Abstract: UK Climatic Conditions applicable to the design of Type B(M) packages.

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For **Package Design**, TS-R-1 2009 specifies insolation parameters considered acceptable for application throughout the world, and specifies the assumption of an ambient temperature of 38ºC. Prior to its withdrawal, a British Standard, BS3895:1976, recommended, for Type B(M) packages travelling solely within the UK, an ambient temperature range of -10ºC to +26ºC to be assumed, and for insolation permitted 50% of the values given in TS-R-1, which would give reduced cost in design and substantiation of packages. In response to climate change, and to better inform guidance for package designers and regulators, a requirement was identified to study the range of temperature and insolation values likely to be experienced in the UK in order to ensure nationally accepted standards remained safe. This orally presented paper evaluates current and predicted climatic conditions throughout the UK, focussing on major transport routes, including motorways, main roads and railways. Comprehensive temperature data from 1961 to 2010 was analysed. Key statistics included: maximum, minimum and mean temperatures over 8-hr, 12-hr and 24-hr periods annually and for each month. Data analysis then predicted estimates for high and low extreme values experienced in a 1-year, 10-year, 100-year and 10,000-year period. Insolation was considered, albeit with a much smaller dataset, to give 8-hr and 24-hr statistics annually and for each month, and to consider the ratio of exposure between vertical and horizontal surfaces at Northern latitudes of 51-54°. General temperature and insolation trends were then extrapolated over two decades to estimate future temperature ranges and profiles. The output of this research indicated previous assumptions were no longer valid, so guidance was developed with industry and other regulators providing for a more flexible approach for package design that incorporated risk of operational availability as part of the design, to be balanced against development costs; for example a package intended for near constant utilisation may now focus its design for a limited range of conditions that have a high degree of probability of occurring in the UK, without meeting the more demanding Type B(U) requirements. Regulators are better able to assess the adequacy of a submission for a proposed operational role.

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UK CLIMATIC CONDITIONS APPLICABLE TO THE DESIGN OF TYPE B(M) PACKAGES

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ABSTRACT

For Package Design, TS-R-1 2009 Edition specifies insolation parameters considered acceptable for application throughout the world, and specifies the assumption of an ambient temperature of 38ºC. Prior to its withdrawal, a British Standard, BS3895:1976, recommended, for Type B(M) packages travelling solely within the UK, an ambient temperature range of -10ºC to +26ºC to be assumed, and for insolation, permitted 50% of the values given in TS-R-1, which would give reduced cost in design and substantiation of packages. In response to climate change, and to better inform guidance for package designers and regulators, a requirement was identified to study the range of temperature and insolation values likely to be experienced in the UK in order to ensure nationally accepted standards remained safe. This paper evaluates current and predicted climatic conditions throughout the UK, focussing on major transport routes, including motorways, main roads and railways. Comprehensive temperature data from 1961 to 2010 was analysed. Key statistics included: maximum, minimum and mean temperatures over 8-hr, 12-hr and 24-hr periods annually and for each month. Data analysis then predicted estimates for high and low extreme values experienced in a 1-year, 10-year, 100-year and 10,000-year period. Insolation was considered, albeit with a much smaller dataset, to give 8-hr and 24-hr statistics annually and for each month, and to consider the ratio of exposure between vertical and horizontal surfaces at Northern latitudes of 51-54° (equivalent to the UK). General temperature and insolation trends were then extrapolated over two decades to estimate future temperature ranges and profiles. The output of this research indicated previous assumptions were no longer valid, so guidance was developed with industry and other regulators providing for a more flexible approach for package design that incorporated risk of operational availability as part of the design, to be balanced against development costs; for example a package intended for near constant utilisation may now focus its design for a limited range of conditions that have a high degree of probability of occurring in the UK, without meeting the more demanding Type B(U) requirements. Regulators are better able to assess the adequacy of a submission for a proposed operational role.

Introduction

Package type design requirements are well defined in TS-R-1[1], including defined temperature ranges to be considered for the design of some Industrial Packages, Type A, Type B(U) and Type C packages, and further temperature requirements and insolation conditions for the latter two types.

