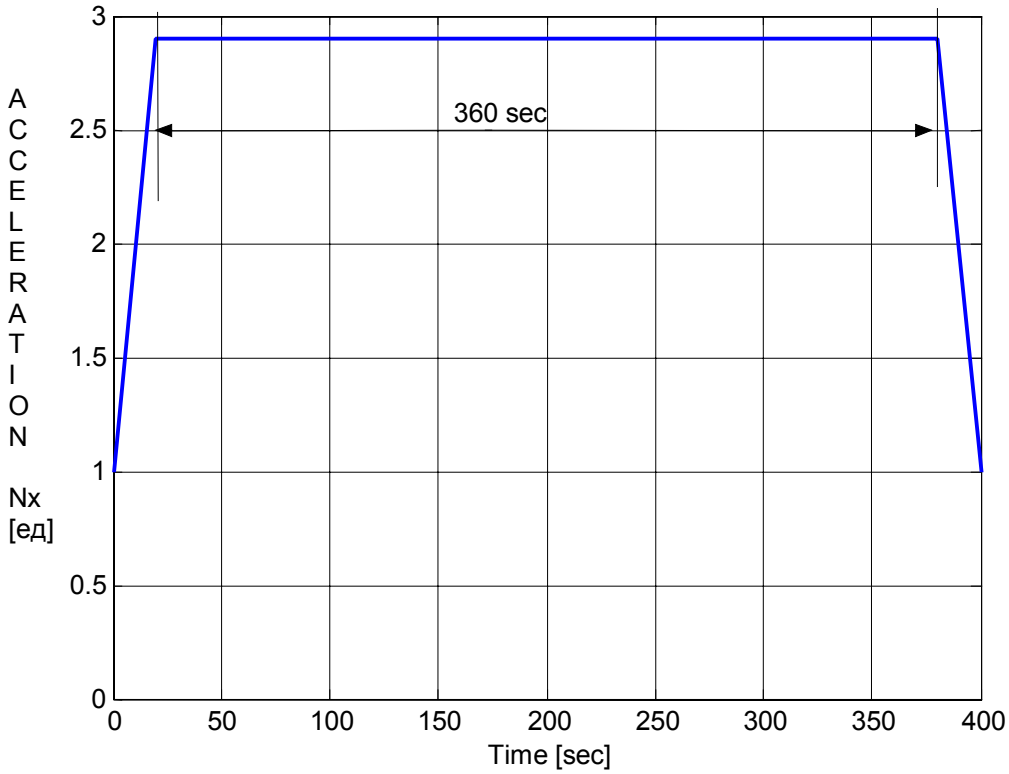


Fig. 50: Simulated sparing descent profile with constant G- load

The improvement of further post-landing support was not a part of the TEMOS project. It is currently subject of the discussion. The pilot scenario should be tested with selected partners within the first half of 2004.

The following findings were made in the process of test validation of the emergency medical care procedures during the exposure to g-loads:

- Health diagnostics and medical care as stated in the concept are plausible, though difficult, under all above-mentioned g-loads,
- During g-loads, the hardest diagnostic-therapeutic procedure was to turn and stabilise the position sideways relative to the patient,
- Against the constantly changing +Gx values (nominal profile) implementation of the diagnostic-therapeutic procedures is much more arduous as compared with the +Gx plateau (sparing profile); this was particularly hard to do against continuously changing g-loads of more than 3 units in magnitude (peak of the nominal g-profile),
- The rigid spacesuit gloves complicate diagnostics and treatment, and the pressure helmet narrows the field of vision,
- The Ambu bag cannot fully unfold at g-loads above 3 units.

Exposure to microgravity during space flight impacts gravitational tolerance of cosmonauts, first of all of their cardiovascular and respiration systems, and the locomotive musculature. This is the reason, why after staying in space flight the cosmonauts subjectively perceive the descent g-loads and 1-g gravity as being 1.5 – 3 times more than real values; this causes the sensations of abnormally heavy body, arms, legs and head, and external items. Objectively, this is revealed by the susceptibility to collapses, deterioration of the physical performance and disturbances in movement co-ordination. Hence, maximum possible reduction of values and gradients of the descent g-loads is essential for saving the patient's life, and so for successful implementation of the diagnostic and therapeutic procedures.

In fact, reduction of g-loads of up to 3 units during descent in the modern vehicle Sojuz-TM can be achieved by manual control. However, manual control may, to begin with, significantly impact (or exclude) the diagnostic and therapeutic efforts and, secondly, the crew commander, who possesses the skills in piloting DV during descent, may happen to be one of the patients. For this reason, deorbiting should be performed in the automated mode to ensure sparing g-loads. Theoretical preliminary investigations fulfilled co-operatively by experts from RSC-Energia and Gagarin CTC attested feasibility of the technical resolution of this problem. It was also shown that maximal values of the g-loads during descent in Sojuz can be controlled within 2.7 to 3 g-units without a substantial redesign of the DV descent controlling system.

Difficulties associated with surgeon's maneuvering and stabilising sideways relative to the patient dictate the need to develop a diagnostic/therapeutic console to be placed, for instance, in the lap of the cosmonaut monitoring health and attending the patient. This suggestion concerns also the Ambu bag. In general, forced automated ventilation of the lungs is preferable under these conditions.

3.2.2 Testing of artificial respiration at deorbiting conditions

We considered the BREAS LTV 1000 (Pulmonetics Inc., USA) to be the most practical ventilation device. The "LTV 1000" is a compressorless ventilator designed with unique miniaturisation technology allowing a broad range of ventilation and control functions in a unit no larger than a laptop. It is a compact (height 8 cm, width 23 cm, depth 30 cm), lightweight (6.1 kg) and easily portable unit. No wall air supply or compressor is required, its autonomy from external power supply and O_2-supply. High pressure oxygen can supply internal blender or a low flow source can be used. This is a main advantage for the closed environment inside the Sojuz-rescue vehicle because there is no contamination with oxygen or a change in air pressure. Furthermore, its capability to use normal environmental air for ventilation, allows a long-duration ventilation without any increase in air volume of a sealed system, like the Sojuz capsula (approx. 4,5 m^3 air volume). The testing of the ventilation device at deorbiting condition was kindly supported by Pulmonetics, USA.
The digital port on the device enables data storage and transmission to the medical support team at MCC. Technically, the possibility also exist to control the device remotely from the MCC. The feasibility of operational implementation of LTV 1000 is currently being investigated by the experts at IMBP and NPO Energia.

The possibility of artificial respiration at increased g-loads during deorbiting is verified in a centrifuge. The experiments were carried out on the one-person rated centrifuge of the GCTC Gagarin Cosmonauts' Training Centre.

Ther material included:

1.) Breast LTV 1000 ventilation device,
2.) Artificial lung (Siemens, 1 l),
3.) Standard centrifuge (7 m),
4.) Video camera,
5.) Ruler, adapted to artificial lung,
6.) Plank (60 cm).

At first, a baseline at 1 g is created. The tidalvolume is set to 900 ml and the expansion of the artificial lung is recorded by ruler and video camera. Therefore, ruler, lung and camera are fixed on a plank to assure the same conditions at 1g and at 4 g in the centrifuge. The respiration unit is attached and respiration is performed for 3 minutes.
The recording unit (lung, ruler, camera and plank) is fixed inside the centrifuge. The centrifuge accelerates until 4 g is reached, and maintains this for 2 minutes. Tidalvolume is recorded by ventilation device and by ruler:

- measurement of ventilation-volume (provided by LTV 1000) at different g- loads (expansion of artificial lung in millimeters measured by adapted ruler, converted to tidalvolume),
- baseline of reference values at 1 g (ground),
- measuring the volume at 4 g during simulated deorbiting,
- data is collected via video camera inside centrifuge.

1.) Collecting the baseline for a volume of 900 ml at 1 g (recording the corresponding values in millimeters of expansion)
2.) Proceed as above, but at different g-loads in centrifuge (4 g), recording data by video camera

G/n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1 g	63	62	64	62	64	63	63	64	63	64	63	64	64	63	63	64	63	64	64	63	64	64	63	63	62
4 g	63	62	62	62	62	62	62	62	62	62	62	62	63	62	62	61	61	61	62	61	62				

Tab. 23: LTV volume at different g-loads

Arithmetic mean 1g: n_{1g} = 63,32 mm
Arithmetic mean 4g: n_{4g} = 61,90 mm

A difference between n_{1g} and n_{4g} of 1,42 mm of lung-expansion could be observed, which means a loss in tidalvolume of ca. 2,24 % or about 20 ml.

The experiment proved the possiblity to use the "Breas LTV 1000" for ventilation of a patient during deorbiting. The changes of the tidalvolume caused by hypergravity during simulated deorbiting are marginal. But before starting deorbiting, an increase of tidalvolume of at least 90 ml should be achieved.

Fig. 51: One-person rated centrifuge of the GCTC Gagarin Cosmonauts' Training Centre

Fig. 52: Fixation of the ventilator to the centrifuge seat

Fig. 53: Lung model with video camera for verification of the lung excursion placed inside the centrifuge

3.3 Experimental simulation in Sojuz-, ISS-mock up and EVA

3.3.1 Experimental simulation in the Mockup

A particularly important phase in the TEMOS project is the testing of the feasibility of urgent medical care in the full-sized mock-ups of the main ISS modules and the Sojuz-TM transport vehicle and during simulation of the egress and post-egress scenarios following a contingency aftermath in which there is the destruction of ISS components, including failure of life supporting systems which entail, in turn, medical emergencies associated with abnormalities in the functioning of life-critical body systems in crewmembers that may require immediate diagnostics and urgent treatment.

Based on the experience of the orbital station Mir, an assumption can be made that the probability of contingency events aboard ISS is highest in the periods of docking of other piloted vehicles when different kinds of technogenic alert conditions may occur with medical consequences requiring an immediate decision as to what assistance should be given to an injured or diseased crewmember.

The primal objective of this TEMOS phase is the simulation of medical cases in the ISS and Sojuz-TM mock-ups in order to experimentally verify the scope of emergency procedures applicable in their settings including the period of crew descent from orbit.

To fulfill the tasks, the following investigations were performed:

- Assessment of aspects of emergency medical care of an injured crewmember in the ISS SM mock-up,
- Assessment of aspects of emergency medical care of an injured crewmember in the Sojuz-TM mock-up.

All these simulations in the mock-ups, on the centrifuge were conducted with the involvement of experts in resuscitation and with the use of a mannequin as an injured crewmember.

The doctor was to test valid methods and means of emergency medical care using the set of instruments and items available on the ISS and in the rescue-vehicle (Sojuz-TM).

3.3.1.1 Preparation for emergency treatment of a suited patient

The resuscitation manipulations included the following: lavage of the stomatopharynx, aspiration of gastric contents from the upper respiratory tracts and the tracheobronchial tree, and injection of medication in the hand veins.

Fig. 54 shows an episode of preparation of the suited mannequin for emergency medical procedures. The way to open the spacesuit helmet is demonstrated. A plastic air pipe has been inserted into the stomatopharynx cavity (Fig. 55).

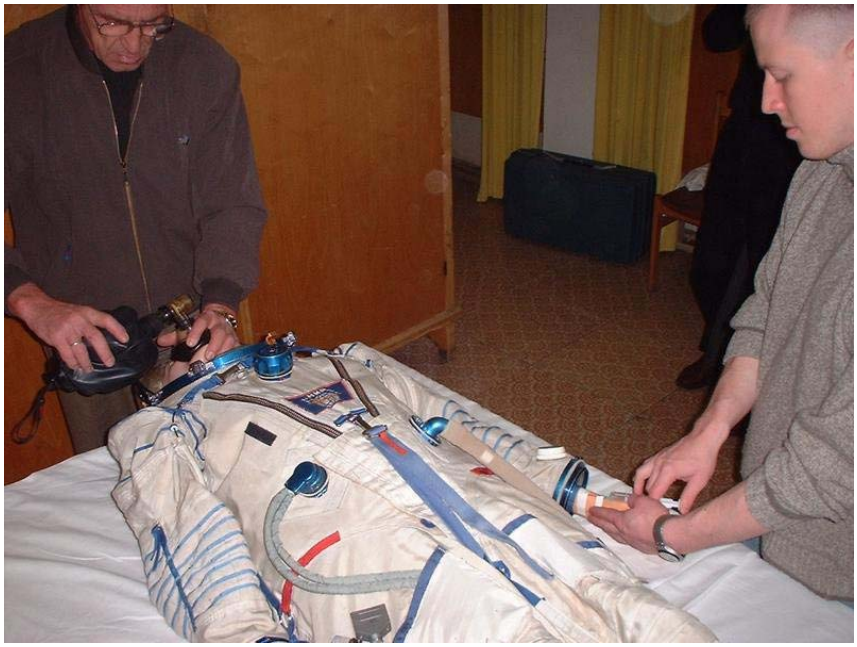


Fig. 54: The preparation of intubation

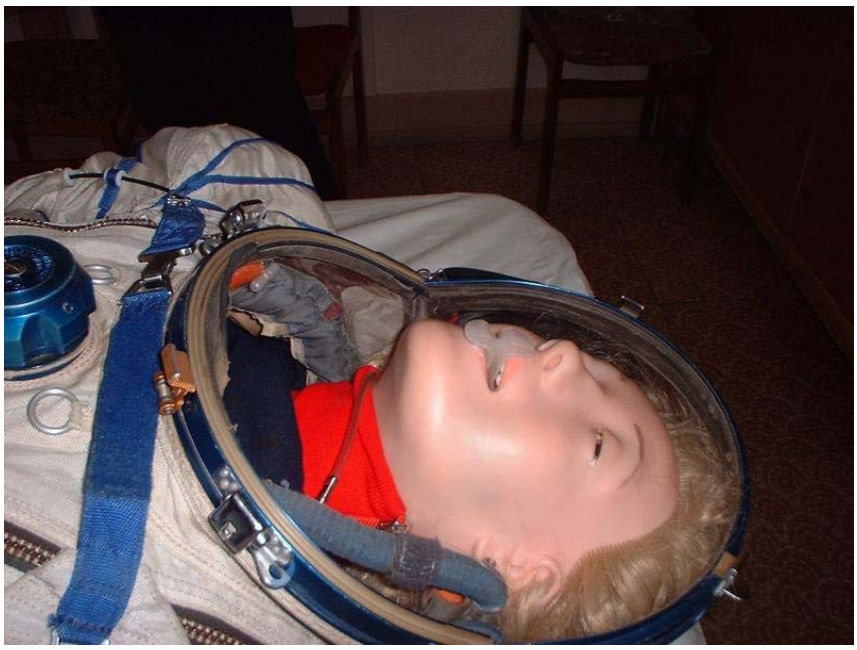


Fig. 55: Oral introduction of artificial airway

3.3.1.2 Emergency medical care in the ISS Service Module

Intubation and artificial ventilation in the ISS module

The mannequin is laid down on the working table in ISS SM. A special restraint system has been secured to the table; the belts of the restraint system were buckled to have the mannequin fixed on the surface of the table during implementation of the medical emergency actions or manipulations.

Tracheal intubation is made with the standard procedure unless there are contraindications (fractures of the upper jaw or cervical vertebrae, vast wounds in the mouth or pharynx, etc.).

If the standard tracheal intubation is impossible, intubation with the help of a special laryngeal mask (AIRWAY), nasal-tracheal intubation or cricothyreotomy should be performed.

Figures 56 and 57 illustrate the APV episodes, heart monitoring (defibrillation, if indicated) on a background of infusive therapy and injection of medicinal preparations.

It should be pointed out that the positioning of the patient on the SM working table is not convenient for the resuscitation procedures; negative factors are the height of the table and the impossibility for the assistent to approach the patient's head.

In our opinion, these problems can be settled by putting the patient on the floor in the wide compartment in SM (Fig. 58). Placing the patient and the restraint system on the floor gives more freedom to the assistant to perform the resuscitation procedures. To fix the patient on the floor, the restraint system is aligned with the longitudinal SM axis, and the assistant has a free access to any part of the patient's body to participate in the resuscitation manipulations and take care of the patient (fig. 59).

