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Research Paper

Insulated Patient Transport Capsule for Chemical, Biological, Radiological and Nuclear (CBRN) Contamination Cases

Ferit İşbilir, M. Fahri Kaynak*, M. A. Alparslan Kesemen

Ems Mobile Systems Inc. Ankara, 06935, Turkey

Abstract

CBRN is used as an abbreviation for the chemical, biological, radiological and nuclear word group. In general, this term refers to hazardous and dangerous situations that are caused by chemical, nuclear, biological and radioactive materials which can be spread intentionally or accidentally causing harm to humans and the environment. Developments in technology, disasters, accidents, war or terrorist events all enhance the risk of CBRN at the present time. These risks can cause situations that can directly threaten the lives of large amounts of people and cause many people to lose their lives or can result in significant life changes for people affected. CBRN risky events cause panic and disorder in society. Most importantly, people who interfere in these events are at great risk like people who are exposed. In this study, working principle, functions and capsule analysis and tests of the insulated patient transport capsule, developed in order to protect both the environment and the interveners in CBRN events were examined. If we think about our country's geopolitical position or regional geography, an isolated patient transportation capsule is a critical life-saving product both at military and civil level. The negative pressure, generated in the capsule protects the environment and interferers from CBRN contamination. It provides treatment and an emergency response opportunity with protective gloves and sealed ports for serum on the capsule as well. The isolated patient transport capsule can be placed on the stretcher with connection apparatus and easily transported.

Keywords: CBRN, Insulated patient transport, Capsule

INTRODUCTION

CBRN is used as an abbreviation for the chemical, biological, radiological and nuclear word group. In general, this term refers to hazardous and dangerous situations that are caused by chemical, nuclear, biological and radioactive materials which can be spread intentionally or accidentally causing harm to humans and the environment (1). CBRN events are undesirable, and when they are experienced they are very difficult events which have a big impact. These events cause panic and disturbance. For example; Ebola outbreak occurred in 2014 and it caused a serious panic in Turkey and all the World. The intervention in these events is difficult and time-consuming because the interventionist is at risk and there is a possibility of transmission of CBRN substances. For this reason, personal protective equipment is required for the handling of these materials.

The Ministry of Health published the Ebola Virus Disease Case Management Guide in 2015 which contained information on the detection, control and treatment of the disease. Underneath the emergency service approach algorithm title, the issue was mentioned about the transfer of the patient and how to intervene in emergency situations. During the transport of such patients, the equipment to be available in ambulances is listed. These equipment's includes gloves (double gloves), liquid impermeable apron, liquid impermeable overalls, safety glasses, face shield / shield, protective headgear-hat (no headgear cap), N95 / FFP3 mask, waterproof foot protector and alcohol-based hand sanitizer (2). As it can be seen, each of the events of CBRN is a heavy burden on health services. It is necessary to be prepared as well. It is essential for our country to be prepared for risky events which are possible due to its geopolitical position and the events in the surrounding geographies. By isolating the patient, the risk of exposure to the environment will be prevented during transport. Transport of the exposed person to the health center will be easy and safe. At the same time, with the use of the insulated patient transport capsule, personal protective equipment will be used at minimum level.

In this study on the insulated patient transport capsule,

*Corresponding authour
Email: fkaynak@ems.tc

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considerations regarding the design of the capsule and the design considerations, the filtering system, the functions of the negative and positive pressure in the capsule and how to generate it, the air flow dynamics in the capsule and the tests to be applied to the capsule are included.

1. General Information About CBRN

CBRN refers to hazardous and dangerous situations that are caused by chemical, nuclear, biological and radioactive materials which spreading to intentional or accidental ways for the humans and the environment (Ebola Vaka Yönetim Rehberi, 2015).

CBRN events are undesirable, but when they are experienced they are very difficult events and impacts. In order to minimize and control the effects of these events, it is necessary to know what the terms are related to CBRN.

