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# Rescue Blankets-Transmission and Reflectivity of Electromagnetic Radiation

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**Abstract:** Rescue blankets are medical devices made of a polyethylene terephthalate sheet coated with a thin aluminum layer. Blankets are used for protection against hypothermia in prehospital emergency medicine and outdoor sports, but totally different qualities are typical for these multi-functional tools. On the one hand, rescue sheets prevent hypothermia by reducing thermo-convection and diminishing heat loss from evaporation and thermal radiation. On the other hand, the sheets promote cooling by acting as a radiant barrier, by providing shade and even by increasing heat conduction when the sheet is in direct contact with the skin. As foils are watertight and windproof, they can function as vapor barriers and even as stopgap bivouac sacks. We evaluated three experimental studies, one on heat loss by rescue blankets according to surface color, one on transparency with ultraviolet radiation, high-energy visible light and visible light, and one on infrared radiation from rescue blankets. When evaluating the effects of different bands of the electromagnetic spectrum on rescue sheets, we focused on ultraviolet radiation (200–380 nm), high-energy visible light in the violet/blue band (380–450 nm), visible light (380–760 nm) and infrared radiation (7500–13,500 nm). Rescue sheets transmit between 1% and 8% of visible light and about 1% of ultraviolet B radiation (280–315 nm), providing sufficient transparency and adequate protection from snow blindness. Reflection of visible light increases detectability in search and rescue missions performed in good visibility conditions, while reflection of infrared radiation increases detectability in poor visibility conditions and provides protection against hypothermia.

**Keywords:** emergency medicine; far infrared; hypothermia; insulation; rescue work; rescue blanket; space blanket; survival blanket

## 1. Introduction

Rescue blankets are medical devices with a characteristic silver and gold surface on either side that are used for protection against hypothermia by emergency medical services (EMS) and by sportsmen in outdoor activities. Accidental hypothermia, defined as a core body temperature of less than 35 °C, is more frequently observed during the winter season, but it occurs throughout the year, even in geographic regions with hot climate [1]. There is a risk of hypothermia whenever the ability to control body temperature through the nervous system, metabolism, circulation and muscle activity is insufficient to compensate for heat loss due to the emission, conduction and convection of infrared (IR) radiation. Both clothing and absorption of infrared radiation reflected by the environment help balance heat loss. Beside acidosis and coagulopathy, hypothermia is one of three life-threatening conditions that constitute a lethal triad in emergency patients [2]. The decrease in core temperature goes along with impaired organ function, clotting disorders and increased mortality.

Hypothermia prevention is important in prehospital treatments involving the external rewarming techniques employed by EMS [3]. When comparing different conventional blankets, e.g., space blankets, bubble wrap, blizzard blankets, ambulance blankets and ready heat blankets, Zasa et al. observed that all tested tools significantly reduced heat loss but could not completely compensate for the temperature deficit [4]. Contrarily, Leung et al. observed an increase in skin temperature of approximately 1 °C, when measured with a thermal camera aimed at a forearm wrapped in a rescue blanket [5]. Allen et al. performed an experimental study on a fluid torso model and observed diminished temperature loss when applying passive warming devices such as space blankets [6]. The authors reported that comparison of medical devices providing either active or passive rewarming did not find striking differences between the two methods [6]. Rescue blankets achieved a heat loss of less than 1 °C within 60 min and less than 2 °C within 120 min. An increase in body temperature was observed only in shivering patients with mild hypothermia. In fact, shivering heat production is crucial for thermoregulation during cold-exposure [7]. Haverkamp et al. confirmed that in the prehospital setting patients can be protected from excessive heat loss by rescue blankets, but cannot be rewarmed [8]. However, the fact that passive hypothermia-prevention devices function independently of electricity means they are especially suitable in remote areas [6]. Rescue blankets act as a vapor barrier and limit the need for shivering thermogenesis [8]. Protection from heat loss was especially efficient when the rescue blanket was arranged between two layers of woolen blankets [8]. In the prehospital setting, plastic bags used as vapor barriers were as effective as the removal of wet clothes [9]. In accident and emergency departments, rescue blankets proved their effectiveness in protecting against hypothermia [10], in particular when applied in combination with woolen blankets [11].