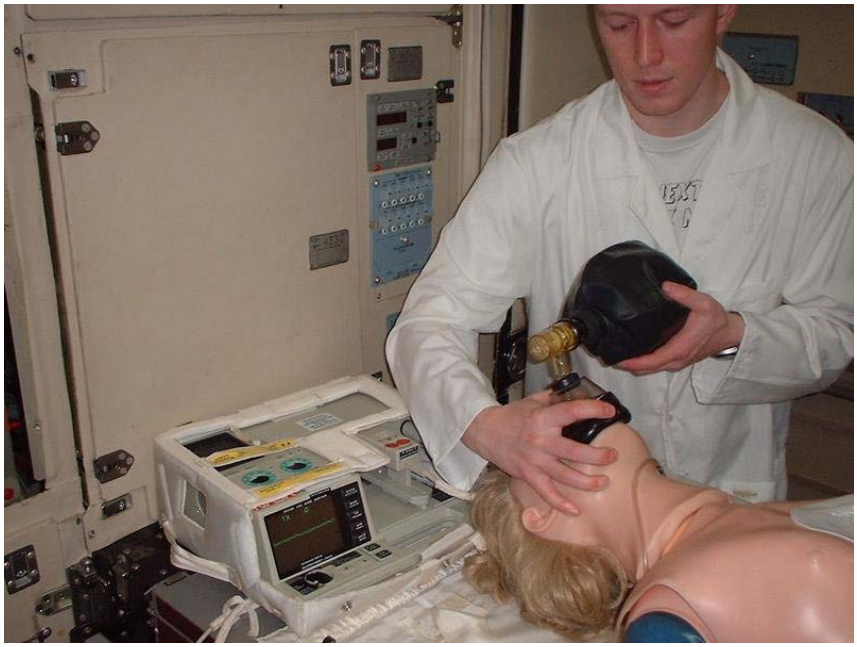


Fig. 56: Artificial pulmonary ventilation and intravenous injection using mannequin in space-suit.

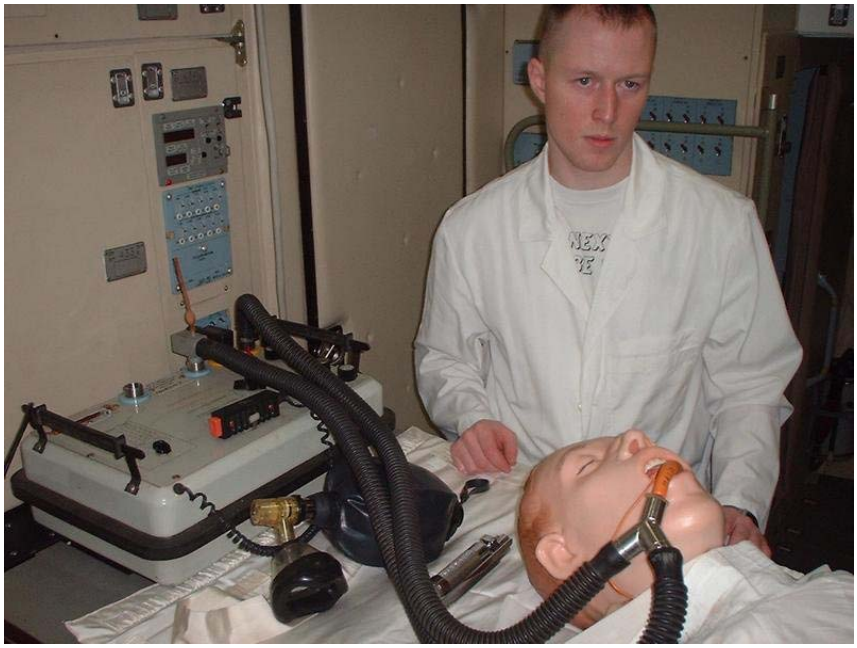


Fig. 57: Tracheobronchial artificial pulmonary ventilation using narcosis apparatus (on the operating table of ISS Service Module model)

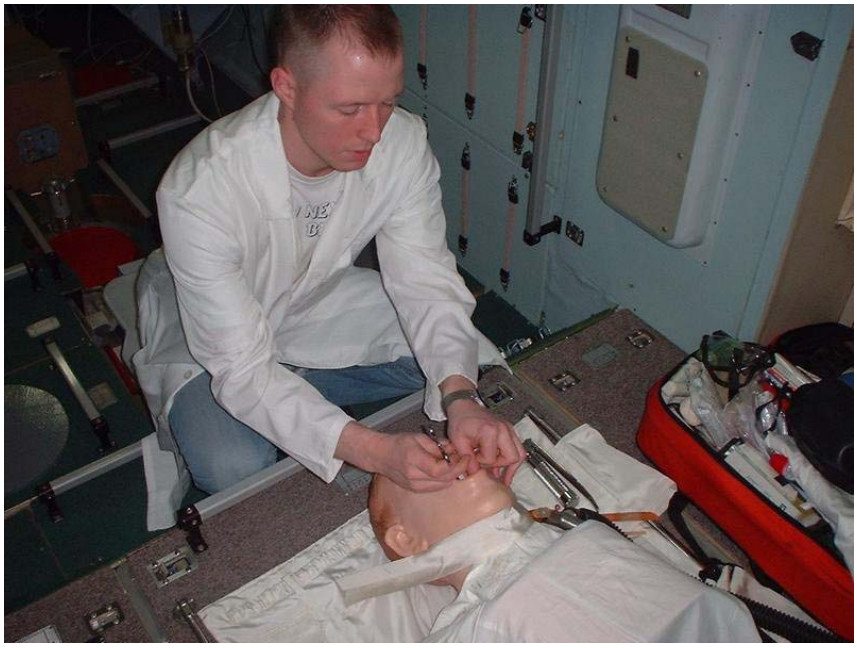


Fig. 58: Lavage of mannequins bronchial tree on the floor of ISS Service Module model

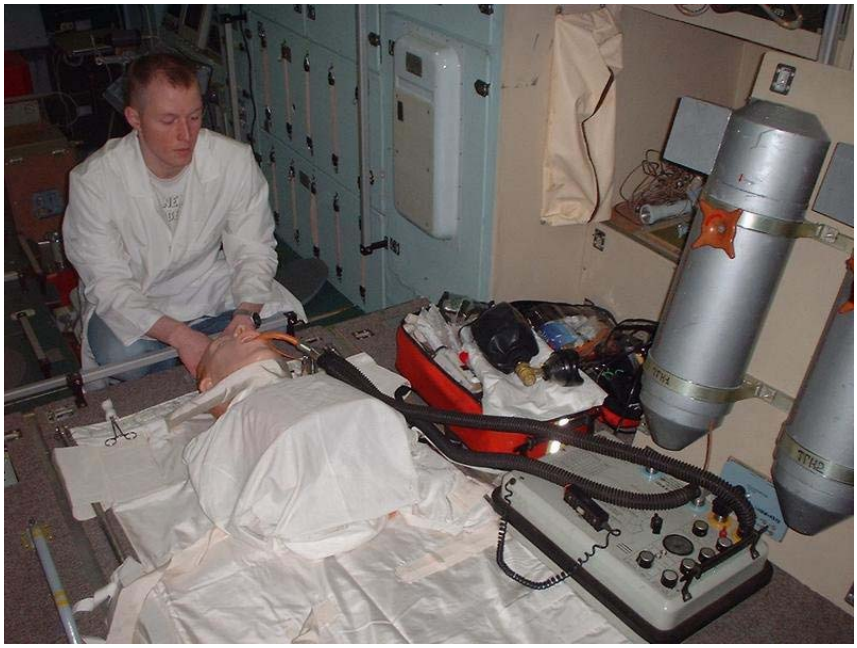


Fig. 59: Conduction of artificial pulmonary ventilation on the floor of ISS Service Module model

Practical training of resuscitation in the ISS Mock-up

A particularly important phase in the TEMOS project is the practical training of resuscitation and ALS procedure on a mannequin in the full-sized mock-up of the main ISS modules in order to verify the scope of emergency procedures applicable in their settings. The focus lies on the assessment of aspects of difficult airway management of an injured crewmember in the ISS SM mock-up. The experiment is conducted with the involvement of experts in resuscitation and with the use of a mannequin of an injured crewmember.

The intention is to validate the new algorithm for difficult airway management using the set of instruments and items available on the ISS.

Therefore, the mannequin is laid down on the working table in ISS SM. A special restraint system is secured to the table; the belts of the restraint system are buckled to have the mannequin fixed on the surface of the table during implementation of the medical emergency actions or manipulations.

The patient is stabilised and has an iv. access. Overall, the start situation is equal to difficult airway algorithm, ETC sequence. A video and a voice link between ISS and ground control is simulated, so that a surgeon could give medical support during the whole procedure.

Three attempts of standard endotracheal intubation failed, so as an alternative airway the Esophageal Tracheal Combitube ETC is used. First, the equipment is checked and ensured that the cuffs are not leaking. A tongue-jaw-lift manoeuvre is performed and the device inserted. The pharyngeal cuff is inflated with 100 ml of air and the distal cuff with 10 - 15 ml. An Ambu bag is attached to the esophageal tube. The placement of the combitube is checked via auscultation as described in ETC algorithm. The combitube is placed in the esophagus and the ventilation via esophageal tube starts.

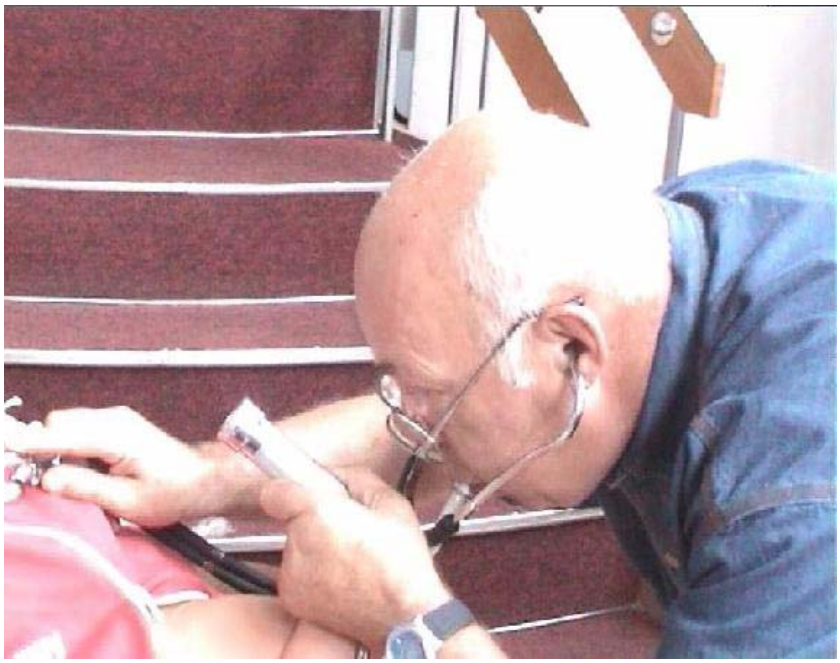


Fig. 60: ETC

3.3.1.3 Emergency medical care in the Sojuz-TM mock-up

A cardiologic emergency was simulated on board the ISS. The patient claimed of sharp pain in the sternum with irradiation in the left hand and epigasrtic area, was placed in an antihorthostatic horizontal position (-4) on the grounf of the floor and fixed by fixation means. Auxillary breathing was admitted by an Ambu bag. The pulse freuquency and the blood showed a weak blood pressure (90/50 mm/ Hg) and a high pulse rate (126) with arrhythmia. An intravenous puncture was performed and 5% glucose infusion applied. The ECG showed a voltage reduction with ST depression (up to 2,9 mm). Therefore, 1,5 ml Prednisolone and 1,0 ml Tramal were applied. Suddenly the patient developed ventricular fibrillation. A cardioversion was imidiatley performed and 1,0 ml epinephrine applied. The ECG showed a sinus rhythm with BP of 100/50 mm/ Hg. Afterwards a tracheobronchial toilet was done and an intubation with arteficial ventilation via APV apparatus performed. Within the whole procedure a televideo conference between IBMP, MCC and clinical centers was provided. After the stabilisation of the patient a ardiac infarction occurred. The patient was stabilized and transferred to the lodgment of the Sojuy capsule attending the command of the MCC.

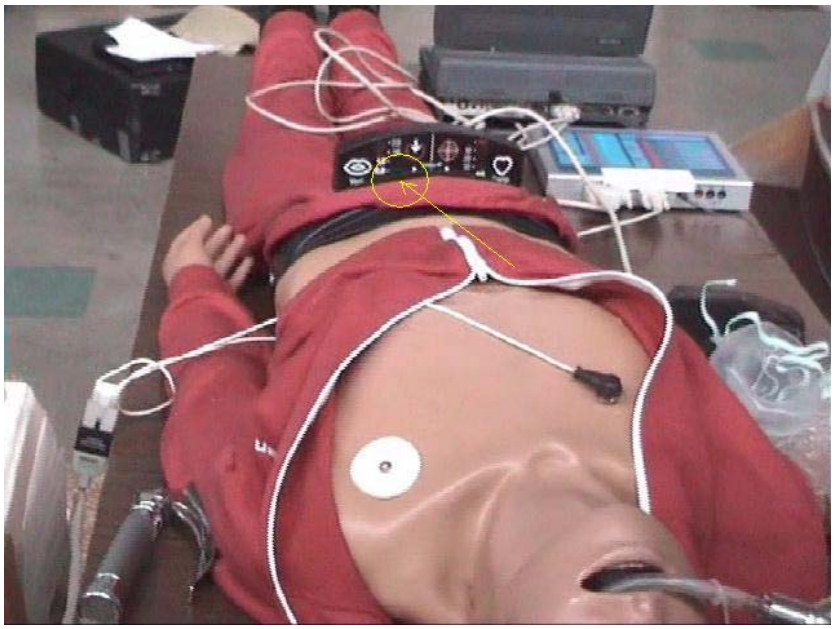


Fig. 61: cardiologic emergency and resuscitation

The injured crewmember is suited in the middle couch (Kazbek) inside the rescue vehicle Sojuz-TM (fig. 62). The assistant in the left couch is doing the stomatopharynx cleansing of the suited patient (fig. 63). A check of the patient's heart rate during preparation for and in the course of descent (fig. 64). Auxiliary respiration is performed while g-loads have not yet begun (fig. 65). In the absence of g-loads the assistant in the right couch is doing APV (fig. 66).

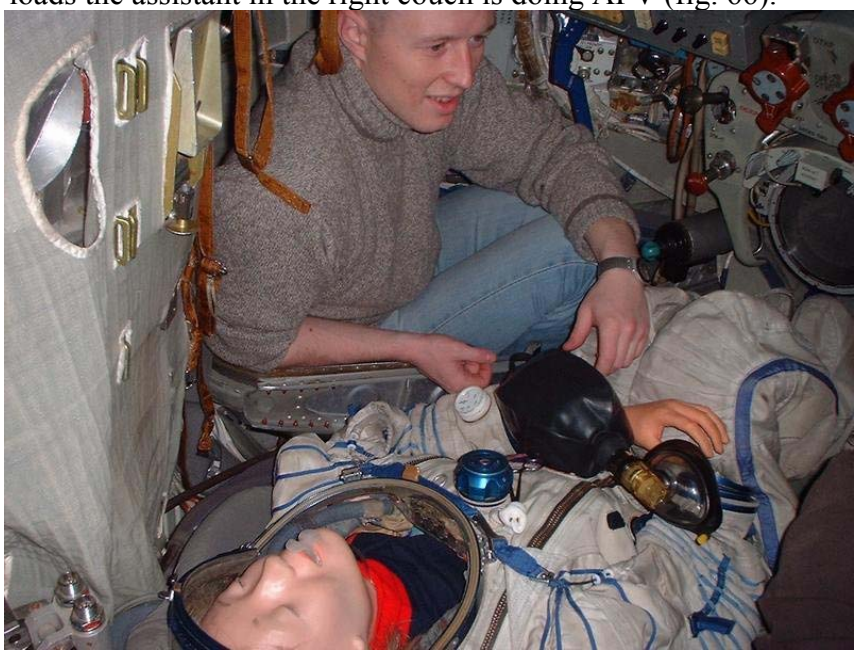


Fig. 62: The overall placing view of ill crewmember and rendering of medical care in Sojuz spacecraft model

Fig. 63: Lavage of bronchial tree of mannequin in Sojuz spacecraft model

Fig. 64: Overall placing view of patient and medical care rendering in Sojuz spacecraft model

Fig. 65: The conducting of assistant respiration in Sojuz spacecraft model

Fig. 66: Artificial pulmonary ventilation from right lodgement in Sojuz spacecraft model

3.3.1.4 Simulation of dagnostic investigations for vertigo in the Mockup

The diagnostic set-up includes mainly non invasive investigations, especially video oculography and otoscopy. Both investigations can be registered digitally via a digital video camera and analysed. The digital video oculography is especially a very precise method to analyse the complexity of eye movements in microgravity. Also a caloric examination of the vestibular organ would be useful. The analyses of these data could be performed on earth.
The digital data can be sent online or after a period of time to earth. With ISDN technology the data can be sent to competition centres where analyses and therapy recommendation may take place.