1.1. Terms Related To CBRN

Chemical Threat: In industrial applications, chemical substances are used as raw materials or intermediates, and in domestic use, cleaning or daily maintenance is widely used. In parallel with the development of the chemical industry, the usage of these substances is increasing day by day. This increase brings with it some threats. Accidents occurring in organized industrial zones and producing, processing or storing chemicals will affect people and the environment negatively.

In recent years, it has been discovered that these substances can be used to harm specific targets as a result of the studies on waste chemicals. Increasing the effects of waste chemicals by changing their structures has caused these substances to become potential weapons. Hence, chemicals have been used in terrorist acts and wars (3).

Biological Threat: Biological threats; all of the threats consist of conditions such as biological agents and unsafe laboratory procedures. This definition; natural biological diseases (non-infectious and non-infectious), environment or animals identified, biological agents that are likely to infect humans, biological agents that contain or emit biological weapons (biological weapons), the terrorist attacks with biological agents (bioterrorism) (4).

Radiological Threat: Radiological events are events in which the public is exposed to radiation or radioactive material for certain reasons. Transport of radiation sources and their use in applications, lost and stolen resources, possible sources of scrap, fire with hardware and planning errors, disasters such as earthquakes can cause radiological events (5).

Nuclear Threat: Used to both benefit from the occurred energy of fragmentation (fission) of nuclear materials (uranium, plutonium, etc.) or the combination of two atoms(-fusion) expresses the destructive pressure wave, lethal radiation, and high heat. A nuclear explosion; is an explosion which occurs a strong light, a wave of heat and pressure show up and the propagation of radioactive substances that contaminate air, water and surfaces (6).

Contamination: CBRN is the transmission of substances to personnel, land, materials, equipment and foodstuffs (7).

Decontamination: It is the process of removing the chemical substance from all contaminated by specially trained people using special equipment and solutions (7).

1.2 National and International Organizations Related to CBRN

As international organizations on the subject of CBRN, International Atomic Energy Agency (UAEA), International Radiation Protection Committee (ICRP), European Atomic Energy Community (Euratom), European Center for Nuclear Research (CERN), Nuclear Suppliers Group (NTG) and Zangger Committee are actives.

Regarding the issue of CBRN and the control and intervention of CBRN events in our country, Turkey Atomic Energy Agency (TAEK), Turkish Armed Forces, Public Health Presidency, Disaster and Emergency Management Presidency, Turkish Red Crescent and Organizations such as the National Poison Center (UZEM) are operating (8).

1.3 Events Related to CBRN

There have been many events in history related to the subject of CBRN. Many people have lost their lives in these events. In fact, in the long term after the events have been found to have consequences that will affect human life. There have been many incidents for each threat identified in Article 1.1. Some of the recent events are given below.

The chemical weapons attacks in Syria in August 2013 caused the deaths of more than 1000 people, including women and children. (Chemical)

In the United States in the weeks following the September 11 attacks, anthrax mail sent to different institutions caused 22 people to be infected in total and 5 people died (Biological)

In 2011, after the magnitude 9 earthquake in Töhoku and the tsunami in Japan, to an accident at a nuclear power plant in the Fukushima area caused a large amount of radiation. (Radiological)

In 1986, a large amount of radioactivity leaked into the environment due to an accident in a nuclear power reactor in the Chernobyl region of Ukraine. (Nuclear) (9).

2. Insulated Patient Transport Capsule

The insulated patient transport capsule, an area contaminated with CBRN agents, primarily affects people of these substances leads to transfer to the center where they are treated, is a mobile patient transport capsule.

This capsule also has features for the user to provide a safe medical intervention to the person in the capsule by means of the ports on it. In addition, the capsule can be placed on the stretchers in the ambulances by means of the connection

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apparatuses on it so that they can be carried easily. It can provide safe transportation with plane, ship and any vehicle independent stretcher. The solid structure which provides isolation in the capsule is resistant to bad fact such as falling and impact. It allows up to 120 kg. The design of the capsule, filtering and pressure generation system, analysis in capsules and tests are explained in the sub-headings.

