TEPELNÁ ZÁTĚŽ ČLOVĚKA ULOŽENÉHO V TRANSPORTNÍM IZOLAČNÍM PROSTŘEDKU OSOB

HEAT STRAIN OF A PERSON PLACED IN PORTABLE ISOLATION UNIT

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Abstrakt

Transportní izolační prostředky osob (TIPO) jsou ochranné prostředky určené pro izolaci pacientů od vnějšího prostředí při převozu do speciálního zdravotnického zařízení. Jsou nezbytnou součástí vybavení záchranářů, kteří musí poskytnout bezodkladnou zdravotní péči pacientům s rizikem vysoce nebezpečné nákazy nebo kontaminace CBRN látkami. TIPO slouží jak pro převoz kontaminovaných pacientů, tak zejména jako ochrana záchranářů před sekundární kontaminací. TIPO mohou fungovat v režimu přetlaku nebo podtlaku. Mikroklimatické podmínky uvnitř jednotky ovlivňují přenos tepla mezi tělem pacienta a okolím a s tím i související fyziologický stav organismu pacienta. V klimatické komoře SÚJCHBO, v. v. i. byly testovány mikroklimatické podmínky uvnitř různých typů TIPO. Získané výsledky jsou prezentovány formou doporučení pro konstrukci a způsoby použití TIPO.

Klíčová slova: *Transportní izolační prostředek osob, TIPO, vysoce nebezpečné nákazy, mikroklimatické podmínky*

Abstract

Portable isolation units (PIU) are protective means to be used for isolation of patients from the outer environment during their transport to a special medical facility. They are necessary equipment of rescue teams participating at evacuation and urgent care of highly contagious patients or casualties in CBRN event. Their function includes transport of the contamined victims as well as the protection of rescue and medical teams against the secondary contamination. The units are capable to work either in negative or positive pressure mode. The microclimatic conditions inside the unit affect the heat transfer from the patient's body and related physiologic state of the patient. Various microclimatic conditions and victims' physiology response inside the PIU of various construction types were tested. The tests were performed in climatic chambre of SÚJCHBO, v. v. i. The results are discussed and put into recommendations for PIU construction and utilizations.

Key words: *Portable isolation unit, PIU, high contagious infectious disease, microclimatic conditions*

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1. INTRODUCTION

Suspicion of contamination of persons either by highly contagious disease caused *e. q.* by viruses as SARS or Ebola, or by contamination by toxic chemical or radioactive agents, requires immediate medical attention. Besides, an isolation of the patient from the ambient environment is necessary to prevent spreading of the dangerous agent and putting other persons at risk – namely the first responders performing the transport of the patient into a specialized medical facility equipped for providing appropriate medical care, and for the medical staff in this facility. For this purpose the portable isolation units (PIU) are used both for the isolation of the patient from the environment as well as the environment from the patient.

Portable isolation units has to be perfectly tight and it has to be provided with air ventilation combined with high efficiency filters for removing ≥ 99,9995 % particles of 0.3 µm size. Besides the mechanical resistance, the PIU construction has to allow rapid assembly and preparation, easy manipulation in complicated terraine and transport with relevant means including the air transport. The PIU has to enable safe manipulation and medical treatment of the victim inside as well as good visibility to prevent victim's claustrophobia, and easy accessibility to decontaminate the outer and inner surfaces.

PIUs are designed to work either in negative or positive pressure mode:

- PIU in negative pressure filter-ventilation mode is used for isolation of the patient with highly contagious disease and protection of the surrounding from dissemination of the agent. Such PIU can be used also for isolation of the victim being contaminated by dangerous chemical or radioactive agents and prevent the secondary contamination of other persons. The contaminated air generated by the patient is released from a PIU through the HEPA/active charcoal filter powered system.
- PIU in positive pressure filter- ventilation mode is used to protect the patient from the external surrounding – either for immunocompromised or severely burnt patients or in case of need to protect a victim from hazardous environment. External (possibly contaminated) air enters into a PIU through the combined filter powered system.