Type B(M) packages are, subject to Competent Authority approval, permitted to deviate from these bounding values, and be certified for use within a narrower range as justified by the applicant. Historically, a suitable temperature range and reduced insolation values for use solely within the UK was suggested in BS 3895:1976, which has since been withdrawn, and no replacement has been published. Additionally, some Industrial Packages[2] are not required to adhere to specific climatological criteria, although good design practice will define an acceptable range for package performance.

For Type B(M) packages, deviations from the regulatory temperature ranges are permitted if the package safety can be demonstrated by the applicant to the satisfaction of the Competent Authority, who may impose limitations on its use. The ranges selected for Type IP-1 or Type IP-2 packages may also vary, and the design approved by the applicant, with suitable documentary evidence justifying the design. The choice of temperature range when making such an application therefore becomes an operational or commercial decision balancing the cost of design, approval, manufacture and use against the risk of unavailability should the prevailing conditions exceed those for which the package is approved.

Considering the time elapsed since the British Standard was published, its withdrawal, and the consequent developments in technological capability and effects of climate change, it was considered appropriate to review existing guidance, with a view to aiding industry and regulators to better understand the prevailing and likely future conditions. The intention is to inform commercial decision making and development of regulation in the future, with the overriding priority of ensuring the safety of people and the environment.

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[1] Throughout this paper, references are made to TS-R-1, as the basis for legislation in the UK (via the UN Model Regulations) for all modes, in order to aid clarity and brevity. However, it should be noted that the legislative texts in the UK are the latest editions at any time of ADR for road, RID for Rail, ICAO Technical Instructions for air, and the IMDG Code for sea, brought into force via various legal instruments. For road and rail in the UK (the subject of this note), this is the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (as amended). These texts should be consulted prior to transport, and take precedence over TS-R-1 for regulatory compliance in the UK.

[2] Type IP-1, and Type IP-2 when not carried by air.

Research Specification

Current Climatic Conditions

Geographical Area of Interest

The selected regions for this study are limited to main UK transport routes by road and rail, and quality controlled to exclude extreme or otherwise inapplicable readings, in order to represent travel conditions in the UK.

Great Britain and Northern Ireland were treated as a single region. While there are notable differences in various parts of the country, this approach provides for bounding conclusions that will be suitable throughout the UK.

Data Extraction

Temperature

The temperatures considered were long-term peak values and averages over 24-hour and high and low 8-hour periods, i.e. 8 hours midday and 8 hours at night.

The peak values give bounding temperature conditions for a package.

The 24-hour range is intended to be suitable for application to substantial, thick-walled packages with significant thermal inertia, for use when assessing cyclical temperature effects.

The 8-hour ranges would be more suitable for packages with low thermal inertia that would respond quickly to changes in temperature. The high 8-hour value represents daylight conditions, and the low 8-hour value represents night-time conditions.

Solar Radiation

The data acquired for solar insolation includes the average of the peak values for each month, 24-hour averages, and high 8-hour averages (the low 8hr average occurs overnight and is effectively zero). The logic outlined above relating to temperatures and the thermal inertia of the package is valid here also when considering which insolation statistic should be used to inform the package design.

Diffuse radiation was included in the insolation values, to better represent the solar radiation experienced by the package, and eliminate variance in design through the use of different approximations to account for this effect.

Extreme Value Analysis & Quality Control

This section describes an overview of the measures taken to calculate the statistics at the extreme of the range of interest, and how the relevance and applicability of the statistics was ensured.

Temperature

The extreme value analysis employed various statistical techniques to compute various probabilistic projections. A confidence level of 95% was selected for all predictions. The range of projections (the difference between the highest and lowest) increases the more extreme the event projected, so a 1: 10 000 year event will have greater range for the given 95% confidence level than a 1: 10 year event.

Consequently, the 'Best' result is the most probable high (or low) figure for the given month or year (i.e. Best estimate). The 'Low' and 'High' figures represent the values on the distribution of predictions beyond which there is a very low probability (<5%) of the value being realised, i.e. the most likely value for a period is 'best', and there is a 95% chance that the actual value experienced is greater than 'Low' but less than 'High'.