2.1. Design of The Insulated Patient Transport Capsule

During the design process, The personnel who will use the capsule and the situation of persons exposed to CBRN that will be in the capsule are taken into consideration. Consultations with persons who have knowledge about CBRN and who have worked in this field previously (AFAD and TSK officials) have introduced the requirements.

CBRN disaster is almost most frightning incident in the World. The people who affect to cbrn agent, are shock and feeling insecure. These factors are most important to design process for us.

In the design of the capsule, it is aimed to instill the psychology of the people in the capsule in a safe place and to heal. Hence the design is shaped around trust, protectionist and color keywords.

We predict The people who affect CBRN agents have a problem with trust. Therefore, we choose first and main keyword as trust. It is emphasized that the human psychology and design can be handled both and we decided to abstract design to factor commanly.

It is aimed to make people feel more secure and to feel that they are in a sheltered place.

One of the most important considerations in the design has been the colors. Each color has a different characteristic and each color causes different emotions in human perception. Which colors to use when starting design is also an important element. Research shows that colors affect the psychology of people. For example; according to research yellow colors gives a sense of temporality. Blue and shades are used in design by considering this principle. According to research blue and shades indicate calmness (10). In other words, blue is a calming color, and even in some European countries, the bridge railings are painted blue to reduce suicides due to the calming effect of blue. In addition, according to research, the blue color represents trust and the purity of blue gives a protectionist psychological effect. In this context, R-171, G-236, B-255 color codes are used.

Considering the human psychology within the capsule, it is decided to use simpler and softer lines instead of the lines that would be perceived by the human eye as complex in design. In the same way, it is paid attention to symmetry in order to make people in the capsule feel safe.

In the design of the capsule, care was taken to ensure that the person within the capsule had the field of vision. People feel more confident in what they see. For example, people would rather travel in the place where they can see every place instead of traveling in an enclosed space. This situation reveals confidently and controlled perception in the subconscious of people. Considering this aspect of the design, attention was also paid to the issue of refreshment, especially considering that the capsule could be perceived as a coffin.

Fans generate negative and positive pressure in the capsule are designed as far from the people in the capsule as possible to minimize the damaging potential of patients who have difficulty in self-control.

The designed capsule is mainly composed of components in Figure-1.

Figure 2 shows the three-dimensional view of the capsule from different perspectives.

Figure 3 shows a picture describing the using of the capsule.

