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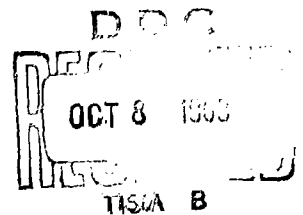
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1. General Approach

Conferences were held with Chemical Corps project monitors, both in our laboratory and at Edgewood Arsenal. In addition, extended discussions were held with several physiologists acquainted with these problems. An initial survey was made of the literature pertaining to protective masks. This work led to the formulation of the following points of view:

Clearly, the principal problems were to improve the comfort and wearability of the mask with respect to (a) Mechanical parameters such as the magnitude and distribution of pressure on the face and head, (b) Respiratory burden, and (c) Thermal burden. The many other factors in mask design were considered subsidiary at this stage of the program.

In approaching the development the mechanical factors relating to wearing comfort were considered primary since the kind of construction required by sealing and harness concepts would determine the extent and disposition of the filtration cells; these, in turn, would determine respiratory impedance. The overall configuration reached thereby would be essentially a starting point for developing types of structures which could be directed toward minimizing heat burdens.

An inverse relationship was found to exist between comfort and sealing effectiveness; much of wearing discomfort could be correlated with the tightness of harness on the M17 mask. Since the tightness of harnessing and sealing effectiveness are related it would not be possible to differentiate between various experimental models as to relative comfort except under conditions of approximately equal sealing capability. Thus, it was considered that means for evaluating mask leakage would be essential to the orderly conduct of the program.

The various aspects of the work were programmed as follows:

1. To develop all test apparatus needed to: (a) evaluate sealing efficiency, respiratory impedance, and thermal load, (b) to measure and control such parameters as facial pressures, harness tensions, respiratory rates, air flow, humidity and (c) to measure the fields of monocular and binocular vision.

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2. To conceptualize various seals and to make crude mock-ups, as the test equipment became operative, to start the evolution of these concepts in the most favorable directions.

3. To initiate a literature survey and to undertake fundamental physiological studies which would serve later to define significant parameters in the mask design.

II. Test Equipment

A. Test Head

It was desired that the burden of testing, until final designs were approached, would be borne by a dummy rather than a human. This approach would remove a large number of variables and permit a more systematic analysis of various masks as well as facilitate work generally. A start was made by defining the sealing area of the M17 mask and selecting a number of standard reference points on the forehead, at temporal regions, at the cheek and around the jaw. A plaster shield was constructed from the standard 50th percentile Army head, and measurements were made on many subjects to establish the mean resilience at these points. It was found that the head of the Rescue Breathing Trainer which we manufacture, matched the sealing area contours quite closely, and such a head was modified to give equivalent resilience at these reference points. This approach was abandoned, however, when the project monitors pointed out discrepancies in the head shape outside the sealing area. Subsequently, a mold was made from the standard head, and vinyl skins were molded for a new test head, anthropometrically equivalent to the standard head.

An adaptor "mask" was furnished by the Chemical Corps, carrying the standard facial contour on one side and the underlying bony structure on the other. This "mask" was used to construct a mold for a rigid skull and mandible which would fit into the head skin. At the present time, this work is nearly completed and a full test head will be available shortly.

This head contains a movable mandible, since it will be critical in the evaluation of the seals to take into account the effect of opening the mouth. A design has been sketched to cycle mouth opening by means of a miniature gearhead motor, mounted in the neck region of the test head.

B. Jolt and Motion Tests

Along with an investigation into the effect of mouth opening upon the seal, it was decided to test for the effect of jolting and other motions, since it is known that seals tend to be broken

through inertial effects when a soldier runs or jumps.

The test head is mounted on a rotary shaft arranged for operation by a gearhead motor, working through a bell crank to give an oscillatory motion of about 20° to each side. The motor is controlled by a Variac to give an oscillation frequency of up to 200 cycles per minute.

