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## 22.3

# Neutronic calculations of cold neutron intensity in a He chamber for ultra cold neutron production

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## Abstract

Neutronic optimization studies were performed to get highest cold neutron intensity in a He-II chamber for ultra cold neutron (UCN) production as a UCN source to be installed at a spallation neutron source. Main components of the system studied were Pb-Bi target·shield system, graphite reflector, $D_2O$ thermal moderator, $D_2$ cold moderator and He-II UCN source. Effect of the size of these components on cold neutron intensity and on heat deposition was studied under the condition of 600MeV proton energy and 20μA proton current. It was found that in the limitation of 1 W heat removal of the He cryostat we would obtain a cold neutron average flux of $7 \times 10^{11}$ (n/cm$^2$/sec) in the He chamber.

## 1. Introduction

In a spallation neutron source the γ ray heating is much lower than that in a reactor, so we may place a He-II super thermal ultra-cold neutron (UCN) source near a spallation target to increase the UCN intensity. At the beginning of our UCN project in Japan, we considered that PSI would be one of a candidate for a spallation source since a plan to build a UCN source was proposed at PSI. The system they planed was different from our source but there was a common part of the structure to be developed in the UCN source.

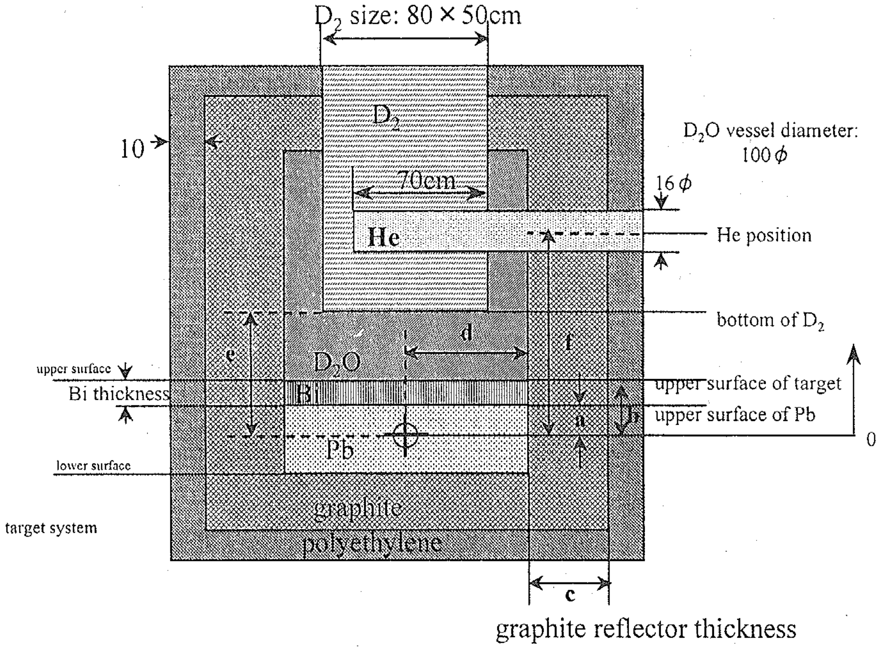
For the optimization study, limit of cooling power of a cryogenic system for a He-II chamber is important parameters. Therefore, in the design of such a UCN source it will be necessary to take into account not only neutronic characteristics but also heat deposition in a He chamber. Each component in a UCN source such as a target, a moderator and so on affects both neutronic characteristics and heat deposition, so we evaluated the effects in detail.

Here, we report results of the simulation calculations of a UCN source, assuming a power of the PSI accelerator, while now we have had a plan to use a small proton accelerator in Japan and optimization studies are being performed for this UCN source.

## 2. Simulation code and model

The LCS (LAHET Code System) with cross section data of ENDF-B/V and VI was used for simulations. The proton energy was 600 MeV and the current 20 μA. We calculated average cold neutron flux and heat deposition in He.

A model of UCN source is shown in Fig. 1, in which parameters studied here are also indicated from **a** to **f**. The sizes indicated are the initial values of this optimization study. Pb was used as target since it has small absorption cross-section although nucleus number density is not so large. Bi was placed above the Pb part for γ shielding. Graphite was chosen as reflector material because of economical reason. $D_2O$ was used as thermal moderator and $D_2$ for cold moderator. He-II chamber with a diameter of 16cm was placed in a $D_2$ cold moderator. Structure material of $D_2$ cold source chamber and He chamber was Zr.