In this manuscript, we focused on experimental research dealing with the transmission and reflection of radiation by rescue blankets. The originality and novelty of this review are based in its investigations of the physical properties that affect the medical applicability of the tools used in emergency care.

## 2. Factors Influencing Electromagnetic Measurements with Rescue Sheets

### 2.1. Ultraviolet (UV) Radiation

When testing metallized rescue sheets for transmission of UV radiation, it must be remembered that the thickness and transparency of foils can differ between production series, and among the variety of available rescue sheet products [12]. This may have a direct impact on transparency. Furthermore, the metallized surface increases the sheet's ability to reflect radiation. The conservation of energy means the relation between transmissivity (T) and reflectivity (R) is complementary (1).

$$\mathrm{T} = 1 - \mathrm{R} \tag{1}$$

A considerable fraction of the electromagnetic spectrum contained in solar radiation is made up of UV radiation and visible light. Manifold environmental conditions influence accurate measurement of the intensity of solar radiation, including geographic location, altitude and reflected radiant energy from the ground [13,14]. Direct effects on eyes caused by UV radiation may be difficult to assess as intense solar radiation leads to pupillary constriction and squinting, which reduce ocular exposure [13,15]. The use of rescue sheets to protect the face from UV radiation entails the risk of rebreathing $CO_2$ when the rescue sheet is kept tight to the skin [12].

### 2.2. Infrared (IR) Radiation

All objects with a temperature greater than absolute zero (0 K) emit electromagnetic radiation arising from the thermal motion of particles. This results in energy losses via surface areas [16,17]. Human beings with a skin temperature of around 33 °C (306 K) emit infrared radiation at peak wavelengths of 10 μm [17]. The human body can control body temperature by means of the nervous system, metabolic system, circulation and muscle activity. In addition, clothing and absorption of infrared radiation reflected by the environment help balance heat loss. Spectral distribution of intensity depends on temperature [18]. The spectrum of hot objects shifts towards higher frequencies and shorter wavelengths. Thus, wavelengths of radiation reflected by objects are shorter than wavelengths of radiation emitted by objects. Ideally, a black body absorbs and emits radiation regardless of frequency (ν). The total intensity emitted by a black body is proportional to $T^4$ according to the Stephan–Boltzmann law [16]. A real body will have both frequency-dependent emissivity (ν) and absorptivity (ν) (2).

$$e(\nu) = a(\nu) \tag{2}$$

Incident electromagnetic radiation on a surface can be absorbed (a), reflected (r) or transmitted (t). For a given radiant power Φ (3) hitting a surface, aΦ is absorbed, rΦ is reflected and tΦ is transmitted, with a, r and t being complementary (4) [16,17].

$$\Phi = dQ/dt \tag{3}$$

$$a + r + t = 1 \tag{4}$$

Emissivity (E), defined as the ability to emit radiation via the surface, depends on various factors such as surface morphology, viewing angle, material composition and temperature. The emissivity coefficient "ε" gives the radiation of heat from various materials as compared with the radiation of heat from an ideal black surface as $\varepsilon = 1$ [16]. The thermal radiative properties of films depend on the content, size and nature of aluminum particles [19]. For anodized aluminum, $\varepsilon = 0.55$ [20]. With increasing concentrations of aluminum, Sonnier et al. observed an increase in R, making it a suitable product for limiting thermal radiation from a body [19], whereas for a thin polyethylene terephthalate sheet T = 1.5, for an aluminum-coated foil T can be expected to be less than 1% [20,21]. E and R are complementary, as radiometric measurements mostly depend on surface E and R of radiation [20]. R is more relevant at short distances as both the heat sustained by the surface and the reflected temperature of the surrounding environment influence measurements [20].