Video signals could be performed and analysed in our vestibular research laboratory. With normal video cameras only the transfer of slow picture rates were possible (50-60 Hz).

Digital video-oculography

For diagnosis of vestibular diseases especially in emergency scenarios a neurovestibular diagnostic equipment would be desirable. The potential of a conventional oculography via Frenzel ocular glasses and a digital examination of the eye movements with a digital video camera has been investigated on earth in the ENT department at Mainz, in the Sojuz and in the ISS mockup in Moscow.

Therefore, a patient with vestibular neuropathy was examined with Frenzel ocular glasses. A nystagmus to the left side could be detected. The movement of the eyes were digitized via a digital video camera (JVC) with a band width of 30 pictures per second. The digital video signal of the camera can be implemented on a DV Recorder via s-video signal input. The video signal of the DV recorder can be transferred to a computer via DV input and stored there in mpeg or wmf. This signal can be sent via ISDN on the internet.

The eye movement could be also digitized by a conventional video endoscopic system (Storz model 20 0420 20) and transferred digitally to a computer via DV recorder (Panasonic NV-VDV2000EC).

The recording of a signal of the eyes via the digital camera and conversion of the digital signal via the DV recorder to a conventional video recorder was examined, too. The signal was transferred to a conventional video recorder and saved as s-vhs signal. This video signal can be implemented to a digital video oculography system where the nystagmus can be analyzed digitally.

Also, the possibility of an implementation of foreign video signals via a digital video oculography unit was tested. Therefore, an s-vhs video signal was implemented on the digital video oculography system and analyzed.

All investigations proved the possibility of digital video oculography and digital examination of the eye movement.

The examination of the implementation of this equipment onboard the ISS and onboard the Sojuz capsule were performed in the mockup in Moscow. The equipment was not conducted by the IBMP for the use in the Soyuz cpasule. It was therefore used for demonstration and testing of the qualitiy of this examination in diagnostic questions. If this equipment should be used on board the ISS and Soyuz caspule it has to be proven for use by the IBMP before.

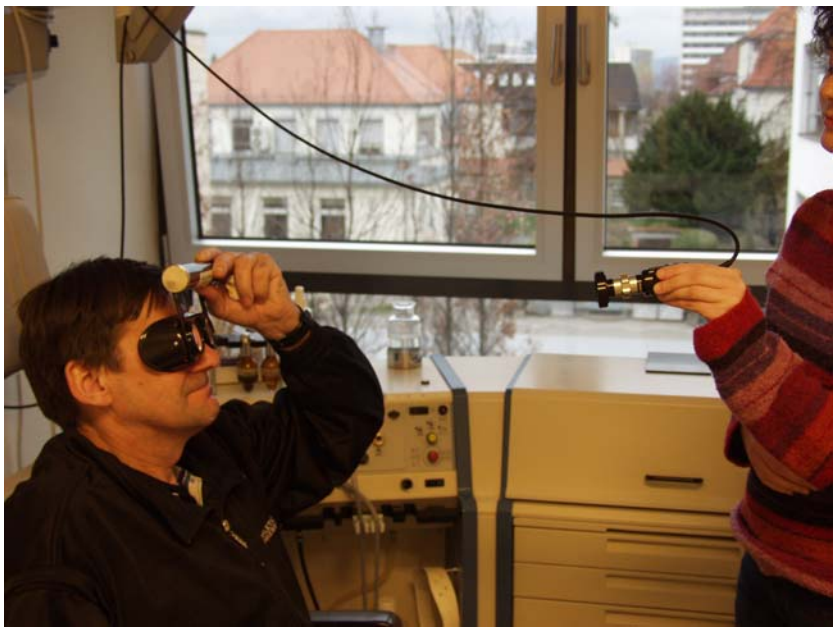


Fig. 67: Digital video-oculography on the ground

Digital oto-endoscopy

In case of vestibular dysfunction the external ear canal and the ear drum have to be examined. Therefore the possibility of digital video otoscopy was examined in the ENT department at Mainz. The external ear canal and the ear drum were examined via a digital video endoscopy unit provided by Storz model 20 0420 20. The system integrates a ½" CCD-sensor 760H with supply unit PAL with image processor module and exports the video signal via s-video. This s-video signal was transferred via a DV recorder to a computer and stored there as mpeg or wmf with a band width of 128 KHz. This digital video signal can be sent via ISDN to the internet.

Fig. 68: Digital oto-endoscopy on the ground

3.3.1.5 Emergency medical care while EVA

To validate means and methods of emergency medical care of injured crewmembers APV and intravenous injection with the use of the mannequin were imitated (fig. 76). The feasibility of applying the above methods to an injured crewmember donned in the spacesuit was demonstrated.

Figure 69 displays the overall view and operating controls of spacesuit Orlan-M. The control panel (on the chest close to the right shoulder), the multiple communications connector (below), the pack opener (under the right shoulder), the hot-cold regulator, injector and emergency oxygen supply switches (near the red bar), handle of the pack closing tether (left of the control panel), pin for the spacesuit attachment to the vehicle ship-way (in the umbilicus area).

The head is behind the three-layer helmet glazing and out of reach for execution of the resuscitation procedures.

Hands are in removable gloves. When the gloves are pulled off, the radial artery can be palpated and an injection made in the dorsal hand veins (fig. 76).

Figure 70 presents the overall view of the spacesuit internal cavity (from the inside).

The pack is open; basic life support components are fitted in the pack and shielded with a textile curtain. In the upper right corner there is a spacesuit ventilation valve (if necessary, pure oxygen can be supplied turning the switch in the position "injector" or "emergency oxygen supply").

The diagram shows the helmet glazing, the shoulder seal bearing on the left arm, radiocommunication and medical sensors cables, liquid cooling suit jets, and the pack opener.

Figure 70 illustrates the initial phase of the unassisted cosmonaut's exit from the spacesuit: the spacesuit is fastened in the hatchway; the head goes out first and then the arms.
The cosmonaut holds on to the upper edge of the spacesuit entrance and is about to fulfill phase 2.
The facial part of the head and the upper extremities are now accessible for investigations and therapeutic procedures (examination of the pupils of the eyes, the common carotid artery pulsation, cleanup of the upper respiration tracts, application of the tourniquet to the upper extremity, intravenous infusions, injections, etc.).
The arms, torso and the head are covered by components of the liquid cooling suit hindering in implementation of the resuscitation procedures. However, subcutaneous and intramuscular injections in the deltoid muscle are still possible through the liquid cooling suit. Veins of the dorsal hand surface are also accessible for injections. To perform the mouth-to-mouth artificial respiration the liquid cooling suit headset cap must be taken off.

Fig. 69: Mannequin in the space-suit.

Fig. 70: Space-suit cavity

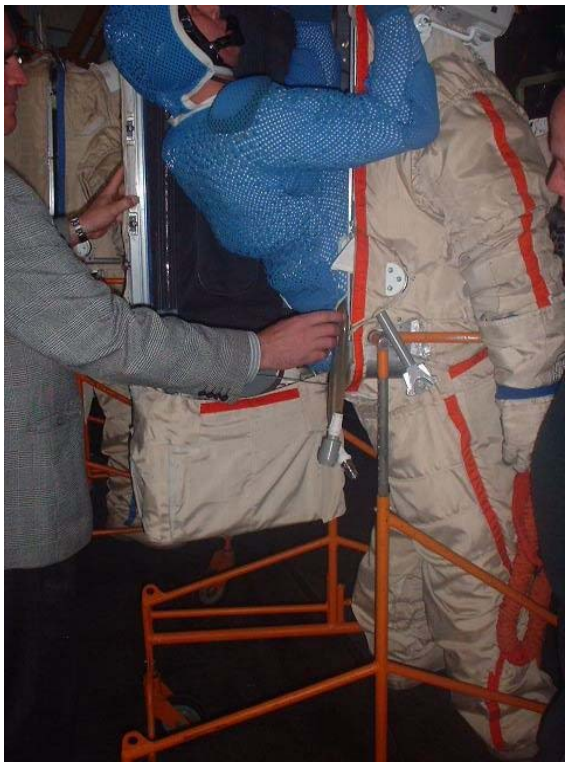


Fig. 71: Space-suit extraction of patient

Figure 72 shows the second phase of the unassisted cosmonaut's exit from the spacesuit. It begins with disconnection of the radiocommunication cable, medical belt, and the liquid cooling suit.

After that, pulling himself up with his hands on the edges of the spacesuit entrance, the cosmonaut withdraws his legs from the trousers-legs, torso and the upper part of the thighs. The cosmonaut is sitting on the lower edge of his spacesuit entrance. All that is left for him to do to get completely out of the spacesuit is to withdraw his shins and feet.

A dark blue figure-of-eight strap in the area of the pelvis belongs to the restraint system and is used to extract a disabled cosmonaut from the spacesuit. A grey connector on the right buttock is a part of the liquid cooling suit.

On this figure, the spacesuit is hooked up in the vertical position in the handling dolly; this made difficulties in the extraction of the disabled crewmember in the ground-based simulations because of the additional loading due to the body weight of the cosmonaut.

Figure 73 demonstrates the onset of extraction of the disabled cosmonaut from the spacesuit (front view, through the helmet glazing).

After opening the pack, the patient's head is flung backward (the unbending movement) to release it from the helmet. The facial part of the head is accessible for the resuscitation procedures. The figure illustrates cleaning of the upper respiratory tracts.

One who will perform resuscitation should have it in mind that oxygen supply to the spacesuit cavity will be terminated the moment the pack has been opened.

Figure 74 illustrates the onset of extraction of the disabled cosmonaut from the spacesuit (side view). The situation is the same as in figure 73. It demonstrates the use of the aspirator to clean the mouth cavity and upper respiratory tracts. Infusive procedures are not yet available.

The next figure 75, demonstrates further actions aimed at extraction of the disabled cosmonaut from the spacesuit – release of the torso (mannequin).

With the head released, the torso of the patient should be encircled with both arms (hands of the assistant should be placed on the chest) and the body should be pulled out of the spacesuit cuirass beyond the entrance edge.

The resulting situation will be the same as in figure 71. The facial part of the head is now accessible for investigations and therapeutic procedures (examination of the pupils of the eyes, the common carotid artery pulsation, cleanup of the respiration tracts).

The arms, torso and the head are covered by components of the liquid cooling suit hindering in implementation of the resuscitation procedures. Immediate subcutaneous and intramuscular injections in the deltoid muscle and the upper quadrant of the buttocks can be made through the liquid cooling suit. To perform the mouth-to-mouth artificial respiration, the liquid cooling suit headset cap must be taken off. Indirect heart massage, defibrillation and immobilisation will be possible following complete extraction of the patient from the spacesuit

Fig. 72: Extraction of patient from space-suit

Fig. 73: Extraction of the patient´s head from space-suit

Fig. 74: Space-suit extraction of patient

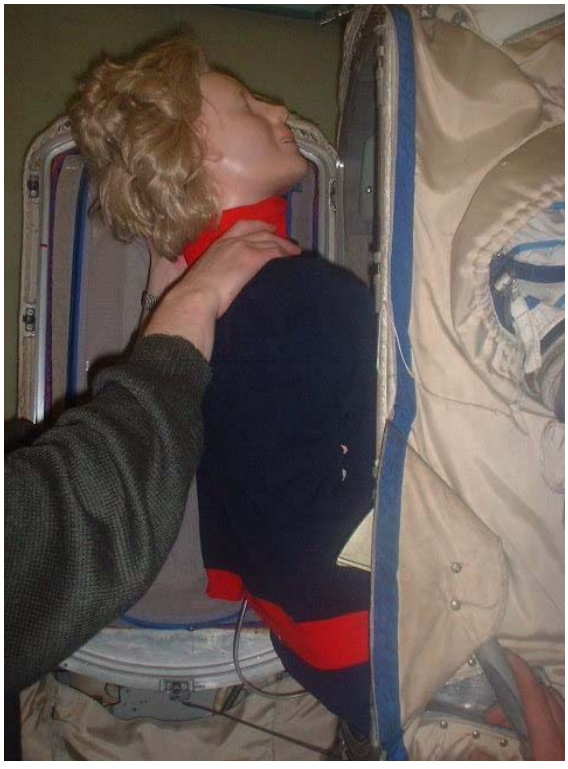


Fig. 75: Removal of a mannequin head from the space-suit

Figure 76 shows palpation of veins of the patient's hand. To reach the hand, the clamp of the hand seal bearing should be opened and the seal glove removed. The pack can be left closed. The spacesuit will be ventilated with pure oxygen out of the vehicles or the spacesuit oxygen tanks after

putting the switch in the position “injector” or “emergency oxygen supply”. One should have in mind that opening the pack terminates ventilation and the patient’s head must be rapidly withdrawn from the spacesuit.
In this situation, oxygen therapy can be performed, and tourniquet application and injection into the hand veins can be fulfilled after removal of the inner cotton glove.
The emergency medical procedures can be complemented by hyperbaric oxygenation. For this procedure pure oxygen is forced into the closed and sealed spacesuit to produce positive pressure of 0.4 atm. Obviously, there is no possibility of direct manipulation and the procedure cannot be performed with unconscious and unstable patient.
Figure 77 depicts a model of the spacesuit entrance. Its diameter is no more than 100 cm. To improve emergency medical care skills in the crew, drill sessions are required to practice the transfer of the disabled suited crewmember through the entrance avoiding impingement on the edges.

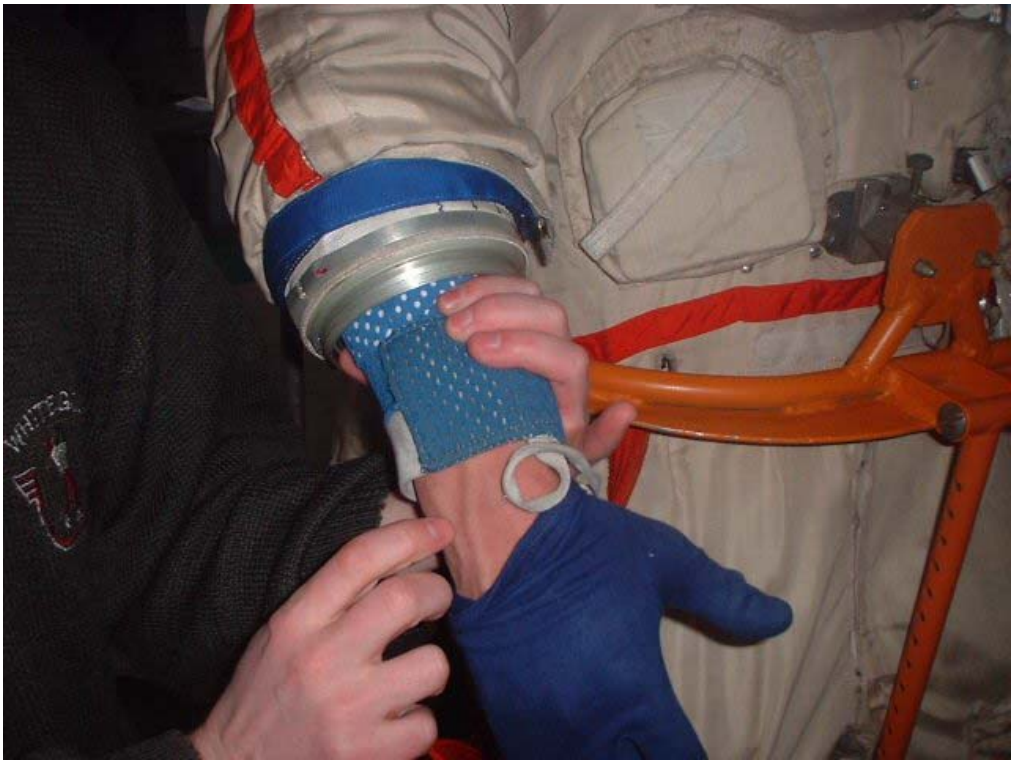


Fig. 76: Vein palpation on patients hand

Fig. 77: Model of emergency oxygenation in the space suit

3.3.2 Accommodation of critically ill patient and diagnostic support equipment in the re-entry vehicle (for specification and development of emergency scenarios)

The precondition for deorbiting a critically ill cosmonaut is the stabilisation of the patient on board the ISS.