**a**: upper surface position of Pb
**b**: target surface position
**c**: graphite thickness
**d**: $D_2O$ radius
**e**: bottom of $D_2$
**f**: He position

Fig.1 Geometry of horizontal extraction system for a UCN source. Numbers indicate initial values of size in cm.

Cold neutron intensity in the He chamber was calculated since the intensity is proportional to the intensity of neutrons with the energy of 1 meV which are the neutrons directly interacting with He to produce the UCN. Heat deposition in the He chamber was also calculated since the cooling power of the He chamber is rather limited, for example, the maximum power is about 1 W.

In this system UCN is extracted in horizontal direction. Both of horizontal and vertical extractions were studied, but we report here the study of the horizontal extraction since the horizontal extraction system gave a little bit higher cold neutron intensity.

## 3. Optimization studies

### 3.1 Upper surface position of Pb in a Pb-Bi target system

First, we examined effect of position of upper surface of Pd in a Pb-Bi composite target system (cf. **a** in Fig. 1). In this calculation the surface of Bi was kept at 25 cm from the proton beam center. The results are shown in Fig. 2. The neutron flux and the heat deposition decrease with moving the surface position upper-ward. However, the neutron flux is within 5.5-6.0x10$^{11}$ (n/cm$^2$/s) and the heat deposition is in a range of 0.85-1.05 W. This result indicates that Pb is effective to shield γ ray while it reduces the neutron intensity a little. Around 20 cm the ratio of neutron flux to heat deposition becomes maximum. We chose a thickness of 15-20 cm for Pb.

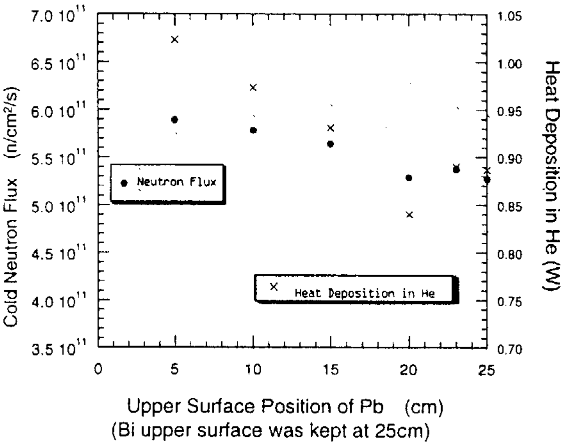


Fig.2 Change of cold neutron intensity and heat deposition in He by Pb thickness in a (Pb-Bi) target system.

### 3.2 Target surface position

Next, effect of the thickness of the target system was studied (cf. **b** in Fig. 1). The neutron flux begins to decrease at a thickness of 25 cm and the heat deposition monotonically decrease with the thickness over 20 cm as shown in Fig. 3. We chose 25 cm for a target surface.