### 2.3. Thermal Imaging

Accurate temperature measurements depend on many factors including, E and R from objects and T from the atmosphere [20]. Detection of IR radiation within the wavelength-range of 6000 to 15,000 nm (mid- to far IR), using thermal cameras, is based on emission, transmission and reflection. Temperatures between −10 and 200 °C give off no radiation that is visible to the naked eye other than what is reflected. Glass does not allow transmission of radiation in the range of 8000 to 12,000 nm. As E from an aluminum layer is negligible, most of the radiation from a metallized rescue blanket will actually be reflected radiation from the environment. Radiometric measurements from distances exceeding 100 m are influenced by atmospheric radiation. Remote temperature sensing using thermal cameras relies on the ability to accurately compensate for surface characteristics, atmospheric interference and the imaging system [21]. Imaging systems provide further adjustments with digital detail enhancement, active contrast enhancement, and high-gain mode with increased sensitivity to temperature differences [20].

## 3. Materials and Methods

Rescue blankets are low-weight and low-bulk medical devices; Category 1, according to Directive 93/42/EEC [22]. Rescue blankets are metallized foils that reflect electromagnetic waves; they are robust, watertight and windproof [8,10,11,23]. We investigated two different brands of rescue blanket commonly used by ground emergency medical services (EMS) and helicopter EMS in Tyrol, Austria. Blankets were obtained from Austrian Red Cross (ARC Rescue Sheet, ÖRK, A-1230 Vienna, Austria), and from Mountain Rescue Tyrol (LEINA-WERKE GmbH, D-51570 Windeck, Germany) [12,24]. The effects of radiation on rescue blankets from UV radiation in the spectral range between 200 and 380 nm, high-energy visible (HEV) light in the violet/blue band range between 380 and 450 nm, visible light in the range between 380 and 760 nm, and IR radiation in the range between 7500 and 13,500 nm, were all evaluated.

There are only a few scientific publications that focus on the T and R of electromagnetic radiation by rescue sheets used in emergency medicine (Figure 1) [25]. PubMed, Web of Science and Google were screened for the combined key words: "survival blanket and hypothermia" (31 in Web of Science, 38 in PubMed and 1,170,000 in Google.at); "space blanket and hypothermia" (14 in Web of Science, 13 in PubMed and 498,000 in Google.at); "rescue blanket and hypothermia" (18 in Web of Science, 10 in PubMed and 1,240,000 in Google.at). There were no findings for: "infrared radiation" and either "survival blanket", "space blanket" or "rescue blanket" according to our query in PubMed. However, when searching for "radiation and space blanket" in Web of Science, five out of 75 papers dealt with the resistance of polymer films to atom oxygen erosion, vacuum UV stability and radiation resistance in low earth orbit. Six papers in Web of Science concerned "infrared radiation and space blanket" (4 astrophysical, 2 environmental), but were not directly related to the topic. After exclusion of papers that dealt with space-flight, therapeutic hypothermia, animal research and in-hospital research, one theoretical and two experimental studies remained that focused on "radiation and rescue blankets in emergency medicine" (Figure 1).