Solar Radiation

The factors affecting insolation include:

- hours of daylight
- cloud cover
- angle of incidence of the sun’s radiation to the surface.

Bounding cases of these factors have been observed for the UK, and in general correspond to the annual cycle, as the days lengthen and shorten, and the position of the UK relative to the sun varies. The exception is cloud cover, although throughout any year, several instances will be observed which feature either total cloud cover, or a complete absence of clouds; extreme values will tend to represent this, such that the peak high values will be observed when there is no cloud cover. Thus, the extreme values with respect to insolation are likely to have already been experienced due to the physics underpinning the effect; the Earth has already seen a cloudless day at peak time on the day of the year with the greatest solar exposure. Therefore the range bounded by the recorded data may be considered also to bound any conceivable extreme condition.

Predicted Trends in Climate Change

Introduction

This part of the study is not directly comparable to the evaluation of current climatic conditions, as it is not possible to tailor the output to match the main transport routes with the data available to a reasonable level of confidence. Effectively, as the data sets for predicted future change cannot be constructed to correlate with the data from past observations, a direct comparison is not possible.

Confidence limits for maximum and minimum values are set at 10% and 90%. Given the uncertainties and shape of the distributions, values outside this range are not considered sufficiently robust to add value to decision making.

UKCP09

The UK Climate Projections project (UKCP09) provides climate information designed to help those needing to plan how they will adapt to a changing climate. The data is UK-focussed.[3]

Future climate information is available from the UKCP09 probabilistic experiments and the underlying regional climate model (RCM) data. This study used UKCP09, which gives a fuller description of the future uncertainties in the projections due to having taken other modelling centre's results into account and captured greater model uncertainties.

This model has its limitations. Probabilistic information is not suitable for looking at particularly extreme events. Not all potential futures are modelled, only the most likely. Finer modelling resolution does not give greater confidence as the number of data points remains unchanged; hence the smaller the area of interest, the fewer data points contribute to the result, with correspondingly weaker statistical strength. Confidence levels vary depending on the climate variable and time period, so the further ahead the estimate, the wider the range for a given level of confidence. Temperature results generally have greater reliability due to the greater data available, in comparison to, for example, solar radiation. Finally, UKCP09 does not have projections for snow, which may have an impact in the winter months for extreme cold values, and the level of reflected solar radiation.

The results from this study are the average throughout night and day, over the entire decade under consideration. The intention is not to provide a bounding case as the UKCP09 approach will not capture extreme values. However, it does provide an indication of the direction and extent of any change. This difference could then be applied to the current equivalent projection to get an estimate for future values.

Further values give the 99th percentile figure for the warmest and coldest days. As an estimating tool, these may be used to suggest what the bounding case is likely to be.

Key Results

Full results from this study are given in Reference 2, available at www.hse.gov.uk/nuclear/transport/guidance.htm. Consequently, only key results are reproduced here.

Current Climatic Conditions

Maximum Temperature Results

Table 1 of the Ref 2 shows a number of values between July and August where the 1 year return value approaches 30ºC, with an 'all-year' value of 31.3 ºC. Designing a package with an upper temperature limit of 30ºC is therefore likely to ensure its availability throughout most of any given year, although there are likely to be occasions over the life of the package where it is not suitable for use.

[3] UKCP09 is funded largely by the Department of Environment, Food & Rural Affairs, and detailed information is available at their website: http://ukclimateprojections.defra.gov.uk

The same table shows 10 year return values for the same months approaching, and in two cases[4] exceeding, 35ºC.

Minimum Temperature Results

The best estimate average one year peak return value given in Table 3 of Ref 2 for cold weather events is -16.3ºC.

Temperatures fall to approximately -30ºC for a probability of an event occurring in a 1:100 year return period, and again to approximately -40ºC for the 1:10 000 year return value. Consequently, designing to accept the lower temperature range specified for Type B(U) packages in TS-R-1 paragraph 664 of -40ºC is likely to be adequate to meet any reasonably foreseeable conditions within the UK.