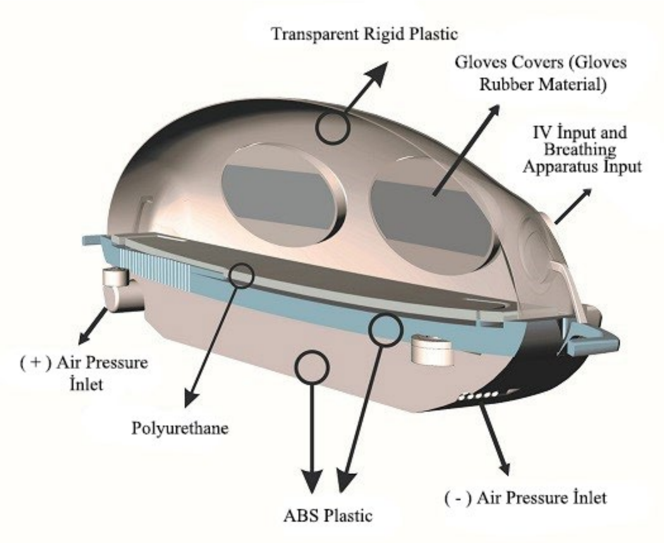

Figure 1- Basic components of the insulated patient transport capsule

Figure 2- 3D design of the insulated patient transport capsule

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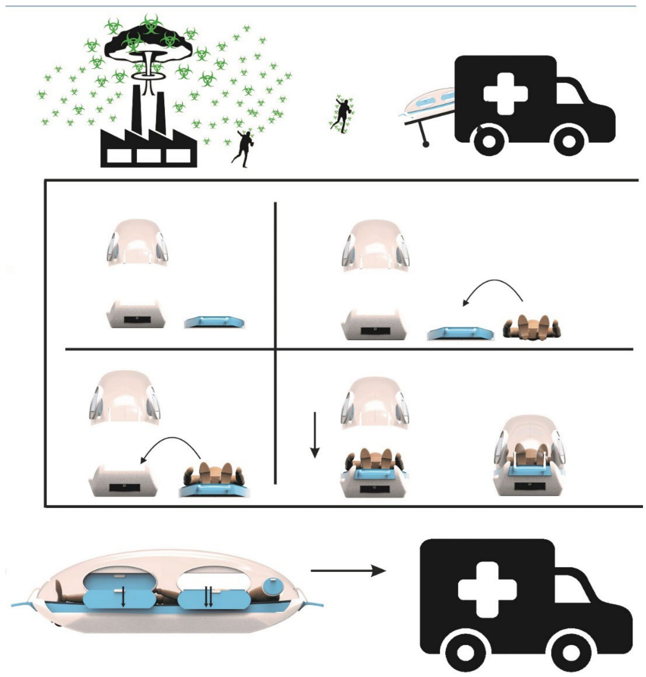

Figure 3-Use of the insulated patient transport capsule

As can be seen from Figure 3, there are caps on the capsule that provide intervention to the patient. With the help of protective gloves that are ready in these caps, to the patient is intervened when necessary. These covers are designed to provide sealing.

In addition, when the capsule is used in conjunction with the stretcher, areas, where medical devices such as ventilators and defibrillators can be mounted in vital situations were also designed.

2.2. Working Method of Isolated Patient Transport Capsule

Negative and positive pressure can be generated depending on the conditions inside of the insulated patient transport capsule. When negative pressure is generated inside of the capsule, as shown in Figure-4, the contaminated air because of the person who exposed to CBRN cleaned by the help of filters discharges outside of the capsule and protects the environment.

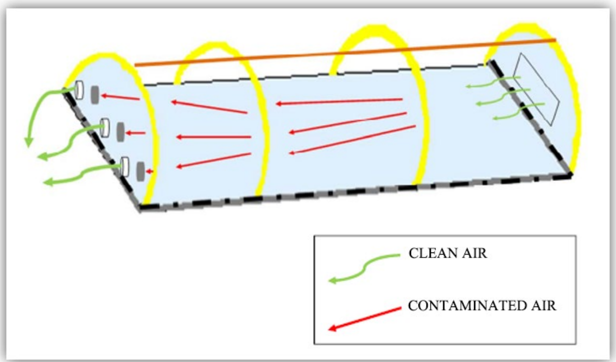

Figure 4- Working principle of the capsule with negative pressure

The pressure inside of the capsule is carried out by the help of two fans. One of these fans is generated positive and the other is negative. Positive pressure works like intensive care logic of hospitals for protects the patient from the external environment. Each one of fans has a separate control unit and the fans can control by the help of these units. The pipe and valve system coming out of the fans pass through the filters and generate pressure inside of the capsule.

The negative or positive pressure values in the capsule can be up to 30 Pascal and these values can be adjusted via the control unit.

The fan system can operate nonstop for 3 hours through to the designed power system and this power system is fully charged for a period of 5 hours.

the HEPA filter system and the ventilation system that clean the contaminated air are found in the capsule. The design of these filters is designed according to the ports formed on the capsule and is in the form of cylindrical.

Laboratories which studies microorganism are carried out are classified as 4 levels according to danger situations. Laboratories which studied on the spreading of avian influenza in aerosol form and microorganisms such as sars and anthrax are defined as BSL3 levels at the High-risk. at the BSL3 clean rooms should be the ventilation system that is single pass recirculation according to TS 11605. The discharged air is cleaned by high-efficiency HEPA filters.