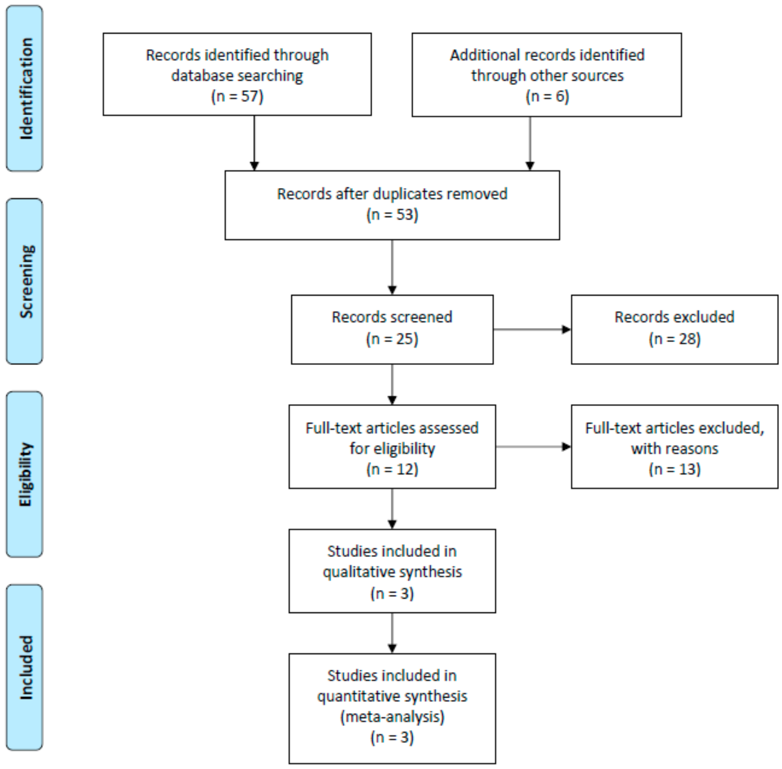



**Figure 1.** PRISMA Flow Diagram of literature research. The PRISMA Group (2009).

### *3.1. Measurement of Heat Loss by Rescue Blankets According to Surface Color*

In order to find out which side of the rescue blanket should be up to protect against hypothermia, Viennot and Décamp applied a linear model in a theoretical experimental study [16]. The authors performed an experiment with 210 $cm^3$ of water in a plastic bowl wrapped in a rescue blanket, with either gold or silver outside. Starting at 38 °C, the bowl was kept in a freezer at −17 °C for one hour. The experiment was repeated four times and the gradients between initial temperature and accurate temperature after the cooling time were compared [16].

### 3.2. Optometric Measurement of Transparency with UV Radiation, HEV Light and Visible Light

The effects of radiation on rescue blankets from UV radiation, HEV light and visible light in the spectral range between 200 and 760 nm were measured optometrically using a lens analyzer (Humphrey Systems LA 360; Carl Zeiss Meditec Inc., Dublin, CA, USA). Measurement were performed with silver or gold side up [24].

### 3.3. Thermographic Measurement of IR Radiation from Rescue Blankets

For thermographic imaging, we used a radiometric thermal camera (DJI Zenmuse XT, Shenzhen, China; uncooled microbolometer, image resolution: 640 (H) × 512 (V); pixel pitch: 17 µm; lens model: 13 mm; digital zoom: 8×; sensitivity: <50 mK at f/1.0; accuracy of +10 °C; image optimization and digital detail enhancement; operating temperature: −10 to 40 °C at a relative humidity between 5% and 95%), mounted on a Zenmuse XT gimbal and remotely controlled [21,23]. The ability to spatially resolve detailed temperature measurements in a thermal image depends on pixel resolution, image focus, blur, and environmental conditions including distance, humidity, temperature, and atmospheric transmission [21]. In order to maintain at least a 10-pixel resolution in the thermal image, the distance between the camera and the object did not exceed 50 m in our study. To diminish reflection, we kept the view angle within 60° of straight-on and oblique measurements [23].

