

Physician and Patient Exposure During Cardiac Catheterization

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SUMMARY A survey of the literature was conducted to establish the anticipated ranges of exposures to both physicians and patients during cardiac catheterization. A brief explanation of a technique for using time-lapse photography and a computer model for exposure calculation is presented. The thermoluminescent dosimeter (TLD) results used as controls for exposure values calculated by the developed technique are presented in detail. Physician eye exposures of approximately 20 mR per cardiac catheterization procedure were measured, which would suggest a limit of five procedures per week for physicians. The average patient skin entrance exposure of 28 R is high, as is the 12 mR gonadal exposure; however, they are accepted because of the possible benefits of the procedure.

CONCERN HAS BEEN EXPRESSED regarding the exposure of physicians and patients during cardiac catheterization procedures. Previous studies indicate wide variation in exposure values. The recommended occupational exposure limits are sometimes exceeded by physicians, which is of major concern to assisting personnel who are thus occupationally exposed. No recommendations have been made for patient exposure to medical radiation other than that exposure should be kept to a minimum and consistent with the information gained by the procedure.

Most previous studies on physician exposure (table 1) consisted of the placement of a dosimeter on a physician during the procedure under study. This method does not allow for the separation or fractionation of exposures during the various subtasks, which would enable determining which subprocedures contribute the most exposure. Riley reported replacing individual dosimeters during the subdivisions of special procedures and concluded that 92% of the exposure to radiologists occurred during the radiographic portion of these procedures, but his study did not include cardiac catheterization.¹ Properzio recorded the exposure area product for cine and fluoroscopic portions of adult cardiac catheterization procedures and concluded that cine accounted for 54% of total exposure (unpublished doctoral thesis, 1975). Similarly, the results reported in this study show that 47% of the total exposure occurred during the cine portion of cardiac catheterization procedures.² This method involved time-lapse photography and a computer model for allocation of exposure during subphases of a procedure. However, this technique is time-consuming and expensive and, except for special purposes, will probably not be used extensively.

The extremely high exposures encountered during early cardiac catheterization procedures led to concern about the exposed patients. In most cases, the information obtained by the catheterization procedure is

of immediate concern to the patient and the exposure is considered a necessary risk. One of the difficulties encountered when comparing patient exposure studies is the different methods of reporting exposure. An additional problem is obtaining exposure information without interfering with the procedure. A fairly common and defensible method for reporting exposure is the Roentgen Area Product. This method considers exposure level and the area of the patient that is being exposed. Other exposure studies have reported only the time or the mAs, or used these values to calculate an estimated skin entrance exposure. Table 2 lists some of the more recent studies of patient exposure.

Method

Time-Lapse Photography

The procedures used in developing the technique for allocation of exposure to subdivisions of subphases of cardiac catheterization are discussed briefly in this section. This technique involved using time-lapse photography by setting up two cameras at right angles (fig. 1). Measuring the locations of the physicians' anatomical parts on film, coding this information and using the computer model enabled us to trace the chosen anatomical sites in space and time. The sites of interest were the eyes and thyroids of the physicians conducting the procedure. This information, along with a previously determined matrix of exposure values to be expected during the procedure, enabled the calculation of accumulated exposure during any specified time interval (or subphase). A vertical slice through this exposure matrix is shown in figure 2 and a horizontal slice in figure 3. Values from this exposure matrix were corrected for varying kVp, mA and patient thickness by use of the response from a monitor detector. The results of this portion of the project have been reported previously.²

Thermoluminescent Dosimetry (TLD)

As a control for the exposure calculations, TLDs (Harshaw TLD-100 $\frac{1}{8} \times \frac{1}{8} \times 0.035$ in. chips) were placed on physicians, other assisting personnel and patients in the special procedures room. The TLD chips were annealed for one hour at 400° C, rapidly cooled to room temperature, and kept for 18 hours at

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TABLE 1. Summary of Reported Mean Exposure During Cardiac Catheterization for Physicians