Mean Temperature Results

24 Hour Mean Temperature

This set of results is applicable to massive, thick walled packages with substantial thermal inertia. The highest 24 hour mean temperature recorded at any of the selected stations during the 1961-2010 period was 30.7°C at London Weather Centre on 10th August 2003. The lowest 24 hour mean temperature recorded at any of the selected stations is -18.8°C, on 29th December 1985 at Fyvie Castle, near the A947 road in Aberdeenshire.

8 Hour Mean Temperature

This set of results is applicable to smaller, thinner walled packages with a quicker thermal response. The highest eight hour mean temperature was 36.3°C at Wisley on 10th August 2003. The lowest eight hour mean temperature was -21°C at Altnaharra, on the A836 road in northern Scotland on 8th January 2010.

Solar Radiation Results

To suit international application, the insolation values provided in TS-R-1 2009 Edition Table 13 are based on the equatorial region, and assume solar radiation occurs perpendicular to the Earth's surface. This is also the basis for the choice of a 12-hour period to reflect night and day. As the model assumes the sun is directly overhead, the insolation seen on various package surfaces decreases as exposure vertically upwards decreases.

This model is a good approximation for design of a package with potentially global use. However, when considering the UK, it becomes apparent that many of these assumptions are no longer appropriate. This is considered in the analysis underpinning this report. For example, instead of using 12-hour values, in order to better represent UK conditions, an 8-hour period was considered more suitable. Allowance must also be made that as the angle of solar radiation relative to the Earth is no longer 90º, the distribution of insolation about the vertical sides of a package will no longer be equal. Therefore, although some non-horizontal sides will receive less energy, some will

[4] Upper bound of 1:10 year value for July 35.1ºC and August 35.8ºC

receive more, and so the assumptions based on equatorial conditions may not be bounding in the UK.

Variations in solar radiation are dominated by sun spot activity, which varies over an estimated 11 to 18 year cycle. As the insolation data analysed for this report covers a 20 year period, there is reasonable confidence that the variations observed in the report will be representative of future variations.

24-Hour Average Insolation

The maximum hourly average insolation rate on the day with the highest total radiation (at Liverpool on 27th June 2005) was 976 W/m^2 for the hour ending 13:00 GMT. Average insolation is greater in the North due to slightly longer periods of daylight, although peak values would normally occur in the south. The average values, over the 24 hour period, peak in June at approximately the value given in TS-R-1 (maximum average of 392 W/m^2 against 800 W/m^2 over 24 hours = 400 W/m^2 average in 12 hours, assuming equatorial conditions).

8-Hour Average Insolation

The peak 8 hour average period occurs between 0800 and 1600 GMT throughout the country. Because the period overnight is excluded, these average values are greater than for the 24 hour period.

Insolation on a Vertical Surface

At no stage does the ratio fall to the value given in TS-R-1 of 0.25. Due to the latitude of the UK, the ratios tend to the other extreme, so that insolation on a vertical surface could be up to nearly four times greater than a horizontal surface (ratio of 3.86 in Lerwick, January). This only applies to the most exposed vertical surface (typically, this would be the surface facing south). Other, less exposed, vertical surfaces receive correspondingly less insolation. Therefore, assuming that all vertical surfaces see the peak vertical surface insolation would be bounding but pessimistic. Correspondingly, while the maximum average insolation levels fall below the values in TS-R-1, this distribution may have an influence over the thermal characteristics of the package.

Future UK Climatic Conditions

Temperatures

Annual ***mean daily temperatures*** between 6˚C and 12˚C by 2020s (6˚C and 15˚C for 2030s).

Summer mean daily mean temperature 15˚C to 21˚C, and daily maximum temperature 18˚C to 27˚C (2020s).

10th percentile runs project a negative change in ***maximum temperature of the warmest summer day***. 50th and 90th percentiles project positive changes to temperatures of up to 2˚C and 6˚C respectively.

10th percentile runs project a negative change in ***minimum temperature of the coolest winter day*** across the whole of the UK, whereas the 50th and 90th percentiles project positive changes to temperatures of up to 4˚C (2020s).

Solar Insolation

Changes in ***summer mean daily maximum solar flux*** of up to 30W/m^2 at the 90th percentile for the southwest of England and parts of Wales (2020s).