Figure 1: Examples of PIU

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1.1 Physiologic comfort inside the PIU

The PIUs are designed to provide a controlled containment and comfort environment for the patient. Providing individual isolation and maintaining comfortable or at least bearable conditions inside the unit is a complex concept which takes into account various factors pertaining not only the environmental conditions and physical state of the patient but also sensorial and psychological aspects.

Environmental conditions such as temperature, air humidity and air velocity along with human respiratory and thermoregulatory systems affect the heat exchange between the human body and the surrounding environment. Increase of body temperature above the natural level is a consequence of heat accumulation inside the body. Body temperature exceeding 40–42 °C is a life threating state demanding immediate medical countermeasures. The body needs to emit accumulated heat into the environment by sweating, however, the sweat evaporation depends on microclimatic conditions at the direct surrounding of the body surface. Besides, the physical state of the person posted in isolated space is influenced by production of carbon dioxide and consumption of oxygen.

1.2 Testing of the physiologic response of the persons inside the PIU

There has been a lot of models of PIUs developed in the world and their technical quality and ease of use of the PIU has been usually assessed by the producers as well as during the first responders thematic exercises. Usually, a healthy volunteer is used as a model victim to be placed inside the PIU during the exercises. However, the PIUs are intended namely for isolation of patients with highly contagious diseases including hemorrhagic fevers so we tested the response of the person with elevated body temperature posted into the PIU and the microclimatic conditions inside various PIU to find out how the technical parameters of the PIUs influence the heat exchange and physical state of the patient.

2. EXPERIMENTAL

2.1 Methods

The tests were performed in a climatic chamber of National Institute for NBC Protection, Kamenna, Czech Republic with volunteer probands – men and women.

The elevated body core temperature up to limit 38.5 °C was achieved by physical activity on treadmill while being dressed in underwear and impermeable protective suit complemented with protective mask and NBC canister.

After reaching the limit temperature (or limit of the heart rate, *i. e.* 220–age), the proband was undressed into underwear and placed into PIU and the physiologic parameters (heart rate, body core temperature and skin temperature) were measured.

Figure 2: Test of physiologic response in climatic chamber

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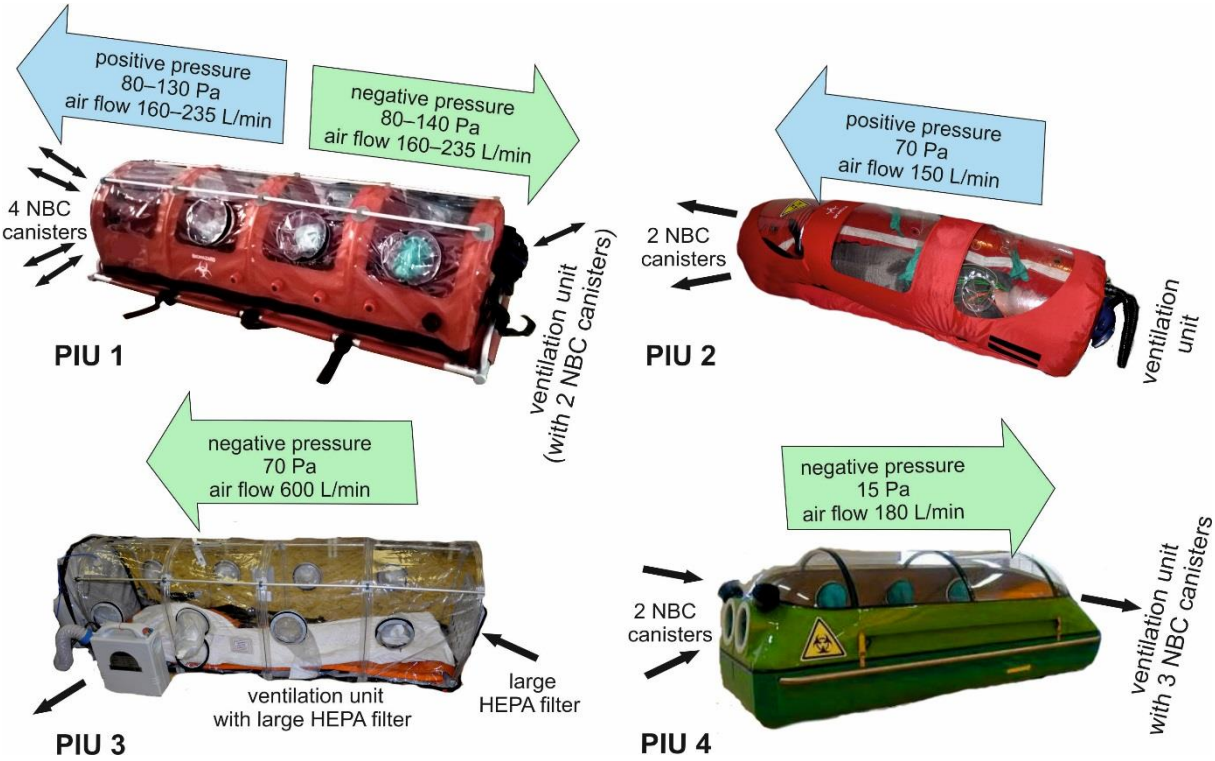
Microclimatic conditions (temperature, rel. humidity and CO_2 concentration) were monitored during the 30–60 min staying inside the tested PIU placed in laboratory in ambient conditions (26 °C and 50–52 % rel. humidity. The tests for each type of PIU were repeated with 3 probands.