## 4. Results and Discussion

### 4.1. Measurement of Heat Loss by Rescue Blankets According to Surface Color

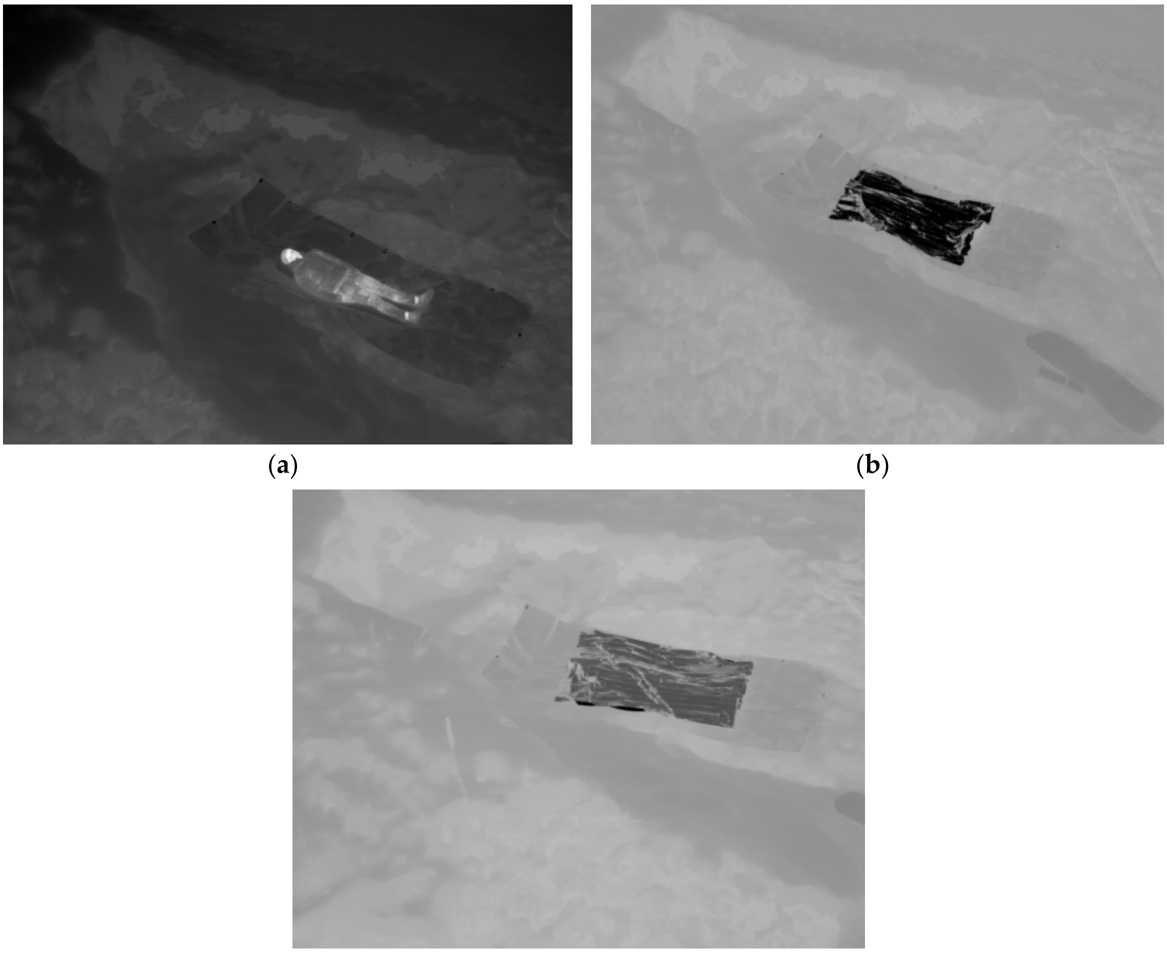
It is still not clear which side, silver or gold, should be up in order to protect sufficiently against cold [16,26]. Viennot and Décamp's discussion and analysis of the topic is restricted to the high reflective power of the silver side [16]. The authors concluded that in the case of hypothermia the common recommendation, with silver down in order to reflect IR radiation, is based on three hypotheses. Firstly, protection against hypothermia using rescue blankets is entirely a radiant process. Secondly, the continuing production of heat from metabolism and muscle activity of the victim is not considered. Thirdly, while interactions between the body and the rescue blanket are taken into account, reflected radiation and blocked absorption of environmental radiation are ignored [16]. When applying a linear model, as used in electricity and increased resistance to heat transfer, silver up is recommended for dry and calm weather, and silver down for rainy and windy weather [16]. Their recommendations were based on an experimental setting with 38 °C warm water in a plastic bowl wrapped in a bag made of an emergency blanket and kept in a freezer at −17 °C for one hour. In the calm and dry environment of the freezer, the authors observed less cooling with silver up [16].

### 4.2. Optometric Measurement of Transparency with UV Radiation, HEV Light and Visible Light

We optometrically investigated the properties of conventional rescue sheets subjected to the electromagnetic spectrum in the range between 200 and 780 nm using a lens analyzer [12]. Regarding protection from UV radiation, we particularly focused on the UVB fraction, as even short exposure to high doses of UVB rays reflected by snow or glaciers at high altitude can cause acute snow blindness. While UVC rays are blocked by the ozone layer of the atmosphere, UVB and most UVA rays penetrate the atmosphere [13]. We found that rescue blankets adequately protect against UV radiation and HEV light [12]. No differences were observed between silver and gold side up. T correlated negatively with the degree of protection from UV radiation. According to our investigation, even a single layer of a rescue blanket can significantly diminish UV light exposure. Single-layer transparency for visible light ranged between 1% and 8%. Transparency for UVB rays afforded by each tested rescue sheet brand was between 0% and 1% for the single layer. Double-layer rescue sheets blocked 100% of ultraviolet B radiation. As there is still sufficient transparency for visible light, a rescue sheet put over the mountaineer's head allows him to descend under his own power while being protected from UV radiation [12].

