UNSATURATED FLOW MODELLING IN HIGH-LEVEL NUCLEAR WASTE REPOSITORY

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Abstract

In the context of high-level nuclear waste repository safety calculations, the modelling of desaturation and saturation processes in low permeable porous media is of first importance. By trapping or not the air in the system, the saturation time scales of the repository components determine the physico-chemical behavior of the repository. Therefore these processes control the host rock confinement properties and the geochemical processes responsible for waste canister failure.

In order to simulate unsaturated flows in the repository host rock media, we developed, in the Cast3m tool, a modified Richard's model with a storage coefficient. This allows to take into account the transient head inside a fully saturated area of the domain. Different spatial schemes are implemented (Mixed Hybrid Finite Elements, Finite Volumes (MPFA)).

In this paper, we present a 3D desaturation and saturation computation of a repository drift. This enables us to evaluate the occurrence of air entrapment in the repository.

1. Introduction

In the context of high-level radioactive waste disposal, the modelling of the processes of host rock desaturation and host rock, backfills, seals and engineered barriers saturation is of first importance [*Andra*, 2005b].

The desaturation processes are strongly coupled with mechanics, and can induce host rock confinement properties changes. The physico-chemical behavior of the repository is highly dependent on the time scale of the repository components saturation. Indeed, the saturation processes mainly control corrosion and other geochemical processes responsible for waste canister failure and waste dissolution [*Andra*, 2005b]. Therefore, radionuclide source term depends on saturation processes.

The objective of this paper is to evaluate the occurrence of air entrapment in the repository due to early repository drift seal saturation. A rapid saturation process of seals can trap air in the system. The trapped air phase building pressure can in turn lead to a retardation of saturation. In this case, two-phase flow processes including air dissolution have to be taken into account in the saturation modelling.

2. Materials and methods

2.1. **Model.** We consider a common form of the Richard's equation (1) including specific storage coefficient [*Miller et al.*, 1998]

$$(C(\Psi) + s.S_s)\frac{\partial \Psi}{\partial t} = \nabla.(K_w(\Psi)\nabla H_w) \quad (1)$$

where C is the specific moisture capacity, S_s is the specific storage coefficient, s is saturation, Ψ is the pressure head and H_w the hydraulic head.

2.2. **Numerical scheme.** The Richard's equation is solved using CAST3M via a Picard non-linear solving algorithm with a fully implicit time scheme. Mixed Hybrid Finite Element [*Dabbene*, 1998] and Finite Volume [*Aavatsmark et al.*, 1998] spatial schemes are available as well as automatic time step calculation strategy.

The resulting CAST3M unsaturated flow tool will be integrated in the Alliances platform [*Montarnal et al.*, 2006].

3. Unsaturated flow around repository drift seal

3.1. **Process description.** In the context of high level radioactive waste disposal, we considered a scholastic modelling exercise where the drilling of a repository drift intercepts a geological system composed of an argilaceous host rock topped by a permeable layer considered as an aquifer [*Andra*, 2005a]. The drift excavation leads to an hydraulic decompression of the geological layers system as well as its desaturation as long as the drift stays open, namely for the repository exploitation duration expected to be of the order of 100 years [*Andra*, 2005a]. The repository is closed by the sealing of the drifts with several argilaceous swelling plugs [*Andra*, 2005a]. For this modelling exercise, we consider that the plug totally seals the drift. After closure, the system constituted of the geological layers and seal will saturate and will reach a new hydraulic steady state. The time scale for the full saturation of the back fields and engineered barriers inside the repository is expected to be of the order of 100,000 years [*Andra*, 2005b]. We are interested in the drift seal saturation time scale.

3.2. **Geometry, initial and boundary conditions.** We reduce the geological system to a 10-meters-high argilaceous host rock topped by a 10-meters-high permeable layer. The lateral extension of the domain is 70×80 meters. A 10 meters in diameter drift [*Andra*, 2005a] is located in the center of the system.

We imposed a lateral head gradient of 10^{-2} [*Andra*, 2005b]. The geological layers are initially fully saturated since the averaged head in the system is of the order of 400 meters.

Taking into account the symmetry of the problem, only half of the domain is modeled (Cf. Figure 1).

