An Evaluation of Test Measurement Data Obtained on the KW-Gard™ RF Protective Suit

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Prepared for

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This report comments on test results obtained by Ilssan America, Inc. in evaluating the radiofrequency (RF) shielding effectiveness of the KW-Gard™ RF protective suit produced by the Euclid Garment Manufacturing Company. The primary objective of the reported test measurements was to establish the performance characteristics of the suit for controlling RF energy absorption in the body of an individual wearing the suit in strong RF fields.

The measurement methodology employed by Ilssan America, Inc. was that of determining the specific absorption rate (SAR) of RF energy inside a full-sized human phantom model. The hollow phantom was filled with a liquid having the same electrical properties of human tissue and, hence, the same approximate RF energy absorption characteristics as a human. SAR values were measured inside the phantom while it was exposed to a near-field source of RF fields produced by a series of corner reflector antennas. SARs were determined with and without the KW-Gard™ suit on the phantom. By examining the difference between the two values of SAR, the suit's ability to attenuate the incident RF fields that result in energy being deposited in the body could be determined. This evaluation was performed at three anatomical locations within the body (the head, chest and thigh) and for four different frequency bands (150 MHz, 450 MHz, 835 MHz and 1,900 MHz).

The use of SAR as the measurement quantity for evaluating RF protective clothing is superior to simply determining the field strength attenuation of the fabric in air since SAR is the underlying basis of virtually all modern RF exposure standards. SAR reduction is particularly relevant for near-field exposure conditions. What is most important is how well the SAR in the body of the subject wearing the protective clothing is controlled and the methodology used in the Ilssan America laboratory gets directly to this factor more directly than any other way.

SARs were found by directly measuring the internal electric field strength within the tissue equivalent liquid that filled the phantom with a miniature electric field probe consisting of three orthogonal elements, each measuring approximately 2.5 mm in length. The SAR in the liquid is proportional to the square of the electric field strength and the conductivity of the liquid at the particular test frequency. Electrical characteristics of the liquids were measured by Ilssan at each of the frequencies used in the tests using a cylindrical copper tube waveguide apparatus, filled with the tissue equivalent liquid, and finding the change in amplitude and phase of a signal applied to one end of the waveguide as a function of distance along the waveguide. Using this method, values of the dielectric constant and conductivity of the different fluid mixtures were determined. The SAR was then able to be determined from the relationship:

$$SAR(W / kg) = \frac{E^2 \cdot s}{r}$$

E is the internal electric field strength in volts per meter, σ is the conductivity of the liquid filling the phantom in the unit siemens per meter and ρ is the mass density of the liquid in kilograms per cubic meter. SAR is expressed in the unit watts per kilogram of body tissue.

RF fields were produced from a series of corner reflector antennas placed very near the surface of the phantom to produce a near-field exposure condition. This approach was taken to ensure that the SAR reduction properties found from the measurements would be conservative estimates of the SAR reduction that would result from far-field exposures as well; because the near-field exposure condition will result in substantially stronger magnetic field coupling to the body than in far-field exposures, it was deemed important to assess the ability of the KW-Gard™ to attenuate such near-field exposures since, in fact, most practical RF exposures in the real world that exceed applicable exposure limits occur in the near field.

I have examined the data obtained by Ilssan America and prepared the following chart to illustrate the measured values of SAR reduction for the KW-Gard™ suit. These values are shown in Figure 1.