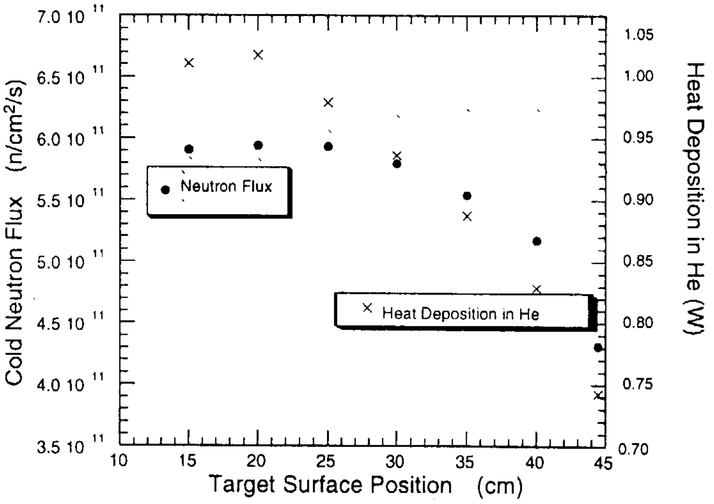


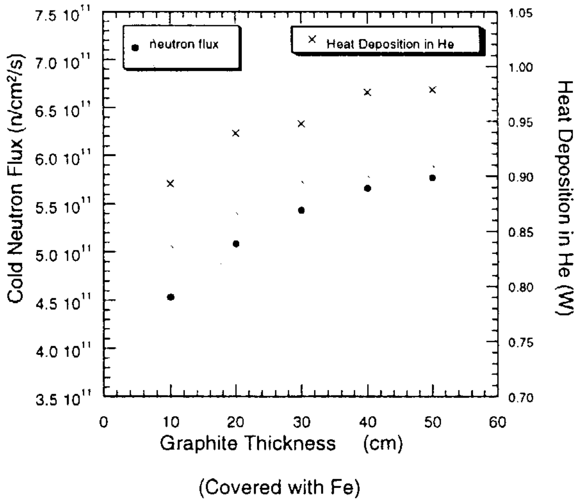
Fig.3 Change of cold neutron intensity and heat deposition by target surface position.

### 3.3 Reflector thickness

The cold neutron intensity and the heat deposition monotonically increase with graphite reflector thickness (cf. **c** in Fig. 1) as shown in Fig.4. The maximum heat deposition is less than 1 W, so the value is not so large since the cooling power of the He chamber is expected to be about 1 W. We chose 40 cm for the graphite reflector thickness.

### 3.4 $D_2O$ thermal moderator radius

$D_2O$ works as a thermal moderator to supply the thermal neutrons to the $D_2$ cold moderator. The radius dependence of the cold neutron intensity is shown in Fig. 5 (cf. **d** in Fig. 1). The intensity increases gradually with radius but the change is very small, since neutrons mainly come from the bottom side of the moderator. The heat deposition is almost constant in the range of radius studied and the value is less than 1 W. We chose a radius 50 cm.



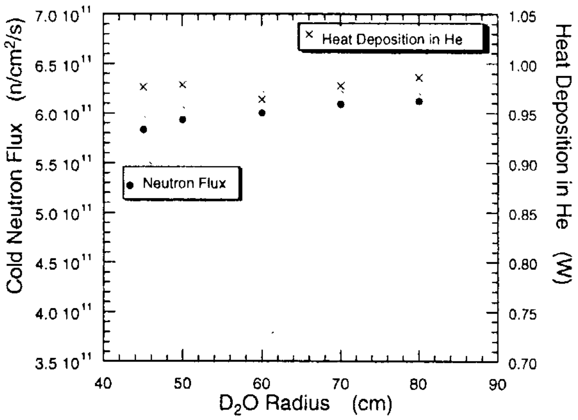


Fig.4 Change of cold neutron intensity and heat deposition in He by reflector thickness.

Fig.5 Change of cold neutron intensity and heat deposition in He by $D_2O$ size.

### 3.5 $D_2$ cold moderator position

$D_2$ is the cold moderator which supplies the neutrons with the energy of about 1 meV, the neutrons interacting with roton of He to produce the UCN by scattering. The vertical position in the thermal moderator is very important parameter. Figure 6 shows the cold neutron intensity and the heat deposition as a function of bottom position of the $D_2$ chamber, namely, distance from the proton beam center (cf. **e** in Fig.1). Both values decrease with increasing the distance. We should chose 35-40 cm for the distance since the gradient decrease in intensity is still small at this range.

