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ABSTRACT

This paper compares theoretical predictions of vitrified nuclear waste glass package collapse with experimental values in order to qualify the mathematical models describing canister deformation under external pressure loads. After briefly outlining the program and describing the experiments performed, the paper discusses the theoretical predictions based on the INCA code from the CEA's CASTEM system.

OVERVIEW

Vitrification has been adopted in France for containment of high level liquid wastes. A vitrification unit known as AVM has been operating at Marcoule since 1978; as of November 15, 1988, AVM had solidified 1246 m^3 of solutions containing 214 MCi.

Two other facilities have been built by COGEMA at La Hague as part of the fuel reprocessing complex: vitrification units "R7" and "T7" will be operated with reprocessing plants UP2-800 and UP3, respectively. R7 and T7 use a continuous vitrification process in which radioactive glass is produced at a rate of 25 kg per hour, and cast at 8-hour intervals into cylindrical metal canisters Each canister is designed to receive two 200 kg melts representing a volume of about 150 liters.

After filling, the canisters are cooled and sealed by a plasma welded metal cover. They are then decontaminated if necessary, and transferred to an interim storage facility in which they will be cooled by forced air convection for a few decades before final disposal, probably in an underground geological repository.

As part of the safety analysis to define the long term behavior of the solidified waste package, a "glass source term" is defined to include not only characterization of the containment material itself, but also of the complete waste package comprising the glass and the metal canister. Tests are conducted to determine the chemical, radiochemical, thermal and mechanical properties of the package. The investigation presented here concerned mechanical distortion of the canister under external pressure.

The total internal volume of the canister is 169.2 liters, although it contains only 150 liters of glass (Figure 1). The void at the top of the canister, with a theoretical volume of 19.2 liters, is therefore subject to deformation, e.g. under pressure loading.

Although it is obviously out of the question to store the containers in a repository without suitable protection, investigation of pressure deformation was considered a good example for developing theoretical models and qualifying them on full scale experimental mockups. Correlation of theoretical and experimental results is the only reliable qualification method to substantiate the use of such models in future safety analyses on other waste packages.

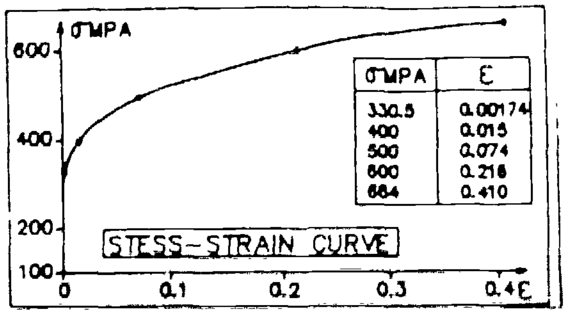
The canisters are made of Z15 CN 24-13 stainless steel with the following chemical composition:

Element:	C	Si	S	P	Cr	Ni	Mn	Fe
%	0.17	0.62	0.01	0.03	22.87	13.70	1 48	rest

Physical properties relevant to the theoretical investigation include the following:

Young's modulus		190 MPa
Poisson's ratio		0.3
Yield stress	σ_y	330.5 MPa
Rupture stress	σ_u	664 MPa
Rupture strain	ϵ_u	41%

The stress-strain curve is shown opposite.



Empty canister heads corresponding to the volume unoccupied by the glass (Figure 2) were tested under hydrostatic oil pressure. Results are presented here for two of the tests conducted by the CEA/DEMT. The purpose of these two tests was to determine the collapse or failure mode and the corresponding pressure value. The principal deformation measurement was the volume variation of the cavity inside the canister; the pressure was also recorded.

The experiment indicated a collapse load of about 28 MPa. Incipient cracking occurred at this load value on one of the two cylinders at point A of the model; the pressure reading dropped suddenly at the same time.

CALCULATION PROCEDURE

For collapse calculations the structure was modeled as an axisymmetric shell using forty-five 2-node shell elements. The CASTEM codes system was used for the analysis: GIBI for the meshing, INCA for the comparison and ALICE for post-processing.

