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DEADTIME CORRECTION IN HIGH COUNT RATE QUANTITATIVE DYNAMIC STUDIES WITH COMPUTER-ASSISTED ANGER-CAMERAS

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INTRODUCTION

The use of ^{99m}Tc and computer-assisted Anger-cameras in nuclear medicine, to perform fast quantitative dynamic studies, makes it possible to obtain a high counting rate with a low absorbed dose. Since the count rate may be about 10^5 sec^{-1}, data correction for deadtime losses is necessary to make a correct quantitative analysis and to reduce the given activity to an amount consistent with the resolving time of the system. BEN-PORATH [8] has reported that, if the maximal acceptable deviation in the observed count rate, compared to the true count rate, is such that a ratio of 50 % in the second one will be recorded as no more than a 10 % deviation in the first, then the true count rate should not exceed 40,000 sec^{-1} with a deadtime of 5 µsec.

Since it is essential to know the value of the deadtime of the system used in dynamic investigations, many authors [4-7, 9-13, 15] have reported their methods of evaluation of the deadtime in different operating conditions and have proposed data correction.

In the work reported in this paper the authors determined the values of deadtime for 2 Anger-cameras (Pho-gamma HP, Radicamera II), both connected to the data-processing system Med-II, equipped with a 16K memory (12 bits) Nuclear Data computer.

METHOD

It is well known [12] that there are 2 different definitions of deadtime, associated with 2 limiting characteristics of the radiation detector: 'paralyzable' and 'non-paralyzable' as they have been called.

The former is described by the formula:

$$n = N \cdot e^{-N\tau} \qquad 1)$$

and the latter:

$$n = \frac{N}{1 + N\tau} \qquad 2)$$

where: N = true counting rate; n = observed counting rate; τ = system deadtime.

Fig. 1 shows the plotting of $n\tau$ against $N\tau$ in the 2 cases, and in the ideal case (linearity: $\tau = 0$).

Key-words: Activity/time curves; Anger-camera; Cardiac output; ^{141}*Ce; Collimators; Computer; Deadtime correction; Dynamic studies; Radioisotope angiocardiography.*

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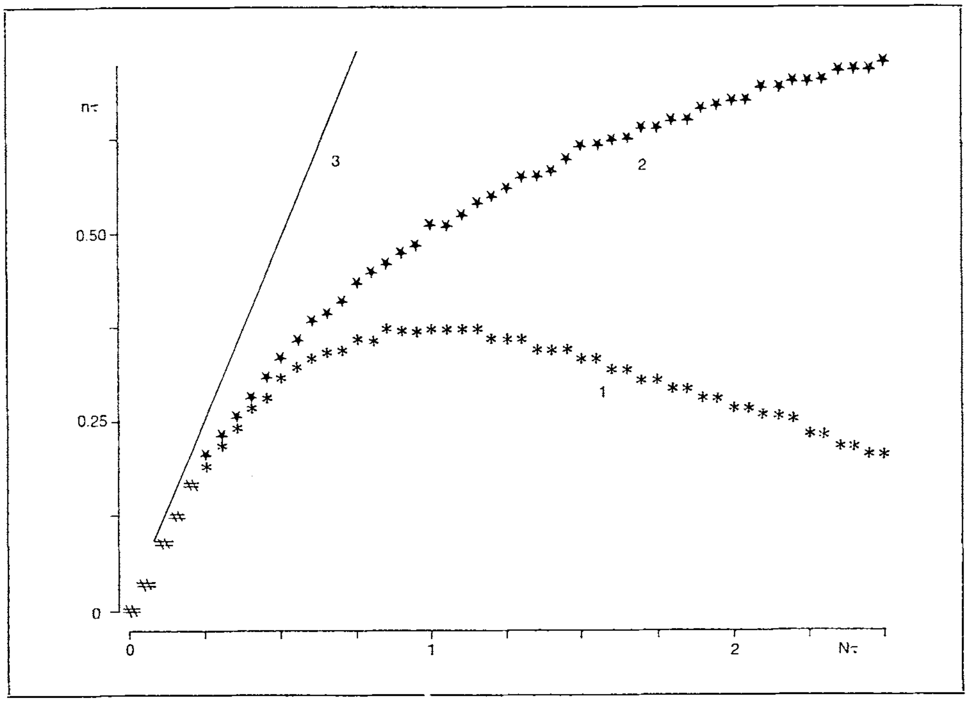


Fig. 1 - Plotting of $n\tau$ against $N\tau$ (τ = deadtime, n = observed counting rate, N = true counting rate). 1 = paralyzable; 2 = non-paralyzable; 3 = linear.