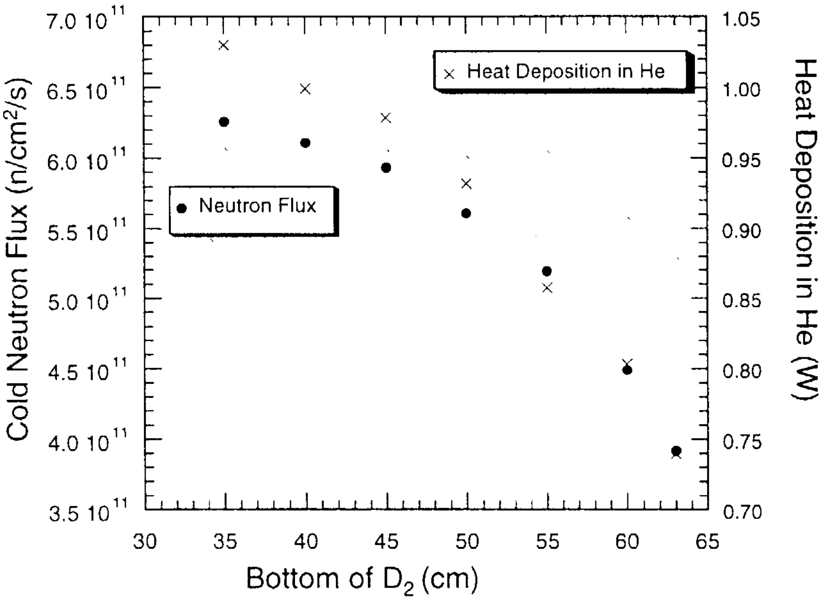


Fig.6 Change of neutron flux and heat deposition by the bottom position of $D_2$.

### 3.6 Shape of $D_2$ chamber

Here, we are using a horizontal extraction. Therefore, amount of $D_2$ along the He chamber is also important so as to get the highest cold neutron intensity. We chose an elliptical shape and studied the effect of the minor axis of the chamber. Figure 7-a shows a cross section of the system and a parameter Rm indicates the minor axis of the chamber. The results are shown in Fig. 7-b. Increase in intensity is observed up to about 30 cm and the heat deposition shows almost the same tendency as the intensity. So, we chose 30 cm as a minor axis.

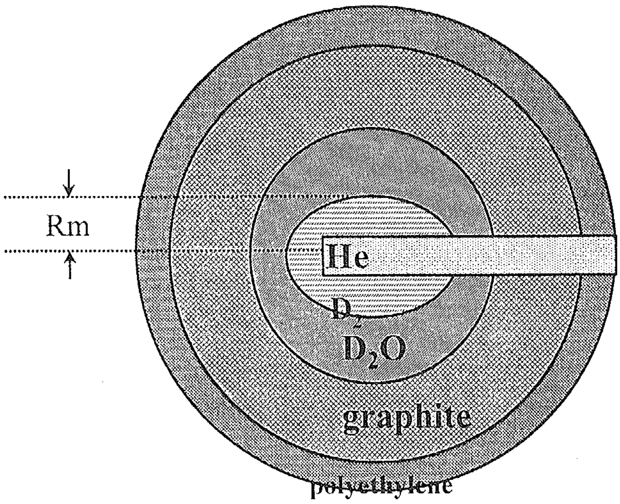


Fig.7-a Cross section of system indicating the shape of the $D_2$ chamber.