Plasticity and large displacement were assumed for the analysis. A global plasticity model was used, i.e. instead of considering plasticity at different points through the thickness, a yield function was constructed based on efforts and bending moments applied to the shell; refer to Hoffmann et al (1973) for more details. A special control technique was used to monitor the post-buckling behavior after the pressure peak. The method consisted in adding a control equation to the equilibrium equations in order to monitor the maximum displacement and thus determine the pressure; refer to Combescure (1986) for further information.

The calculation was performed incrementally by increasing the pressure up to 20 MPa, then using the displacement control algorithm to the end of the calculation. The maximum sustained pressure was 30 Mpa. This was followed by a pressure reduction to 24 MPa and stiffening of the structure up to 40 MPa, where the calculation was terminated.

A special post-processor was developed to obtain the volume variation from the displacement field. The experimental and theoretical results are compared in Figure 3, showing very good agreement. The calculated and experimental deformed shells are shown in Figure 4, also showing very good qualitative agreement. Figure 5 indicates the deformation versus the pressure at point A. The rupture strain ϵ_u was reached at a pressure of approximately 25 MPa, which is fully consistent with the observed crack inception at point A at this load level.

The crack does not substantially reduce the overall stiffness of the shell, but containment integrity can no longer be ensured. In one instance the crack appeared at the same load level as structural collapse. In this sense it may be argued that the shell is well designed, since the two failure modes occurred at the same load level.

CONCLUSION

The investigation showed good agreement between the behavior of an empty canister head predicted from finite-element analysis and observed experimentally. The failure mode was accurately predicted by calculation. Plastic collapse occurred at the same load level as crack inception in this test. The theoretical method may therefore be considered well qualified for use in designing canisters to withstand external pressure.

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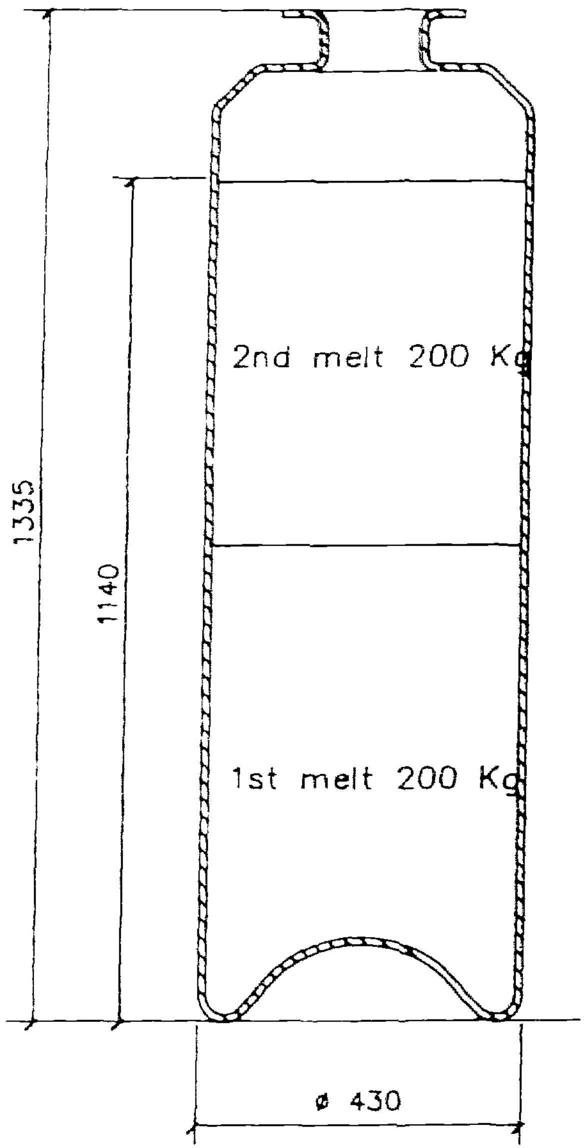

Fi. 1 – R7/T7 NUCLEAR WASTE GLASS PACKAGE.

