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CONSIDERATION OF ASYMMETRICAL HEAT TRANSMISSION AND DISTRIBUTION USING NUMERICAL METHODS

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ABSTRACT

To demonstrate the compliance with IAEA safety requirements with respect to thermal routine and normal transport conditions, numerical analyses are widely used. Usually, a basic assumption for these numerical analyses is the basket centred in the cavity, which is a safe assumption to calculate maximum temperatures for the parts of the internal arrangement. At least, the vertical or horizontal transport position suggests the consideration of effects due to basket positions out of centre. Those thermal effects are an asymmetrical heat transmission into the cask wall and into lid and bottom respectively. This causes additional temperature stresses for moderator materials or plates at shell, lid and bottom, for instance. An additional effect causing asymmetrical heat distribution is solar insolation, which is stronger in the upper parts of the cask than in the parts facing to the ground. Barriers for casks used to keep temperature limits for the readily accessible surfaces according to §653 of IAEA No. TS-R-1 can create an asymmetrical heat distribution, too. Barriers as canopies, for instance, provide areas around the cylindrical cask with higher and lower convection.

In general, the paper investigates the above mentioned effects leading to asymmetrical heat transmission and temperature distribution using numerical analyses methods based on FEA and CFD. The analysis results are compared with experimental results and rather simple analytical approaches. The advantages and disadvantages of the different approaches are demonstrated and discussed. Conclusions are drawn concerning the limitations of these approaches and recommendations for their application are given. The unbalancing effects should be also considered as input data for fire accident analyses according to §728 of IAEA No. TS-R-1. Despite of the fact, that the consideration of canopies or other barriers due to §653 of IAEA No. TS-R-1 requirements are not required by §728. Nevertheless, the paper presents transient calculations to demonstrate this influence.

INTRODUCTION

For the demonstration of package safety with respect to thermal requirements, several IAEA paragraphs have to be considered as §651. Thus, the objective of thermal safety analyses is to provide the temperature distribution corresponding to routine, normal and accident conditions described by IAEA §657 [1]. Using calculations for safety analyses, simplified considerations or calculation models usually take place. Simplifications often neglect the asymmetrical effects. These effects add temperature gradients to the models which has to be taken into account for complete safety assessment.

Asymmetrical effects are caused by movement of internal arrangement out of centre due to transport configuration, by the use of thermal barriers and accompanied air flow or by different absorption of solar insolation also due to transport configuration. The pure addition of the calculated gradients would be a conservative approach. Nevertheless, a superposition of these effects is acceptable and also considered.

The mentioned asymmetrical effects are considered at first for routine conditions of transport. But they influence the analyses for accident conditions also, due to a different initial temperature distribution for the fire test. These influences and the consideration of thermal barriers as canopies is discussed in particular.

ASYMMETRICAL EFFECT: BASKET OUT OF CENTRE

At first, we assume a centred basket with a symmetrical heat dissipation into the structure. In particular, during transport considering a horizontal position of the package, the structure is usually off centred due to gravity. This transport configuration causes a stronger heat input into the lower part of the package. In addition to the asymmetrical heat input, the gap between basket and cavity wall in the lower part of the package is nearly closed, whereas in the higher part of the cavity this distance is larger than for a centred configuration. Sometimes there can be an additional direct contact of the main heat conducting design parts of the basket onto the cavity wall.

These effects increase the temperatures in the lower part of the packaging wall, which can hurt temperature limits of some moderator materials (figure 1). The influence on the internal temperatures is different: Due to the above described asymmetrical gap between internal arrangement and cavity wall, the resistance against heat dissipation is stronger in the upper part, but the heat input is higher in the lower part. In addition, sometimes we have to consider an additional influence of inhomogeneous loadings, which finally determines the areas of highest temperatures in the internal arrangement in combination with the described asymmetrical effects. Nevertheless, the described asymmetrical effects usually lead to higher maximum temperatures of the internal arrangement also, for cladding and basket parts, than a centred transport configuration.

The described effects can be investigated by numerical calculations as finite element analysis (FEA). Based on a model with centred basket, the heat dissipation can be influenced by changing the modelling in the outer part of the cavity between internal arrangement and cavity wall. For a first approach, the properties of some finite elements arranged in this gap can be adjusted to realise a full contact by change the material properties from gas to basket or wall material. In the upper part of the cavity, the thermal properties of finite elements should be lowered for increasing heat resistance.