Study	Mean Exposure (mR)		
	Eye	Collar	Right hand
Ardran & Fursdon ⁷ Cardiologist		3.5 (18)*	4.6 (18)
Gignac† Physician	6.4 (6)	16.7 (6)	7.1 (6)
Malsky et al. ⁹ Cardiologist Sr. Resident	18 (12) 30 (12)	24 (12) 33 (12)	143 (12) 154 (12)
Properzio‡ Physician Technician	7 (13) 15 (13)	15 (13) 16 (13)	5 (13) 25 (13)
Stacey et al. ¹⁰ Cardiologist	12 (13)	15 (13)	49 (10)
Wold et al. ¹¹ Physician	26 (9)	28 (9)	41 (9)
This study Physician 1 Physician 2	19.9 (12) 7.1 (9)	10.0 (11) 6.3 (12)	6.7 (10) 4.8 (11)

*Parentheses indicate number of procedures monitored.
†Unpublished master's thesis, 1974.
‡Unpublished doctoral thesis, 1975.

30° C. The complete batch was checked for individual response, annealing and fading characteristics and energy dependence before being used in the experiment. The readout of TLD chips was accomplished by use of an Eberline Model TLR-5 TLD readout unit using 0.5 l/min nitrogen flow. The readout cycle consisted of a 15-second anneal at 140° C and a 15-second integration of TLD output at 210° C. The minimum detectable value (± 2 SD of the background) was 4 mR. The estimated error was $\pm 30\%$ at 10 mR, $\pm 15\%$ at 20 mR, $\pm 8\%$ at 30 mR and $\pm 5\%$ for values greater than 100 mR. For each group of measurements, a batch of 100 TLDs contained 10 chips for background, 10 chips exposed to 700 mR for calibration and the remaining 80 chips for exposure

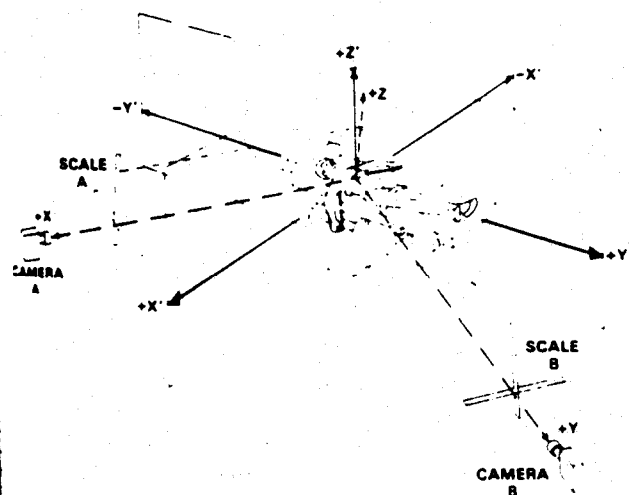


FIGURE 1. Camera setup during time-lapse photography of cardiac catheterization procedures.

TABLE 2. Patient Skin Exposures During Cardiac Catheterization Reported in the Literature

Study	Patient population description and number	Total exposure
This study	Adults (n = 12)	28 (13-58) R
Properzio ⁹	Adults (n = 21)	20 (1-60) R
Malsky ⁹	Adult males (n = 12)	(24-73) R
Ardran ⁸	Adults Fluro only (n = 54) Plus cine only (n = 23)	21.4 (1.2-91.8) R 2.5 (1.8-9.2) R
Gough ¹²	Adults (n = 85)	47 (1-131) R

*Unpublished doctoral thesis, 1975.

measurements. The chips were wrapped in thin polyethylene which was attached to surgical tape with a small piece of transparent tape. The completed package resembled a small bandage. These packages were placed on the back of the physicians' hands, over the thyroids, over the bridge of the nose and on the forehead. Additional chips were placed at the collar, outside the apron and behind the lead apron worn by physicians and other personnel in the room. A TLD was placed over the thyroid, at the base of the sternum and near the pubic symphysis of the patient. The TLDs did not interfere with the procedure or with the radiographic images obtained by the procedures.

Special Procedure Room

The monitored special procedures were conducted at a large teaching and research hospital, using two Siemens Gigantos 3-phase, 12 pulse generators. A rotation cradle was used and a Siemens Bi 150/30/50R undertable x-ray tube was coupled with a 7 in. Rohre RBV 17H overtable image intensifier. The horizontal x-ray tube was a Bi 150/30/101 RG coupled to a 10 in. Rohre RBV 25/15H image intensifier. Video monitors were used for fluoroscopy, and 16 mm (50 or 100 frames per sec) cameras were mounted on both horizontal and vertical intensifiers for cineradiography. The average fluoroscopy parameters were 1.5 mA and 96 kVp with a 1.95 R/min exposure rate at the tabletop. The half value layer was 4.5 mm Al-equivalent and the target-to-tabletop distance was 21 in.

