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Study of the mechanical consequences of HAC drops for R72 and R73 radioactive material transport packages without impact limiters while handled on operating sites

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ABSTRACT

Type B transport packages are generally equipped with impact limiters whose purpose is to absorb shocks under Accident Conditions of Transport. During operation on nuclear sites, these impact limiters can be removed to allow lifting and transfer in order to carry out the loading phases for example.

Several studies have been conducted jointly by ROBATEL Industries and EDF to justify the safety of the R72 spent fuel rod transport package and the R73 activated wastes transport package for onsite potential handling event when these packages are not equipped with their impact limiters.

- Dynamic studies using the LS-DYNA finite element program were performed on the R72 transport package, considering:
- Different types of impact ground: elastic or reinforced concrete, impact-absorbing cellular materials;
- Drop heights between 8 and 28 meters;
- Different orientations: end or corner drops, rear impact limiter facing down.

Similar studies were conducted on the R73 packaging, considering:

- A rigid ground,
- Drop heights of 2 meters
- Different orientations: end or corner drops, lid facing down.

In any configuration, both studies showed that the contents of the packages are held in the package cavities by the containment system. In addition, the containment sealings maintain a significant compression ratio.

This article will present the assumptions and methods used to calculate these specific accidental conditions, thus demonstrating the robustness of type B packages designs in a context that extends beyond transport regulation.

INTRODUCTION

Electricité de France (EDF) uses packages for radioactive material transportation designed and manufactured by ROBATEL Industries, including R72 and R73 packages. These transport packages are sometimes handled without their impact limiters while being transferred on the installations on which they are used.

In order to verify the maintenance of safety in handling accidents, EDF and ROBATEL Industries have studied the mechanical consequences of the fall of these packages in different configurations representative of their use:

- Concerning the R72 packaging not equipped with its impact limiters 12 drop calculations using dynamic calculation software were performed – axial and angle drops, heights from 8 m to 28 m.
- Concerning the R73 packaging not equipped with its impact limiters 2 drop calculations using dynamic calculation software were performed – axial and angle drop, heights of 2 m, impact on a rigid target.

In each configuration, the damage status of the packaging bodies, the containment enclosures and of the closure systems (lids and bolts), as well as the compression rate of the containment gaskets or the loss of the biological protections thickness (lead compaction for instance) were examined in order to assess on the safety of the packages and their radioactive material containment performances.

BRIEF OVERVIEW OF THE R72 AND R73 PACKAGES

ROBATEL Industries designed and manufactured the R72 and R73 casks which both are type B transport packages. It has indeed specialized for decades in designing, application for approval and manufacturing of packages for the transport of radioactive material.

Founded in 1830, the business started in the early 50’s with the development of the first transport packaging in France and is now exclusively working for the nuclear industry. It has thereby followed up the evolutions of this sector in terms of safety requirements and technical innovations. With its strong experience, it proposes worldwide turnkey solutions integrating all the technical and operational aspects of projects.

Upon the last 70 years, the company has thus designed over 80 type B packages and manufactured over one thousand units (all types included) for the transportation of miscellaneous types of radioactive material: spent fuels, waste, sources, radioactive liquids or activated pieces...

Each package designed by ROBATEL Industries is unique and specially developed to meet the applicable transport regulations requirements, but integrating all operating needs and specificities arising from users as well.

For the R72 and R73 casks, this especially included additional assessments addressing their safety performances in case of hypothetical on-site transfer incidents.

Description of the R72

The R72 package is generally cylindrical in shape (see Figure 1). It is intended to transport irradiated fuel rods. The rods are placed in a quiver, which is itself placed in a case in the packaging cavity. This packaging can carry up to 10 UOx or MOx rods.

It mainly consists of a body and two impact limiters. The body is hermetically sealed at each end by two lids. The diameter of its body is 0.95 m for a length of 5.5 m (excluding its impact limiters). When loaded, its mass is 21.5 tons.

