F_1 Hybrid G) changed sharply with time of harvest, the pattern (relative amounts of each) was similar. For this reason, these harvests were placed closely together in the table. Since most of the varietal data represent three heads, the least significant ratio for triplicate analyses at the bottom of the table may be used to show differences. A statistical study showed a greater variation in glucosinolate concentration from head to head within open-pollinated varieties than within hybrids. This was also true with common cabbage, *B. oleracea* (VanEtten et al., 1976).

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γ Irradiation of Subtropical Fruits. 1. Compositional Tables of Mango, Papaya, Strawberry, and Litchi Fruits at the Edible-Ripe Stage

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Total sugar, protein, and lipid contents of the edible portions of four mango, two papaya, one litchi, and two strawberry cultivars were determined as well as certain vitamins and trace elements. Both control (unirradiated) and fruits irradiated at the commercially recommended doses were analyzed. The chemical composition of the four species of fruit examined was very similar. Statistical analyses of the constituents of the irradiated and nonirradiated fruit showed no difference between them.

Papayas, mangoes, litchis, and strawberries suffer from severe shelf-life problems as a result of postharvest diseases, premature ripening, and insect infestation. The preservation of foodstuffs by ionizing radiation has received much attention over the past few decades and, in South Africa, detailed investigations have been undertaken into the possible use of this process for solving the problems encountered with these fruits (Brodrick et al., 1976, 1977; Thomas and Brodrick, 1977).

One obstacle which thus far is retarding rapid commercialization is the problem of safety for consumption. The work of the International Food Irradiation Project (IFIP) in evaluating the wholesomeness of irradiated foods is directed at answering this question and the positive result of the Expert Committee Meeting convened by WHO/IAEA/FAO (WHO, 1976) in September 1976 is a large measure of the success of the IFIP to date. At this Expert Meeting, following the scrutinizing of detailed, multigeneration, and multispecies feeding studies, two of the above-mentioned fruits, viz. papayas and strawberries, were recommended for unconditional clearance for public consumption. However, in view of the exceedingly high cost and effort involved in executing such feeding studies, it is unreasonable to expect investigations of similar magnitude to be carried out in each and every fruit considered for radiation treatment. Indeed, the WHO has endorsed the principle: "when in-depth toxicological, nutritional, microbiological and chemical data are collected on a representative food of a given diet class, limited data would suffice for evaluating the safety of such irradiation processes for other foods within the same class". In this context it is important to note that classification of foods into diet classes is by chemical, and not botanical, similarity. Accordingly, due to the apparent chemical similarity between mangoes, papayas, and strawberries, the IFIP has commissioned only a limited feeding study on mangoes, using one species (rats) and over a period of 2 years. However, it was recommended by the IFIP that the results of these studies be complemented by chemical analyses confirming chemical similarity to the two fruits studied in detail. As far as is known, no feeding studies have been carried out on litchis and none are contemplated.

Although compositional observations on the fruits in question are available, much of the information has been

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Table I. Analytical Methods

analysis	95% confidence limits $\alpha = 0.05$	no. of runs	method	comments
water	±2.32	8	AOAC (1970), 7.004	Modified Mohr pipet replaced by Dean Starke distillation head
fat	±0.03	9	AOAC (1975), 7.044 and 7.045	4 × 30 mL extractions substituted for continuous extraction. Wet sample used
ash	±0.02	11	AOAC (1975), 22.025	Olive oil omitted
acidity	±0.05	16	AOAC (1975), 22.061	10 g of fruit/100 mL and 0.01 N NaOH used
protein	±0.18	19	Lowry et al. (1951)	
starch	±0.06	7	Saunders (1956)	Determined on dried residue after sugars had been extracted
sugar	±1.49 (I), ±4.61 (II)	13 (I), 4 (II)	Sumner (1925) (I), *S. Afr. Gov. Gaz.* (1971) (II)	Extracted with 80% aqueous ethanol. II used for Haden mangoes, I for all other fruits
carotene	±529	9	Bickoff (1957) Bunnel et al. (1958)	
ascorbic acid	±2.41	11	Baraket et al. (1955),	Evered (1960) used for strawberry analyses
riboflavin	±0.01	8	AOAC (1975) 43.036	
niacin	±0.28	8	AOAC (1975) 43.044	
thiamin	±0.009	8	AOAC (1975) 43.024	
phosphorus	±1.39	9	Fiske and SubbaRow (1925)	
calcium			AOAC (1975) 2.096	Ash dissolved in concn HCl, diluted to 100 mL. See Crosby (1977) for general review
iron	±0.30	6	AOAC (1975) 2.096	
sodium	±1.12	10	AOAC (1975) 49.001	
potassium			AOAC (1975) 49.001	

generated on a wide variety of cultivars, grown in different geographical areas and done in a large number of different laboratories using different techniques (Coetzee, 1953; Fox, 1966; Hulme, 1970, 1971; Watt and Merrill, 1975; Wenkam and Miller, 1965). It was, therefore, considered desirable that a comparison be made of the chemical compositions of the popular cultivars of these fruits using standard methods within one laboratory. This report gives the results of these determinations, done on both nonirradiated and irradiated fruits so that any definite effect of the irradiation process on any of the constituents may be observed, as well as to enable a direct comparison of the chemical compositions of the four fruits with one another.

EXPERIMENTAL SECTION

Cultivars. Mangoes (*Mangifera indica* Linn.): Kent, Zill, Haden, and Peach. Papayas (*Carica papaya* Linn.): Hortus Gold and Papino (a type similar to the "Solo" variety grown in Hawaii). Litchis (*Litchi chinensis* Sonn.): Mauritius. Strawberries (*Fragaria ananassa* Linn.): Selekta and Parfait.