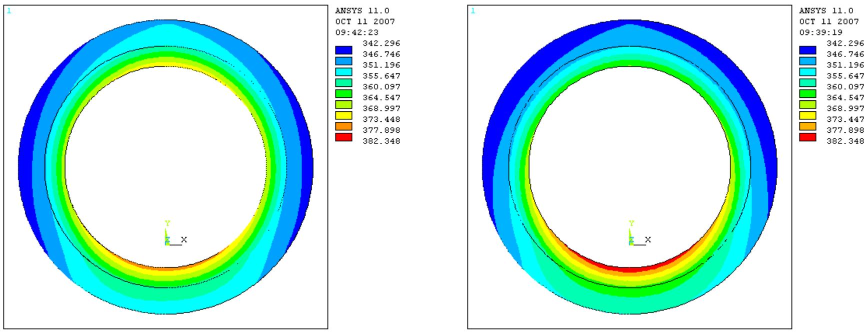

Figure 1: Increased temperatures in the lower part of the cavity wall due to basket off centring

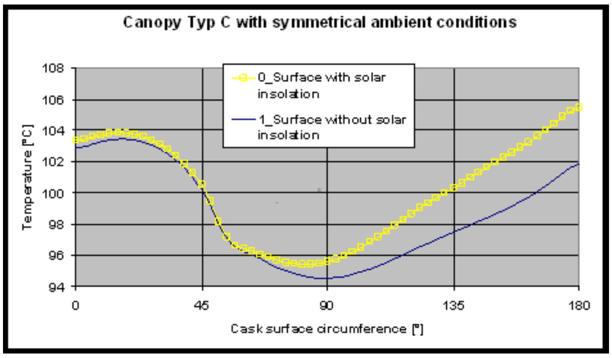

Figure 2: Influence of solar insolation on the package surface temperature

ASYMMETRICAL EFFECT: THERMAL BARRIERS AND SOLAR INSOLATION

Again, assuming a horizontal transport position, a package suffers at least a natural convection according to its heat generation and ambient conditions as the 38°C regime. Though analytical approaches as for the flowed cylinder for instance exist, they provide only an average temperature. Nevertheless, a temperature gradient will exist anyway.

In addition, solar insolation effects the surfaces of the package in a different way due to the surface orientation to the sun. In particular for packages with lower heat generation, solar insolation causes a temperature gradient on the package surface at least. Natural convection provides also higher temperatures in the upper part of the package surface as solar insolation. The resulting temperature gradient depends strongly on the level of heat generation and the ambient conditions as ambient temperature and the level of solar insolation (figure 2, with 0° at the lowest point of the cask surface and 180° at the highest one).

Using thermal barriers, the ambient conditions for the package are changed. Canopies, for instance, realises a complete embedding of the package. Therefore, solar insolation and the ambient temperature are applied for the outer surface of the canopy at first. Nevertheless, openings in the canopy at different heights enable a natural flow in the area between package outer surface and canopy interior surface. The heat dissipation by radiation is

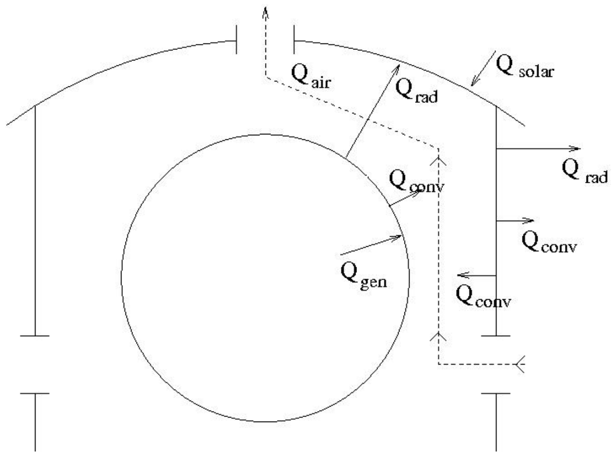

Figure 3: Thermal equilibria using a canopy according to [5]

determined by the temperature of the canopy interior surface in addition to geometry and emissivity coefficients. A temperature gradient on the canopy generated by solar insolation and natural convection on the canopy outer surface influences the heat dissipation and the gradient on the package surface. As for packages without thermal barriers, there is also a temperature gradient for packages using thermal barriers as canopies, but the characteristic of the gradients will be different.

The gradients mentioned above effects the package surface at first. They will be reduced in the interior parts of the package. Nevertheless, moderator materials, for instance, are usually placed in the outer part of a package and will be hurt by this asymmetrical effect. Additionally, the temperature limit for a readily accessible surface in accordance with §653 of TS-R-1 [1], which is 85°C for a package under exclusive use, should be met even considering gradients for a canopy or if not present, for the package itself.

To calculate an average temperature, analytically based approaches can be sufficient. With realistic convection and emissivity coefficients for the package surface, well known empirical approaches provided by [2] [3] will be sufficient for that. To quantify additionally the temperature gradients described above, numerical methods as computational fluid dynamics (CFD) should take place. CFD enables to place the package in an air flow and to calculate the generated natural convection. Radiation models are also available.