The intake shaft has been arranged for linear motion, connecting to an air cylinder for this purpose. A microswitch is operated by the oscillating motor to intermittently open and close a solenoid valve which actuates the air cylinder for part of a cycle and opens the cylinder for the remainder of the cycle. This jolting motion is controlled by the oscillatory-motor speed-control to give up to 200 cycles per minute. The system can provide either oscillatory motions, jolting or both.

C. Leak Testing

A survey indicated that there were no quantitative methods available to measure leakages in the range of 10^4 to 10^6 in a form which would be useful for development purposes. The spore-culture method entails a long time-delay for obtaining leakage data, may be difficult to quantify, and can yield only total leakage over a given exposure time. A method was required which would show leakage as a function of the respiratory cycle, and the cycles of jolting, oscillation and mouth opening. A number of approaches were considered including chemical reactions, mass spectrometry, and others, but a preferred method proved to be the use of a radioactive gas.

Essentially, the method consists of placing the test head, with mask in position, within a sealed enclosure containing a controlled quantity of a radioactive gas. Any leakage in the mask seal would result in flow of the radioactive gas into the mask and its breathing system. By monitoring the radioactivity in the enclosure and in the mask exhaust, the leakage ratio may be determined directly.

Discussions were held with a consulting physicist and outlines of a practical system were prepared. It had been hoped that Carbon 14 might be used as a tracer, but it was soon found that the cost of labelled carbon compounds would be prohibitive, particularly for highly effective seals, where leakages of the order of 10^6 might be achieved. It may be noted that the counting rate of the radiation detectors in the mask air flow system must be high enough over background for clear and non-ambiguous results. This activity must be multiplied by the leakage factor, and it may be seen that high leakage ratios would require very high concentrations within the enclosure.

It was found that Krypton 85 would be an ideal gas for this purpose, since it is very low priced (at \$15.00 per curie a routine test would entail a gas cost of less than 50¢). Being inert, health hazards would be minimized. Since 99.5% of its activity is in low energy beta radiation, shielding would present relatively simple problems. This gas was chosen, and a system designed as described below. It may be noted that this system was submitted to the State of New York and was accepted for licensing. It was also accepted by the City of New York, indicating that it meets all requirements for safety, subject to operation in accordance with a Manual of Procedures which will be prepared shortly.

Krypton 85 has been ordered from the Oak Ridge Nuclear Laboratories, and will be received in a container which will be heavily shielded, both by a lead-shot casing and by a lead-brick barrier (the latter is required to hold the background for the radiation detectors to a minimum rather than for safety considerations). Gas is introduced to the enclosure by means of a two-stage regulator valve, designed for such service.

Three detectors are used:

- a) At the enclosure
- b) In the inspiration line of the breathing simulator
- c) In the mask exhaust.

The first detector establishes the activity level surrounding the mask. The second detector establishes the activity due to leakage which will occur principally on the inspirator cycle. The third detector will yield data on dead breathing space within the mask on the basis that leakage will cease as the inspiratory flow decreases, and probably all entrained Krypton will be expelled. However, should the Krypton concentrate in a dead space within the mask, this will tend to be expelled on the expiratory phase and may be detected at the mask exhaust. A switch system has been ordered through Atomic Accessories and is expected to arrive shortly. This will provide for use of the three detectors with but a single rate meter and recorder.

A very considerable effort has been devoted to establishing the safety of this system under all foreseeable conditions.

The following features have been added to the system and are complete or approaching completion:

1. The test setup has been located within a small, virtually air-tight room. A tritium monitor has been procured, with an attachment that will be used to survey the enclosure for leaks before the start of the test.

It will then be set to a level of activity such that any malfunction or mishap will be detected, sounding an alarm. The room then can be evacuated and the enclosure exhausted to the atmosphere by a system described below.

2. All flow connections passing through the enclosure to the mask (breathing simulator and mask intake and exhaust) are protected by solenoid valves such that if there is power failure at the simulator on the exhaust system, the gas is isolated within the enclosure.

3. The normal exhaust of the radioactive gas through the breathing simulator takes place in a 12 in. dilution stack, extending 30 ft. above the roof of our building. This stack has a blower interlocked electrically with the solenoid valves. The extent of dilution provided by the overall system is well within AEC safety requirements.