2.2 Materials

Four types of PIU were tested as described on the picture below. The types included PIUs in negative as well as in positive pressure mode: PIU 1 is designed to work in positive or in negative mode depending on the mode of the provided ventilation unit. PIU 2 worked only in positive mode and PIU 3 and PIU 4 worked only in negative pressure mode. PIU 1, 2 and 4 and their ventilation units were provided with 2–4 NBC canisters on the entry and exit. PIU 3 was provided with a large-scale filter on the entry and exit.



3. RESULTS

The physiologic response of the body to the thermal strain can be measured and demonstrated using measurement of the body core temperature and the heart rate. As shown on the picture below, the heart rate responses rapidly to the physical activity – it increases during the activity and rapidly decreases during the rest or the stay inside the PIU. The body core temperature increases and decreases slowly and with inertia. Heat output from the body depends on the microclimatic conditions – a body with elevated body temperature needs to transfer the heat and cool due to lower ambient temperature or due to sweat evaporation.

Measurement of the microclimatic conditions in the positive pressure PIU showed that the relative humidity increases up to 100 % almost immediately after closing the proband into the unit, as shown at *Fig. 3*, and the inner surface becomes covered with moisture.

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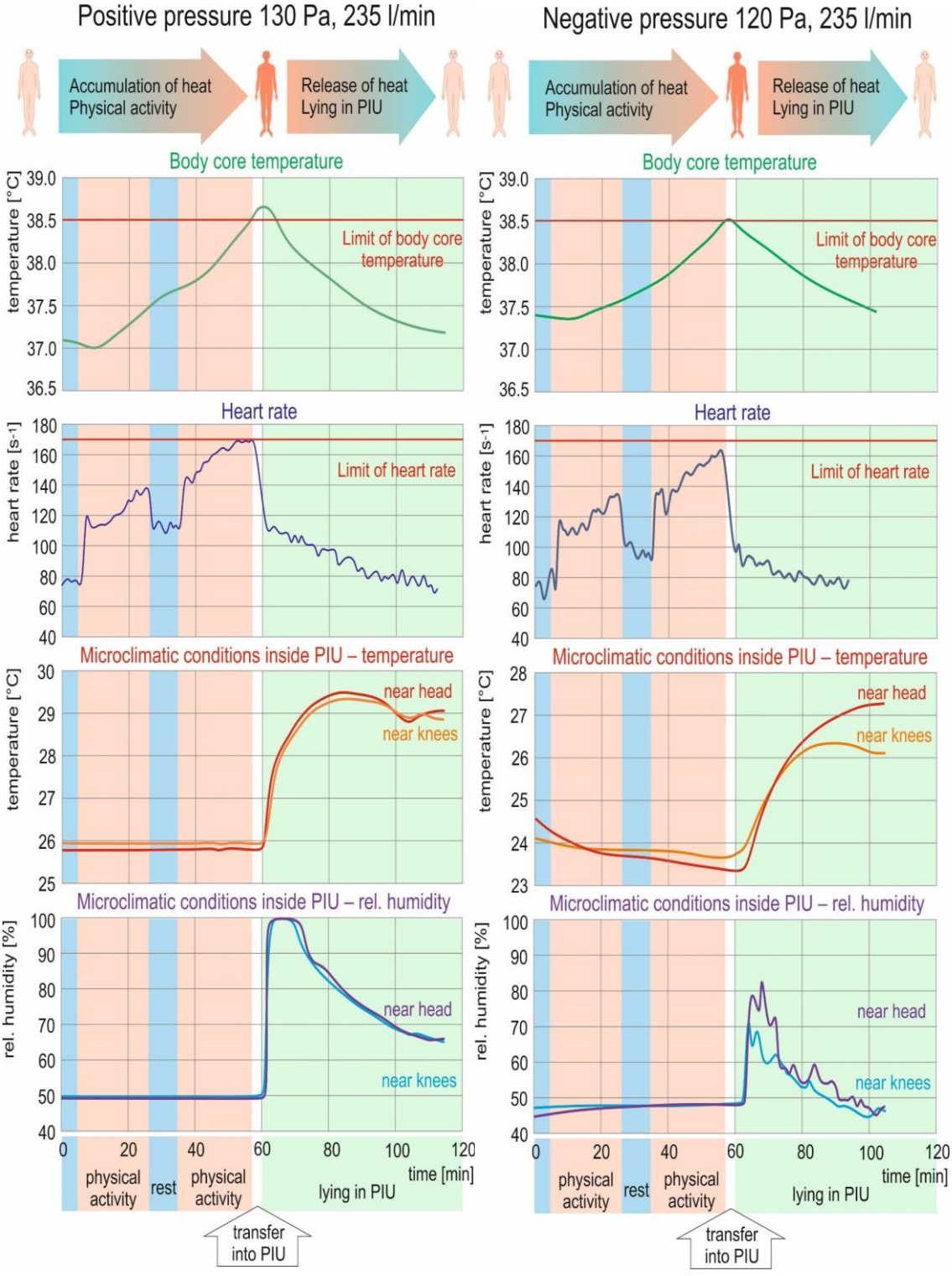

Figure 3: Results of proband's physiologic response and microclimatic conditions in PIU in (a) positive pressure 130Pa, 235 l/min, and (b) negative pressure, 120 Pa, 235 l/min.

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When the ventilation unit is on, the rel. humidity slowly decreases after few minutes depending on the air flow and on the individual evaporation rate of the proband. The microclimatic temperature increases slowly up to balance given by relation between the body heat output and outer climatic conditions. Similar situation is with the PIUs in negative pressure mode, however, the increase of rel. humidity is not so significant – for some probands it even did not reach the level 100 %.

3.1 Body core temperature

Regarding the decrease of the pobands' body core temperature demonstrating the cooling ability of the body exposed to various microclimatic conditions in various PIUs we compared average values for several probands in each type of the PIU, as shown at *Fig. 4*.

The results show that there were not any significant differences between the PIUs in negative pressure mode.

However, the positive pressure PIU 2 with low air flow rate (150 L/min) was unable to change the air volume sufficiently, the rel. humidity was at 100 % level for more than 20 minutes which was manifested by inability of the body to cool and the body core temperature almost did not decrease. The inside of the PIU 2 was covered with moisture which condensed and the proband was extremely wet at the end.