Considering a canopy, average temperatures for canopy and package surface can be calculated with sufficient accuracy by approaches based on natural convection laws, thermal equilibria and pressure differences developed by P. Zeisler [4] and shown in figure 3 [5]. For temperature gradients again CFD analyses are necessary.

Numerical models can be enlarged to incorporate in addition to the canopy partially the environment. That enables the consideration of solar insolation directly in the CFD model. Applying CFD in this way, the gradient effects due to solar insolation and natural convection can be superposed.

The comparison with measurement results of packages with a canopy demonstrates, that calculation approaches usually provide higher temperature gradients (figure 4) [6] [7]. Do not take credit of symmetry in a two dimensional CFD analysis and consider the hottest cask section as a whole, lowest pressure differences between left and right hand

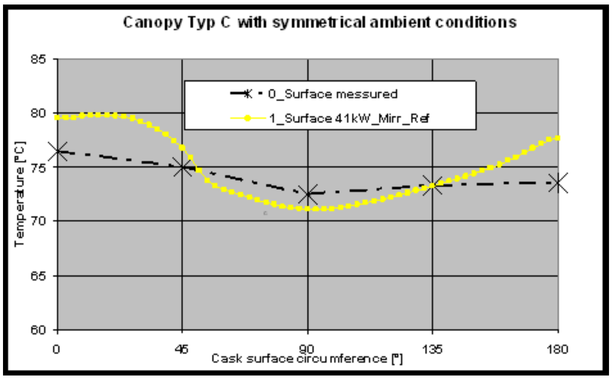

Figure 4: CFD analysis provides higher temperature gradients than measurement results

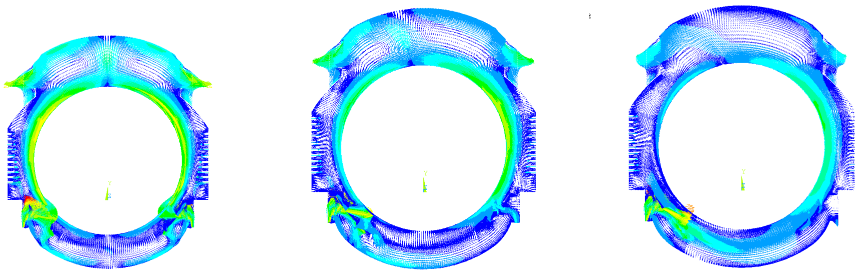

Figure 5: Increased turbulence due to lowest pressure differences between left and right hand side

side improves the heat dissipation in a CFD analysis due to increased turbulence (figure 5). This effect has an significant influence on areas, where only a slight flow is present. For instance, the heat dissipation on the lower part of the package will significantly better (figure 6), and therefore the temperature gradient decreases and will be nearer to the experimental results (figure 7). Even experimental results depend on effects, which do not enable a perfect modelling of TS-R-1 requirements. But analysis can fill this gap. If analysis models are validated on experimental results, the required perfect conditions can be considered by accurate analysis afterwards.

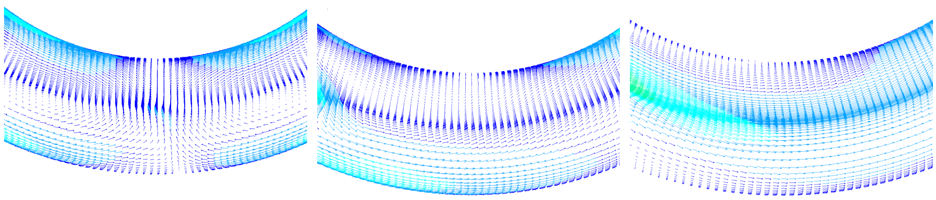

Figure 6: Increased turbulence at the lower part of the package due to pressure differences

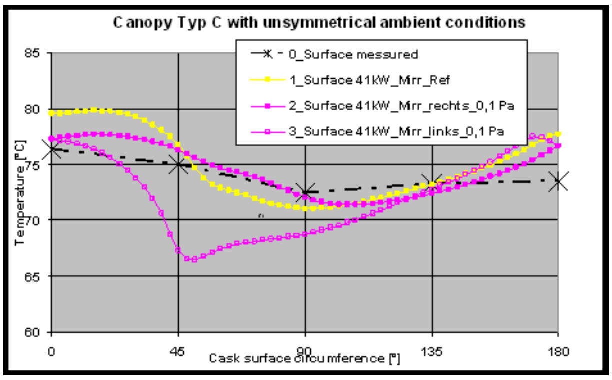

Figure 7: Consideration of pressure differences provides results nearer to measurements

SUPERPOSITION OF ASYMMETRICAL EFFECTS

In addition to the already discussed superposition of solar insolation and natural convection, the influence of an off centred basket can be included. The off centred basket increases usually the temperatures in the lower part of the package. For solar insolation and natural convection, the tendency is vice versa. Therefore, to get a realistic view on the temperature gradients, the mentioned effects should be overlayed. For most packages, the temperatures in the lower part of the package will be the highest ones and they will be decreased by superposition of the asymmetrical effects.