4. At the conclusion of the test, a by-pass line is opened so that gas will flow from the enclosure up to the stack at a safe and controlled rate. A flushing stream of air enters through a 3-way valve in the filling line. This air is brought in through a regulator at low pressures to establish a steady and continuous flow. It is anticipated that levels within the enclosure will fall to ordinary background levels in a reasonable time.

5. All other lines into the enclosure are vented at the roof, with sufficient separation of the various vents to prevent re-circulation.

6. A complete operating manual is being prepared to cover the operation. This will include control of charging the enclosure so that no more gas is introduced than is required for clear leakage readings. Thus, for earlier prototypes, where high leakage may be expected, gas usage will be at a minimum. The testing room has been so laid out as to afford good distance protection to personnel, and dose rates will be far below permissible levels.

D. Breathing Simulator and Breathing Parameter Control

The breathing simulator developed at Edgewood has been adapted for use in our test set-up. The rotary valve furnished by Edgewood was modified by the addition of O-ring seals to prevent leakage of radioactive gas, and the drive motor was replaced to give a broader range of respiratory rates. Two blowers were procured and adapted to the system to produce inspiratory and expiratory flows. Each blower is controlled through a Variac supplementing the iris flow control.

The desirability of humidity control was pointed out, particularly, since moisture will affect operation of the mask valves and, possibly, the face seal as well. Following the Edgewood suggestion, a water chamber was constructed to permit looping several folds of absorbent cloth into a water bath and to present an appreciable cloth area to the expiratory air flow. A Variac-controlled immersion heater will control the humidity level.

Flow rates will be monitored by a pneumotachograph, supplied by Edgewood. The strain gauges required for reading the differential pressures will be like those used for head and harness pressures and tensions (see below). This system will be calibrated by a standard laboratory flow meter. The pneumotachograph is required because all commercially-available flow meters are undesirably high in flow impedances.

The simulator and control system described above will reproduce flow and respiratory rates and humidities covering the entire range of interest in human respiration.

E. Mask-Pressure and Harness-Tension Measurement

Eleven points were chosen around the sealing region of the head for monitoring pressures. These are distributed throughout the forehead, temporal regions, cheeks and mandibular regions to give a full mapping of the pressures, which will be essential in comparative evaluation of the M17 masks and the new masks being developed here. Provision has also been made for monitoring tensions in up to six straps. Baldwin-Lima-Hamilton bonded strain-gauges were selected, and circuit was designed so that up to 20 strain gauges could be used consecutively through a high quality selector switch. Each gauge has its own balancing potentiometer, but all share the same thermal compensation unit within the test enclosure. This instrumentation will provide rapid handling of all measurements without requiring step-by-step balancing.

F. Range-of-Vision Testing

The standard Army head was modified for installation of miniature, high intensity lamps at the top, bottom, corners and center of each eye. A metal arc has been arranged to pivot about the horizontal axis passing through the line of the eyes. This arc is slotted for light to pass through and appear on a plastic strip bonded to the metal.

A series of arc elevation angles for each mask configuration to be tested will be used, and the radial extent of the light field will be recorded for each angle. Thus, the envelope of the light field will be plotted for each eye, separately, giving ranges for monocular and binocular motion. This apparatus is nearly completed.

III. Mask Prototypes

A. Sealing Concepts

After several preliminary attempts, a seal was dipped from latex in the form of a longitudinally-convoluted bellows, following the center of the sealing area as defined by the present M17 mask. This seal was cemented to a vacuum-formed shell representing a 1/2 in. outward expansion of the contours of the sealing area. In the first test, this seal was totally closed off with internal air at atmospheric pressure. Immediately, it was found that the seal exhibited highly promising characteristics. When this combination was donned, pushing the seal up against the bottom of the chin and back against the forehead caused additional pressure to be developed and expansion to occur at the temporal and cheek regions. The seal thus followed very closely the contours of the face, both at rest and in motion.