Stabilisation on board the ISS

The stabilisation on board should be performed according to the new algorithms and the recommended devices like LTV 1000 and Alaris MedSystem III. (q.v. 3.5.1.2 and 3.5.1.3)

Monitoring

The vital signs (O_2-Saturation, blood pressure and heart rate) have to be continuously monitored by pulse oximeter and Automatic Blood Pressure Cuff (ABPC). The existing 3-leads-ECG can be used for detecting dysrhythmia. Therefore, a 12-leads-ECG should be used in order to recognise ischaemia during deorbiting.

Ventilation

The airway has to be secured by intubation on board of the ISS and the patient has to be ventilated, if the Glasgow Coma Scale index is less than 8 or respiratory distress occurs; refer to intubation algorithm, chapter 4.2.1.

Up to now, the ventilation during deorbiting is only provided by manual ventilation with Ambu bag. Therefore, one cosmonaut is permanently handicapped by the one-handed ventilation. In addition, the manual ventilation will never be as physiological as an artificial respiration. Also, there is no feedback about ventilation parameters like tidalvolume, pressure, capnometry during manual ventilation. We would therefore recommend the use of a ventilation device, e.g. the "BREAS LTV 1000" (Pulmonetics, USA). Also, a feasibility for capnometry is highly recommended in order to optimise and control the ventilation.

I.v fluid application

Each critically ill patient must have iv. access to apply intravenous fluids and drugs (e.g. sedation, analgesia, circulation) via infusion pump. Indications are shown in chapter 4.1.2 (fluid substitution to prevent shock in case of bleeding, burns or cardial problems and for intravenous drug substitution).

Each patient must have iv-access to give intravenous fluids and drugs (e.g. sedation, analgesia, circulation) via infusion pump. The available pump onboard ISS is only an one-channel iv-pump. We propose the ALARIS MedSystem III® Multi-Channel Infusion System due to the fact that it combines three independent infusion channels (with infusion rates 0.1-999ml/h for each channel) in an unparalleled small size. It is essential to have more than one channel because in some situations it is necessary to infuse more than one drug continuously, e.g. catecholamines, propofole and morphine. Furthermore, if volume substitution is obligate, a rate of 3 l/h (3 x 999 ml/h) can be performed by MedSystem III, but not with the existing infusion pump (900 ml/h).

The ALARIS infusion pumps have been used for several years on the jet aircraft and rescue helicopters of Swiss-Air Ambulance with very satisfactory results and is currently investigated by the experts at IMBP and NPO Energia. For technical specifications of LTV ventilator and ALARIS pump see appendix.

Drugs for transport of a critically ill patient

An intubated patient needs a general anaesthesia. Therefore we recommend a continuous infusion with propofole 2% (3-8 mg/kg/h) for sedation. A opioid-derivate (morphine, fentanyl, remifentanil) should be given. Fentanyl and Remifentanil have a stronger analgetic potence and are easier to control than morphine, because of their shorter half-life period. Furthermore, the begin of the analgetic effect takes less time.

Ketamin should be used for analgosedation in combination with midazolam. Contraindications are myocardial infarction and brain traumata. It is recommended for patients with a hypovolemic shock or for sedation of intubated and ventilated patients. Because of its bronchodilatated potence, it is also recommended for patients suffering a status asthmaticus.

If ketamin is contraindicated, the use of propofole for sedation is indicated. Propofol reduces the peripheral vascular resistence and is therefore contraindicated for cardiovascular insufficiency and hypovolemia.

A device for evaluating the brain activity could be useful for accessing the narcosislevel during deorbiting, i.e. the BIS.

Muscle relaxation should be considered for the transport in Sojuz rescue vehicle. Rocuronium should be used because of its shortened period until relaxation effect starts, so its possible to use it for rapid sequence induction. We would not recommend tuhe use of succinylcholine because of its adverse effects, i.e. increasing of potassium level or triggering of cardiac arrythmia. Preferable is the use of a monitoring device for depth of relaxation.

BIS and other systems for evaluating narcosislevel and relaxation status have to be tested in further projects.

A pack with emergency drugs should be onboard the Sojuz.

3.4 Practical Application of telemedical Data Transfer between Spacecraft, Ground Control and Consulting Centers

3.4.1 Definition of telemedicine equipment, system architecture and link performance

Now at the realisation of information exchange between the participants of the project: University of Mainz, Institute of Medical and Biologic Problems (IMBP), the Russian Association of Telemedicine (RAT) and the Control Centre of space flights (MCC) of the Russian aerospace agency - the circuit submitted on fig. 1 has been created.
Variants of opportunities in the given circuit are determined:

- Functional tasks of each participant to specify the application software and technical means (ASTM),
- Organisational presence, rules of law and arrangements for participants of the project including the adjacent organisations (Russian aviation Space Agency , RKK "Energy", ESA, the Centre of Preparation of Cosmonauts (CPC).

The following points should be considered:

- Development of organisational rules for the information exchange between proprietors of various telemedical centers: CPC , RKK "Energy", IMBP, University of Mainz, ESA - and its consumers,
- Requirements to structure the functions of integrated databases (DB),
- The co-ordinated requirements for the means of protection of the information from non-authorised access,
- Descriptions and co-ordination of program interfaces between participants of the project, including interface HPS,
- Development of the organisational rules in the complex of information exchanges by ASTM,
- Development and co-ordination of functions for the participants in the maintenance of the ISS by using ASTM.

Results of the first stage have shown the necessity for the expansion and modernisation of the participants´ equipment for the data exchange in constant operation. Hence, the following tasks have already been clarified:

- Development of ultimate goals and tasks of the project, definition of functions of each participant of the project at all stages of its realisation,
- Essential expansion of developed procedural documentation at the end of each stage of the project,
- Creation of a permanent digital channel for interaction between MCC and the University of Mainz for optimising the information exchange. Thus, it is expedient to consider the creation of the integrated liaison channel together with ESA, by which the creation of a liaison channel between Darmstadt and MSS is provided (productivity up to E3),
- Introduction of ASTM of switching and distribution of information streams,
- Introductions of billing monitoring systems in the information traffic,
- Deciding the rules for videoconferences with focus on the telemedical maintenance in manned programs,
- Development of medical equipment structure while connected to a local computer via network (LAN),
- Optimising the cost for communication services in the use of information resources.

The telemedical information includes medical telemetering parameters: electrocardiograms, pneumogrammes, etc., measuring by the onboard equipment during de-orbiting of the Spaceship, carrying out of medical experiments and EVA. Besides this, the telemedical information, other telemetering parameters necessary for the analysis of medical information, i.e temperature, pressure, humidity, parameters of the radiation control, etc. can be contained.
For the transfer of telemedical information from MCC-t to other organisations hardware environment and software of a regular telemetering complex are used.
Telemetering Information (TMI) is transferred to the MCC via broadband liaison channels. Some full streams TMI from different telemetering boards can act simultaneously; for example, TMI of a spacecraft, TMI of two telemetering systems of the service module and TMI of two telemetering systems (like FOB) of the international space station.
The MCCe developed a telemetering payment structure, where an access with full stream buffer via TMI is allowed and the exact time codes of the equipment can be sent with integration of the data at a workstation via standard interface.
Reception of full streams of the telemetering information is carried out on 16 workstations of preliminary processing with architecture RISC and operational system UNIX of version HP-UX 10.20. For management of the telemetering computer complex of operators 2 similar workstations are used. They are used for scheduling stations of preliminary processing. During a session of communication(connection) on them the information on an operating mode of the onboard equipment and on quantity (amount) of failures in TMI is given out. At stations of preliminary processing allocation from full stream TMI and a filtration from handicaps of all telemetering parameters and, in particular, values of medical parameters is carried out.
The program of preliminary processing can be broken into some subroutines which carry out the following actions conditionally:

- Allocation from full stream TMI of the staff,
- Allocation from the telemetering staff and a filtration from handicaps of telemetering parameters in view of their frequency of interrogation,
- Filtration calibration levels,
- Calibrating TM parameters,
- Translation of values of telemetering parameters in physical sizes,
- Processing TM of parameters of onboard computers.

The processing results are transferred in real time as packages to the central system where they could be displayed. Also, the possibility of data archiving and of data exchange in TICS structure is available. The received information can be transferred to workplaces of management experts. The information of the TMI structure and error is transferred from stations of preliminary processing to a reception hall of telemetering stations or to a management group. Full stream TMI on all telemetering boards automatically enters the name in archive which through station of external exchanges is accessible to the removed users. A personal computer with the operational system LINUX serves as the station of external exchanges.
Transfer of the telemetering information from the stations of preliminary processing and of external exchanges is carried out with use of UDP report. The station of external exchanges serves clients from other organisations under TCP report. Exchanges inside TICS and with external subscribers are carried out by packages whose format meets the recommendations of the international committee CCSDS. This format has been used for information interchanges between MCC-i and MCC- Houston and between MCC-i and the European space agency for a number of years. The telemetering information can be transferred from MCC in real time and from archive.
Application software of stations of preliminary processing and the station of exchanges is developed with use of the programming system C/C ++. The client workplace is written in Java language and can be carried out on the removed workplace of any COMPUTER with any one operational system (UNIX, LINUX, WINDOWS-95,-98,-NT,-200(V XP). The application software of a client receives schedules of parameters in real time, and after the session recieves

files of TM parameters in a binary and in a text format. The structure of the TM parameters is determined interactively by the client workplace. The application software of a client can be developed by the processor of the telemedical information. The archival system stores the full stream TMI of all sessions on hard disks under the ISS program up to 6 months. On magnetic tapes the TMI is kept during all ISS flights. Now the archival system is being developed on the basis of a disk file «hp superstore disk array XP-1024». This system will allow external subscribers to receive TMI for more than 1 year of subscription.
Information exchanges between MCC-i and the removed subscribers are carried out through a Complex of External Information Exchanges (CEIE) with the use of standard application software and the allocated broadband channels on the basis of the Optical Fibre Communication Lines (OFCL), allowing the exchange with a speed of 2 Mbit/ sec. In the CEIE the established program and hardware of protection of the information is included.

Specification of hard- and software
The tools of the telemetrical equipment should include:

- A relational data bank server with enhancement of elements of data mining,
- A picture archiving system with DICOM standard format including modalities for transmission of x-ray and ultrasound signals,
- The possibilities of an interface for signals and time series to standard signal format of the Russian partners and HPS.

An integration of the use of web-technologies is desirable, too.

In the course of the project the IDL/ION Fa. Research system and the Matlab/Matlabwebser (Fa. MathWorks) for telemetrical data bank server were compared.
In the beginning of the project better requirements were achieved by the IDL system.
But further improvements by Matlab were integrated:

- A development of a Matlab web server with DICOM interface,
- An interface to all data bank formats,
- An enhancement of statistic tools.

Also, an interface of leading Echo-PACS has been integrated in the running system in 2003.
Because of the open source access with self developed functions and the wide dissemination in the surrounding of the universities the Matlab system should be recommended by now.

The following web based data bank server were tested:

- ASP with integration to MS Access ,
- ION with IDL integration,
- Transfer of MS Access and MS Excel data bank files to Mysql data format.

An integration of the Matlab system was also tested. An easy transfer to a web based solution on the basis of sql was achieved, too.

Therefore the Matlab system provides all demands for a telemetrical solution.

Web technologies and video
In case of a web-based architecture for data storage, processing and presentation the following web-based platforms may be used:

- Intranet for clinicians behind the firewall,
- Extranet with optional latest technologies depending on the provider (Fa. Strato AG),
- Configuration of a web server according to the project (i. E. outsourcing by Strato AG).

The solution of a central and project oriented data server turned out to be inflexible and time consuming. Therefore, data was stored by each partner separately while an access through the firewall with VPN was prepared.
The possibilities of VPN differ between the partners. An RAS server based on Windows XP for ISDN connection was therefore constructed. In this server all partners had access to the data under special organisation of the access rights. The web based resources of the university intranet and TEMOS data could be transferred within this server.
The Russian technologies for telemetrical equipment were mainly concentrated in the field of teleconference and videoconference systems. A direct connection between MCC and the telemetrical partners using teleconsulting facilities was expanded by the Russian side by commercial videoconference systems. With the restriction of information transfer the following problems of displayed information and data were solved:

- Change of interface to biomedical tools,
- Safety problems,
- Independence of platform,
- Differences between Internet and intranet structure.

The existing standards (H.320 for ISDN, H.323 for I.P, T.120 for data exchange) and the professional supply for technical equipment by the university simplifies the data transfer.
The connection between Moscow and Germany was tested via the Polycom system and net-meeting with H.261 (352x288) video standard. An improvement of the transfer velocity is planned. A data exchange up to 100 Mbytes/s (in DFN up to 1 Gbyte/s) can be achieved by the German side. Successful connection including teleconsultation and transmission of PC contents in XGA format and with analogous camera consultation (Fa. Tandberg 2Mbit/s) was tested, too.

3.4.2 Practical training with interactive TM-link using different transmission channels

The structural differences exist in different degrees of the Internet construction and different possibilities of investment. Therefore, a different ISDN connection is provided at the Russian side. In Germany, an extended infrastructure with area wide Internet access exists.
Therefore, in Germany the provision of VPN technologies is essential for telemetrical connection. The existing technological and technical equipment also achieves an easy access.
The experiences of the TEMOS project were integrated in the routine work of the telemetrical connection of the University Erlangen.
A web-based platform with 2Mbit/s was developed via VPN for heart catheter investigations. A telecommunication was possible via net-meeting.

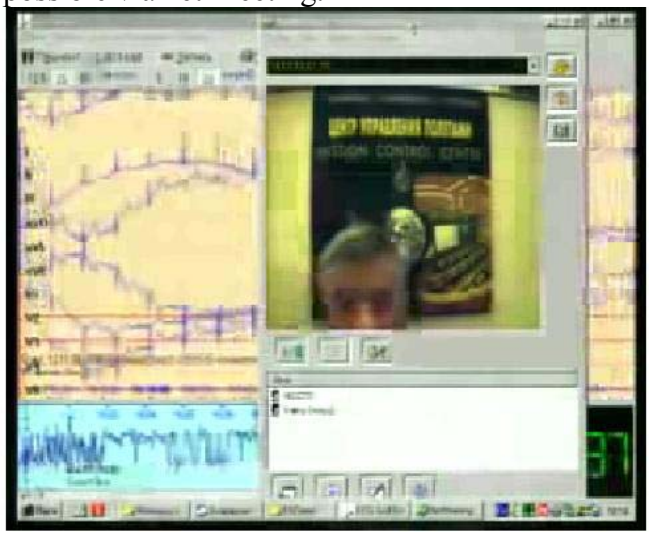


Fig. 78: Telemedical conference between Mainz, RST and Mission control center

3.4.3 Specification of optimal monitoring and diagnostic set-up

According to part I of the project all standard medical equipment onboard the ISS is defined and described, i. e. the GAMMA-1M onboard the ISS, the BETA 08 for EVA, the ALPHA 11 system onboard the Sojuz capsule. In case of emergency only minimal systems are scheduled, i. e. BETA 08 and ALPHA 11 system. The integration of the standard system REFLOTRON for blood analysis and UROFLUX for urine diagnostic test should be discussed. The BETA 08 system also provides facilities for telemedical communication and is highly recommended in emergency scenarios. All parameters of these systems can be transferred online with the existing telemedical communication. The parameter can also be integrated into a data bank server. That means an individual profile of the patient onboard the ISS can be registered and integrated in biomedical programs. A telemedical concept was provided by the Russian side; "Development of server and client software of removed workplace telemetry information computer system (TICS) MSS-I". A special reconstruction of each diagnostic tool would be unnecessary by transposition of the server developments.

Concerning the health oriented plans modern diagnostic tools can be integrated into the telemedical system without need of optimisation. But in an emergency scenario a different protocol of the integration of the diagnostic tools is essential. The main differences between the routine use and the use in emergency scenario persists as follows :

- The routine use can be used in buffered modus. The ground control team can perform more extensive evaluations with time delay. The integration and evaluation of the HPS should be automated.
- The routine use of diagnostic tools is planned and can be optimised on the ground. When needed, investigations can be postponed. The investigations should be easy in use and the communication has to be determined to guarantee a minimum of failures. A secure and self-depending work is favoured.
- In need of deorbiting in the Sojuz capsule the current telemedical equipment can be attached only in parts. The "TICS" concept could be a possible solution.