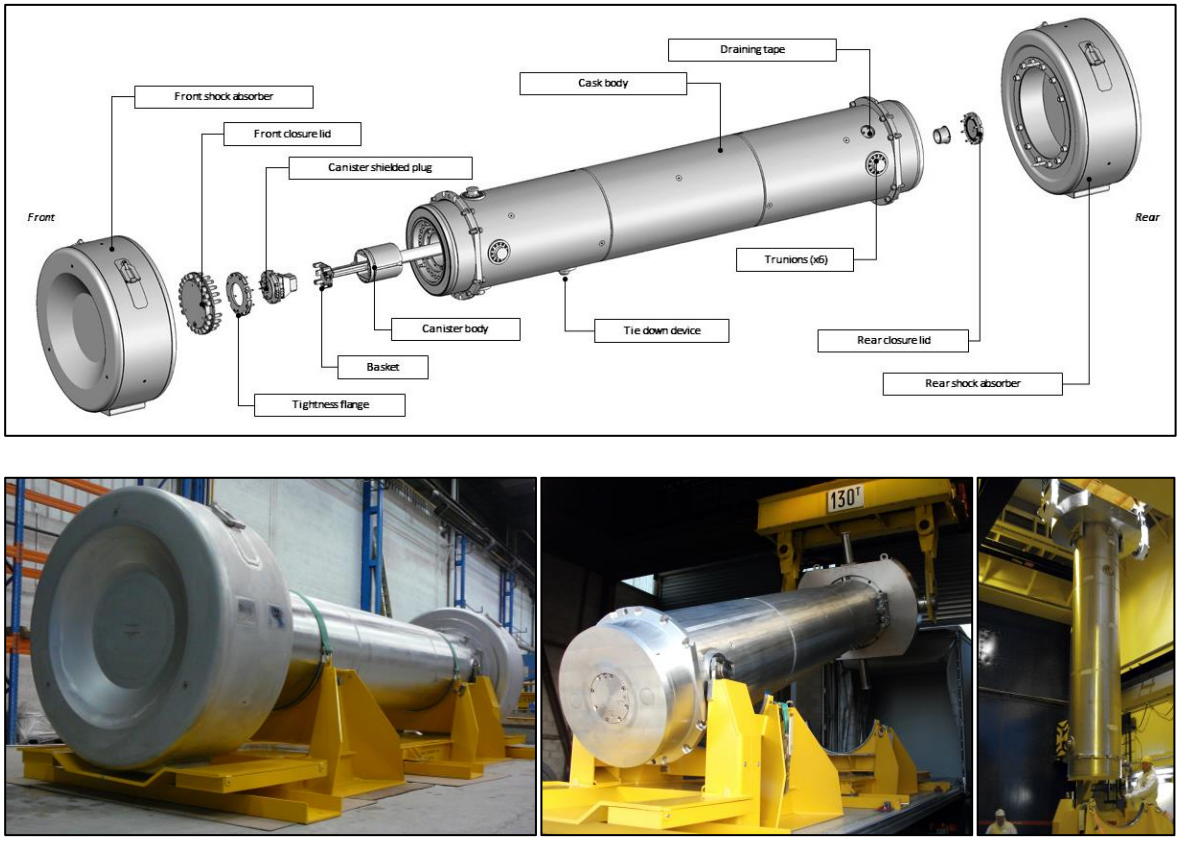

Figure 1 : Overview of the R72 package

The content transported by the R72 package (radioactive material + internal fittings) are placed inside the internal cavity of the package's body. This cavity can be equipped with a canister, for example, containing the radioactive material to be transported.

The R72 is a double containment packaging: the first barrier consists of the canister closed by a plug, the second is the cask's cavity closed by the front and rear lids.

Description of the R73

R73 packaging is generally cylindrical in shape (see Figure 2). It is designed to transport activated metal waste from decommissioned nuclear power plants, cut up and placed in a specific basket. This packaging can carry up to 2,000 kg of waste.

It mainly consists in a body, a sealed plug, a lid fixed by 30 bolts and two impact limiters.

The body has a diameter of 1,744 m and is 1,473 m high (excluding its impact limiters). When loaded, its mass is of 20.9 tons.