It was found that this assembly could be quickly pushed against the face, creating a seal almost instantly, and that the effectiveness of sealing was very non-critical with respect to the position of the assembly with respect to face.

In its present form, the seal is highly inadequate with respect to materials, stability (with respect to reproducing a desired mode of action) and donning (in that the prototype must be moved about the face for a full fit.) The shortcomings are due to the crude first prototype, its materials, and the simple seal construction.

The following refinements are now under way:

1. A series of Adiprene materials was developed by our chemist to give varying durometers and elastic moduli. One such formulation, basically equivalent to the M17 rubber, will be used for the first precision seal to be made.

2. The first seals were made by dipping, but tests have shown that Adiprene does not lend itself to this process. To obtain uniform cross-sections, and to develop proper characteristics, vacuum-casting techniques will be used. The construction of molds and mold cores to these intricate shapes would normally present very difficult problems. It has been found, however, that the seals can be cast in flat, circular form and bent to the required shape without excessive deformation. If such deformation is encountered, it will be corrected by hand-patching in the interest of time economy during this phase of the work.

3. A drawing of three different seals is attached. View A shows the seal described above. Views B and C show seals with an extra flap to be bonded to the shell, inside the mask. It is expected that inspiration and expiration pressures acting upon this flap will cause a rhythmic distortion of the seal cross-section to serve two extremely important functions:

a) To continuously change the contact line of the seal on the skin. By analogy with pulsating cushions and mattresses, this is thought to be in the right direction for decreasing tissue fatigue due to seal pressure.

b) By exposing various parts of the contact surface of the seal both internally and externally, there will be a tendency for evaporation of moisture generated at the contact area. Such moisture is a basic source of discomfort for prolonged wearing.

B. Structural Development

The structure is defined as the mask without seal or harness. It is planned at this time that the shell to which the sealing mask is bonded will be essentially rigid, although with a flexible "hinge" down the center line of the face to give a clam-shell action for donning. The shell design has been deferred pending definitization of the seal cross-section, which will impose certain requirements upon the shell. It is also deferred pending the following data which will be acquired shortly:

1. Permissible limits of protrusion from the face to maintain satisfactory binocular vision. In making this study, the M17 mask, with lenses and nose piece intact, will be progressively stripped down to obtain baseline range-of-vision data.

2. An analysis will be made of the shape and contour of a visor which will not restrict the field of vision. A study will be made of the possibility of connecting the visor flexibly or through hinges to displace it when the helmeted soldier sights a rifle.

These data will lead to the blocking out of one or more overall designs for shields to be integrated with filtration cells. Since the area of the filtration cells relates inversely to breathing impedance, this design will seek to maximize the area, while maintaining shapes which will lend themselves to a uniform flow. The use of the vizor area and the entire face periphery are contemplated.

C. Harness

Strap harnesses are being fabricated for initial tests of seals. As noted above, these will be strain-gauged to provide data for harness configurations which would impose minimum pressure on the head.

Studies are being made currently under the NYU sub-contract strain-gauge sections for determining pressure tolerances for short and long wearing times. These studies will be useful not only in providing reasonable facial loading patterns, but also in determining the best locations of harness straps and the form of a reaction pad at the back of the head. Actual design work will be deferred, pending further elaboration of the mask concept.

IV. Other Areas of Inquiry

1. Tests are being started to establish equivalence between the dummy test head and the human head with respect to leakage. A rubber bag will be bound around both a human and a vinyl forearm and inflated to a known pressure. Loss of pressure for a given time period through a rubber-band seal will be a reasonable indicator of the degree of equivalence.

2. Prior to design of the air-flow system in the mask, the validity of a new concept will be tested. This concept would locate the mask exhaust high on the mask (the relatively low expiratory impedance would permit the use of connecting tubes for this purpose). An experiment will be conducted to study the effects of moisture saturation of a fabric outer covering of the mask upon cooling (by the canteen principle). Although it is not known whether the moisture in expired air would be sufficient to produce a noticeable cooling effect, there seems little reason why a small water chamber might not be provided to augment the supply if appreciable thermal relief were found to be obtainable.