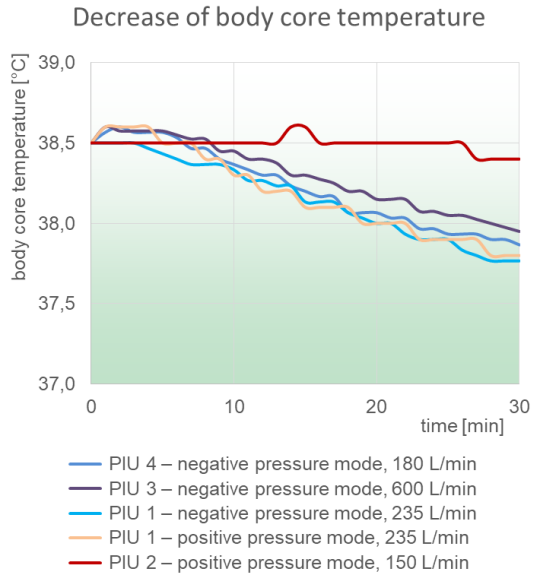

Figure 4: Decrease of body core temperature

Figure 5: Rapid increase of moisture up to 100 % rel. hum. caused that the proband was all wet after 20 minutes.

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3.2 Skin temperature

Regarding the cooling of skin at various parts of the body, the back is the part of the body which is almost not cooling at all. Most of the PIUs are provided with isolation mat which is extremely important as in most cases the proband‘s back is wet and more sensitive to conductive heat transfer. The skin temperatures showed that the position of the ventilation unit and the positive/negative pressure mode affects the part of the body which would be cooled the most rapidly. In PIU 1 setting for positive pressure mode, the fresh air entries the PIU above the proband‘s head and the skin temperature decreases mostly at the upper part of the body (chest and arm) whereas in PIU 1 setting for negative pressure mode, the fresh air entries near feet and moves from the lower part of the body (calf and leg) to the other parts of the body, as demonstrated on figure 6.

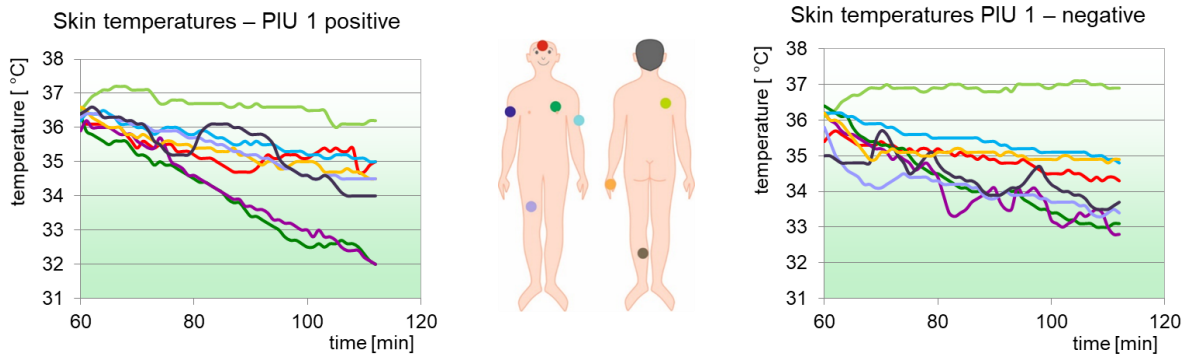

Figure 6: Skin temperature data of probands lying in PIU in positive or negative mode.

3.3 CO_2 concentration

The CO_2 concentration was measured after placing the proband into the PIU 1 in positive and negative mode with the ventilation unit turned on the minimum and maximum its air flow rate (160 L/min and 235 L/min, respectively).

The concentration of CO_2 increased rapidly over 2000 ppm immediately after closing the proband into the PIU while the ventilation units were working. Within 3–5 minutes the CO_2 concentration decreased below 1500 ppm except of the PIU in positive pressure mode with the air flow rate 160 L/min. The concentration of CO_2 above 1500 ppm may cause sleepiness, fatigue and dizziness.