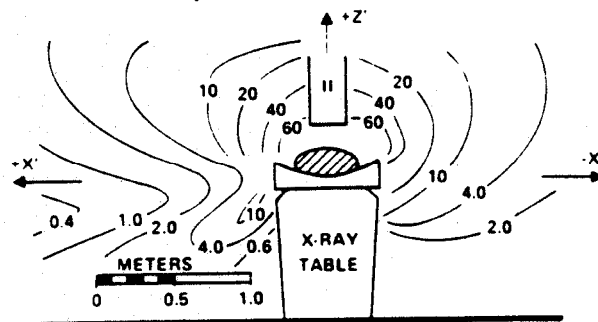


FIGURE 2. Pattern in the vertical plane of exposure values (mR/hr) during cardiac catheterization. Typical values of 96 kVp 10 x 10 cm field and 1.95 R/min tabletop exposure rates were used.

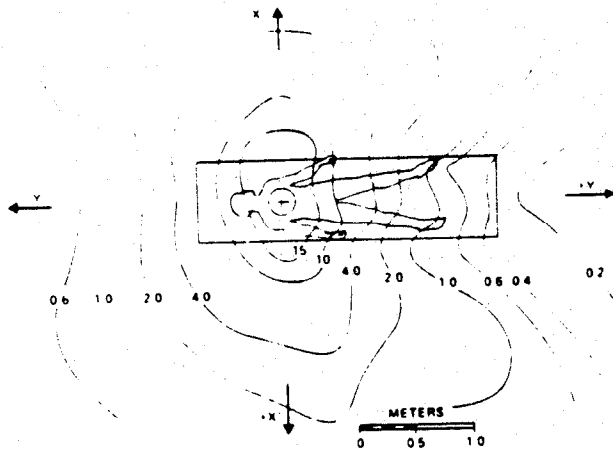


FIGURE 3. Pattern in the horizontal plane of exposure values (mR/hr) during cardiac catheterization. Typical values of 96 kVp, 10 × 10 cm field and 1.95 R/min tabletop exposure rates were used.

Results

The results of exposure calculations using the computer model and associated time-lapse photography are summarized in table 3. These results are from four subphases of three cardiac catheterization procedures. This complicated technique of exposure assessment required the functioning of many individual instruments, and the failure of any one resulted in the failure of the exposure calculation technique for that procedure. The technique could only be used during three procedures when "everything worked." The various subphases of these three procedures are listed, with the average time and range, as well as eye and thyroid exposure for the surgeon and assistant surgeon. The surgeon was the physician who surgically prepared the blood vessel for the catheterization and performed most of the catheter manipulations. The other physician assisted the surgeon and was designated the assistant surgeon. These were the two individuals in continual proximity to the patient throughout the procedure. The eye and thyroid exposure for the surgeon and the assistant surgeon was about equally divided between the four major subphases. These exposure and time values include both fluoroscopy and the cine portion of each subphase. As previously mentioned, the overall cine portion of the procedures resulted in 47% of the total exposure.

Additional information produced by the computer

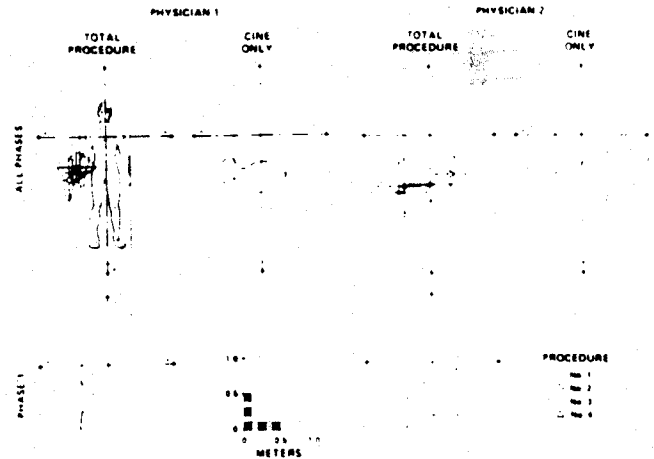


FIGURE 4. Area bounded by ± 1 SD of x and y coordinates of eye position during four cardiac catheterizations.