3.4.4 Telemedicine in Post-landing Support

Under the nominal conditions, the established system of post-landing recovery, with defined on site resources, is fairly autonomous with little need for an outside support. The landing with critically ill patient on board will be normally planed at the nominal landing site; the medical staff on the ground will be capable of rendering full ALS support. The ALS hardware set-up, proposed for uses during de-orbit, is also applicable for a continuous treatment during the transport into the designated medical facility if such need arises. It enables vital data storage in the period between the emergency event and the onset of full treatment in a tertiary facility. We propose that the ALS medical hardware used by the ground team should be identical, or at least compatible, with the hardware onboard the spacecraft in order to ensure the continuity of vital data monitoring and to increase the system redundancy in the case of a component failure.

The application of an additional telemedical and telecommunication link would be beneficial in the following situations:

- Collection, transmission, consultation, and documentation of real medical vital parameters immediately post-landing and in the following hours, when the effects of de-conditioning and re-adaptation are most apparent.
- Improvement of logistic and medical support in non-nominal landing situations with Sojuz TM spacecraft.

The improvement of further post-landing support was not a part of the TEMOS project. It is currently subject under discussion. The pilot scenario should be tested with selected partners within the first half of 2004.

4 Data synthesis, creation of recommendations

4.1.1 Telemedical support for accurate diagnosis and treatment

The telemetrical equipment must be easy in use and always available. It should not only be used for routine protocol onboard the ISS but also for set-up and educational purposes. A complete integration or an integration in parts of the tested telemetrical equipment onboard the Sojuz capsule should also be desired.
In an emergency scenario an online access of these data cannot be guaranteed. A possible solution might be the transfer of unselected and unprepared data via telemetrical integration of the on-screen information by the ground control centre.
An integration of all telemetrical connections should be achieved via a data bank server but cannot be guaranteed in emergencies. An ftp server could provide a technical solution of an online access to the raw data of the ISS and the prepared data of the MCC. Also, an adaptation to the latest generation of telemetrical equipment could lead to a better integration and access to these data by competitive centers.
The tools of the telemetrical equipment should include:

- A relational data bank server,
- A picture archiving system with DICOM standard format including modalities for transmission of x-ray and ultrasound signals,
- The possibilities of an interface for signals and time series to standard signal format of the Russian partners and HPS.

The Matlab system provides all the demands for a telemetrical solution and is therefore recommended.
Technical information of various diagnostic tools is described in 3.3 and an integration after specific adaptation especially in emergency scenarios seems to be possible. The telemetrical problem could be solved by the transmission of on-screen information but the use should be practised beforehand. Also, a verbal communication with the ground control is mandatory.
In emergency cases an online evaluation is necessary. The integration and evaluation of the specific situation by the HPS should be automated and possible without time delay. This point should be achieved without special tools.
In emergency cases no time delay may take place. Therefore the use of difficult and complicate investigations should be avoided. Following the education of the use of these tools in an emergency scenario, the form of communication should be also clarified to guarantee a minimum of failures due to the misuse of these tools. A secure and independent work of the diagnostic tools should be demanded. It should also be kept in mind that in an emergency scenario only basal functions of these tools are available. An individual adaptation of the systems onboard the ISS is essential because of the small amount of cosmonauts.
The integration of special telemedical equipment onboard the Sojuz capsule is still under investigation. The “TICS” concept could be a possible answer. With permanent duplication of the information of the server to the MCC and the Sojuz capsule a flexible pool could work independent and a patient oriented function could still be achieved.

4.1.2 Methods of CPR and AALS in space flight

Algorithms for medical treatment

Measures to provide early medical care for victims with life-threatening emergencies gained large efforts in the training of medical lay persons. Beside medicolegal aspects, life saving therapy is provided by trained and certified non-physicians available at the scene of a trauma or cardiac arrest. Both the American Heart Association and the European Resuscitation Council have developed programs for the education and training of physicians and non-physicians in life support. Moreover, a lot of algorithms have been designed for many critical situations in medicine, e.g. the difficult airway algorithm. The adapted algorithms we recommend for ISS are a synthesis of the existing algorithms on ISS and the newest recommendations from the European Rescue Council, considering the special changes in microgravity.

The existing algorithms on ISS are very detailed but too complex to perform an efficient treatment in a emergency situation.

In addition, they did not take into account the current emergency standards.

So it was necessary to shorten the existing algorithms, combine them with the newest guidelines and adapt the advise to conditions in µ-gravity.

The main changes in the algorithms were as follows:

1. The existing diagnosis algorithm had to be shortened and simplified. The first step in any medical emergency treatment on ISS should be the transport of the victim to the examination table in the ISS near the medical equipment. This will take less time than carrying the medical equipment to victim.
2. The treatment for cardiac emergencies had to be divided into different shorter algorithms to make it possible for medical non professionals to treat them in the right way and in the right time.

Cardiac emergencies were divided into the following algorithms.

2.1. CPR algorithm: The main change here was in the technique of chest compression. In µ-gravity environment the victim has to be fixed and the rescuer has to be fixed perpendicular to the long axis of the victim with the feet on the ceiling to be able to compress the chest effectively.

2.2. VF (Ventricular fibrillation) algorithm was shortened and combined with the new algorithms.

2.3. Myocardial infarction algorithm.: The application of Diazepam and Esmolol in addition to the existing medications is advised including a 12- lead ECG for infarction diagnosis.

2.4. Bradycardia algorithm: It is necessary to mention the risk factors for asystole. Cosmonauts should be educated to recognise them.

2.5. Tachycardia algorithm: The additional medication of adenosine for supraventricular tachycardia, amiodarone for ventricular tachycardia and esmolol for atrial fibrillation/flutter is advised. For treatment of tachycardia it is necessary to perform a blood analysis to check the potassium-level and substitute it if necessary. In need of cardioversion a short time narcosis with etomidate is recommended.

3. The following changes of the shock algorithm are purposed:

3.1. The shock position to increase venous return from legs doesn't make sense in the condition of microgravity. Theoretically, the use of inversed pressure gradient – (positive instead of negative)in LNBP device could provide an effect similar to the MAST (Military Anti Shock Trousers) or an anti-g suit.

To increase the peripheral vasopressure during hypovolemic shock, consider etilefrine or noradrenaline.

3.2. Up until now, on the ISS, only saline infusions are intended for the prevention and treatment of shock. We recommend the additional use of colloid fluids as mentioned in the terrestrial guidelines. Because of the increased extravasal volume in µ-gravity conditions small volume resuscitation (SVR) should be performed. The concept of SVR using hypertonic solutions encompasses the rapid infusion of a small dose (4 ml per kg bodyweight, i.e. appiximately 250 ml in an adult patient) of 7,2 –7,5 % NaCl/colloid solution. The SVR has a rapid onset of the circulatory effect. With respect to the actual data base of clinical trials SVR seems to be superior to conventional volume therapy with regard to faster normalisation of microvascular perfusion during shcok phasis and early resumption of organ functions.

3.3. In the initial phase a BP cuff can be used to put pressure on the infusion. Later on an infusion pump, which can infuse 3 infusions at the same time can be used (ALARIS MED.SYS. III).

4. One difficulty in the burn algorithm is the local cooling. Here we admit cool pads or wet towels because cooling with water is not possible in µ-gravity.

5. It should be possible to send all medical parameters and a video link to ground control to make it possible for a surgeon on Earth to give further advise.

Recommended algorithms:

1. Diagnosis

Patient in distress

First of all carry the patient to the table nearby the medical equipment. Contact surgeon.

CMO1: unstow CMRS, restrain and unstow patient
CMO2: unstow defibrillator, Ambu Bag
CMO1: check responsiveness, assess breathing:
look listen and feel for normal breathing

Breathing
set patient on high flow oxygen (with mask) (6l/min)
go to **post resuscitation algorithm**

Not breathing
give 2 effective breathes using Ambu bag or
mouth to mouth
assess circulation (max. for 10 sec.)
signs of circulation: coughing or movement
only if you are trained to do so check carotid pulse

Circulation present	**No circulation present**
continue rescue breathing and go to	Go to **CPR algorithm**
intubation algorithm	
after intubation algorithm check pulse, BP and	
analyse wave form by attaching large defi pads and	
turning defib to defib on/analyse	

Normal pulse and wave form
go to Post resuscitation algorithm

ECG signs present
Q- waves suspected, ST depression or elevation
suspected go to Myocardial infarction algorithm

Heart rate < 50 go to Bradycardia algorithm

Heart rate > 100 go to Tachycardia algorithm

Tab. 24: Diagnosis

2. CPR algorithm

Equipment:
automated external defibrillator
ECG with capability of NIBP and O_2 saturation
O_2, iv access, Intubation set,
drugs
(adrenaline, amiodarone,
atropine, pacing puffer
and for intubation)
temperature indicator,
blood glucose-stix,
arterial blood gas analysis

Treatment:
if you see the moment of cardiac arrest you may perform a precordial thump
attach defibrillator pads and turn defib to defib on/analyse (CMO2)

NO shock advised
Begin CPR (CMO2)
(locate the middle of the lower half of
the sternum with your hand
place the heel of your hand down the
sternum and the heel of the other hand on
the top of the first
extend or interlock the fingers
position yourself vertically above
the victim's chest (fix yourself with your feet on the ceiling)
with your arms straight, press down the
sternum between 4-5 cm
release all the pressure without loosing contact
repeat at a rate 100 times a min
after 15 compressions give two effective
breaths (CMO1)
CMO1 during CPR think of intubation go to **Intubation algorithm**
and about venous access go to **Venous access algorithm**
attach ECG electrodes
after the first minute of CPR assess pulse and wave form again

Shock advised go to VF algorithm

QRS complex present and pulse present
stop CPR
set patient on high flow oxygen

Normal pulse and wave form
go to Post resuscitation algorithm

Heart rate < 50 go to Bradycardia algorithm
Heart rate > 100 go to Tachycardia algoritm
Electrical activity but no pulse continue CPR

No QRS and no pulse
continue with CPR like above
give epinephrine 1 mg iv

(repeat up to 3 times)

after every minute of CPR
check pulse and wave form like above
if no pulse continue your resuscitation
until you get advised by surgeon

Tab. 25: CPR algorithm

3. VF algorithm

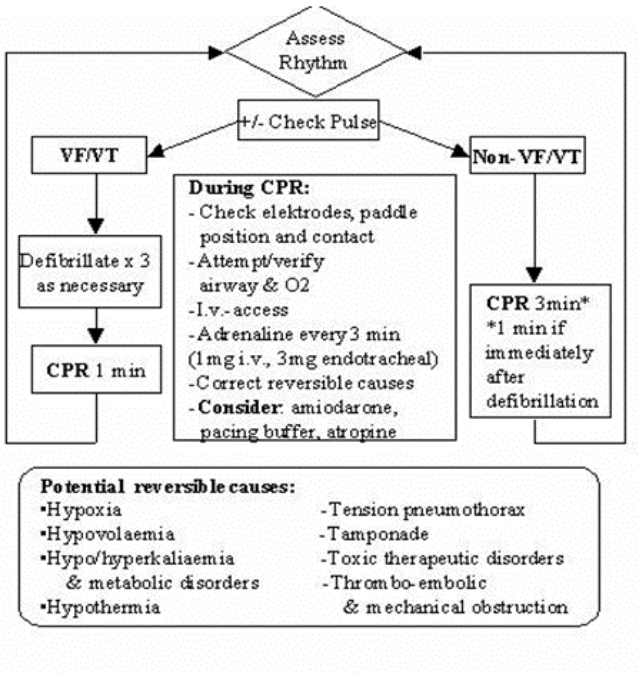
CMO1
Select energy 200 J, press charge, call clear, discharge, assess pulse and waveform
if no pulse press analyse. Shock advised?
shock advised, select energy 200 J press charge, call clear, discharge, assess pulse and waveform
if no pulse, press analyse. Shock advised?
shock advised, select energy 360 J, press charge, call clear, discharge, assess pulse and waveform

After 3 attempts pulse present

QRS complex present and pulse present
stop CPR
set patient on high flow oxygen
Normal pulse and wave form
go to **Post resuscitation algorithm**
Heart rate < 50 go to Bradycardia algorithm
Heart rate > 100 go to Tachycardia algorithm
Electrical activity but no pulse go to CPR algorithm

After 3 attempts no pulse present

start CPR (description CPR algorithm)
resume CPR for 1 minute
press analyse button on defibrillator
if shock advised:
Select energy 360 J, press charge, call clear, discharge, assess pulse and waveform
if no pulse, press analyse. Shock advised?
shock advised, select energy 360 J, press charge, call clear, discharge, assess pulse and waveform
if no pulse, press analyse. Shock advised?
shock advised, select energy 360 J, press charge, call clear, discharge, assess pulse and waveform
still no pulse, restart CPR and continue like above
Think of reversible causes and drug substitution ; if patient is intubated, but i.v.-access is impossible, give 3 mg adrenaline endotracheal every 3 minutes instead of 1 mg i.v.



pulse present treat like described above
no pulse present continue resuscitative efforts until you get advise from surgeon

Tab. 26: VF algorithm

4. Myocardial infarction algorithm
Assess BP, heart rate, breathing and O_2- saturation
attach, and print ECG (12-leads-ECG)

Any serious signs or symptoms of infarction?
flat or inverted T waves
ST segment elevation or depression
Q waves present in 2 leads
severe chest pain
light-headedness, sweating

No signs present:
Normal pulse and wave form
go to **Post resuscitation algorithm**
Heart rate < 50 go to Bradycardia algorithm
Heart rate > 100 go to Tachycardia algorithm

signs present:
set patient on high flow oxygen (6l/h)
give nitro-glycerine (only if BP > 90/60 mm Hg) 1 tab (0,4mg) under
tongue
Give morphine 2 mg i.v.
Consider diazepam and esmolol (1mg/kg BM)
write down time medications given
assess pulse and rhythm

if normal pulse and rhythm are present, go to post resuscitation algorithm
Heart rate < 50 go to Bradycardia algorithm
Heart rate > 100 go to Tachycardia algorithm

if severe symptoms, give morphine every 5 min. until pain subsides

Tab. 27: Myocardial infarction algorithm

5. Bradycardia algorithm

assess rhythm, BP, HR, breathing, O_2-saturation
attach ECG
set patient on high flow oxygen (6l/min)
confirm pulse < 50

Adverse signs ?
systolic blood pressure < 90 mm Hg
rate < 40/min
ventricular arrhythmia
requiring suppression
heart failure

No adverse signs →

Risk of asystole ?
recent asystole
Mobitz II AV block
complete heart block
with wide QRS
ventricular pause
greater than 3 s

NO → go to post resuscitation algorithm

adverse signs present
give Atropine 0,5 mg iv
satisfactory response → **YES**

NO ↓

← **YES**

Interim measures:
repeat Atropine 0,5 mg iv. up to
max. 3 mg
prepare to pace using multi function
electrodes
call clear and turn defibrillator to PACER ON
set pacer rate to 70 bpm
increase pacer output until each
downward spike has associated QRS
complex

successful pacing patient recovers
normal sinus rhythm go to
post resuscitation algorithm

If pacing is not successful
continue with Atropine and monitor patient
contact surgeon as soon as possible

Tab. 28: Bradcardia algorithm

6. Tachycardia algorithm
If not already done, set patient on high flow oxygen (6l/min)
establish iv access (go to iv access algorithm)
assess pulse

no pulse go to VF algorithm

pulse present
look for adverse signs
systolic BP < 90 mm Hg
chest pain
heart failure
heart rate >150 bpm

No adverse signs

Adverse signs present
prepare for synchronised cardioversion
contact surgeon as soon as possible
if patient is responsive
short time narcosis useful (20mg etomidate)

start cardioversion
press LEAD button to select lead II
select energy 100 joule
press SYNC
press CHARGE
call CLEAR
press DISCHARGE
Assess pulse and waveform
press LEAD to select electrodes
press ANALYSE
shock advised, go to VF algorithm
no shock advised, look for adverse signs
no adverse signs, go to post resuscitation algorithm
still any adverse signs present
repeat cardioversion with energy levels in this order
200 J
300 J
360 J

During this perform a blood analysis to check potassium
if potassium is too low, give potassium chloride up to
60 mmol, maximum rate 30 mmol/h via iv access
using the infusion pump

Atrial fibrillation/flutter
(wormlike p-waves with QRS / sawtooth waveform)
esmolol, up to 1mg/kg BM until normal rhythm occurs
Supraventricular Tachycardia
(superfast rate with normal PQRS)
vagal manoeuvres (carotid massage on only one side,
valsalva)
Adenosine 12-18 mg as fast iv injection
Ventricular tachycardia with pulse
(wide QRS complexes with or without P-waves)
Amiodarone up to 300 mg iv

if normal sinus rhythm occurs, go to **post resuscitation algorithm**
If adverse signs remain, perform cardioversion

Tab. 29: Tachycardia algorithm

7. Post resuscitation algorithm

Continue to monitor patient as mentioned in
the specific algorithms
treat upcoming problems following the specific algorithms

look for additional injury
if patient suffers from burns go to **burns algorithm**
always think about shock and go to **shock algorithm**

if the patient is not intubated set on high flow oxygen
If patient is intubated: consider analgosedation
write an ECG
perform an arterial blood gas analysis
monitor urine output
control BP, HR, RR, O_2-saturation continuously

contact surgeon for further diagnostics
send all parameters to ground control and try to perform a video link
prepare for transport into Sojuz

Tab. 30: Post rescucitation algorithm

8. Shock algorithm

Indication
prevention or treatment of hypovolemic
shock caused by external/internal bleeding,
burn injury, diarrhea or vomiting.
loss of 20% of normal blood volume causes
hypovolemic shock
prevention easier than trying to tread it!