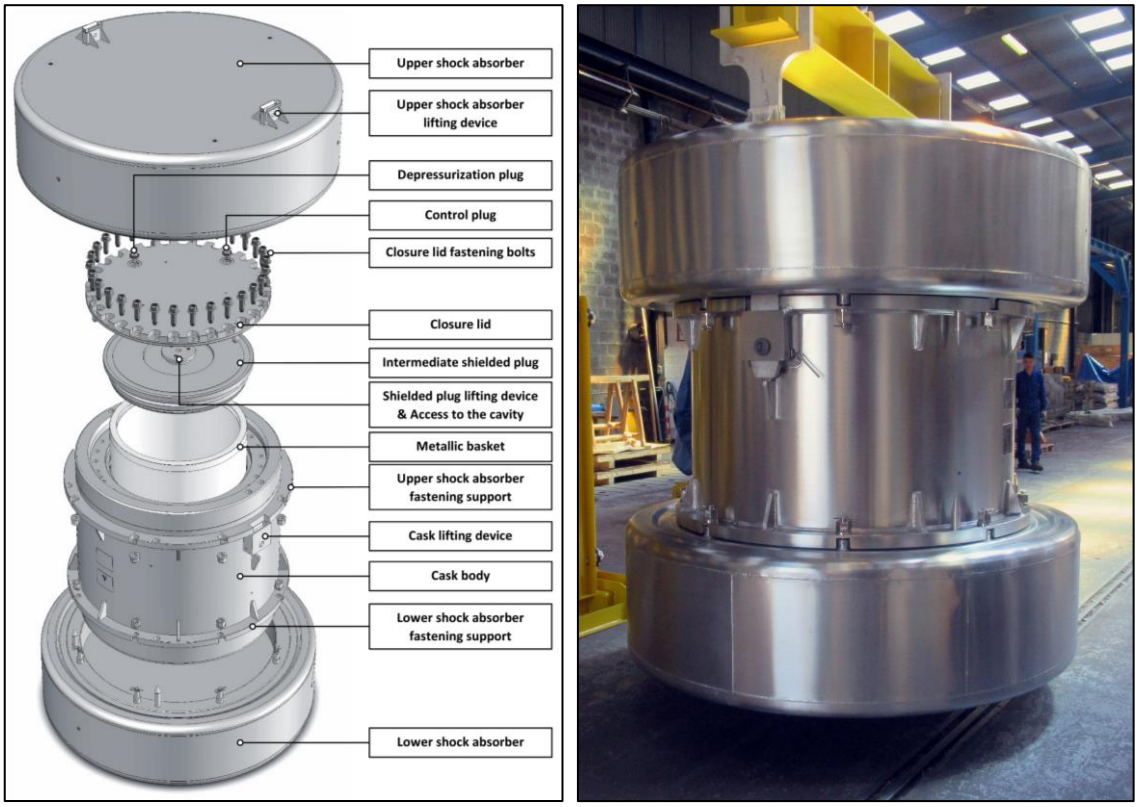

Figure 2 : Overview of the R73 package

DROP CALCUATIONS CONDITIONS

Drop conditions of the R72 package without impact limiters

A total of 12 falls in different configurations were considered. The LS-Dyna dynamic calculation software was used for these studies.

- A first scenario including 4 falls of the R72 packaging body from a height of 8 m, without impact limiters, on a 2.5 m thick floor, either purely elastic or represented by a bi-linear law.
- A second scenario involving 4 falls from the body of the R72 packaging on a deformable floor (a 0.80 m thick reinforced concrete slab or a 3.80 m thick cellular concrete block).
- A third scenario involving 4 falls from the body of the R72 packaging on a deformable floor (a 3.34 m or 2.00 m thick cellular concrete block). In these configurations, the R72 is loaded and filled with water.

For each of these floor configurations, one fall is made in the vertical axis of the packaging and one fall is made at an angle of 9.2° (see Figure 3). The front of the packaging is always facing upwards. The following Table 1 summarizes all the configurations analyzed.

Scenario	1.1	1.2	2.1	2.2	3.1	3.2
Concrete Target	Linear	Bi-linear	Reinforced	Cellular	Cellular	Cellular
Target thickness	2.50 m	2.50 m	0.80 m	3.80 m	3.34 m	2.00 m
Height	8 m	8 m	21 m	28 m	17 m	13 m
Impact velocity	12.53 m/s	12.53 m/s	20.30 m/s	23.43 m/s	18.26 m/s	15.97 m/s
Water	no	no	no	no	yes	yes

Table 1 : R72 – Drop calculations scenarii.