model was the location of the monitored anatomical sites during the procedure. Figure 4 represents the position of the eyes during the four procedures. The location of the physicians did not vary significantly. Each procedure was divided into phases. Phase 1, shown in figure 4, is the right heart catheterization, or initial manipulation of the catheter, which represents considerably more motion than the following phases. Most of the subsequent phases show little variation (i.e., standard deviation) of the mean position coordinates, which indicates that the physician and assistant physician were essentially stationary during those phases of the procedure.

Table 4 presents the TLD data used as the control information for the major portion of this study. There were 13 procedures monitored by TLD chips. TLDs were lost during some procedures, and a smaller number of reliable data points are available for those affected sites.

Discussion

Based on a recommended maximum dose of 5 rem/yr (100 mrem/wk) to the lens of the eye for occupational workers,³ the surgeon should be limited to approximately five procedures per week (1R exposure approximately equals 1 rem). Similarly, the assistant surgeon should be limited to 14 procedures per week.

TABLE 3. Average Calculated Time and Exposure for Eye and Thyroid During Three Cardiac Catheterization Procedures

Phase	Time-min Average (range)	Eye exposure-mR		Thyroid exposure-mR	
		Surgeon	Asst. Surgeon	Surgeon	Asst. Surgeon
		Average (range)	Average (range)	Average (range)	Average (range)
Right heart catheterization	15.3 (12.4-18.9)	4.9 (1.5- 6.8)	3.5 (1.2- 4.8)	4.2 (1.7- 5.7)	3.1 (1.1- 4.5)
Left ventriculography	9.4 (2.6-14.4)	3.3 (0.6- 5.4)	2.0 (0.2- 2.9)	2.8 (0.8- 5.1)	4.2 (1.4- 7.1)
Right coronary angiography	10.5 (3.9-18.5)	9.1 (4.4-18.3)	4.8 (1.4- 9.7)	7.7 (4.4-12.6)	4.2 (1.4- 7.1)
Left coronary angiography	7.0 (1.9-15.4)	6.5 (4.0- 9.6)	2.7 (1.4- 5.4)	6.2 (2.6-11.0)	2.6 (1.4- 5.3)
Total procedure	50.4 (40.9-69.0)	31.1 (21.1-39.4)	16.4 (12.6-20.2)	27.6 (25.8-33.8)	14.5 (12.2-16.0)

TABLE 4. *Physician Exposures During Cardiac Catheterization Procedures*

Site	Surgeon Exposure-mR			Assistant Surgeon Exposure-mR		
	Mean \pm sd	No.	Range	Mean \pm sd	No.	Range
Eye	19.9 \pm 15.6	(12)	<4-57	7.1 \pm 6.2	(9)	<4-23
Forehead	20.5 \pm 13.6	(12)	6-53	8.0 \pm 5.2	(10)	<4-19
Collar—outside apron	10.0 \pm 4.2	(11)	5-18	6.3 \pm 4.4	(12)	<4-17
Back of hand						
Right	6.7 \pm 3.8	(10)	<4-12	4.8 \pm 2.4	(11)	<4-9
Left	12.7 \pm 11.2	(11)	<4-40	8.7 \pm 12.4	(11)	<4-40
Over thyroid						
Right	16.0 \pm 7.2	(10)	7-27	7.6 \pm 4.4	(7)	<4-15
Left	16.6 \pm 8.8	(10)	8-35	8.1 \pm 5.1	(8)	<4-16
Ratio of exposures						
Eye/Forehead	0.92 \pm 0.27	(12)	0.21-1.23	0.96 \pm 0.22	(9)	0.56-1.29
Eye/Collar	2.01 \pm 1.55	(11)	0.23-4.83	1.40 \pm 0.87	(9)	0.44-3.00
Thyroid/Collar	1.70 \pm 0.75	(9)	1.06-3.33	1.05 \pm 0.29	(7)	0.78-1.67