There are pressure, temperature and humidity indicators on the capsule, to inform about the inside of the capsule to the user, who is using the isolated patient transport capsule. With the help of these indicators, the person who is in the capsule can be monitored and taken measures for the necessary situations.

2.3. Analyses of Isolated Patient Transport Capsule

In the insulated patient transport capsule, it is a technical obligation that the interior space is small and that the protective gloves are in the direction of the targeted air flow corridor.

As the HEPA filter efficiency is directly related to geometrical sizing, the geometric design of the capsule was first performed. The 3D model designed in Solidworks was checked for their suitability by testing by selecting HEPA filters which provide the desired parameters at the end of the geometric design.

Hygienic minimum fresh air flow rate in hospitals, at the intensive care unit (for patients with infection and transport hazard) is determined as 30 m^3 / hour. Although the volume in the capsule is not as much as an intensive care unit, this criterion is taken as reference for the purpose of maximizing efficiency. The internal volume of the capsule is 0.58 m^3 and it is considered as 1 m^3 in calculations and fan selection. In this case, an air flow rate of 30 m^3 was calculated to need in the capsule.

In the insulated patient transport capsule, air flow in the capsule was modeled using computational fluid dynamics (CFD) technique to determine the presence of stagnant zo-

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nes without air flow. ANSYS software was used to carry out this technique. ANSYS is a general-purpose software, used to simulate interactions, physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. The air flow distribution into the capsule was analyzed in the turbulent flow conditions. The time-dependent continuity and momentum equations for analysis were solved. Turbulent flow is defined by the k-ε model. Finite volumes method is used in numerical solution of flow equations. In the analysis, a digital network consisting of approximately 1.5 million triangular pyramid elements was used. The boundary conditions of geometry have been chosen to represent the physical structure and flow dynamics of the capsule in a realistic manner. The geometry of the insulated patient transport capsule was modeled to partially simplified in order to keep the calculation cost of flow analysis reasonable.

After modeling, analyzes were started. The flow distribution around the inlet from the fans through the pipe is given in Figure-5. There are relatively high speeds at near the pipe inlet is mentioned.

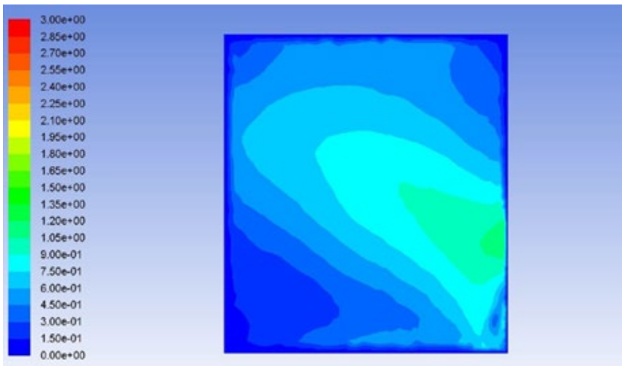

Figure 5 - Flow Distribution (Space Around the Pipe Entry)

In the capsule, flow rates were generally observed to be over 0.2 m / s. As seen in Figure-6 shows, there is no any a stagnant region of air flow.