These values are approximately 31-32 dB in the 450, 835 and 1,900 MHz frequency bands. Lower values in the range of 22 dB were measured in the 150 MHz frequency band. An important observation made from the Ilssan America data is, however, that when the KW-Gard™ suit was on the phantom, it was so effective in reducing the RF fields inside the phantom that the SAR measurement system noise floor was not adequate to determine the actual reduced SAR. Hence, all values of SAR reduction shown in Figure 1 are based on using the inherent SAR measurement system minimum detection limit in combination with the SAR that occurred without the suit. This process will result in values of SAR reduction that are less than the actual reduction afforded by the suit. To further examine just how effective the suit is would require substantially greater transmitter power and/or higher electric field strength probe sensitivity. In any case, the Ilssan America data support the contention that the KW-Gard™ suit, for the conditions evaluated, will exhibit an SAR reduction of at least that value shown in Figure 1 or better. The lower values of SAR reduction found for the 150 MHz frequency band are simply a function of the fact that the near-field absorption characteristics of the body are less pronounced at 150 MHz than in the higher frequency bands. Again, essentially no measured field was found with the KW-Gard™ suit on the phantom during exposure, but less absorption occurred without the suit and, hence, the ratio of the two values (SAR without suit to noise level of the measurement system) was somewhat less than at the higher frequencies.

The SAR reductions are expressed in Figure 1 in the unit of decibels (dB) which is a logarithmic expression for conveniently displaying very large numbers. The reduction in decibels is equal to 10 times the logarithm of the ratio of the peak SAR without the suit to the peak SAR with the suit. An SAR reduction of 20 dB is equivalent to a factor of 100 times reduction; an SAR reduction of 30 dB is equivalent to a factor of 1,000 times.

The measurement process consisted of scanning the absorptive fluid in the region of the phantom adjacent to the driven element of each corner reflector antenna, with the KW-Gard™ suit on the phantom, and determining the peak value of the SAR. This process was then repeated without the KW-Gard™ suit and, again, the resulting SAR was determined using the same net incident power to the antenna. In this case, as described above, the resulting SARs were below the measurement system's noise floor. This process is illustrated in Figure 2 which shows the results obtained at 835 MHz for the chest region of the body. Figure 2 reveals the noise floor of the measurement system relative to the peak SAR obtained without the KW-Gard™ suit on the phantom. Dividing the peak measured SAR value of 17.4 W/kg by the noise level of the system (0.01 W/kg), a reduction factor of 1,736 times is obtained. This means that the presence of the KW-Gard™ suit was responsible for reducing the resulting SAR in the body by 1,736 times! Expressed in logarithmic fashion, this is equivalent to 32.4 decibels (dB).

The data obtained in the Ilssan America tests strongly support the observation that the KW-Gard™ suit can substantially reduce personnel exposure to strong RF fields. I presume that this was observed because of the relatively high stainless steel content (25%) of the KW-Gard™ fabric.

Another aspect of the Ilssan America tests was the investigation of any possible inhomogenity in the KW-Gard™ fabric that might be manifested as a polarization dependence on the attenuated RF fields. The RF field power density, determined in air, was measured with a 24 inch square test sample of the fabric as the fabric was rotated through a 90 degree angle. Their tests, conducted at 450, 835 and 1,900 MHz, showed no detectable influence on attenuated RF fields caused by orientation of the KW-Gard™ fabric exposed to near-field conditions.

In conclusion, the evaluation data obtained by Ilssan America, Inc. indicate that, for the test conditions used (frequencies, anatomical regions of the body and near-field exposures), the KW-Gard™ suit exhibited substantial SAR reduction characteristics, ranging between 136 (21.3 dB) and 1,510 (31.8 dB) times relative to the unclothed phantom. Further, the tests revealed no detectable orientation effect of the fabric, meaning that the KW-Gard™ suit possesses the same SAR reduction capability, regardless of the RF field polarization.

The SAR reduction characteristics of the suit, while very high, must, however, be interpreted with some caution. For example, in the 900 MHz frequency range, the test data indicate that the suit reduces the SAR in the exposed subject by over 1,200 times. This could lead one to assume that by wearing the suit, one could enter RF fields as intense as 1,200 times greater than the Maximum Permissible Exposure limit adopted in regulations of the Federal Communications Commission (FCC). This would be comparable to working in a field with a power density of 3,600 millwatts per square centimeter or 3.6 watts per square centimeter! (The MPE at 900 MHz is set at 3 milliwatts per square centimeter.)