However, because of the large standard deviations, there can be no assurance of remaining under 100 mrem each week by restricting the number of procedures. Additionally, since the dose/response relationship is linear, exposure should be minimized whenever possible. These occupational exposure limits are based on scientific data and philosophical arguments which, in general, established an "acceptable risk" level with an additional safety factor. The actual risk involved with a 5 rem/yr exposure may be derived from the vast accumulation of data.⁴ Translated to the estimated present number of cardiologists, if 5,000 cardiologists were exposed to 5 rem/yr for a 20-year professional lifetime, 0.23 additional cancer cases could be expected per year. The majority of these would be neoplasms involving the thyroid. This same population would normally have 8.85 cancer deaths per year. Cataract formation appears to be a threshold phenomenon, with a distributed (in time) dose threshold of approximately 1,000 rem. Thus, there would not be any change in cataract incidence.

As noted, eye and thyroid exposures are greater than collar exposures. This indicates an increase in exposure values with height above the floor at the positions normally occupied by physicians (i.e., greater than 0.5 m out from the table edge (fig. 2). The exposure to the hands and thyroid does not seem excessive and does not approach the occupational exposure limits recommended for these body areas.

The eye-to-forehead ratio was obtained to assess the effect of placing a TLD dosimeter on the forehead, as opposed to precise placement at eye level. Considering the standard deviations, there is little difference in exposure between the eye or the forehead level. The eye-to-collar ratio permits the assessment of eye exposure from assisting personnel who are monitoring procedures. This ratio requires a film badge or some other dosimeter placed at the collar level outside of the lead apron. While the exposures appear higher at the eye than at the collar levels, the standard deviation is large and the actual difference is questionable. The evidence seems to indicate that the eye exposures are

higher by a factor of 2. The thyroid-to-collar ratio could also be questioned, but the evidence suggests that thyroid exposure is approximately 1.7 times the measured collar exposure.

Table 5 summarizes the mAs and time factors utilized during the 13 cardiac catheterization procedures for which these detailed exposure data are reported.

Table 6 summarizes patient exposure during cardiac catheterization for the 13 procedures. Also listed are the exposure values for the same anatomical sites as determined by Properzio (unpublished doctoral thesis, 1975). Properzio's study was conducted in approximately the same manner and at a similar time as this study but at a different geographical site. The results are strikingly similar, particularly in averages; however, the ranges appear to be broader in his study. Because of efforts to preserve the patients' privacy, the exposure measurements in the pubic area may be questioned in that the precise locations of the dosimeters are often not known and are not reproducible.

Methods of Exposure Reduction

It is impossible to prescribe specific radiation protection measures which could be universally applicable to all cardiac catheterization laboratories. Each laboratory can reduce radiation exposure by applying certain general radiation protection principles to its individual needs. Many of these principles are obvious, yet are overlooked in the haste of per-

TABLE 5. *Machine Factors During the 13 Monitored Cardiac Catheterization Procedures*

Parameter	Mean \pm sd	No.	Range
mAs			
Flouro	3950 \pm 2140	(13)	1710-9080
Cine	7630 \pm 1160	(11)	5500-9600
Total	11930 \pm 2000	(11)	9400-16280
Time-min			
Flouro-min	29.9 \pm 13.7	(13)	18.5-68.4
Cine-sec	74.4 \pm 20.6	(11)	37.5-106.0

TABLE 6. Patient Exposure During Cardiac Catheterization

Site	This study			Propertio (1975)		
	Mean \pm sd	No.	Range	Mean \pm sd	No.	Range
Exposure (mR) over thyroid						
Right	243 \pm 122	(12)	110-480	231 \pm 214	(21)	9-756
Left	278 \pm 138	(12)	120-540	240 \pm 218	(21)	11-784
Base of sternum*	1109 \pm 518	(12)	520-2320	—	—	—
Mid sternum*	—	—	—	839 \pm 646	(21)	40-2430
Patient						
Pubic area exposure (mR)	12.1 \pm 12.1	(11)	<4-41	3.3 \pm 2.8	(21)	1-10
Height (in)	68.3 \pm 4.1	(12)	62-77	66.6 \pm 3.3	(21)	61-72
Weight (lbs)	160.5 \pm 33.9	(12)	105-208	151.7 \pm 30.0	(21)	108-209
Age (yr)	54.3 \pm 9.6	(12)	37-67	46.9 \pm 19.6	(21)	16-71
Fluoro						
Time (min)	29.9 \pm 13.7	(13)	18.5-68.4	15.43 \pm 8.10	(21)	4.3-39.0

*These represent exit exposure for an undertable x-ray tube. Thyroid and pubic area exposure are primarily due to scatter and hence representative of true exposure at those sites.

forming a specific complex task. Following is a brief enumeration of several basic principles:

1) Always use the smallest x-ray beam possible. This will greatly reduce exposure to the patient and to the attending staff.