Signs of hypovolemia and volume of blood loss (ACS 1989)

Parameters

	I	**II**	**III**	**IV**
heart rate	<100	>100	>120	<140
blood pressure	normal	normal	low	very low
pulse	strong	weak	weak	thready
respiratory rate	14-20	20-30	30-40	>35
capillary refill time	<2 s	longer	longer	longer
(press finger nails and measure how long it takes until they become scarlet again)				
mental	normal	anxious	anxious/confused	lethargic/unconscious
volume of blood loss	<750ml (15%)	<1500ml (>30%)	>2000ml (>40%)	>2000ml (>40%)

Equipment
venous access kit
gauze pads to control bleeding
ear thermometer
ECG with blood pressure and O2 saturation
infusion pump
Blood gas analysis
laboratory tests (CBC)
colloid fluids
cristalloid fluids
hyperhaes
oxygen
Treatment
keep the victim warm
if bleeding stop bleeding by applying direct
pressure using gauze pads
try to increase venous return from legs using

modified LNBP device
put the victim on high flow oxygen (2-6l/min)
do not give fluids by mouth
apply one or two large bore venous accesses
(see venous access algorithm)
Replace fluid:
initial infusion with cristalloid fluid
20ml/kg BM in 10 min
or colloid fluid 10-20ml/kg BM in 10 min
Small volume resuscitation
start infusion with 4ml/kg BM of hyperhaes
then continue with cristalloid / colloid fluids
like above

For the first infusions, use BP cuff to put pressure on the infusion because high infusion rate is needed, later on you can use infusion pump

try to perform an arterial
Blood gas analysis and laboratory tests
monitor body temperature and
vital parameters(ECG,BP, HR, RR, O_2-saturation)
Consider intubation using the guidelines
in intubation algorithm

contact surgeon as soon as possible

To increase the peripheral vasopressure during hypovolemic shock, consider etilefrine or noradrenaline.

Tab. 31: Shock algorithm

9. Burns algorithm

Equipment:
Intubation / ventilation Kit
venous access Kit
volume substitution Kit
sterile gauze pads
cooling pads
Treatment:
protection of non-affected crewmembers and the integrity of the station is most important
Control fire, chemical contamination or electrical damage (ISS emergency manual)
1. remove patient from burning area
2. check vital parameters (ABLS-Algorithm)
3. smouldering clothes have to be removed
4. place patient under a clean, try sheet to minimise contamination
5. Local cooling with cool pads or wet towels
- as soon as possible
- not with ice cold pads
- if patient is shivering stop cooling
- after introduction of narcosis stop cooling
6. estimate the percentage of body surface area burn using the
"rule of nines"
Chest and abdomen front 18%
Chest and abdomen back 18%
Legs (2 x 18 %) 36%
Arms (2 x 9%) 18%
Head 9 %
Perineum and genitalia 1%
"Rule of the palms"
The palm of the hand is assumed to be
equal 1% of the total body surface area
Burn depth:
1° superficial reddening of skin and pain
2° area is erythematous, moist and swollen
with blisters and bullae
3° white or charred appearance, dry and
leathery, pain often minimal

Note
electrical burn often causes severe organ injury inspite of minimal skin injury
contact surgeon via ISDN as soon as possible for diagnosis and further treatment
7. look for concomitant injury
8. place patient on high flow oxygen
9. apply one or two large bore peripheral venous access (see venous access algorithm)
10. start infusion with Ringer lactate (colloid fluids only if patient suffers from acute bleeding)
11. Fluid replacement
- 2-4 ml/kg x BSA/24h
- half of the volume given in the first 8 h (use BP cuff)
- a quarter in the second 8 h (use infusion pump)
- final quarter in the last 8 h period (use infusion pump)
12. placement of an urinary catheter to monitor hourly urine output
13. analgosedation (only in contact with surgeon)
14. Think about intubation and go to intubation algorithm if necessary
absolute indication:
1. unconscious patient (see Glasgow coma scale)
2. pulmonary insufficiency (dyspnea, bronchospasm, cough and hypoxia)
3. clinical signs of a inhalation injury(facial burns, singed nasal vibrissa, carbonaceous sputum, pharyngeal injection, wheezing, hoarseness and a history of smoke in a closed space) with impairment of spontaneous ventilation, trend worsening
4. polytrauma
- relative indication:
1. more than 40% BSA II° + III°
2. large or circular areas around the chest
3. facial burns
4. suspecting a inhalation injury

Tab. 32: Burns algortihm

10. Venous access algorithm

Indication
fluid substitution to prevent shock
in case of bleeding, burns, or cardial
problems - or iv drug substitution

Equipment
large bore peripheral venous access
disinfectant
rubber gloves
tourniquet
stripes to fix access(e.g. leukoPlast)

Proceeding
fix victim to make treatment easier
Put tourniquet on one arm of the patient
above the point you want to use for punction
try to see and feel a vein which you can punctate
Disinfect skin in area of punction - use rubber gloves
take venous access and place front in vein
if front is in vein take plastic part and place it
deeper in vein
replace iron part and fix the access with stripes
connect infusion with venous access

Tab. 33: Venous access algorithm

11. Intubation

indication:
inability to ventilate a non-breathing patient
inability of patient to protect own airway
Glasgow Coma Scale less than 8 points

Glasgow Coma Scale:		
eye opening	spontaneous	4
	to speech	3
	to pain	2
	nil	1
best motor response	obeys	6
	localises	5
	withdraws	4
	abnormal flexion	3
	extends	2
	nil	1
verbal responds	oriented	5
	confused conversation	4
	inappropriate words	3
	incomprehensible sounds	2
	nil	1

equipment:
stethoscope
Ambu bag/mask
intubation set:
sirenge,10ccm,20ccm
ETT with stylet size 7,8
laryngoscope handle
laryngoscope blade
LMA, size 4,5
ILM size 4,5
COPA size 11

lubrication gel

tape
suction unit
ventilation unit
magill forceps

proceeding: (CMO 1)
1. contact surgeon, if practical, while proceeding
2. restrain patient, put gloves on, stand at patient's head — if patient conscious, go to rapid sequence induction
open the airway using the head-tilt, chin-lift manoeuvre
raise the patient's head slightly with a towel (sniffing position)
if pat. is unresponsive, insert oro- or naso-pharyngeal airway
3. ventilate patient with the Ambu bag
frequency 12/min with high flow oxygen (4-6l/min) — no mask ventilation possible
go to mask ventilation algorithm — go to **difficult airway algorithm**
4. preparing for intubation:
5. remove endotracheal tube (ETT)
6. lubricate the stylet and insert it into the tube
assure that the distal end of the stylet is
not projecting out of the ETT
7. fill syringe with 10cc air
8. insert syringe into the inflation port of cuff of ETT
9. inflate balloon, check integrity
10. deflate balloon
11. leave syringe attached to the inflation port
12. extend laryngoscope blade to 90 ° and check light
13. open moth with finger from right hand
with laryngoscope in left hand
14. insert laryngoscope blade into right side of mouth
displacing tongue to the left
CAVE: avoid pressure on lips and teeth
15. advance laryngoscope blade into space between
base of tongue and epiglottis
16. lift tongue forward with laryngoscope blade tip
to expose vocal cords
(17.)when unable to visualise vocal cords due to fluid remove
laryngoscope and use suction device to clear fluid — go to **suction algorithm**
ventilate with Ambu bag again for about one min — after 2 failed attempts
then reinsert laryngoscope and attempt intubation — go to **difficult airway**
18. advance cuff end of ETT along right side of mouth — **algorithm, use combitube algorithm**
into trachea until entire cuff is about 1cm below vocal cords
19. holding ETT in place, remove laryngoscope
20. inflate cuff with syringe until it feels tight(6-10ccm)
21. remove stylet
22. connect Ambu bag to ETT
23. resume ventilation as soon as possible
24. squeeze bag until chest rise,

allow passive expiration
frequency 10-12/min with high flow oxygen (4-6 l / min)
25. verify tube placement with stethoscope
26. listen over upper stomach for one ventilation
if gurgling, deflate cuff, withdraw tube,
ventilate with Ambu bag and reattempt intubation
27. listen for breath sounds on both lung sides
28. if not equal, withdraw 1cm, check sounds again
if not heard, deflate cuff, remove ETT
ventilate with Ambu bag and reattempt intubation
if heard, continue ventilation
29. fix ETT with tape
30. If secretion is noticed in endotracheal tube or resistance
increases: consider endotracheal suction go to **suction algorithm**

Tab. 34: Intubation

12. Difficult airway algorithm (CMO 1)

mask ventilation not possible
1. check head and chin position
2. check the mask seal to ensure that no air is escaping from around the mask
3. Reposition your fingers and the mask to attain a tight seal or try both handed
mask ventilation (CMO 2 squeezes Ambu bag)
4. Assess for obstruction, inspect inside the mouth, remove the foreign body
with a finger sweep or with magill forceps and laryngoscope, consider suctioning
go to suction algorithm
retry mask ventilation: if possible proceed with algorithm

mask ventilation still not possible
use ILMA as an alternative airway
1. Completely deflate the cuff of the mask. Place introducer tip into strap at the
junction of the cuff and two tubes. Fold the tubes around the introducer and fit
the proximal end of the airway tube in the matching slot. Apply lubricant on the
posterior surface of the cuff.
2. With the head extended and the neck flexed,
carefully flatten the mask tip against the hard palate
3. Keep the introducer blade close to the chin and rotate the ILMA inward
in one smooth circular movement following the curve of the introducer.
4. Advance into the hypopharynx until a definite resistance is felt.
5. Before removing the introducer, hold the ILMA tube with the non-dominant
hand to stabilise the tube. At this point, the ILMA should be correctly
placed with its tip firmly pressed against the upper esophageal sphincter.
6. Remove the introducer. Inflate the cuff with 20 ml air to obtain a seal.
Never overinflate the cuff.
7. Connect Ambu bag to ILMA and ventilate for 1 minute
frequency 12/min with high flow oxygen (4-6l/min)
Intubation through ILMA
1. Visually inspect and inflate ETT to verify cuff integrity and symmetry.
Deflate cuff, lubricate ETT and pass through ILMA tube (rotate with up/down movement)
to distribute lubricant. Pass the ETT to 15 cm depth marker or the transverse line
on the ILMA ETT which corresponds to passage of tube tip through the epiglottis
elevating bar.
2. Use the handle to gently lift the device 2 - 5 cm as the ETT is advanced.
Carefully advance until intubation is complete. Do not use force.
Inflate ETT cuff and confirm intubation.
3. Remove connector and gently ease the ILMA out over the ETT into the oral cavity.
Use stabiliser rod to "hold" ETT in position as ILMA is withdrawn over tube.
Remove the ILMA completely, unthreading the inflation line and pilot balloon of the ETT.
Replace the ETT connector.
4. Continue with intubation algorithm step 22.

If intubation through ILMA not possible, remove ILMA and go to **ETC algorithm**

Esophageal Tracheal Combitube (ETC) algorithm
indications: - possible spine injury
- bleeding or vomiting obstruct the visualisation
1. Hyperventilate patient at a rate of 24 ventilations per minute for 2 min
2. Assemble and check the equipment, ensure the cuffs are not leaking
lubricate the distal end of the tube, place the patient's head in a neutral position
3. Perform a tongue-jaw-lift manoeuvre and insert the device to the level of the black rings
4. Use the large syringe to inflate the pharyngeal cuff with 100 ml of air
5. Inflate the distal cuff with 10 - 15 ml of air (small syringe)
6. Attach the ventilation device to the longer of the 2 tubes (esophageal tube)
7. During ventilation auscultate over epigastrium and listen for gurgling sounds.
If no sounds are heard, watch for chest rise and auscultate for breath sounds.
If equal breath sounds and chest rise are present bilaterally and no gastric sounds are heard,
continue to ventilate through tube 1.
8. If you hear gurgling sounds over the epigastrium, assume that the device has been placed in
the trachea and ventilations are going in the esophagus. Cease ventilation immediately and
reposition the ventilation device on the shorter tube 2. Auscultate over the epigastricum and
listen for gurgling. If gurgling is present, remove the tube. If no gurgling is heard, assess breath
sounds. If the breath sounds are equal bilaterally, continue to ventilate through tube 2.
9. Hyperventilate for 2 min, then resume normal ventilation.
10. Reassess tube placement after each move involving the patient. Periodically check the pilot
balloon located on each tube to ensure the cuffs are adequately inflated.
11. Continue with intubation algorithm step 30.

Tab. 35: Difficult airway algorithm

13 mask ventilation (CMO 1)

1. open the airway using the head-tilt, chin-lift manoeuvre
raise the patients head slightly with a towel (sniffing position)
if patient is unresponsive, insert oro- or naso-pharyngeal airway
2. Place the upper, narrower part of the mask over the bridge of
the nose and lower it over the mouth and into cleft of the chin
3. Position your left thumb over the top half of the mask and your
left index finger over the bottom portion of the mask
use left ring and little fingers to bring the patients jaw up to the mask
4. Begin ventilation as soon as possible: Squeeze the bag with right
hand while watching for adequate chest rise and fall
5. Each ventilation should be delivered over a 1.5 to 2-second period
at a frequency of 12 per minute

Tab. 36: Mask ventilation

14 Suction algorithm (CMO 1)

1.) Position at patient's head, turn on suction unit
2.) Connect suction catheter to suction unit
3.) Insert catheter to oral cavity without suctioning
4.) Begin suction after catheter is positioned, moving
catheter from side to side, suctioning for 15 seconds

Endotracheal suction (CMO 1)

Indication: - secretion in endotracheal tube
- poor compliance or increase in resistance

1.) Pre-oxygenate patient using normal positive pressure ventilation
with supplemental oxygen, hyperventilation at a rate of at least 24 ventilations / min for 2 min
2.) Assemble and check all equipment (CMO 2)
3.) Measure the catheter length from the lips to the ear and down to level of the nipple
5.) Set suction unit between 80 and 120 mm HG (negative pressure), disconnect tube from
Ambu bag or ventilator
6.) Insert the catheter down the endotracheal tube with no suction applied
7.) Advance the catheter as measured before
8.) Apply suction. While doing so, withdraw the catheter in a twisting motion.
Do not apply suction for longer than 15 sec. Reconnect Ambu bag or ventilator to tube
9.) Hyperventilate the Patient for 2 min. Procedure can be repeated if necessary.

Tab. 37: Suction algorithm

15. Rapid sequence induction
indication: Intubation for a conscious patient

1. Apply high flow oxygen (6 l/min) for 2-3 min
   prepare intubation
   see intubation algorithm step 5 - 12
2. Avoid mask ventilation
3. CMO 1:
give - Fentanyl 3µg/kg BM
- Etomidate 0,3 mg/kg BM
- Esmeron (Rocuronium) 0,8 mg /kg BM
4. After 2 min intubation is possible,
go to intubation algorithm step 13

CMO 2:
when drugs are given perform cricoid pressure
(press cricoid cartilage slightly in posterior direction)
until ETT is blocked

Tab. 38: Rapid sequence induction

4.1.3 Recommended equipment of diagnostic and therapeutic instruments and medication for critical care treatment

4.1.3.1 Equipment for monitoring the vital signs

The vital signs (O_2-Saturation, blood pressure and heart rate) have to be continuously monitored by pulse oximeter and Automatic Blood Pressure Cuff (ABPC). Up untill now the Russian part of ISS has not had a pulse oximeter; it is only included in the Americans` equipment. A pulse oximeter is absolutely necessary for monitoring a critically ill patient. The ABPC onboard is adequate for taking automatic BP and HR readings. HR and BP are determined within 1 minute of manual activation by oscillometric technique. The ABPC includes a redundant pressure transducer to prevent over inflation of the cuff.
Furthermore, onboard the ISS a monitoring with 6-leads-ECG is available. It is imperative to have a 12-leads-ECG in order to recognise dysrhythmia or myocardial infarction.
To control the renal function and the hydration of the cosmonaut a bladder catheter should be included. As an alternative, the use of a condom catheter should be considered.
For monitoring the temperature we propose an ear probe thermometer.