If $N\tau \ll 1$ formula 1) approaches 2) and if $n\tau < 0.05$, n differs from N by less than 0.1 %. It can be noted that the function 1) has a *maximum* for $N\tau = 1$, the value of the *maximum* being $n\tau_{max} = 1/e$.

Using the classical two-source method we determined the deadtime with both the models described.

The following, not approximated formula was used to calculate the non-paralyzing deadtime:

$$\tau = \frac{-B - \sqrt{B^2 - 4AC}}{2A}$$

with $A = n_1 n_2 n_{12} + n_1 n_2 f - n_1$; $B = 2(n_{12} f - n_1 n_2)$; $C = n_1 + n_2 - n_{12} - f$;

where: n_1 = observed rate with the 1st source; n_2 = observed rate with the 2nd source; n_{12} = observed rate with both the sources; f = background rate.

Adams and Zimmerman[5] compared 8 approximated formulas derived from different authors and they pointed out that as a result of the approximations there were significant variations in the calculated deadtime with the true counting rate.

The paralyzing deadtime was calculated by an iterative Newton-Raphson method.

Instead of the short-lived ^{99m}Tc, the most widely used isotope in nuclear medicine, we used ^{141}Ce which has a half-life of 33 days and makes it possible to perform the measurements without having to consider the radioactive decay occurring during the measurements. Fig. 2 shows the ^{141}Ce decay scheme. It should be noted that there is a 145 keV γ-ray emission similar to ^{99m}Tc (142 keV), and a 36 keV X-ray emission from ^{141}Pr. However, our measurements indicated that, in spite of this peak, ^{99m}Tc and ^{141}Ce can be considered equivalent for the determination of deadtime.

The observed deadtime depends on the fraction of detectable events passing through the analyzer window and it varies according to the scattering conditions (scattering medium, energy of γ-rays, collimators).

Measurements were made under different scattering conditions, namely with sources in free air at 40 cm from the collimator and with sources inserted into a paraffin cube (simulating the human body, with an edge length of 25 cm) arranged with its face 10 cm from the collimator. Moreover, in accordance with other authors[5,7], the observed deadtime in relation to the counting rate was studied, using different collimators and different analyzer windows.

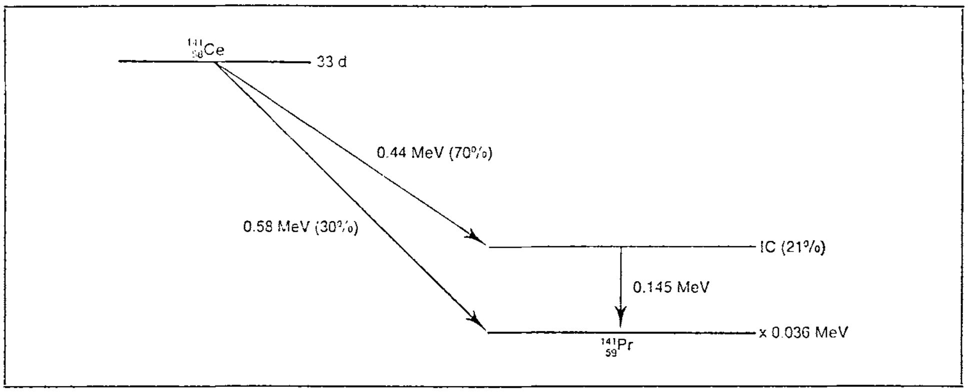


Fig. 2 - Decay scheme of ^{141}Ce.

RESULTS AND DISCUSSION

In fig. 3 the paralyzing and non-paralyzing deadtimes are plotted against the count rate. The data refer to two cameras with the following conditions: high resolution collimator, window 20 %, sources in free air without scattering medium.