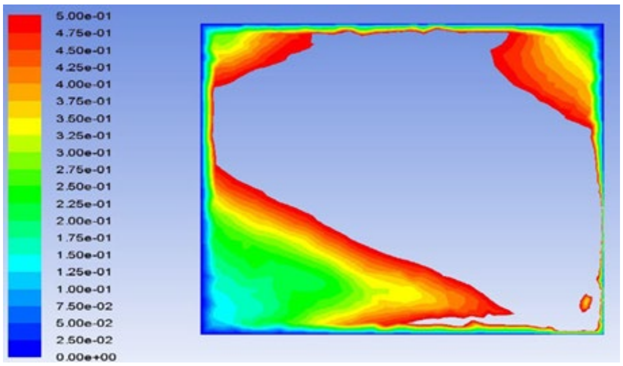

Figure 6- General air flow distributions in the capsule

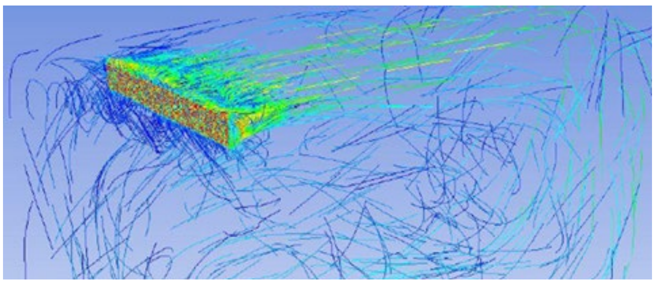

Figure 7- Velocity flow lines in the capsule

In Figure-7, the velocity flow lines are shown as a result of the CFD analysis of the capsule.

As a result of CFD analysis, it was found that there was generally no stagnant area in the capsule and the air flow was efficient.

2.4. Tests Applied to Isolated Patient Transport Capsule

In the insulated patient transport capsule, the following tests were carried out to check the operation of the system as well as to verify the studies such as design and analysis.

2.4.1. HEPA Filter Impermeability Test (IEST-RP-CC034.2: 2005)

In the HEPA filter system contained in the capsule, two 100x100 mm / H 13 HEPA filters were tested with PAO (suppressed aerosol smoke generated by heat evaporation of mineral oils). The HEPA filter and the permeability test of the HEPA filters nests have been successfully completed.

2.4.2. Air Flow and Flow Measurement

The purpose of this test is to understand that the performance of the fan system in the insulated patient transport capsule does not deviate from the desired performance values due to HEPA filters and pressure changes. Therefore, the total number of air changes in the test was calculated. As an evaluation criterion EU / GMP Volume 4 Annex: 1 2008 CGMP / FDA-Din 1946/4: 2008 is taken as reference and the measurement results are in accordance with TS EN ISO 14644/1 ISO 5 class and the results are given in Table 1.

Table *1- Air Flow and Flow Measurement*

ROOM	AMOUNT OF THE AIR SUPPLIED (m^3/h)	AMOUNT OF THE FRESH AIR (m^3/h)	AIR EXCHANGE NUMBER (times/h)	ACCEPTABİLİTY CRITERIA (times/h)	RESULT
Fans	36	0	35	30	Ok
Hepa Filter-1	15	15	5	3	Ok
Hepa Filter-2	15	15	5	3	Ok

2.4.3. Difference Pressure Measurement and Air Flow Aspects

Pressure difference and air flow direction in the insulated patient transport capsule measured according to IEST-RP-CC012.2 and EU / GMP Volume 4 Annex: 1 2008 as well as the religion standards 1946/4: 2008.

The air flow directions (for negative pressure condition) should be from the outside air to inside the capsule. This is because the dirty air caused by the person with the CBRN element does not go out of the capsule. The septic (BSL-4) areas related to the pressure flow directions will be inward negative.

Table *2 - Difference pressure measurement results*

Name of the Room	Air Flow Direction	Room Class	Compare of Field	Measured Pressure	Acceptability Crıterıa	Result
Insulated patient transport capsule	Left to right	BSL-4	External Environment	-34 Pascal	Greater than (-30) Pascal (Absolute Value)	Ok

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The measurements are given in Table 2 and the results are appropriate.

2.4.4. Particle Count and Room Classification

At the measurement points, the 95% upper-reliability limitation at the clean room, counting of the particles have done according to ISO 14644-1 and EU/GMP Volume 4 Annex:1 2008.

The measurement results are in accordance with the TS EN ISO 14644/1 ISO 5 criteria. ISO 5 class particle numbers were determined in 7.3 in the article. Measurements and results are given in Table 3.