Intubation and airway management
Every unconscious patient is at risk of aspiration of gastric contents or blood and other particles, originating in the upper respiratory and digestive tract. One of the protective measures is to position the victim in a lateral position with head-down tilt in order to facilitate a drainage of the mouth and oropharynx. This action is useless in microgravity and a suction device must be available for immediate use. Prolonged manual ventilation via facial mask and resuscitation bag, or mouth-to-mouth ventilation, will increase the danger of regurgitation and aspiration and should be kept to an absolute minimum. The insertion in the oral airway makes the mask ventilation easier, but does not protect the airway. Tonus of the lower part of the esophagus might be decreased in microgravity, making regurgitation more likely; no results of studies were found. Therefore, we recommend the rapid sequence induction for intubation.
Up untill now, there is no recommendation for failed airway. At the moment the alternative for failed intubation is the cricothyrotomy. Hence, we have designed a difficult airway algorithm for this scenario. This is really necessary due to the probability that a failed airway is higher in microgravity. With an untrained operator in an emergency, the rate of failure to intubate is high, even in terrestrial situations. If facial mask ventilation is difficult, we propose the use of an Intubation Laryngeal Mask Airway (ILMA) and for a failed intubation the use of an esophageal tracheal Combitube airway. We prefer the ILMA instead of the normal laryngeal mask in order to

secure the airway by intubating with the ILMA. The LMA doesn't provide complete protection against aspiration. These alternative advanced airway adjuncts (ILMA, Combitube) are not yet part of the medical package onboard the ISS. The handling of both alternatives is comparatively simple and safe even with a less proficient operator. After tracheal access has been secured, the patient should be connected to an automatic ventilator as soon as possible so that personnel, who provided manual ventilation, can concentrate on other tasks.
Cricothyrotomy is indicated if all other attempts to establish sufficient gas exchange failed, or if extensive facial injury makes mask ventilation and subsequent intubation impossible. An instrument set for cricothyrotomy is available onboard. Previous practice with the procedure is essential; severe bleeding or misplacement of the endotracheal catheter may result from improper technique. In terrestrial clinical situations, the patient after cricothyrotomy could be ventilated in HFJV (High Frequency Jet Ventilation) mode using a relatively small catheter. This option is not available in current spacecraft; insertion of a full size endotracheal tube will be required to perform IPPV efficiently with a conventional ventilator. The extubation in space shall be avoided in such a situation and continuos ventilatory support under general anaesthesia should be used during transfer and de-orbit.
Theoretically, the use of a fibreoptic intubation bronchoscope with image transmission and verbal guidance from the ground centre is possible, but this method would hardly work in practice and should not be relied upon in space. During tests in clinical situations, we noticed considerable delays in the procedure, which would result in severe hypoxia in the real situation.
The ventilation onboard and during deorbiting is only provided by manual ventilation with Ambu bag. Therefore, one cosmonaut is permanently handicapped by the one-handed ventilation. In addition, the manual ventilation will never be as physiological as an artificial respiration. Also, there is no feedback about ventilation parameters like tidalvolume, pressure, capnometry during manual ventilation. Therefore, the use of a ventilation device, e.g. the "BREAS LTV 1000" is recommended. The "LTV 1000" is a compressorless ventilator designed with unique miniaturisation technology allowing a broad range of ventilation and control functions in a unit no larger than a laptop. It is a compact (height 8 cm, width 23 cm, depth 30 cm), lightweight (5.7 kg) and easily portable unit. No wall air supply or compressor required. High pressure oxygen can supply an internal blender or a low flow source can be used. This is the main advantage for the closed environment inside the Sojuz-rescue vehicle and also onboard the ISS, because there is no contamination with oxygen or change in air pressure. Also, a feasibility for capnometry is highly recommended in order to optimise and control the ventilation. Therefore, the use of a ventilation device, e.g. the "BREAS LTV 1000" is recommended; refer to chapter 3.2.2 for technical details. Also, a feasibility for capnometry is highly recommended in order to optimise and control the ventilation.

Medication
The following medications are advised; for details see algorithms in chapter 4.1.2:

- rapid sequence induction: fentanyl, etomidate, rocuronium,
- sedation for cardioversion: etomidate,
- cardiac dysrhythmia: adenosine, amiodarone,
- narcosis : Propofol 2%, fentanyle,
- hypotension/ hypovolemic shock: etilefrine, noradrenaline, dopamine,500 ml hyperhaes, 10 l saline, 2 l haes,
- hypertension: urapidil,
- severe acidosis: pacing buffer (sodium-bicarbonate).

4.1.3.2 Vertigo

The diagnostic set-up should mainly include non-invasive investigations, especially video oculography and otoscopy. Both investigations can be registrated digitally via a digital video camera and analysed. The digital video oculography especially is a very precise method to analyse the complexity of eye movements in microgravity. Also a caloric examination of the vestibular organ would be useful. The analyses of these data could be performed on earth.

The digital data can be sent online or after a time period to earth. With ISDN technology the data can be sent to competition centers where analyses and therapy recommendations may be taken. The video signal can be analysed in specialised vestibular research laboratories. With normal video cameras only transfer of slow picture rates were possible (50-60 Hz). Eye movements can occur in a velocity up to 500°/s. Therefore, the transfer of a higher transmission rate would be preferable. An "eye-tracking-system" which uses CMOS sensors is now available. It can be adapted to a digital video system and permits real time analysis. The transfer rate is 400°/s. The system is proved for use in microgravity by NASA and DLR and may be used for digitising, storage, transmission and analysis of eye movements. The developer (Prof. Clarke) would also provide the system for further studies in combination with a continuation of the TEMOS project.

The examination of the peripheral nerves should include the examination of the nervus glossopharyngus, facialis, vagus, hypoglossus, accessorius, oculomotorius, trochlearis and ophtalmicus.

An examination of the external ear and ear drum should be also included via digital video endoscopy. The digital data can be transferred to the earth and analysed in competition centers.

To differentiate between central and peripheral vestibular vertigo an examination of the coordination including diadochokinesis and of the spinal and cerebellar ataxia should be undertaken. In case of inner ear symptoms a therapy with hemodilution and intravenous application of plasma expanding fluids in combination with cortisone is advised. The treatment of peripheral vestibular vertigo a treatment of the symptoms. Also, an advancement of the adaptation and a recovery of the function with physiotherapeutic management should be included in the strategy of treatment.

The medication of Phenergan (Promethacin) 25-50 mg/ 4 h is advised by the ISS MED protocol and should be recommended. The effect of Promethacin can be enhanced with the combination of Scopalamin. With the application of Scopalamin the reduction of intensity of vertigo without influence on the mental status was shown. On earth the application of several medications proved to be effective in case of nausea. In severe cases the sedative medication of Lorazepam (Tavor ®) or Diazepam (Valium ®) 5-10mg im. or iv. every 4-6 h could be added. These medications should also be tested by IBMP for effectiveness in microgravity. In clinical studies on earth the application with Dimenhydrinat (Vomex A ®) 25-50mg every 4-6 h supp., Sulpirid (Sulpirid ®) 50mg 3 times a day or Triflupromazin (Psyquil ®) 25mg tb. once a day were effective as treatment of the symptoms. In case of application of sedative medication the prolongation of the central compensation of the vertigo should be kept in mind. An antiemetic effect was also proven in antihistaminic like Meclozin (Peremesin ®) 12,5-25mg/d p. o. divided in up to 4 portions, Flunarizin (Flunarizin ®).

4.1.3.3 DCS/ Bends:

For clarification of the cardiac and pulmonary situation an inspection, auscultation and percussion of the thorax, heart and complete examination of the skin should be included. Also, an ECG of the heart and measure of the O_2-saturation should be performed. In case of the suspicion of a pulmonal barotrauma a radiological investigation (i. e. via x-ray) should be performed. To control the renal function and the hydration of the cosmonaut a bladder catheter should be inserted. Next to a complete neurological examination including the examination of the reflexes, muscular tonus, ataxia and mental status an inspection of the inner ear should be performed. The inner ear

examination should include a digital video oculography and a digital otoscopy. The initial therapy of DCS includes an artificial respiration with hyperbaric oxygen. The recompression should achieve a level of 1,8 bar and an oxygen saturation of 100% over a time period of 60 minutes. Subsequently a hyperbaric respiration with a level of 0,9 bar with pure oxygen over a time period of 120 minutes should be achieved according the the ISS MED protocol. These steps can be prolonged for 30 minutes. Under the treatment of recompression the size of the bubbles gets smaller so that an absorption is facilitated. The prognosis with early treatment is good. In case sufficient respiration cannot be assured an early endotracheal intubation should be performed. In the beginning the respiration should be performed by IPPV with 100% oxygenand a volume of 15 l/min continuously. A dysuria should be counteracted by an application of intravenous medication and fluids. Medication with glucose infusion should be provided due to damage of the central nervous system. But the application of acetyl acid 0,5g iv. should be kept in mind in order to prevent aggregation of thrombocytes.
Also the application of a bladder catheter can be useful to control the urine production, edema of the central nervous system can be prevented by the application of Dexamethason 100 mg iv. The application of catecholamines, antiarrhythmics, anticonvulsivs, analgetics and sedatives has to be decided for each case. For prevention of DCS a respiration with 100% oxygen is recommended by the NASA 4 hours in front of the EVA.

4.1.3.4 Barotrauma

The treatment for the middle ear barotrauma contains the application of decongestive nasal spray (i. e. intranasal Oxymethazolin, oral Pseudoephdrine), antihistaminics and analgetics. In case of otorrhea and perforation of the ear drum an additional medication of antibiotics (Amoxicillin/Clavulan acid 500mg/125mg three times a day or Clindamycin 300mg three times a day) are advised. In the case of inner ear symptoms a haemodilution with intravenous application of plasma expanding fluids in combination with cortisone is advised. In the case of persisting symptoms over a period of days a surgical exploration, including a closure of a perilymphatic fistula, should be discussed. When pulmonal barotrauma occurs the application of 100% oxygen is recommended. Therefore, the partial pressure of the tissue can be guaranteed. In the case of an unconscious cosmonaut an early intubation is necessary to prevent aspiration. In case cardiovascular, pulmonal or neurological complications arise a symptomatic treatment should be done. This includes the application of catecholamines, reanimation or anticonvulsive therapy. For pain therapy the medication with opoids is recommended. For anxiolytic therapy the treatment with benzodiazepines is effective. In severe cases of an emphysema of the mediastinum, pneumothorax or pneumopericard an early surgical intervention should be performed. The mission abortion or retransport has to be decided per case. In the case of retrosternal air in combination with an arterial gas embolism a hyperbaric oxygen treatment should be performed as soon as possible. This can be also performed in the Orlan spacesuit. Because of hypohydration the additional intravenous treatment with fluid solution is advised.

4.1.4 Recommendation for the use of the HPS

The applications of the HPS system in the context of ISS space missions can be seen in the field of telemedical consultations and training purposes.

4.1.4.1 Telemedical consultations

Telemedical consultations currently can only be done on the basis of educational simulation. The model for a cosmonaut in a certain phase in flight can be simulated and compared to real cosmonaut's behaviour. The choice of the model does not depend on the individual cosmonaut, but on the current phase of the space flight and environmental conditions. The model can describe the general behaviour of a cosmonaut in that phase but not exactly the behaviour of the specific cosmonaut.

In the case of a medical problem in space procedures and therapies can be simulated on earth and used for recommendations in space. These simulations refer more to problems that are not extremely critical in time.

Simulation of procedures is possible for a broad range of applications, including feasibility of transports of ventilated patients or changes on patients due to changing environmental constraints like partial pressure of oxygen.

Simulation of therapies would mean that after the diagnosis of the medical, the referring scenario could be loaded on the simulation model and a therapy could be started. The result on the simulated patient then could be used for recommendations for the real problem in space.

As an example a burn injury of a cosmonaut in space could be simulated on earth in the following way: The simulator is started in the appropriate model for the referring phase of flight together with a burn scenario. Then the staff on earth could physically stabilize the patient and start a therapy. The treatment of the simulator is communicated to the crew in space via teleconsultation equipment (e.g. videochannel). The steps of the simulation to treat their real patient can be followed. Due to the described limitations of accuracy of the simulation the communication of the treatment refers more to the methodology and the procedural side of the therapy than to the recommendation of the dose of a drug that was used in the simulated therapy.

4.1.4.2 Training of ISS crews with the simulator

The HPS simulation system is and can be used in various applications for training purposes:

1. Training of technical skills for critical medical situations
   This includes the training of life support algorithms for critical medical situations in space, training in diagnosis of medical problems and their treatment. The simulation can be repeated for teaching purposes and performance can be debriefed through video recording and data produced by the simulation. The performance can be evaluated both on the procedural side as well as in effectiveness of the treatment. The simulated patient can be set-up in mockups of ISS segments or transport vehicles to simulate a realistic environment and to experience the constraints of the environment.

2. Training of non-technical skills of crewmembers in critical medical situations
   Precise communication, spread of workload and building of hierarchies is needed for optimising the performance of a team under stress. Training in a simulated environment facilitates this kind of training. The concept of Crisis Ressource Management can also be applied to medical crisis in space. Similar trainings are

being carried out by a group from the NBSR in corporation with NASA or in terrestrial applications by the Mainz Simulation Center. Training classes based on the cosmonaut models developed in the TEMOS project offer the possibilities to train the crewmembers on a cosmonaut's physiology during specific phases of a spaceflight.

To summarize, the use of the online simulation and the gaining of therapy recommandation has to be studied further as the adaptation of the simulator models to real situation of a cosmonaut is uncertain. The consequence of the inability to perform online consultations currently increases the need of the training of critical incidents and certain medical situations that may happen during flight in real-time and in a realistic environment.
This kind of training can propably only be performed on a full scale simulator.

4.1.5 Recommendations for the rendering of medical aid to the members of ISS crew in emergencies including deorbiting on "Sojuz TMA"

Recommendations for the organisation of the rendering of emergency medical aid

In all emergencies two versions of organisating the rendering of emergency medical aid to the damaged crew member are possible:

1. In an emergency on ISS, allowing the continuance of flight, all emergency help to the damaged crew member is conducted in one of the ISS modules (for these purposes an SM module is represented, where all medical treatment and diagnostic instrumentation and medication is concentrated). Diagnostics and the rendering of the emergency help are conducted in SM ISS on a desktop or on a floor, nearby the "Gamma" equipment, thus the damaged cosmonaut is fixed on a special means.
   All of the emergency diagnostics to control the efficiency therapy are conducted before stabilisation of the cosmonaut. Basic investigations should be transferred to the GMO GOGU (medical support group) and leading clinical experts to decide the recovery and an evacuation of damaged or ill crew member.

2. In an emergency situation requiring immediate transition in the spacecraft "Sojuz TMA" and undocking from ISS, preparation of the damaged or ill crew member and medical aid is performed in the living compartment of "Sojuz TMA" with a consequent transfer to a spacecraft lodgement. The ill crewmember is fixed in the seat on the right without space-suit. The medical aid should be proceeded during deorbiting of the "Sojuz TMA" up to the moment of touchdown.

Recommendations for modified descent module re-entry profile with reduced g-loads

The analysis of the capable maintenance of more comfortable conditions for the crew on an atmospheric section of deorbiting has shown technical feasibility for a solution of the given problem.
It is advised to decrease the g-loads on an atmospheric section of the descent at the expense of trajectory use with smaller atmosphere entrance angle in comparison to the angle in normal mode and also more use of aerodynamic properties of the descent vehicle.
The research on the sparing mode at the descent of the atmospheric segment of the descent vehicle "Sojuz TMA" with manual control and use of a simulator "Pilot-732" in static and dynamic modes have confirmed a capability of the the fullfilment of this mode with minimum g-loads.