It can be seen that with the paralyzable model the deadtime was practically independent of the counting rate; with the non-paralyzable model, however, the dependence is clear. The paralyzable model thus seems to describe adequately the behaviour of the Anger-cameras examined.

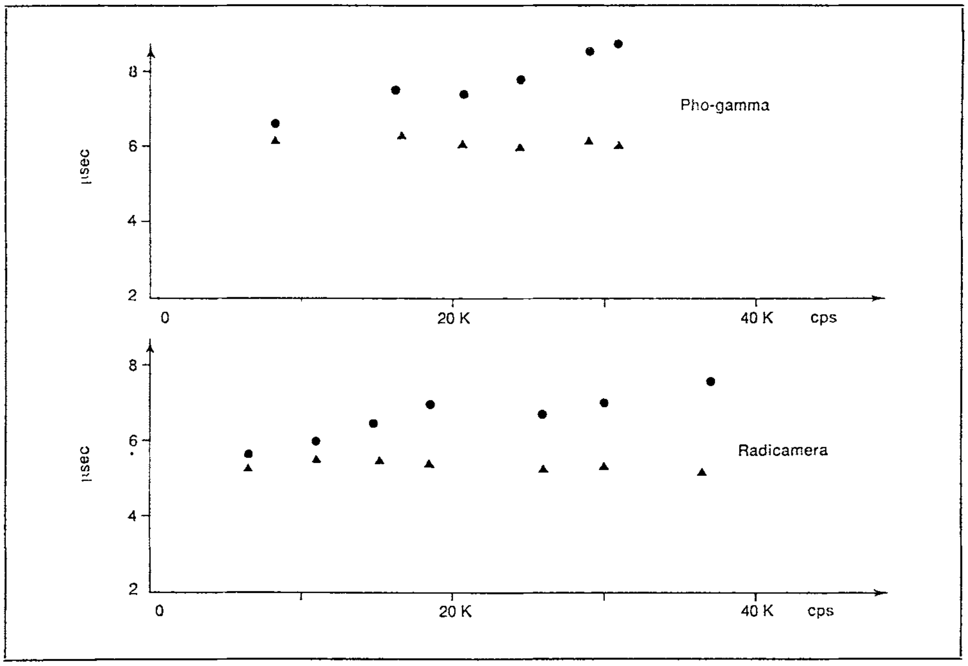


Fig. 3 - Plotting of deadtime against counting rate (Pho-gamma and Radicamera). With the paralyzable model the deadtime is practically constant. Black triangles = paralyzable; black circles = non-paralyzable.

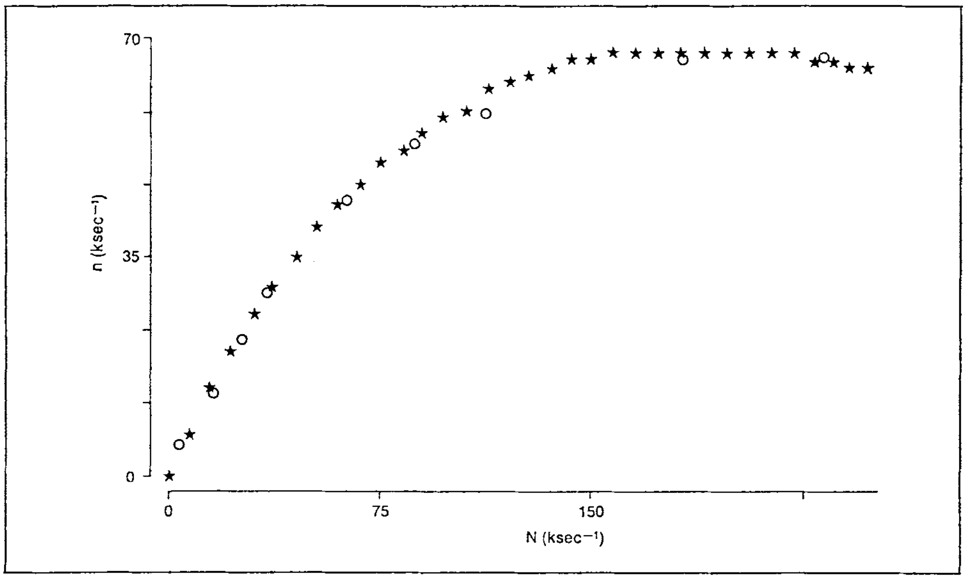


Fig. 4 - Plotting of n against N for theoretical and experimental values with the paralyzable model (Pho-gamma, diverging collimator, source in air, window 30 %, $\tau = 5.4$ µsec). Black stars = theoretical values; open circles = experimental values.