We considered the drift drilling as instantaneous. The boundary conditions imposed inside the drift during the desaturation phase is calculated from the Kelvin relation (2)

$$\Psi = -\frac{RT}{Mg}\ln(h_r) \quad (2)$$

where Ψ is the imposed pressure (m), T is the temperature (K), h_r is the hygrometry $(-)$, $R = 8,314\, Kg.m^2.s^{-2}.mol^{-1}.K^{-1}$ is the universal gas constant, $g = 9,81\, m.s^{-2}$ is

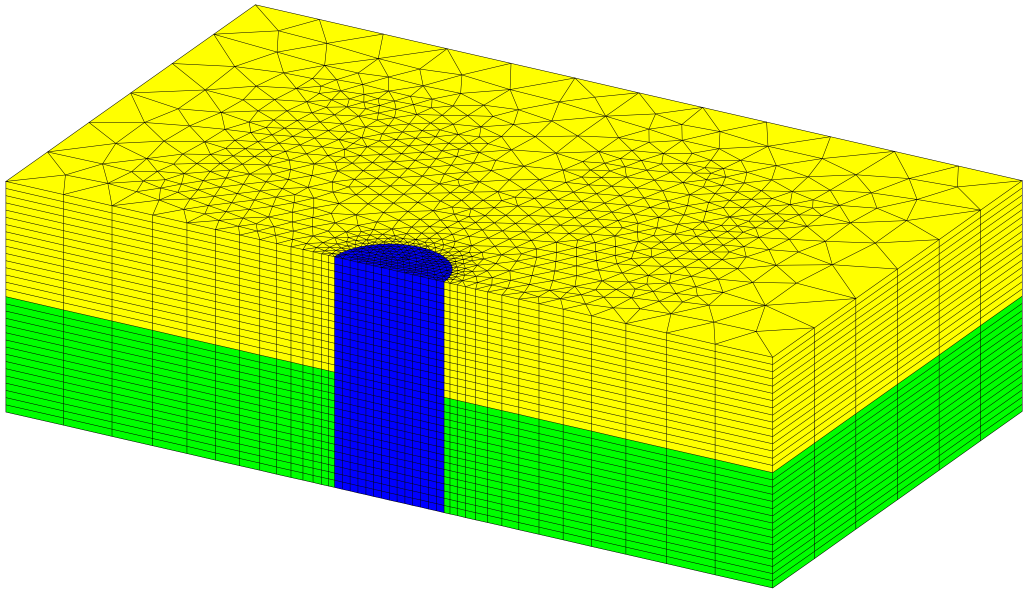

FIGURE 1. Mesh of the domain (40000 cells) constituted of host rock (green), permeable layer (yellow) and seal (blue).

the gravity acceleration and $M = 0,018\,Kg.mol^{-1}$ is the water molar mass. On the basis of an averaged hygrometry $h_r = 0.8$ and temperature $T = 10°C$ [*Andra*, 2005b] we found an imposed pressure of $\Psi = -2973\,m$.

3.3. **Physical parameters.** The values of the physical parameters needed to model the desaturation and saturation processes of the layers and seal are given in Table 1.

	Host rock	Permeable layer	Drift seal
$K_0\,(m.s^{-1})$	10^{-14} [*Escoffier*, 2002]	10^{-8} [*Andra*, 2005a]	10^{-11} [*Andra*, 2005b]
$S_s\,(m^{-1})$	$5\,10^{-7}$ [*Escoffier*, 2002]	10^{-4}	$5\,10^{-7}$ [*Andra*, 2005b]
$\omega\,(-)$	0.14 [*Escoffier*, 2002]	0.15 [*Andra*, 2005b]	0.3 [*Montes et al.*, 2005]
$\theta_r\,(-)$	0.005 [*Genty et al.*, 2002]	0.01	0.02
Relative permeability			
$K\,(m.s^{-1}) = K_0 s^3$			
Suction (van Genuchten expression)			
$s\,(-) = (1 + (\beta h)^n)^{-m}$			
$\beta\,(m^{-1})$	$5\,10^{-5}$ [*Genty et al.*, 2002]	$5\,10^{-2}$	$5\,10^{-5}$
$n\,(-)$	0.8 [*Genty et al.*, 2002]	0.8	0.8
$m\,(-)$	3 [*Genty et al.*, 2002]	3	3

TABLE 1. Physical parameters values

3.4. **Modelling.** Modelling is conducted using the FV spatial scheme of the CAST3M tool [*Le Potier*, 2004]. Desaturation is conducted over a period of 100 years. After what, a seal with initial conditions of $\Psi = -2973\,m$ is introduced inside the drift and saturation calculation performed over a period of 100 years.