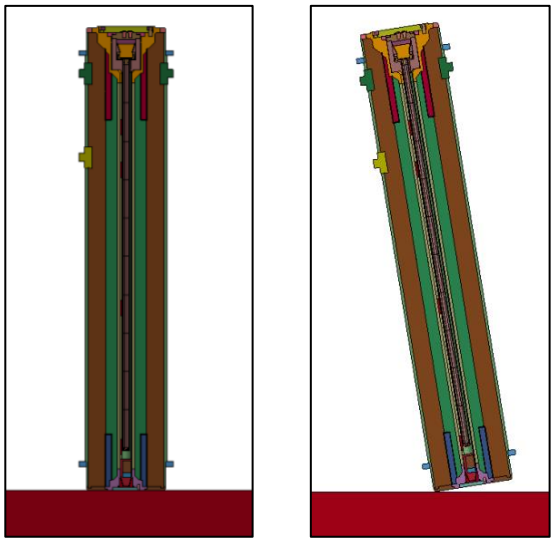

Figure 3 : R72 – Illustration of the drop configurations (axial & angle for each scenario)

Drop conditions of the R73 package without impact limiters

As the on-site handling heights would not exceed 2.0 m, only one drop height has been studied for the R73 packaging. The calculations were also performed using the LS-Dyna software. Two calculations were performed at two different angles of fall (45° and 25°: see Figure 4).

In both configurations, the lid of the R73 package is oriented downwards and its content is initially shifted to the bottom of the cavity in order to observe the consequences of an internal delayed impact. The ground (target) is considered rigid.

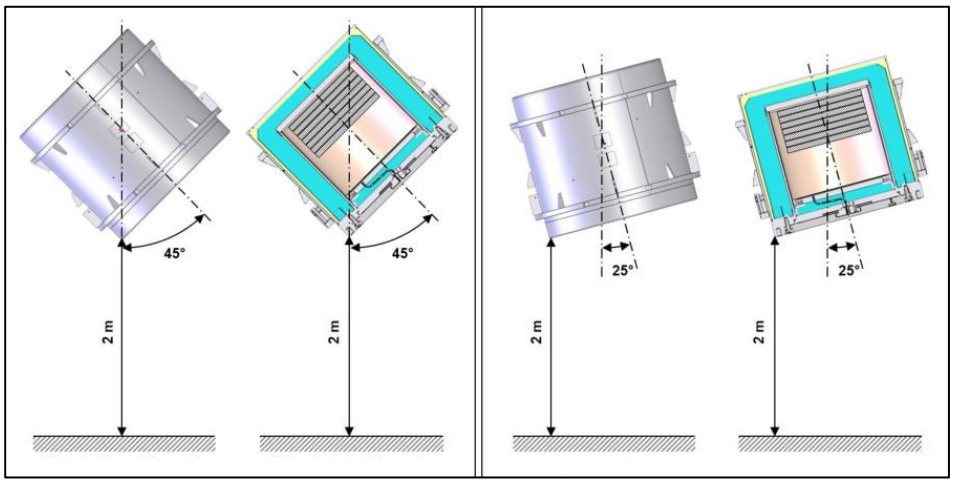

Figure 4 : R73 – Drop configurations

MAIN RESULTS AND R72/R73 PACKAGES PERFOMANCES

Deformations

In all configurations and for both packages, the flange and outer shell of the packages undergo significant plastic deformations without risk of rupture in the containment (plastic deformations values are much lower than the standard rupture deformation value of stainless steels used on the packages).

For R72 packaging, regardless of the configuration, the most deformed element of the containment system following the falls is the rear flange to which the lid is bolted. The maximum deformation rate (22.0%) is reached in the angle drop of scenario 1.1 (see Figure 5), which is much lower than the breaking deformation of the steel used on the R72 packaging (37.5%). From this point of view, there is no risk of a containment failure.