To confirm this assumption, fig. 4 shows the good fit between the experimental and theoretical values of the observed counting rate (n) against the true counting rate (N).

Tabs 1 and 2 summarize the results obtained with different collimators and windows using the paraffin phantom (data according to the paralyzable model).

The following can be noted:

a) the deadtime increases in the presence of a scattering medium, due to a reduction in the ratio of photopeak events and total events;

collimator *	window	deadtime (µsec)
diverging	30 %	5.6 ± 0.1
	15 %	13.8 ± 0.3
high resolution (parallel holes)	30 %	5.5 ± 0.1
	15 %	11.5 ± 0.2

* collimator	FWHM ° sup.	FWHM ° 75 mm	relative sensitivity	focal length	energy limit	diameter 75 mm
diverging	7 mm	13 mm	65 %	500 mm	400 keV	320 mm
high resolution (parallel holes)	2 mm	8 mm	60 %	—	200 keV	260 mm

° Full Width Half Maximum.

Table 1 - Radicamera-^{141}Ce paraffin phantom. Collimator-phantom distance = 10 cm.

b) the deadtime increases with decreasing window width, due to an increase in the events falling outside the window that is responsible for count losses.

On the basis of the experimental results a computer program in *Nutran* (a nuclear medicine oriented language specific to the Med-II system 14)) was prepared in order to correct the activity/time curves referring to the transit of a radioisotope through regions of interest in dynamic investigations in nuclear medicine.

The correction was carried out by multiplying the values of the curve points by f, where

$$f = \frac{N}{n}$$

n being the observed counting rate and N the true counting rate, both over the full field of view of the camera.

N was obtained by 1), using a Newton-Raphson iterative method, where the first approximated value is derived from 2), i.e.:

$$N_1 = \frac{n}{1 - n\tau}$$

$$N_j = \frac{n\,(1 - N_{j-1}\tau)}{e^{-N_{j-1}\tau} - n\tau}$$

The program was organized so as to make the data input very simple for the operator, as shown in fig. 5.

In order to demonstrate the value of this type of correction, a simple fluid-dynamic circuit was prepared (fig. 6), and the pump output (P_v) was determined exactly by the transit time of a known volume of water.

Then the pump output was also measured by means of a radioactive tracer as follows:

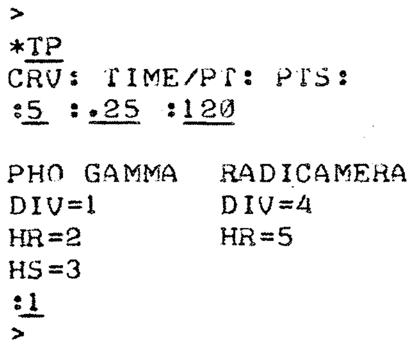
a) injection into the circuit of a radioactive bolus (^{99m}Tc, 7 mCi);

collimator *	window	deadtime (µsec)
diverging	30 %	8.8 ± 0.2
	15 %	14.5 ± 0.3
high resolution (parallel holes)	30 %	7.2 ± 0.2
	15 %	12.4 ± 0.3
high sensitivity (parallel holes)	30 %	7.5 ± 0.2
	15 %	12.2 ± 0.2

* collimator	FWHM ° sup.	FWHM ° 2"	relative sensitivity	energy limit	diameter 2"
diverging	6.9 mm	9.6 mm	103 %	140 keV	11.9"
high resolution (parallel holes)	6.1 mm	7.6 mm	65 %	140 keV	9.75"
high sensitivity (parallel holes)	6.3 mm	9.6 mm	220 %	140 keV	9.75"

° Full Width Half Maximum.

Table 2 - Pho-gamma-^{141}Ce paraffin phantom. Collimator-phantom distance = 10 cm.