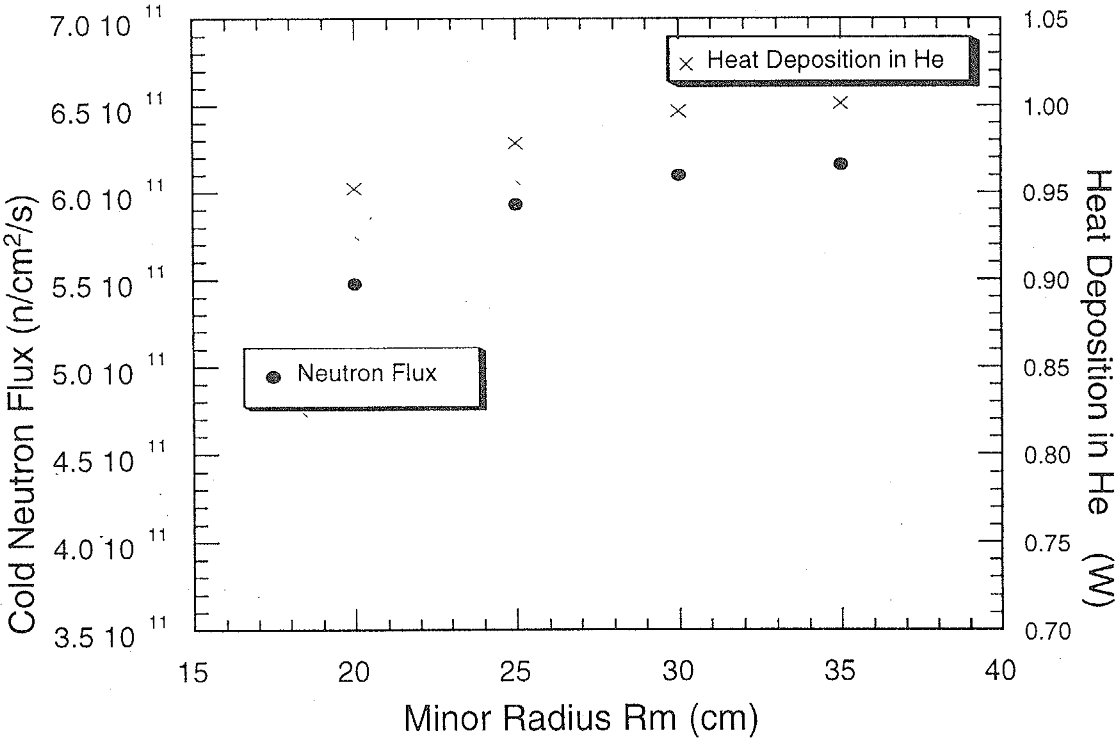


Fig.7-b Change of neutron intensity and heat deposition by the minor radius of $D_2$ chamber.

### 3.7 He chamber position

Finally, we studied the effect of the He chamber position. Figure 8 shows the neutron intensity as a function of the distance from the proton beam center to the center of He chamber (cf. f in Fig.1). The cold neutron flux reaches the maximum value at 60 cm and at this distance the heat deposition is about 1.45 W. The heat deposition decreases monotonically with the distance. From the neutronic point of view we should choose 60 cm but the heat deposition is much higher than 1 W. Therefore, we need total optimization taking into account both neutron intensity and heat deposition since the heat deposition would limit the neutron intensity.

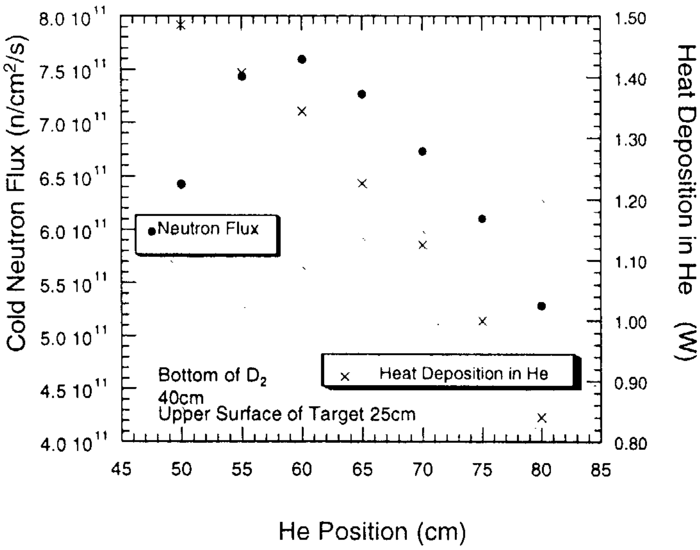


Fig.8 Effect of He position on cold neutron intensity and heat deposition in He.

Figure 9 shows neutron temperatures (peak energy) of the energy spectra as a function of the He chamber position. The neutron temperature decreases with increasing the distance from the proton beam center and saturates around 70 cm. However, the change is very small. This result indicates that the assumption that the intensity of 1 meV neutron is proportional to the average flux has been valid.