Although the stainless steel component of the KW-Gard™ suit reflects a very significant amount of the incident RF energy, there will always be a certain amount of energy that is dissipated as heat in the suit fabric due to the RF currents that will flow within the conductive fibers. In extremely intense RF fields, the magnitude of these induced currents could eventually become great enough to cause noticeable heating of the fabric. In such RF exposure situations, and depending on the local environmental conditions, the additional heat loading contributed by the heating of the suit would have to be considered in assessing the acceptable upper limit for exposure of workers wearing the suit. This upper limit would, of course, be orders of magnitude greater than what the unprotected worker could tolerate. Without additional test data, the extent of fabric heating in very high field strengths cannot be stated but the high stainless steel content of the KW-Gard™ suit would suggest that relatively high intensity incident RF fields would be necessary before suit heating would become significant, especially when compared to lower metal content fabrics. Based on these insights, a degree of conservatism should be used in establishing a ceiling power density limit for use of the suit.

Finally, the very high RF shielding performance of the KW-Gard™ suit may lead some users to attempt work in extremely intense RF conditions. I would suggest consideration of inclusion of a practical warning with the suit recommending that users should never continue to work in RF fields that produce noticeable heating in any part of their body, regardless of whether they are using the KW-Gard™ suit.

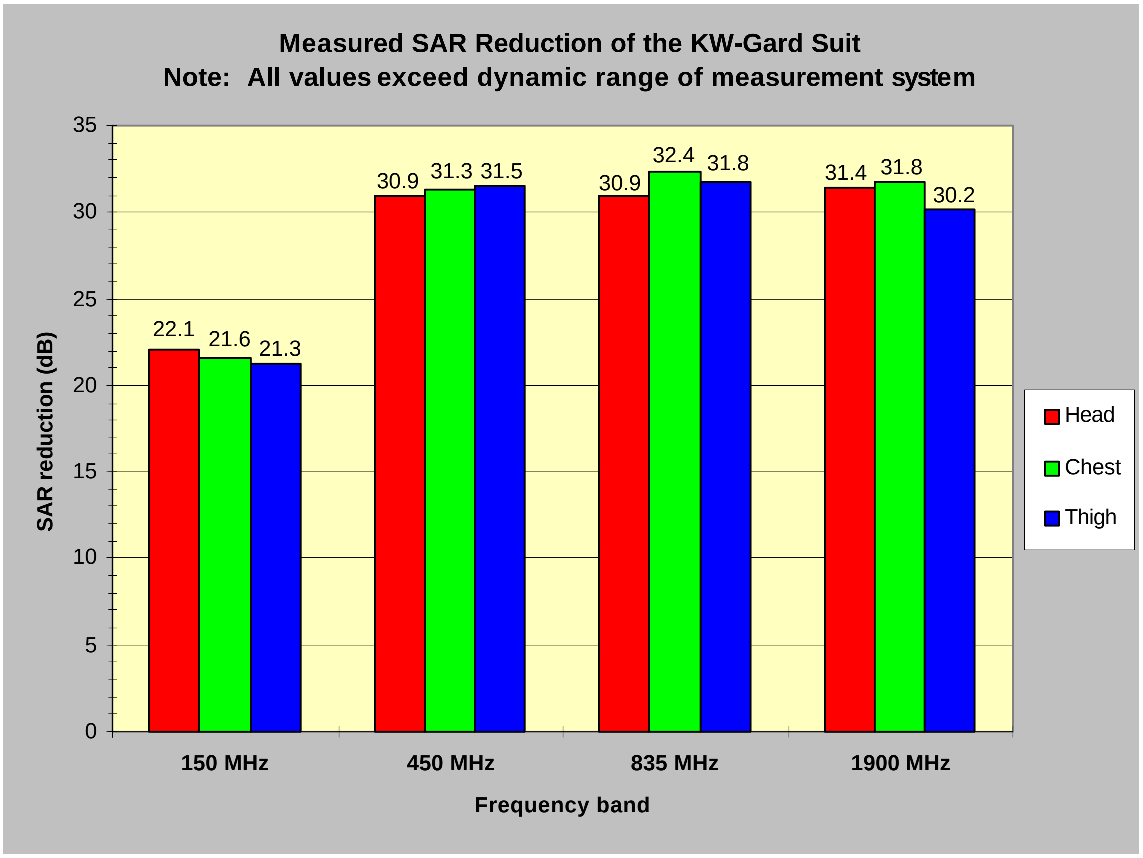

Figure 1. Measured SAR reduction of the Euclid KW-Gard™ RF protective suit.