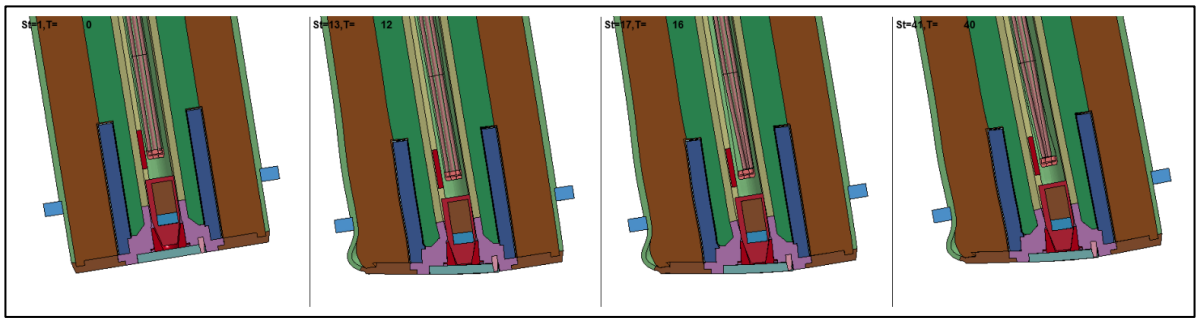

Figure 5 : R72 – Scenario 1.1 angle drop deformation

Concerning the R73 package (see Figure 6), since the drop heights studied were significantly lower, only the values of the deformation rates of the lid screws were examined. They are presented further in this article.

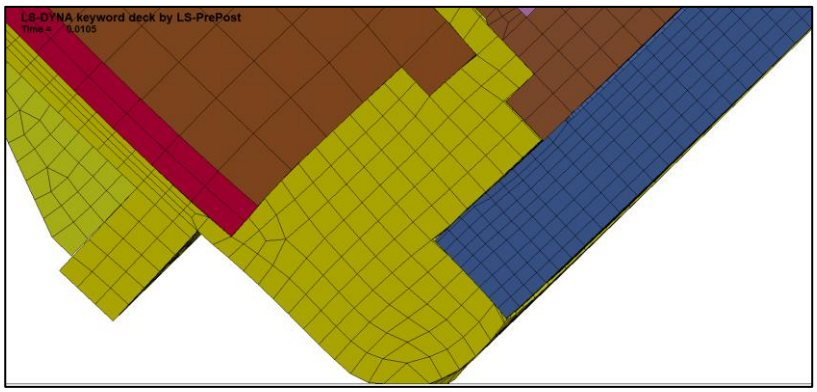

Figure 6 : R73 – 45° orientation drop flange deformation

Closure system

For both packages, the flanges on which the lids are fixed are deformed, which leads to plastic deformation of the closure screws. These bolts hold the lid of each of the packages studied. For the various calculations, the tightening strength of the bolts was taken into account in the two numerical models.

Regardless of the packaging or drop configuration, the lid of the closure system remains in position without any risk of losing the contents. The following Table 2 details the results regarding the bolting system of the packaging lid:

Package	R72	R73
Lid bolts number	8	30
Max deformation in a bolt	9.2% *(2 bolts out of 8 concerned)*	6% *(2 bolts out of 30 concerned)*
Broken bolts	None	None

Table 2 : Deformation levels in the bolts

Air tightness

The sealing at the rear lid of the R72 packaging is ensured by a double seal system whose containment O-ring has a torus diameter of 6.99 mm. The maximum depth of the groove of the rear cover containment joint is 5.55 mm.

Among all the calculations carried out on the R72 packaging, the maximum local splitting of the joint plane – between the lower surface of the lid and the upper surface of the flange at the diameter of the containment O-ring – reaches 1.25 mm at the very moment (maximum value, in dynamic) and 1.20 mm permanently afterwards (see Figure 7). These values are obtained for the angle drop of scenario 1.1. Given the crushed thickness, the R72 package remains sealed at its containment O-ring even after falls without impact limiters as described in this article.