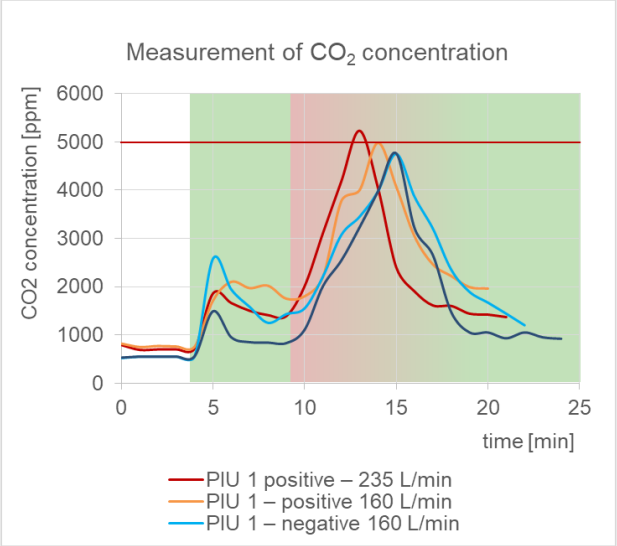

Figure 7: Measurement of CO_2 concentration inside PIU

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In case the ventilation unit was turned off (represented in the figure as pink area starting at minute 9), the CO_2 concentration in 3–5 minutes gets up to PEL 5000 ppm (permissible exposure limit), as shown on Figure 7.

Then the ventilation was turned on again and higher CO_2 concentrations were not tested in this tests, though, it has to be expected, that the CO_2 concetration would increase further.

4. CONCLUSION

Testing of the microclimatic conditions in various types of PIUs with probands with elevated body core temperature as simulation of real PIU usage showed that regarding the physiologic and thermal comfort, the most critical issue is the parameters and position of the ventilation unit.

The patient transported in the PIU needs to exchange heat with the environment and if the microclimatic conditions do not enable such an exchange, the body core temperature may arise above acceptable limits. As long as the ambient temperature is above 25 °C and the inner space of PIU gets covered with moisture, the service staff should be aware that the patient may get overheated after some time even when the ventilation unit is working. The higher the ambient temperature is, the higher is the risk of patient‘s overheating, especially when using the PIU on direct sunlight.

The PIUs working in positive pressure mode pose slightly higher risk of the overheating than the PIUs working in negative pressure mode, supposing that other design features of the PIUs are comparable.

It should be mentioned that the probands‘ subjective feeling was strongly affected of the position of the fresh air entry into the PIU. The entry of the fresh air should be near head. The fresh air flows around face and makes the breathing much easier. As measured, the temperature, humidity and CO2 concentration may arise above bearable limits in first few minutes after closing the patient into the PIU. In one case, where the entry of the fresh air was located near feet (PIU in negative pressure mode with the ventilation unit located above head) the proband had to get out of the PIU as he was not able to breathe, lying the opposite direction did not evoke such problem. The setting of PIU in negative pressure mode with ventilation unit above head is hazardous for another reason also – the air flows from feet to head and in case of placing a patient contaminated with dangerous chemical or radioactive material into such PIU, the patient breathe the contaminant releasing from the whole body surface.

The PIU service staff should be aware, that turning the ventilation unit off may harm the patient within few minutes due to rapid increase of the CO_2. Such situation may happen in case the ventilation unit battery gets low or during the PIU decontamination process when some time interval while the ventilation unit off is needed for disinfection agent action.

The PIUs have become usual equipment of biohazard teams and hospitals in many EU countries. They should be used for evacuation of every patient suspicious for any kind of highly contagious disease as hemorrhagic fevers, tuberculosis, measles, SARS, MERS and many others. They are

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used in real situations and often also during the first responders thematic exercises. PIU are designed to protect the rescue teams and medical staff from deadly infection, however staying in such means (what may take even several hours in real situation) should not pose a health threat neither for the contagious patients nor for the patients with unconfirmed diagnosis nor for probands subsumed in thematic exercises.

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