For the reduction of g-loads in a mode of automatic controlled descent the range of values of retroburn (96 - 98 m/s) allows for the execution of a more slanting planning of the descent vehicle with entrance angle in the atmosphere of Θ вх. = - 1,3°.
The offered technique of plant determination of the descent control system allows for the execution of the reduction of g-load maximum values on teh descent without changes of instruments and algorithmithm in the descent control system of the transport spacecraft "Sojuz TMA".
It is shown that the reduction of g-loads at sparing descent results in minor increase of the spread of landing points of the descent vehicle (3d = 60 kms.).
In connection with that, on the modification of the transport spacecraft “Sojuz TMA” a new hardware-software is used as a part of the descent control system. The additional research on software engineering in sparing automatic controlled descent mode is neccessary.
The doctor or assisting crew member inspects in time of "sparing" descent the functions of the damaged cosmonaut and renders medical aid developed and adapted for placement in the descent vehicle.

Recommendations for a structure and allocation of additional diagnostic means and rendering of medical aid in the spacecraft "Sojuz TMA"

In an optimal situation, during communication sessions on the Earth the basic parameters of a damaged condition (ECG; PG; SG) are transmitted.
The additional means of diagnostics and rendering should locate the crew member in the left lodgement. He can execute and control the parameters of the critically ill crew member of (place in the right lodgement).
By the selection and development of medical means of rendering assistance it is necessary to take into account the following:

- small volume of the landing module for damaged allocation and instrumentation,
- limitation of the common weight characteristics at deorbiting that introduces essential weight restrictions of medical instrumentation,
- fixed position of the crew members during deorbiting, that introduces limitations in allocation of instrumentation and complicates procedures of rendering medical aid.

The experimental research on the simulation of rendering emergency help at deorbiting conducted in models of the spacecraft "Sojuz TMA" have shown the insufficiency of standard means for the rendering of effective medical aid. Therefore, it is necessary to add modern portable diagnostic and reanimation instrumentation to the means of medical support of the "Sojuz TMA" spacecraft.
These activities have already begun in IBMP and a list of necessary medical means for the rendering of medical aid damaged is recommended as follows:

- apparatus for ALV (artificial lung ventilation),
- system for intravenous infusion of blood substitute and medication,
- portable electrocardiogramm with recording on HD and screen monitor for the control of heart activity by the assisting crew member,
- portable pulse oximeter,
- aspirator for cleansing tracheobronchial tree and fauces
- set of medication for emergency treatment in ready-to-use syringes.

The equipping of the transport spacecraft "Sojuz TMA" with specified components will allow the transport of a critically patient from orbit. According to the document of the requirements of the ISS medical support (ISS Medical Operation Requirements Document MORD, SSP-50260, rev. B, p.4.3.4.5), medical intervention and the treatment should include a capability of stabilisation and transportation of the ill or victim crew member. This item is not yet completely executed, since the conditions for transportation of the critically ill or damaged crew member are absent.

Recommendations for a structure of additional means of diagnostics and rendering of medical aid in SM ISS

In addition of the nominal medical instrumentation available on board the ISS the following on board diagnostic means are recommended:

- portable x-ray vehicle,
- telemedical complex, including instrumentation for otolaryngologic research, ophthalmoscope, dermatoscope, laparoscope, phonendoscope with a set of sound filters,
- portable electrocardiograph with monitor and recording on HD and removable disk,
- portable pulse oximeter.

For the rendering of emergency medical aid a defibrillator with indication of cardioversion and a set of transcutaneous cardiac pacemaker is necessary.

Recommendations for rendering emergency medical aid with the use of telemedical technologies in the post-flight period

Because these issues were not a subject of the given contract but are actual for space medicine, it is recommended to conduct joint activities in the framework of the new projects.

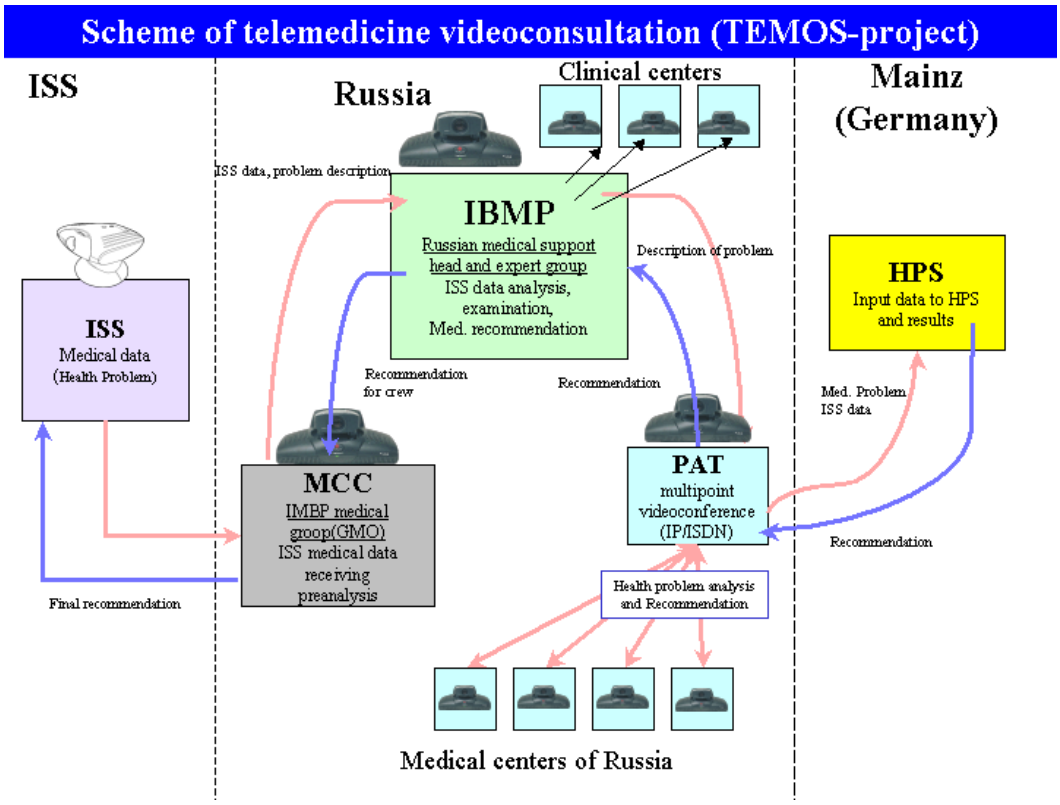


Fig. 79: Telemdical support between ISS, IBMP, PAT, MCC and Mainz

4.1.6 Offers on development of project

4.1.6.1 Offers on the development of a server and client software of mobile workplace to be used on the telemetry information computer system (TICS) MSS:

Basic directions of development

In the context of the development of a server application software solutions for a client workplace are offered as follows:

- the development of the server software, allowing to transfer any telemetering parameters in real time to a mobile client workplace, including an electrocardiogram and pneumogram at EVA stages,
- the development of application software for a mobile workplace, allowing to display and transmit any telemetering parameter in real time as tables or schedules,
- the completion of application software of a mobile workplace for the possible reception of help information of the operating procedure with TMI archive on the basis of the XP 1024 disk file Control centres of flights with use of a WEB-browser on the basis of programming languages HTML and PHP and databases PostgreSQL,
- the completion of application software of a user workplace regarding integration of the telemetering information into program environments,
- the completion of application software under private technical projects of the user (a problem of the analysis, modelling, calculations, etc.).

Completion application software of a server of an exchange

Created software of server exchanges of preliminary processed compleces should provide the interaction with the means of operative processing telemetering information TICS and client workplaces and should carry out the following functions:

- the establishment of communication of client places with the means of preliminary processing TICS,
- the reception of UDP report in real time from the means of the preliminary processing of telemetering ISS information,
- the formation of data parameters on the structure set and transfer of these under TCP/IP report of all measured values on these parameters on client places.

Completion of application software of the removed workplace

The software of the removed workplace will provide:

- the establishment of communication with a exchange server of a preliminary processed TICS complex,
- the reception of streams of the data in real time or a after communication session in a mode from a exchange server of complex of preliminary processing TICS,
- the formation and display of schedules in real time.

Thus, the opportunity to choose the information data card with the certain set of telemetering parameters for their display in real time, constructions of several schedules on one field (screen) simultaneously, and also construction of several schedules of telemetering parameters in one coordinate axis will be given to clients. For the indication of various parameters colour is used.

The use of the created software can be carried out on the following technology:

- before a session of communication the scheduling of all TICS means is carried out,
- on the mobile workplace the choice of the information data card with a set of telemetering parameters, and the number of the workstations for preliminary processing is determined.

Completion of application software for reception of help information

The results will be submitted as complex application software which will give convenient and fast access to the help information on references to the MSS telemetering archive.

The current system for help information provides input, storage and search of the necessary information.

The user access the system with his name and password.

The following opportunities are presented:

- a report of the inquiry on all users,
- the sight of personal inquiries,
- the input of necessary comments of the communication session.

Further improvement of a search service of the system that will allow a quick reception of the information about the most frequently required parameters, sessions of communication, users, etc. is supposed.

Means of the complex

A server application software is established on a server in MSS in TICS structure. The application software of the mobile client workplace is developed in JAVA and can be established on PC or workstation with diverse operational systems (UNIX, LINUX or WINDOWS on various versions).

4.1.6.2 Restrictions of exchange information between the International Space Station ISS and the Mission Control Centre (MCC) upon realisation of telemedical technologies

Restrictions in telecommunication

- Presence or absence of the radiocoverage zones of the ISS by the Earth-based devices,
- Limits of the efficiency of the on board radiodevices of the ISS,
- Limits of the efficiency of the satellite communication channels.
- Limits of the efficiency of the earth-based communication points (includes the one of the ISS and consultative medical centers),
- Radiocoverage restrictions while passing through the plasma-layer at the descent area.

Restrictions of the on board technical equipment

- Restrictions by the composition of the on-board medical equipment,
- Restrictions by technical specifications of the radiochannel between the ISS and the base on Earth (ISS-Earth) including the sufficiency to provide the diagnostics quality of the transmitted video and medical images,
- Restrictions by the skilled level and medical training of the spaceship team to perform recommendations for the MCC.

Final recommendations

The purpose of the project was to provide a contribution to the improvement of operational procedures on board of the ISS and Sojuz TM transfer vehicle, to the enhancement of in-flight telemedical support, to the improvement of crew training and to the optimization of decision-making process by the ground support teams. The emphasis was on a reduction of medical risks associated with the ISS operation.

Technical constraints in implementation of new hardware and procedures were considered wherever applicable. The rationale and more detailed description can be found in the full text. All recommendations will be subject to standard approval and certification procedures and their operational implementation depends on the decision of agencies and institutions involved in the operation of space and ground segments.

The essential TEMOS recommendations include:

- Modification and addition of telemedical equipment in space segments and in ground facilities.
- Specification of protocols for telemedical consultation and data transfer from existing and proposed medical devices.
- Standardization and improvement of telemedical interfaces and procedures including broadband video transmission.
- Definition of operational requirements for telemedical data evaluation.
- Specification of communication structure and protocols between institutions involved in operational support and project participants, including the optional link with the DLR.
- Development, in collaboration with partner institutions, of server and client software with possibility of online access and consultation for operational, scientific and educational purposes (TICS MCC).
- Implementation of safety and encryption standards for ISDN and IP transfer as tested during the project.
- Implementation of standard protocol for data collection and transfer to the Human Patient Simulator (HPS).
- Use of HPS for training purposes by th GCTC, including crisis resource management in simulated in-flight emergencies.
- Use of HPS as an additional tool for decision making support in operational space medicine and in scientific investigations.
- Improvement of Advanced Life Support treatment algorithms on board the ISS and Sojuz TM spacecraft, including the use of added drugs and instrumentation.

- Improvement of existing ISS medical equipment by addition of hardware for Advanced Life Support.

- Addition, to the ISS medical equipment, of diagnostics and monitoring devices, including equipment for endoscopic and other imaging procedures.

- Modifications of procedures related to the provision of emergency medical assistance and stabilisation of critically ill crewmember in the ISS SM and to the preparation for transport in the descent vehicle.

- Specification of additional equipment and procedure definition for accommodation and de-orbiting of critically ill patient in Sojuz TM spacecraft under continuous medical treatment between undocking from the ISS and landing.

- Modification of the Sojuz TM re-entry trajectory in order to achieve reduced and constant g-loads with less adverse effects on de-conditioned crewmembers.

- Modifications of Sojuz TM descent module to accommodate an additional equipment for Advanced Life Support.

- Investigation, in the framework of a follow-up project, of the optimal structure for post-landing telecommunication and medical support in nominal and in emergency situations.

List of abreviations

%	percent
3-5 Gx	effect of accelerate in the line of head-pelvis (value 3-5 units)
4-8 Gx	effect of accelerate in the line of breast-back (value 4-8 units)
5-HT1A	5-hydroxytryptamine-1A-receptor
5-HT2A	5-hydroxytryptamine-2A-receptor
AALS	adult advanced life support
ABPC	automatic blood pressure cuff
ADH	antidiuretic hormone
ALS	advanced life support
ALSP	advanced life support package
ARDS	acute respiratory distress syndrome
Atm	atmosphere pressure
Bpm	beats per minute
CBP	central blood pressure
CBV	circulating blood volume
cc	cubic centimeter
CPR	cardiopulmonary resuscitation
CRV	crew return vehicle
DCS	decompression sickness
DLR	German Space Agency/ Deutsche Luft- und Raumfahrtgesellschaft
DV	deorbiting vehicle
e. g.	exempli gratia
ECG	Electrocardiogram
EchoKG	echocardiography
EDV	end-diastolic volume
EEG	Electroencephalogram
EEG	electroencephalogram
EOG	electrooculogram
ESA	European Space Agency
ESV	end-systolic volume
etc.	et cetera
EVA	Extravehicular Activity
G	gauge
GCTC	Jury Gagarin Cosmonaut Training Center Moscow, Russia
GIT	gastrointestinal tract
GMO	general medical officer
G-load	gravity load
Hg	quicksilver
HPS	Human Patient Simulaltor
HR	heart rate
hr.	hour
i. e.	id est
IBMP	Institue of Biological and Medical Problems, Russia
IEBT	inner ear barotrauma
IP	internet protocol
IPL	incremental physical load
ISDN	digital network with integrated services

ISS	International Space Station
ISU	International Space University, Strasbourg, France
IV	intravenous
IVF	intravenous fluid
Kbit/ Kb	kilobit
KCG	kinetocardiogram
kg	kilogram
kHz	kiloherz
km	kilometer
kPa	kilopascal
LBNP	lower body negative pressure
LCD	liquid crystal display
LSS	life support system
M.	musculus
min.	minute
ml	milliliter
mm	millimeter
MS	Microsoft ®
N2	nitrogen
N/A	not available
NASA	National American Space Agency
NK1	neurkinin 1
O_2	oxygen
PAP	pulmonary artery pressure
PPP	point to point protocol
PS	pressure signal
psi	pounds per square inch
RAAS	renin-angiotensin-aldosterone system
RH	relative humidity
RPG	rheogram
RST	Russian Society of Telemedicine
RV	reentry vehicle
s	second
SG_{fem}	femoral artery sphygmogram
SG_{rad}	radial artery sphygmogram
SMS	space motion sickness
SV	stroke volume
TCP	transfer comunication protocol
TICS	Development of server and client software of removed workplace telemetry information computer system MSS-I
TM	transport module
TO/ TK	tacho-oscillogram
TPG	temporal pulsogram
TR	tissue ratio
UA	unauthorized access
USA	United States of America
USSR	Union of Soviet Socialist Republics
V	voltage
VAP	venoarterial pulsogram
VOR	vestibular ocular reflex
АОП	active orthostatic sign

БК- 5000 м	lifting in pressure chamber on height 5000 м
Вестибул тренир	vestibular training
ВКД	EVA
ВЭ	bicycle ergometer
ГЛ	hydrolaboratory (EVA operation execution)
График 1	(schedule 1) rotation on centrifuge according to schedule of orbital injection of spaceship
График 2	(schedule 2) rotation on centrifuge according to schedule of spaceship landing
МК-5	(Medical Control -5) exercise tolerance test on bicycle ergometer
ОДНТ	negative pressure on lower half of body
ПКУК –	interrupted accumulation of acceleration (Кориолиса)
покой	Research in quiescent state.
ППП- (PPT)	passive postural test
Трен. Гемодин	emodynamic training
Тренировка в ГЛ	training in hydrolaboratory
ЦФ - (CF)	Centrifuge

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