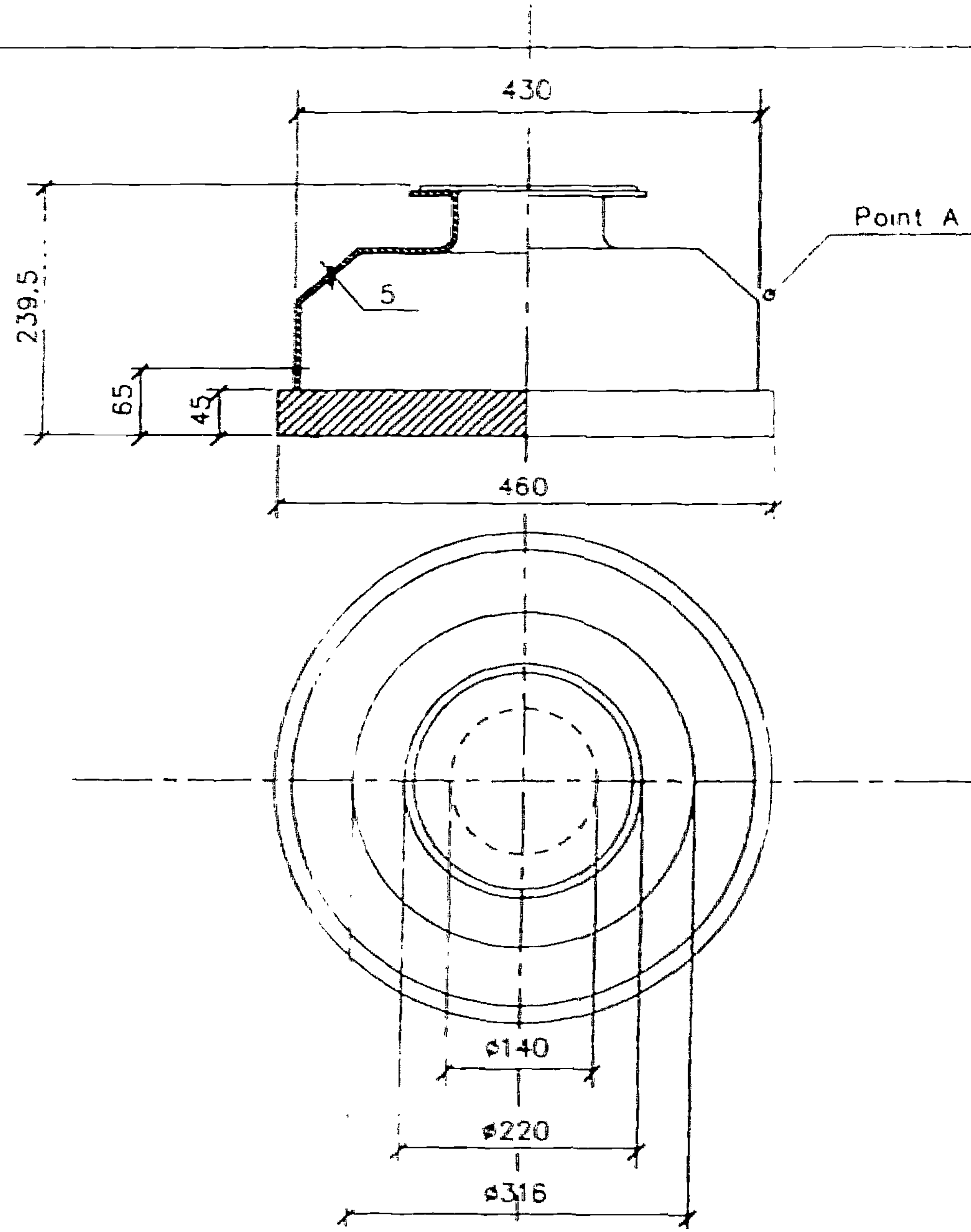

Fig. 2 – SPECIMEN GEOMETRY (Dimensions in mm).