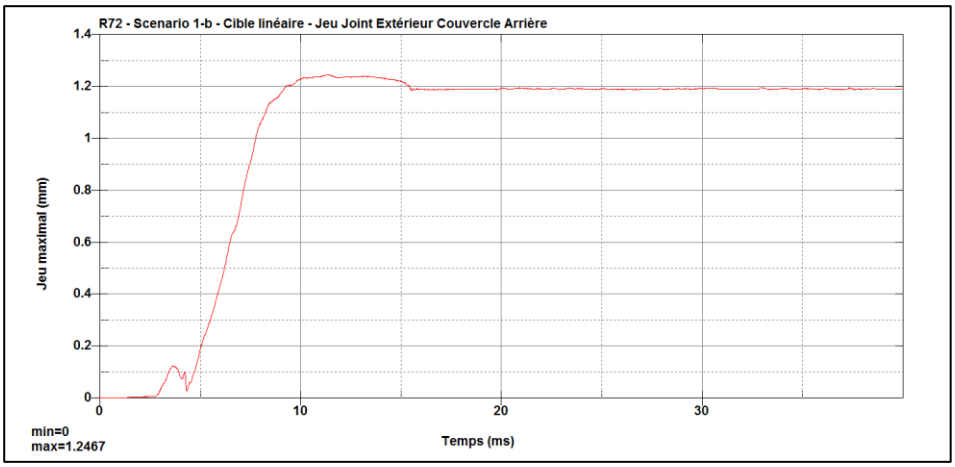

Figure 7 : R72 – Maximal O-ring gap opening (scenario 1.1)

For the R73 package, the O-ring that provides containment between the cover and the flange is a 12.00 mm diameter O-ring. The configuration that leads to the most significant joint plane splitting is the 45° configuration, an illustration of the maximum deformation of which is shown in Figure 5.

The maximum joint plane splitting reaches 1.30 mm at the very moment (maximum value, in dynamic) and 1.20 mm permanently afterwards (see Figure 8). Under these conditions and taking into account all the uncertainties, the compression rate of the containment joint remains above 6%. Air tightening is therefore also ensured at this level.

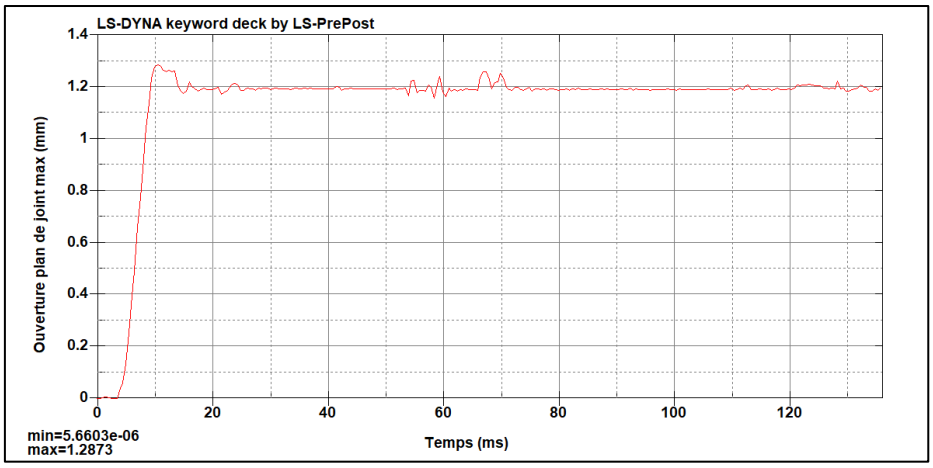

Figure 8 : R73 – Maximal O-ring gap opening (45° configuration)

Containment

R72 and R73 packages, when not equipped with their impact limiters, are able to withstand the falls described above ensuring that:

- The containment joints remain compressed;
- The components of the containment enclosures reach deformation levels well below their failure limit;
- The closure systems remain closed, no bolts are threatened of failure.

The containment of radioactive content is thereby ensured regardless of the configuration.

CONCLUSION

The “off-regulation” additional analyses presented above shown that the design of the R72 and R73 transport packages enables them to maintain their safety functions during on-site handling phases even when they are not equipped with their impact limiters.

The deformation levels reached in the containment enclosures, in the closure systems bolts and the compression rate of the containment seals remain sufficient to ensure tightness and thus to prevent any significant activity release.

Finally, these studies would also tend to point out two main conclusions:

- The first outcome is that the ground actual properties to be considered (i.e. the target for drop test) and the way to represent or model it are probably among the major key points addressing the overall mechanical behavior of packages in case of accident drop. This is especially true when looking at fall of the packages without their impact limiters.
- The second point, is that the design of type B transportation packages, which are supposed to withstand the very severe accident regulatory conditions, should usually be strong enough to ensure safe on-site operation as well even in case of hypothetical handling incident. This is likely due mainly to the extreme conservatism of the regulations regarding to the drop test target which should be considered as totally rigid. Actually, according to the previous conclusion, such an assumption results thus in really robust type B package designs.