Implications for Radioactive Material Transport Package Design

Current UK Climatic Conditions

Generally, designing to the temperature and insolation values given in TS-R-1, based on equatorial conditions, will accommodate all but the most extreme conditions in the UK. Even considering the significantly increased ratios between vertical and horizontal surfaces, this is true due to the lower total values of insolation; the highest ratios occur in winter when the angle of the sun is lowest, and the days are short.

It is worth noting that the common temperature range currently in use in the UK, and as previously quoted in BS 3895:1976 prior to its withdrawal, was from -10ºC to +26ºC. Given these results, it suggests that in any given year, this temperature range is likely to be exceeded on at least one occasion per month, for several of the hottest months of the year. There is therefore a significant chance that shipments may be disrupted as a result, with consequent operational issues.

The current range quoted in TS-R-1 has a high peak value of 38ºC. Table 2 of Ref 2 gives 1:100 return values, of which only three[5] of the upper limit monthly estimates exceed 38ºC. A practical interpretation is therefore that any package designed against the full temperature requirements of TS-R-1 is likely to be operable in the UK throughout any given 100 year period, although there is ~95% probability that on one occasion during this period the peak ambient temperature will exceed this value, and that this occurrence will almost certainly be during one of the three months of June, July and August.

Similarly, the range quoted in Table 2 of Ref 2 for 1:10 000 year return values, suggests that a design temperature of ~50ºC would be required to ensure availability of a package throughout most of any given 10 000 year period, with a corresponding probability of 95% that this value will be breached on one occasion during this period. Designing to suit this temperature value is well in excess of what is currently required by the regulations, and almost certainly over-engineering, due to the probable lack of capability of the transport infrastructure in these conditions.

Where there is a requirement to deviate from the values in TS-R-1, there is a commercial risk to be considered regarding the availability of the package, i.e. the smaller the operating range, the greater the risk that conditions on any given day will exceed those permitted, and the package will not be acceptable for use. The confidence limits applied in this study are intended to inform this decision making.

[5] Upper bounds of 1:100 year value for June 38.8ºC, July 38.5ºC and August 42.9ºC

A second key point is that although average insolation levels are below those given in TS-R-1, they can peak in the UK above the equatorial average. The distribution of insolation about the package differs markedly from that at the equator, and this may have implications for the thermal case of a package, as the sides will receive a greater component than the lid. Dependant on the design, it may be appropriate to ensure this is reflected in the safety assessment, for example in the conditions applied in computational analysis.

Due consideration should be given to the thermal inertia of the package, as this will influence the choice of input data to thermal modelling; for example, where the thermal response is rapid, it is recommended that the generally more onerous 8 hour values are applied.

Future Predicted Climatic Conditions

Results presented concur with the wider literature, and so can be accorded greater confidence - annual and seasonal mean and maximum temperatures across the UK can be expected to rise under scenarios of continued climate change. These same factors that affect package design are likely to also influence the design of supporting infrastructure and vehicles, which should be considered as part of the complete transport system.

There is likely to be a UK-wide increase in the summer mean temperature of the warmest day. Selection of a temperature range up to 26˚C is likely to become increasingly limiting over time. However, minimum temperatures, as well as the winter mean temperature of the coolest day are also very likely to rise, thereby reducing the frequency of cold extremes, and hence a minimum operating temperature of -10˚C is likely to become increasingly forgiving.

There is a slight increase in the range of expected average insolation values over the next few decades (The maximum peak values have already been experienced – see earlier discussion). The results cover the period up to the 2030s, and it is conceivable that new packages would have an operational life of some decades; these results may be applicable to packages currently being designed.

The predicted changes would bring the average daily values for June to a point closely approaching the value given in Table 13 of TS-R-1 of 800 W/m^2. Consequently, it is likely that as the time period in question (2020s) is approached, the Competent Authority may increasingly question the suitability of a reduced set of insolation values for general use in the UK, and may require additional operational controls to be in place for packages designed to an alternative range.

Existing packages seeking re-approval may benefit from consideration of these results in design review to assess any implications arising, and potentially to determine appropriate operating envelopes that may restrict use of the package in order to maintain safety, noting that it is, in general, more awkward to monitor insolation than, say, temperature.

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