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>
*TP
CRV: TIME/PT: PTS:
:5  :.25  :120

PHO GAMMA   RADICAMERA
DIV=1       DIV=4
HR=2        HR=5
HS=3
:1
>
```

Fig. 5 - List of the commands to perform the correction. The instructions required from the operator (underlined) are: curve number, time/point, number of points in the curve, Anger-camera and collimator.

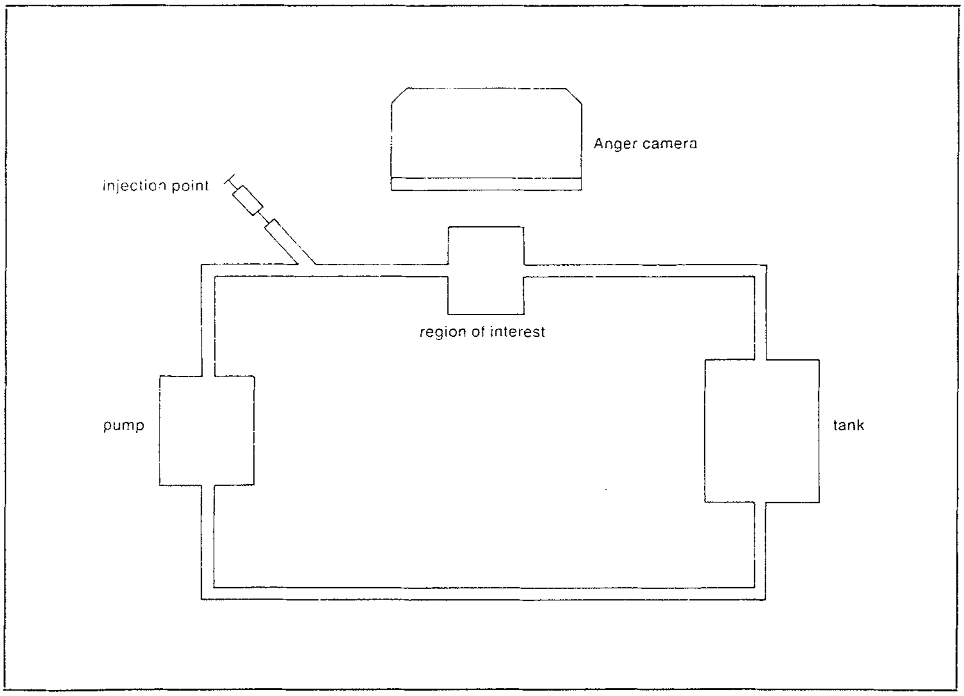
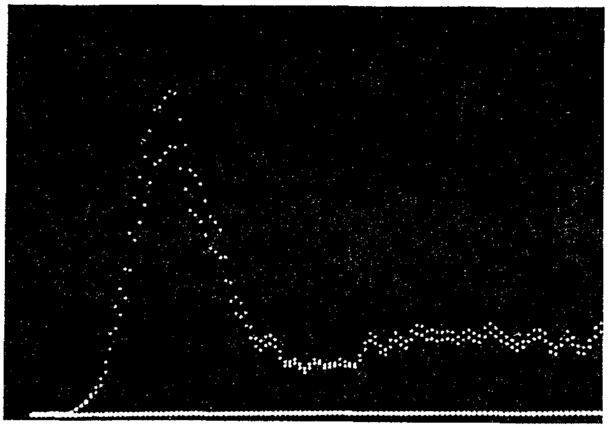
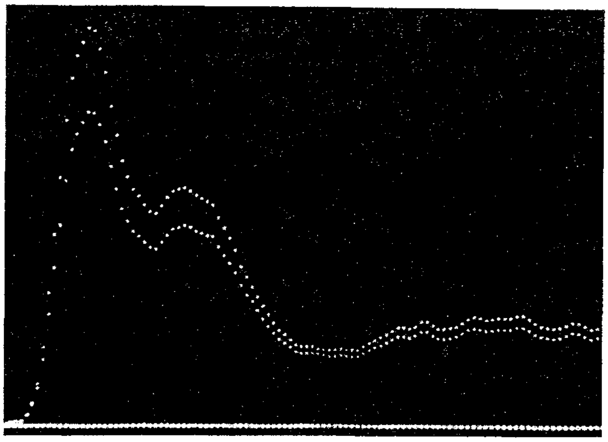


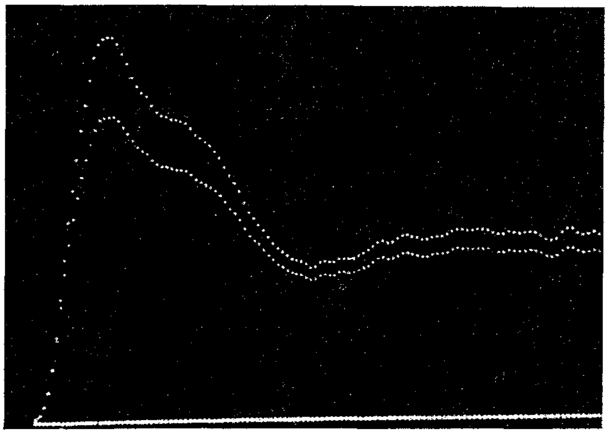
Fig. 6 - Scheme of the fluid-dynamic circuit.



A) Right lung. Shunt index variation 12 %.



B) Whole heart. Cardiac output variation 8 %.



C) Full field of view.

Fig. 7 - Some aspects of a radioisotope angiocardiograph. Curves (1 point every 0.25 sec) referring to the transit of a radioactive bolus (10 mCi serum albumin ^{99m}Tc) through right lung (*A*), whole heart (*B*), full field of view (*C*). In every picture the upper curves are derived from the lower ones, after deadtime correction. The shunt index and cardiac output decrease by 12 % and 8 % after correction, respectively.

b) detection of the transit of the bolus with the Anger-camera (Pho-gamma, diverging collimator, window 30 %), recording on a magnetic disc one frame every 0.25 sec;

c) activity/time curve production and display (Med-II system);

d) calculation of the pump output (P), using the Stewart-Hamilton method;

e) deadtime (8.8 μsec) curve correction;

f) calculation of the pump output (P_c), after correction.

The results were:

$$P_v = 6.51 \pm 0.08 \text{ l/min}$$
$$P = 7.35 \text{ l/min}$$
$$P_c = 6.49 \text{ l/min}$$

A good agreement can be observed between P_c and P_v.

Fig. 7 shows some aspects of a radioisotope angiocardiograph in man (serum albumin ^{99m}Tc, 10 mCi bolus, injected in the right jugular vein; operating conditions: Pho-gamma, diverging collimator, window 30 %), obtained according to a method described elsewhere [1, 2, 3]. Activity/time curves refer to the transit of the radioisotope through regions selected on the right lung (fig. 7A), the whole heart (fig. 7B) and the full field of view (fig. 7C). The upper curves were obtained after deadtime correction (τ = 8.8 μsec).