### 4.3. Thermographic Measurement of IR Radiation from Rescue Blankets

Our study with optometrical measurements also showed that transmission of near-IR radiation in the IR–visible radiation boundary region is very low, regardless of whether gold or silver is up [12]. In a further experimental study, we measured thermoradiation in the spectrum 760–13,500 nm from probands in a snow-covered backcountry environment. Radiometric measurements were performed on a model in supine position on an insulating sheet covered with rescue blankets, either silver side up or gold side up (Figure 2).



(**a**) (**b**) (**c**)

**Figure 2.** Thermal images in a snow-covered backcountry environment. (**a**) Model in supine position on an insulating sheet. (**b**) Model in supine position on an insulating sheet covered with a single-layer rescue blanket, silver side up. (**c**) Model in supine position on an insulating sheet covered with a single-layer rescue blanket, gold side up (air temperature: −6.2 °C; snow temperature: −7.6 or −6.3 °C when considering the emissivity coefficient ε = 0.83 for snow).

Thermal imaging was performed with an IR camera lifted to altitudes of 5 and 50 m above ground with a gas-filled balloon. Thermal images of rescue blankets on a snow surface, exposing either their gold or silver side, indicated different surface temperatures. As compared to forehead temperature, IR radiation was diminished between 72.6% and 92.3%, depending on the number of covering garments. The median percentage of IR transmission blocked by a single-layer rescue blanket when the gold side was up was 82.1% [20]. With a single layer recue blanket, body shape was completely hidden (Figure 2). With three layers of rescue blankets, up to 100% of transmission was blocked. Our findings indicate that rescue blankets can effectively block infrared radiation. A single-layer rescue blanket is sufficient to render detection of a body shape impossible.

## 5. Implications

Rescue blankets have the potential to protect from solar radiation in the electromagnetic spectrum between UV radiation and far IR. A single-layer rescue sheet put over a person's head provides sufficient transparency with regard to visible light for one to walk under one's own power, with the eyes and skin being adequately protected from UVB radiation. Thus, rescue blankets have the potential to function as makeshift sun goggles against snow blindness during outdoor activities under high solar irradiation [12]. As transmission of radiation in the near, mid- and far IR region is very low, it does not matter whether the gold or silver is up when rescue blankets are used to protect against hypothermia in wilderness emergencies [12,24]. It is more important to arrange the blanket under the outer layer of clothing but without making direct contact with the skin. Viennot and Décamp discuss a potential advantage when keeping silver up during dry and calm weather, and silver down during rainy and windy weather [16]. In search and rescue (SAR) missions, the actual temperature measured with thermal cameras is of less importance than the gradients of IR radiation between objects and environment [16,24]. As victims covered with a rescue blanket are difficult to detect, the camera operator should not exclusively concentrate on human body shapes but additionally watch for objects of 1 to 2 m lengths with strikingly low temperatures [24]. In SAR missions where thermal imaging is used by unmanned aerial vehicles to search for victims, rescue blankets should be removed from the body to increase the chance of being sighted [24].

## 6. Conclusions

Summing up the scarce information, based on our own measurements and on literature research, we conclude that, with regard to protection against hypothermia, it does not matter whether silver is turned down or not. There are several factors to be considered, including convective and conductive effects, vapor barrier function, and distance and moisture between the body and the blanket, among others. In the case of windy and wet weather and whenever protection from sunlight is desired, silver should be up. However, for SAR missions in snow and ice, having the gold side up will facilitate detection of the missing person during daytime. In low-visibility conditions and during the night, victims should remove the blanket whenever they expect surveillance from rescue personnel, as indicated by engine noise from drones and quadricopters. Operators of thermal cameras should not only focus on body shapes, but also be on the lookout for objects with a size of 1 to 2 m. Giving consideration to the different physical properties of rescue blankets increases the scope of medical applicability. This review accentuates the multi-functional applicability of rescue blankets in emergency medicine.

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