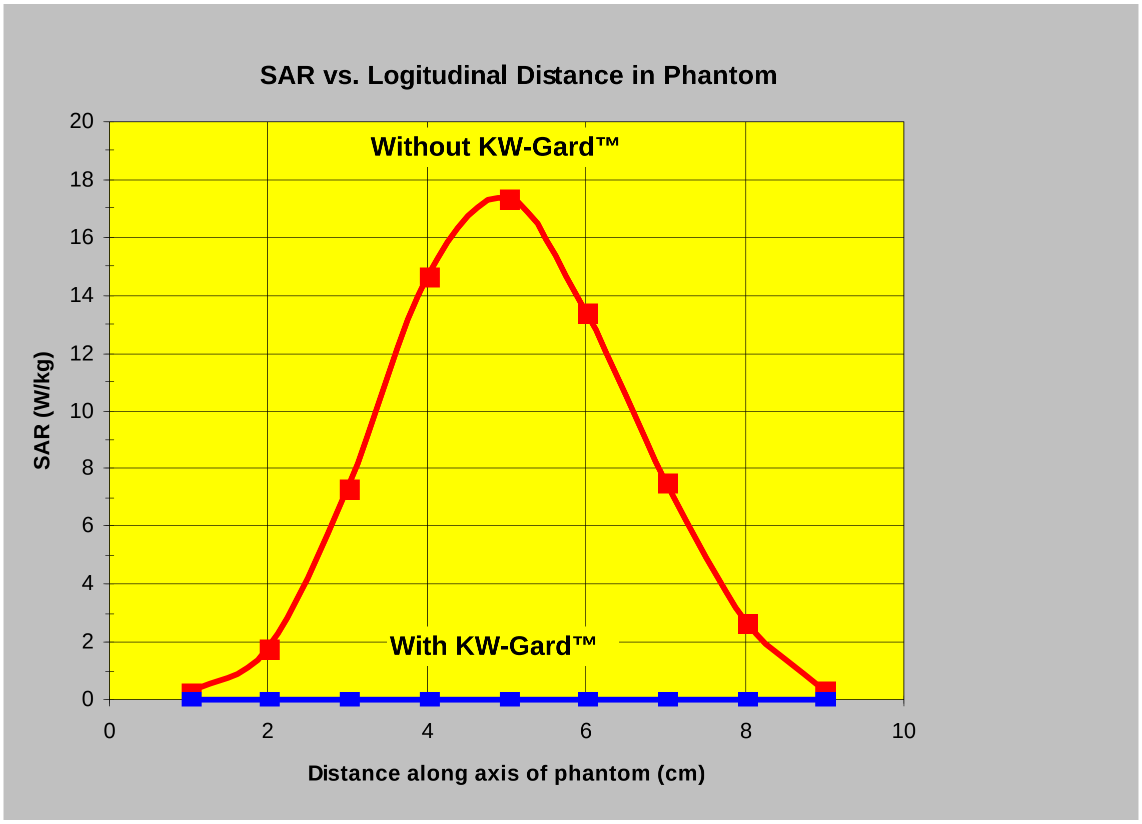

Figure 2. Example SAR measurement data showing the peak SAR in the chest region of the phantom with and without the KW-Gard™ suit. The straight horizontal line along the bottom axis represents the SAR measurement system noise floor (i.e., minimum detectable SAR). The presence of the KW-Gard™ suit reduced SAR in the phantom to below the systems's minimum detection level.