It is possible to note not only the clear modification in the shape of the corrected curve, but also the change in the parameters usually calculated. In this case, the shunt index, derived from the pulmonary curve, and the cardiac output, derived from the cardiac curve decreased, respectively, by 12 % and 8 % after correction, with a maximal count rate of 21,700 sec^{-1}.

CONCLUSIONS

As shown above, the importance of data correction of counting losses due to system deadtime is clear, when rapid dynamic phenomena are to be examined using a high radioactive dose, especially when there is a considerable variation in the counting rate during the examination.

Therefore, careful measurements of the deadtime of the whole system (Anger-camera and computer) must be made, taking into account that the observed deadtime depends on the following factors: γ-ray energy, scatter conditions, collimation, window setting, the electronic and data-processing systems.

Among the various methods for experimental deadtime determination, the so-called 'two-sources' method, which we used, is highly reliable and reproducible. The use of short-lived sources requires a correction for the radioactive decay, so it is convenient to use γ sources with the same energy but a longer half-life.

SUMMARY

The use of tracers with high radioactivity in rapid dynamic quantitative studies (such as radioisotope angiocardiography), performed by the Anger-camera and data-processor, makes it possible to obtain a high counting rate. For correct interpretation of the results of the analysis of activity/time curves in regions of interest, the authors determined, under different working conditions, the deadtimes of two Anger-cameras (Pho-gamma HP and Radicamera II), both connected to a data-processing system (Med-II). The problems inherent in this determination are analyzed and discussed. A computer program for curve correction was written and some examples of applications of it are presented, including an experiment to test the accuracy of the correction.

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