4. Results

4.1. **Desaturation phase.** The results of the desaturation calculations are presented in terms of pressure in Figure 2 and in terms of saturation in Figure 3.

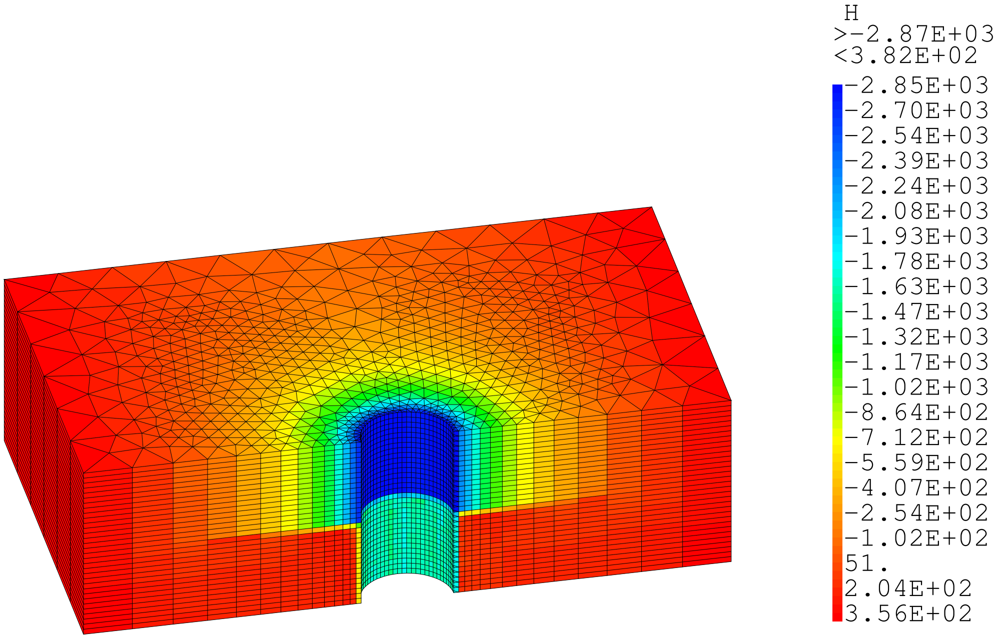

Figure 2. Pressure head inside the system at time $t = 100\,years$.

After 100 years of desaturation phase, the desaturation extent in the host rock is very small (less than $1\,m$) due to the very high capillary pressure of the argilaceous media. The desaturation extend in the permeable layer is about $30\,m$. Hydraulic decompression around the drift in each geological media is linked to their diffusivity values.

It is to note that differences in saturation at the boundary between the host rock and the permeable layer (Cf Figure 3) is not a numerical oscillation but is due to the heterogeneity of the system (check from Figure 2 that pressure head is continous at the boundary between the layers).

4.2. **saturation phase.** The results of the saturation calculations are presented in terms of pressure in Figures 4 and 5, and in terms of saturation in Figures 6 and 7. The simulations show that the argilaceous host rock resaturation is very slow but the hydraulic pressure building as well as the saturation of the permeable layer is very fast. The saturation of the seal is due to the incoming water from the permeable layer. The upper part of the seal reached full saturation in about 50 years while the bottom part is still unsaturated ($s \simeq 0.6$). Bottom of the seal then reach full saturation due to the incoming water from the permeable layer.