2) Always use the least amount of time necessary to accomplish the procedure.

3) All personnel should remain as far from the patient (i.e., the source of the scatter) as possible. These efforts must be evaluated in light of functional needs, but constant attention and thought to "keep distant" will result in a significant saving of exposure to staff.

4) Job rotation of personnel results in a more even distribution of exposure and less likelihood of any one individual receiving excessive exposure.

5) Shielding should be considered. The usual arguments against shielding are interference with manipulation of the catheter and an inability to maintain a sterile field. Movable shields, drapes or a bead-chain curtain are possible if designed properly with the consideration of specific requirements of cardiac catheterization procedures.⁵ The Minnesota Special Procedure Room uses several innovative shielding techniques which reduce scatter radiation significantly to the physician.⁶ Specifically, a metal disk or plate surrounding the image intensifier and movable side flaps or drapes would greatly reduce scatter upwards to the region of the eyes. In addition, side shields on the rotation cradle would reduce side scatter. Constant care must be exercised to assure that movable shields are down or in place when such positioning will not interfere with the procedure.

6) Constant attention to exposure-related items during equipment maintenance will result in exposure reduction. In addition, involving the facility radiation safety group, particularly in establishing routine periodic evaluations of equipment performance, will help to assure the best performance as well as lowest exposure levels. A routine check of radiation output while utilizing a standardized phantom will detect aging or malfunctioning image intensifiers with automatic brightness controls and the resulting high exposure rates.

7) Lead glass eye shields will provide protection for

the eyes, but to be effective, eye shields must be between the eyes and the x-ray source (i.e., the patient). The physician seldom looks directly at the part of the patient that is being irradiated. Usually his gaze is on the TV monitor or the area of insertion of the catheter and the x-rays are not perpendicular to the eye shields. Thus, the protection provided is never the stated attenuation of the eye shields.

Conclusion

The limiting occupational exposure to physicians conducting cardiac catheterization is the exposure to the eyes. Although there is considerable variation from facility to facility, 20 mR per procedure is an average value. To remain within the recommended exposure level of 100 mR per week, a physician functioning as the primary physician would be limited to five procedures per week. The assistant physician or surgeon would be limited to 14 procedures per week. Naturally, any trade-off of duties would result in a proportional change in procedures allowed. Although cine portions of the procedures account for 47% of the exposure, a reduction in this time would result in a significant overall reduction of exposures. This applies to both the patient and occupationally-exposed personnel. The duties, location and duration of time of other personnel in the room must be evaluated carefully to determine their exposure. If appropriate lead aprons are worn and proximity to the patient (i.e., the source of the scattered radiation field) is avoided, little exposure will be accumulated by support personnel. During this study, no other personnel received a measurable exposure during a procedure.

Eye exposures may be estimated from collar dosimeter measurements by applying a correction factor of 2. Similarly, the thyroid exposure may be calculated from collar dosimeter measurements by multiplying by 1.7. These values enable assessment of eye and thyroid exposure if the exposure patterns are similar to those experienced during this experiment and the film badge used in personnel monitoring is located outside the lead apron and at collar level.

Patient exposure is still a problem. Estimated incident exposures averaging 28 R would be considered

significant; however, since the procedures were performed on critically ill patients and the information was felt necessary for the clinical management, the exposure was considered acceptable. Table 2 suggests a trend in decreasing exposure, both average and maximum value, during the last decade. However, with the limited number of exposure studies, one cannot be sure whether this trend is reliable. As mentioned before, any reduction of cine time should yield considerable reduction of overall exposure. However, any technique for the reduction of fluoroscopic time, such as electronic radiography, should not be overlooked in the efforts to reduce patient exposure. A basic decision must be made on the balance of exposure risk vs possible gain resulting from the diagnostic procedure.

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