Table *3*- Particle counting and measurements of isolated patient transport capsule

Name of Room	Total Particle Counting Point	GÜS (UCL) % 95 0,3 mm/CM	GÜS (UCL) % 95 0,3 mm/CM	Conditions	Result
Insulated Patient Transport Capsule	3	6,559	1,706	No patient	Ok
		Average	Average	At Rest	

2.4.5. Decontamination Time Tests

At the measurement points, the 95% upper-reliability limitation at the clean room, counting of the particles have done according to ISO 14644-1 and EU/GMP Volume 4 Annex:1 2008. The measurements were evaluated according to the decontamination time. The duration of decontamination is the time to decrease to the level of ISO Class 5 after polluting the air in the insulated patient transport capsule.

The measurement results are in accordance with TS EN ISO 14644/1 ISO 5 class. ISO 5 class features were determined in 7.3 in the standart.

3. Findings and Discussion

The following conclusions are given below about to researches about the methods used for the intervention of the CBRN events and the transfer of the people exposed to these events to the related centers.

A scientific publication in the United States deals with the emergency aid process for an Ebola patient. In this study, all the surfaces in the ambulance, including medical devices in the ambulance, were covered with a 6 mm thick plastic film during the patient's transplantation. Similarly, ''the named Prevention and Decontamination of Chemical, Biological, Radiological and Nuclear Pollutants for Emergency Medical Personnel During Ambulance Services" published in South Korea was taken into consideration and all surfaces of ambulance were covered with plastic film (11). With this application, it is aimed to protect those who intervene in CBRN events. In this article, don't need to cover the ambulance with the plastic film while an insulated patient carrying capsule is using. The capsule can generate negative pressure as a method of working and consequently the environment and the interveners are protected. Moreover, the impermeable ports on the capsule also allow emergency intervention to the person exposed to CBRN.

There are some patient transport cabins developed around the world to be used in CBRN events. The common feature in these cabins, including the products of the companies that sell these products as distributors in our country, is the material used for isolation tent format. Insulated patient carrying capsule provides isolation with solid plastic. Tent type material has lightness, foldability aspects advantageous. It is also at great risk in terms of deformation and tearing conditions. In case of a possible tearing, the isolation function will be disabled, and the environment and those who intervene will be at great risk. Also, the tent format is less likely to protect the patient in cases such as falls. For isolation in the insulated patient carrying capsule, the use of a solid material is very safe both in terms of deformation and fall.

Conclusion And Recommendations

CBRN events are undesirable, but when they are experienced they are very difficult events and impacts. These events cause panic and disorder. For example; The Chernobyl Incident that took place in 1986 affected almost all of the Black Sea region in our country. Intervention in CBRN events is difficult and time consuming. Because the first responder is at risk and there is a possibility of transmission of CBRN substances. For this reason, personal protective equipment requires the use of materials.

The insulated patient transport capsule provides rapid intervention to those exposed to the CBRN risk events, ensuring that the interveners are exposed to the same risk at the minimum level. Thanks to the isolation, the risk of exposure is prevented from spreading to the environment during transportation and the transport of the exposed person to the health center becomes easy and safe. The insulated patient carrying capsule and personal protective equipment are used at a minimum level, and as described in the findings and discussion section, ambulances that do not require special equipment arise.

In this study on the insulated patient transport capsule, the design of the capsule and the considerations in the design, the filtering system, the functions of the negative and positive pressure in the capsule and how to generate them, the air flow dynamics in the capsule and the tests applied to the capsule were examined. The capsule successfully completed the tests. The CBRN is also looking for people who are exposed to CBRN and hospitals.

The insulated patient carrying capsule is designed to be compatible with the manufacturer's existing stretchers used in ambulances. Developing the connection adapters, which will enable the capsule to work in harmony with other stretcher groups, will promote the use of the capsule, CBRN events will be more effective.

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