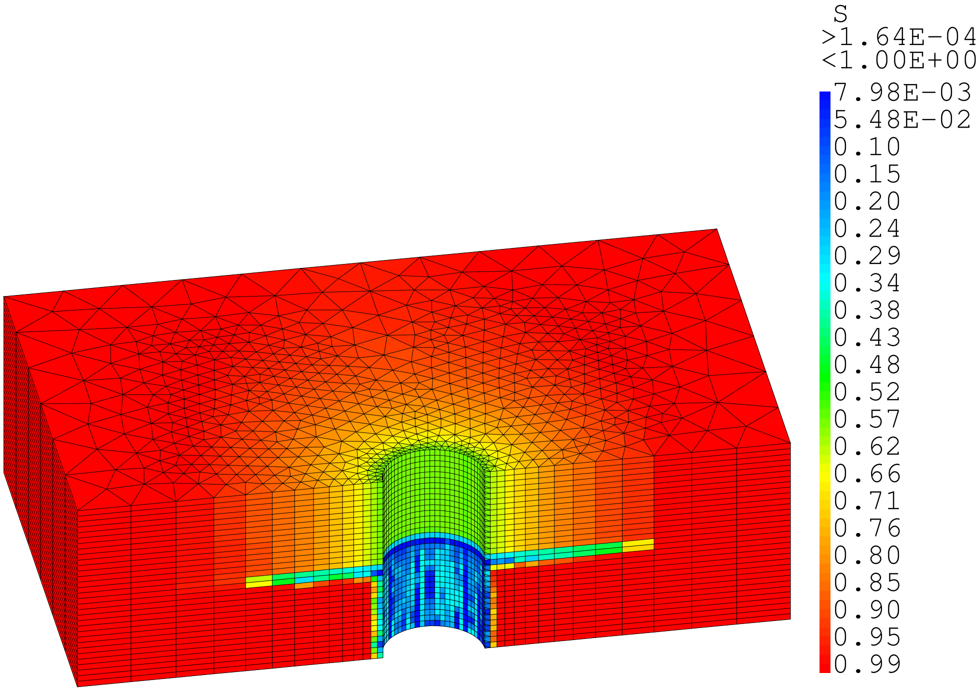

FIGURE 3. Saturation inside the system at time $t = 100\, years$.

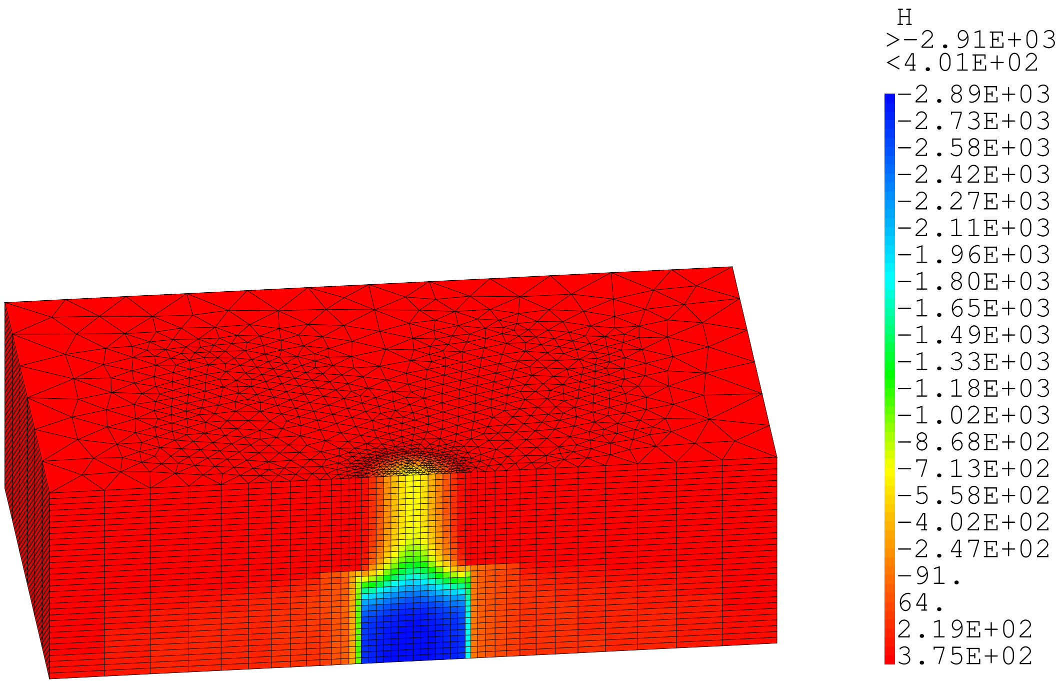

FIGURE 4. Pressure head inside the system at time $t = 15\, years$ after closure.