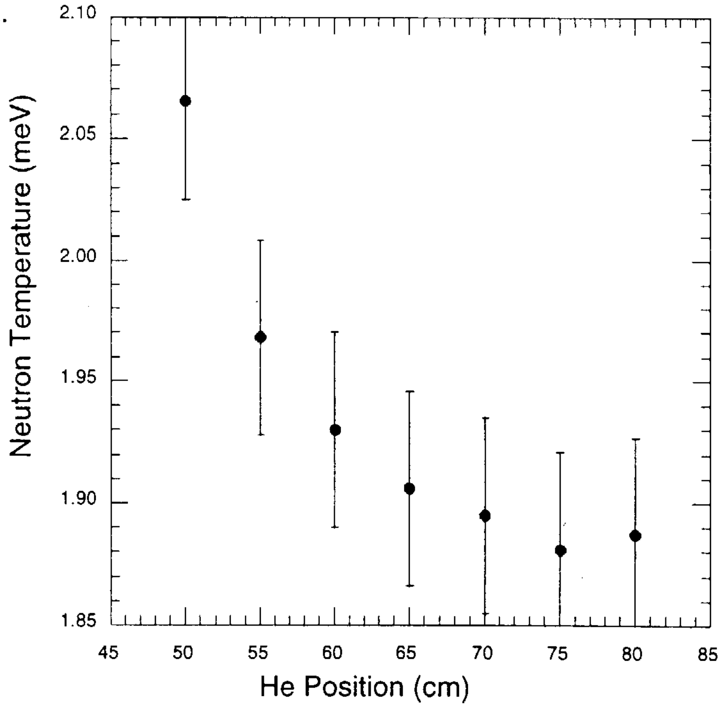


Fig.9 Effect of He position on neutron temperature.

### 3.8 Total optimization

Here, we assume the maximum cooling power of the He chamber is 1 W. We should look for the highest cold neutron flux in the He chamber under the condition of maximum cooling power of 1 W. Figure 10 shows maximum intensity at each distance from target center to the target surface for various $D_2$ and He chamber positions under 1 W condition. It is indicated that we can obtain the highest cold neutron flux of the order of $7.3 \times 10^{11}$.

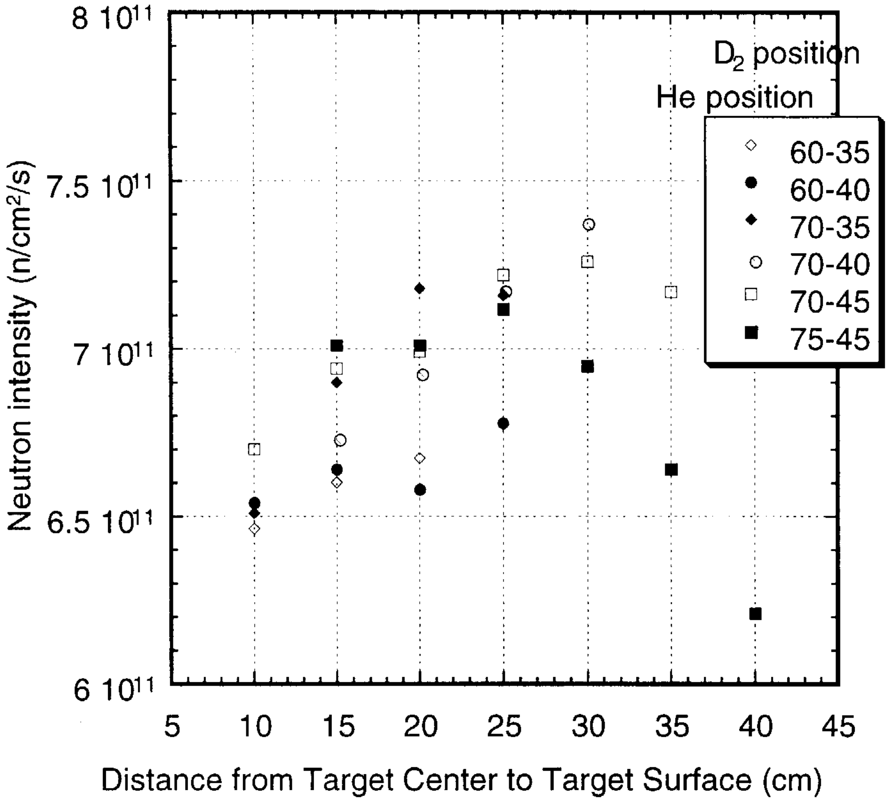


Fig.10 Neutron intensity under the condition of heat deposition of 1W.

## 4. Conclusion

Average cold neutron flux and heat deposition in He chamber were calculated at various conditions. It was found that maximum average neutron flux of $7.3 \times 10^{11}$ (n/cm$^2$/sec) in He chamber was obtained at the condition of target thickness around 25-30 cm, $D_2$ position around 40-45 cm, and He position at 70 cm. Ideally we would obtain $4 \times 10^5$ UCN/cm$^3$ by this flux.

If maximum cooling power of the He chamber is around 1 W, the intensity of the neutron flux is restricted by this cooling power. In such a case the accelerator power of 12 KW is too high, so we should look for optimal accelerator power suite for this cooling power.

## Acknowledgement

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