Again, CFD analysis will be the first choice. For this kind of analysis, the two dimensional CFD model should include the package wall enlarging the already modelled package surface. That means the CFD code should provide sufficient thermal options to give valid results for the fluid problem and the thermal problem.

Figure 8 shows the asymmetrical effects due to free air stream without a canopy and the gradients with canopy as well as the superposition of basket off centring and canopy effect in relationship to the average temperature. The canopy design used here provides the highest temperatures at the lower part of the package surface (0°), whereas the free air stream gives a temperature maximum at the upper part at 180°. Considering the gradient due to basket off centring additionally to the canopy, the temperature decreases, but the maximum remains in the lower part of the package surface. In addition, figure 8 gives an impression of the influence of basket off centring only.

INFLUENCES ON ACCIDENT CONDITIONS

For thermal accident conditions, the calculation is splitted into three parts according to §728 [1]: At first, the initial temperature distribution has to be determined. Following, the thirty minutes fire event takes place. Finally, ambient conditions has to be considered again until temperatures in the package are everywhere decreasing or steady state conditions are approached. Asymmetrical effects will be present during each step, but the influence will be different.

As an example, we discuss the following scenario: Using a canopy during transport and loss of the canopy directly before the fire accident starts. That means usually a higher temperature level in the package due to the decreased heat dissipation. Figure 9 shows the

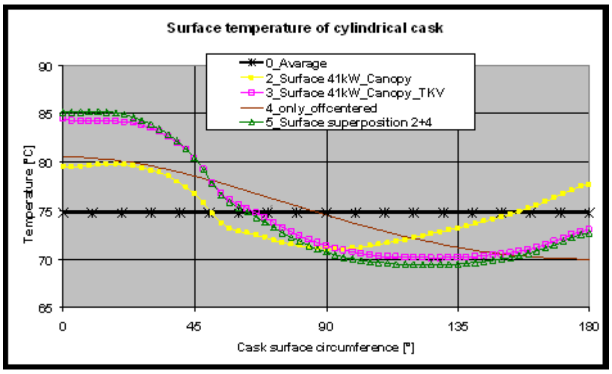

Figure 8: Superposition of asymmetrical effects

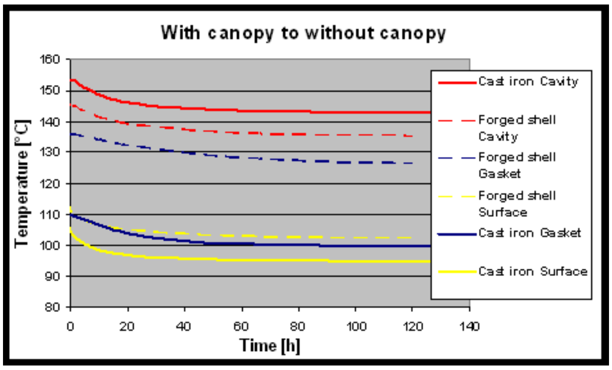

Figure 9: Time after canopy loss to reach the same temperature level as without canopy

time needed after canopy loss to reach the same temperature level as a package without canopy. In comparison to the boundary conditions for a package without canopy, the bulk temperature for convection will be the average temperature of the air under the canopy and the reference temperature for radiation will be the temperature of the interior surface of the canopy. For a package without canopy, we could assume ambient temperature for both cases.

Despite this scenario seems to be realistic, IAEA safety regulations do not require the consideration of this case today [1]. §653 of TS-R-1 says, that there is no need to subject thermal barriers to any test.

CONCLUSIONS

The argumentation and the examples provided by this paper demonstrates clearly, that asymmetrical effects and following temperature gradients effect significantly the temperature maxima in the package. Therefore they have to be addressed sufficiently in package safety analysis for completeness of safety assessment.

In addition, the paper provides advice for the determination of the temperature gradients and the usefulness of experimental and numerical approaches: Based on experimental results, which prove the validity of numerical models, the conformity with IAEA requirements can be demonstrated by numerical analysis considering perfect IAEA boundary conditions.

The superposition of asymmetrical effects to get a rather realistic view on package temperature distribution can be performed by using the options of already available numerical codes.

Asymmetrical effects will possibly hurt all steps of fire accident analysis. Even, CFD enables a look behind IAEA requirements to check rather realistic scenarios concerning initial temperature distributions for the fire accident.

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