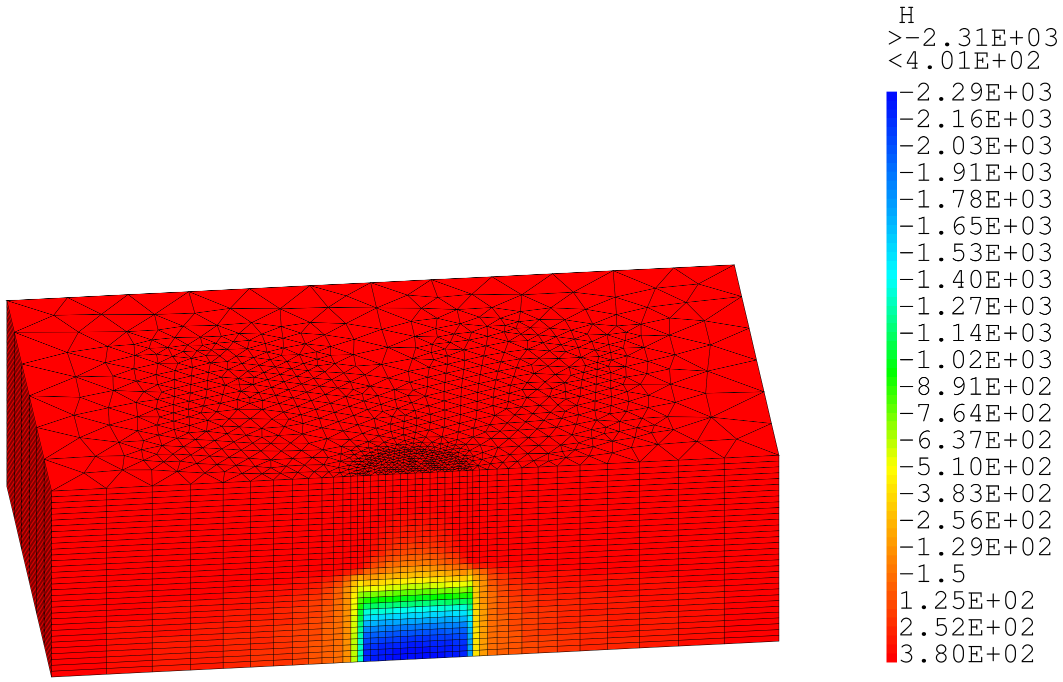

FIGURE 5. Pressure head inside the system at time $t = 50\,years$ after closure.