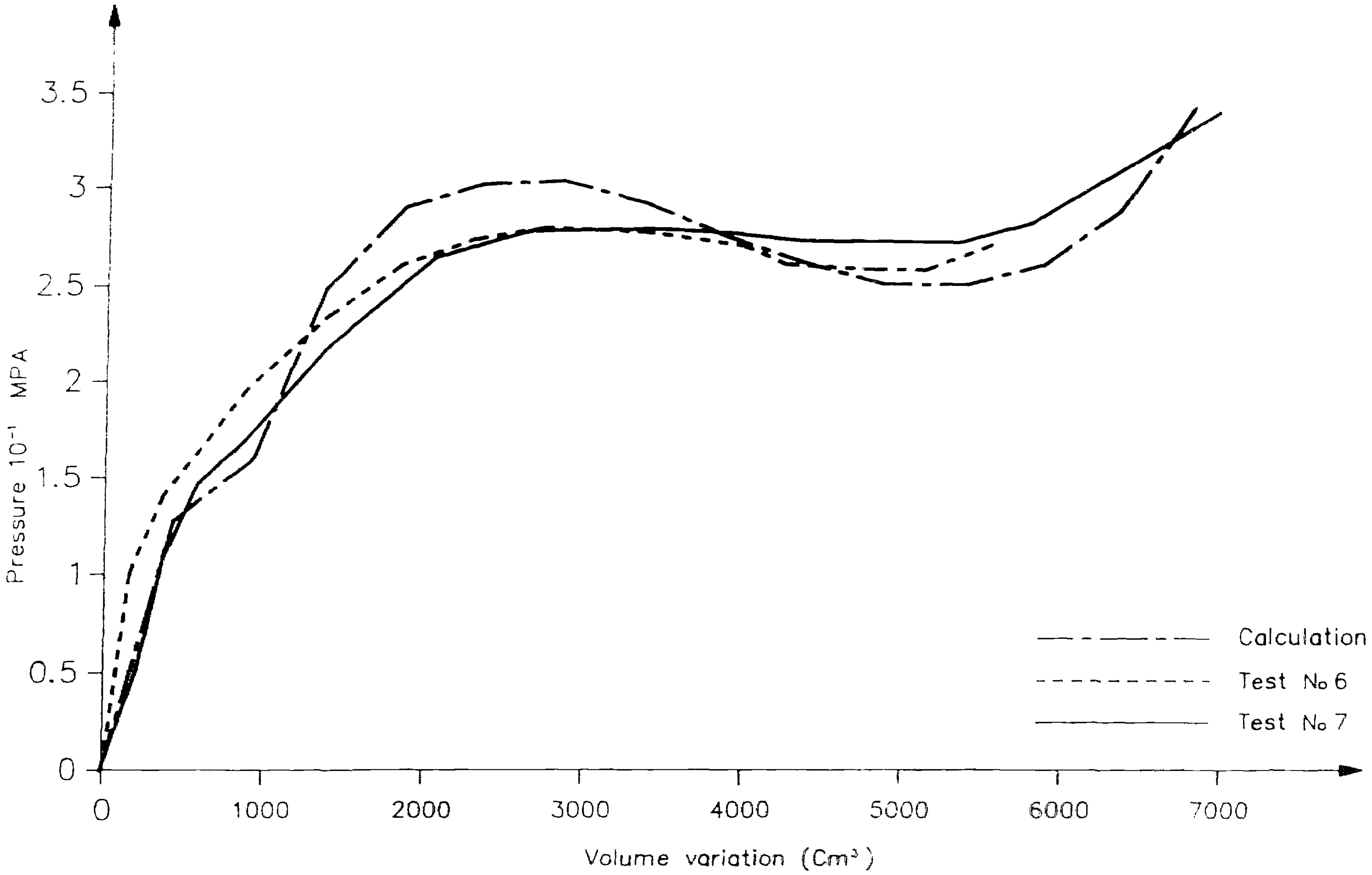

Fig. 3 – VOLUME VARIATION VERSUS PRESSURE.