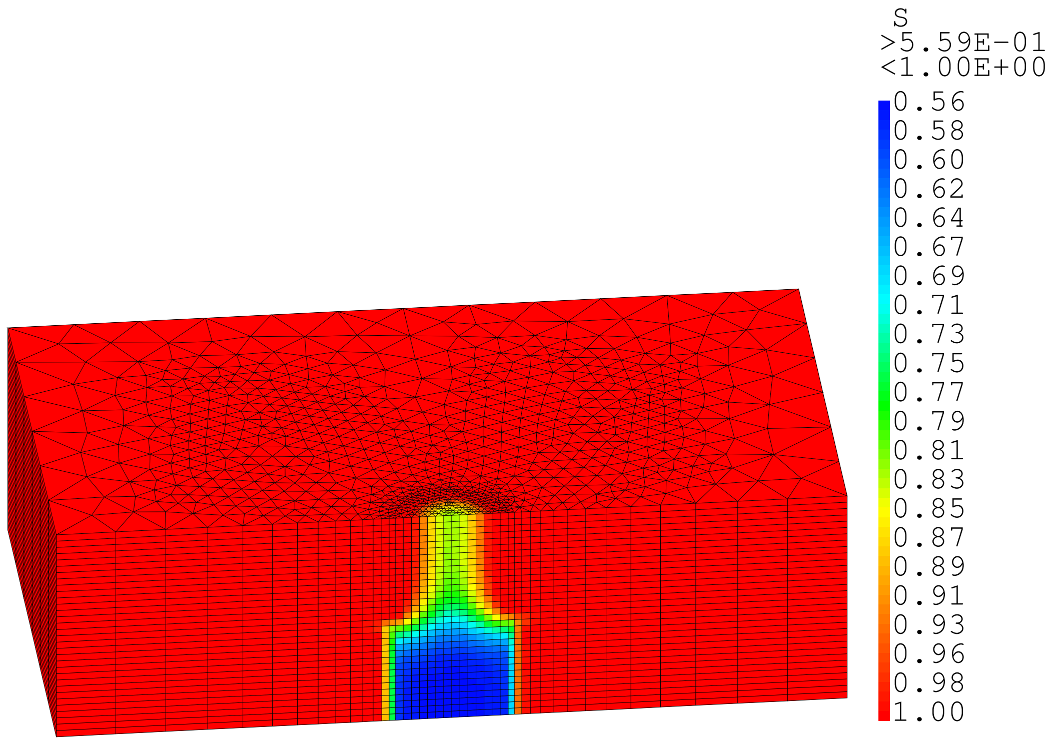

FIGURE 6. Saturation inside the system at time $t = 15\,years$ after closure.

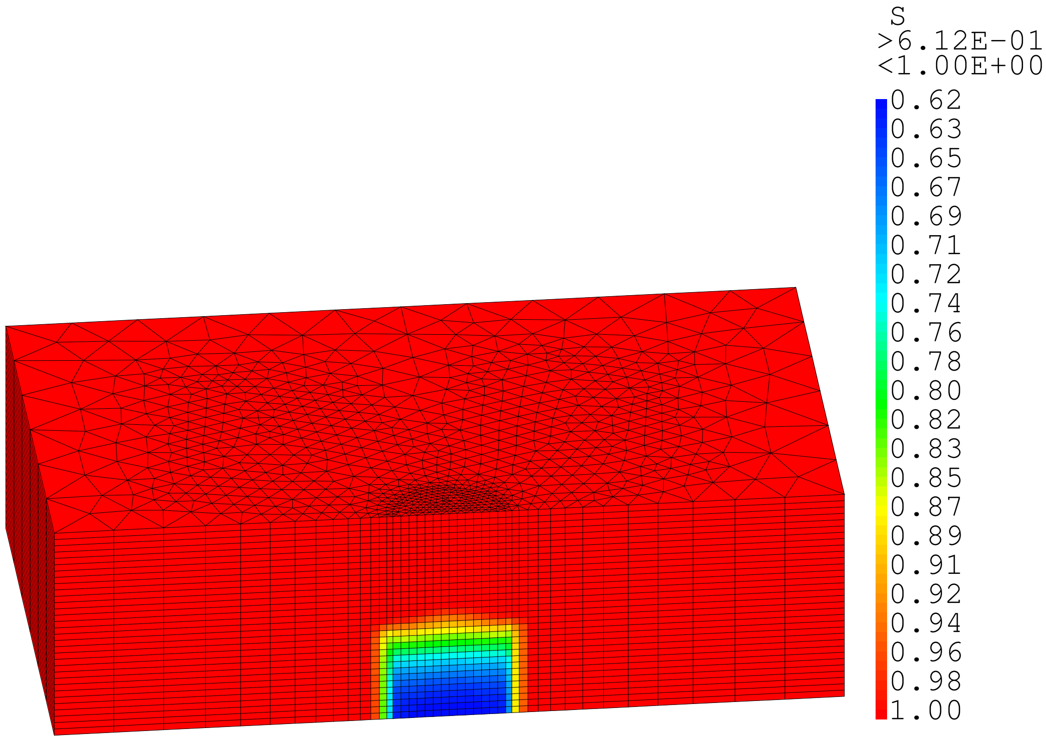

FIGURE 7. Saturation inside the system at time $t = 50\, years$ after closure.

This modelling exercise showed that drift seal saturation is instantaneous with regards to the fully saturation time scale expected for the repository (100,000 years) and suggested that a large volume of air was trapped in the repository.

5. Conclusions

We performed an unsaturated flow modelling of the saturation processes occurring for a high-level radioactive waste repository in a simplified configuration representing a disposal drift seal in clayed host rock surrounded by a more conductive layer. The calculations show that during the desaturation phase the host rock desaturation extension around the drift is small. But the more important results is that due to the presence of a more permeable layer at the top of the host rock, the total saturation of the repository drift seal is very fast. The air enclosed in the backfills of the repository is then expected to be entrapped. Due to this air entrapment, the use of Richard's model to evaluate saturation time of components of the repository like backfills or engineered barriers may be not relevant and the use of a two phase flow model including air dissolution should be considered.

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