Source of Fruit. Mangoes, papayas, and litchis were supplied by the Letaba Co-operative, Tzaneen. Strawberries were kindly supplied by Glenwood Farm, Hartebeespoort.

Preirradiation Treatment. Mangoes: 50 °C hot water dip for 5 min and waxed. Papayas: 50 °C for 10 min and waxed. Litchis: 50 °C for 10 min.

The heat treatment was applied to reduce fungal spoilage of the fruits. The coating was a paraffin-based wax used to prevent moisture loss through the skin of the fruit.

Irradiation. Mangoes and papayas were irradiated in a mature-green state, while litchis and strawberries were treated at the edible-ripe stage. Fruits were irradiated 24–48 h after harvesting. The research "loop" of the commercial ^{60}Co irradiation facility or the ^{60}Co "gammabeam 650" (AECL Ltd) at Pelindaba, at dose rates of ca. 0.80 or 0.50–0.80 kGy/h, respectively, were used for all irradiations. Dose rates were determined by means of the Fricke dosimeter. The total irradiation doses, which are those recommended for commercial irradiation of these fruits, and the number of fruits/treatment are as shown in Chart I.

Chart I

fruit	irradiation dose	no./treatment
mangoes	0.75 kGy	
Kent		5/8
Zill		8/10
Haden		8/10
Peach		9/10
papayas	0.75 kGy	
Papinos		8/10
Hortus gold		5/6
strawberries	2.00 kGy	50/100
litchis	2.00 kGy	50/100

Storage and Sampling. Mangoes and papayas were stored at ambient temperature (20–24 °C) until they softened. Strawberries and litchis were stored for 24 h after irradiation. The inedible parts of the ripe fruits (skin, seeds, and calyces) were removed. The edible portion of each treatment was then either chopped into small pieces, which were mixed thoroughly, or homogenized. Substances which deteriorate upon freezing, such as ascorbic acid and carotene, were determined on the fresh pieces or pulp. For all other analyses the correct mass of pulp or pieces was measured into a disposable weighing boat, each boat sealed into a small polyethylene bag and stored at −15 °C until the relevant analysis could be done. Duplicate weighings of both control and irradiated pulp or pieces from each consignment of fruit were analyzed. At least two consignments per cultivar were received during each of three harvests.

Analytical Methods. Methods adapted to analysis of fruits and plants were selected as far as was possible. At least two analysts made independent observations in each of the methods employed. Duplicate analyses were performed on the relevant extracts of each measured portion of fruit pulp or pieces. The various analytical methods that were used are summarized in Table I.

Precision of the Analytical Methods. The 95% confidence limits for the various analytical methods are given in Table I. The limits for each method were cal-

Table II. Mango Composition (c = Control, γ = 0.75 kCy)

	Kent			Zill			Haden			Peach		
	c	γ	γ-c	c	γ	γ-c	c	γ	γ-c	c	γ	γ-c
g/100 g												
water	81.85	80.11	−1.74	78.52	78.35	−0.17	82.26	82.40	+0.14	80.50	81.01	+0.51
fat	0.08	0.09	+0.01	0.09	0.09	0	0.07	0.08	+0.01	0.05	0.06	+0.01
ash	0.32	0.32	0	0.32	0.30	+0.02	0.33	0.33	0	0.48	0.48	0
acidity[a]	0.24	0.23	−0.01	0.25	0.36	+0.11	0.29	0.30	+0.01	0.41	0.46	+0.05
protein	0.46	0.49	+0.03	0.47	0.46	−0.01	0.34	0.33	−0.01	0.50	0.52	+0.02
starch	0.74	0.73	−0.01	1.60	2.51	+0.91	1.45			0.49	0.53	+0.04
sugar	12.36	11.46	+0.90	10.53	10.55	+0.02	5.27	5.40	+0.13	8.13	7.16	−0.97
IU/100 g												
carotene	5169	5456	+287	11021	10018	−1003	4693	5506	+813	6024	7089	+1065
mg/100 g												
ascorbic acid	20.05	19.68	−0.37	10.17	10.47	+0.30	4.43	2.28	−2.15	14.38	14.38	0
riboflavin	0.06	0.05	−0.01	0.09	0.08	−0.01				0.06	0.05	−0.01
niacin	0.42	0.38	−0.04	1.65	1.78	+0.13				0.09	0.07	−0.02
thiamin	0.06	0.05	−0.01	0.09	0.09	0				0.05	0.03	−0.02
calcium	8.73	9.37	+0.64	10.35	8.16	−2.19	10.90	11.45	+0.55	22.45	17.70	−4.75
phosphorus	10.18	10.27	+0.09	14.58	16.62	+2.34	9.90	9.50	−0.40	14.00	15.20	+1.20
iron	0.16	0.17	+0.01	0.34	0.22	−0.12	0.19	0.38	+0.19	0.45	0.34	−0.11
sodium	0.84	0.73	−0.11	0.29	0.33	+0.04	0.30	0.41	+0.11	1.20	0.85	−0.35
potassium	115.00	120.50	+5.50	66.45	74.55	+8.10	64.75	71.50	+6.75	103.95	100.20	−3.75

[a] Calculated as g of citric acid/100 g.

Table III. Papaya Composition (c = Control, γ = 0.75 kGy)

	Papinos			Hortus Gold		
	c	γ	γ-c	c	γ	γ-c
g/100 g						
water	86.10	86.40	+0.30	87.85	87.50	−0.35
fat	0.11	0.07	−0.04	0.07	0.07	0
ash	0.44	0.46	+0.02	0.46	0.46	0
acidity	0.08	0.09	+0.01	0.12	0.14	+0.02
protein	0.68	0.66	−0.02	0.52	0.57	+0.05
starch	0.079	0.055	−0.02	0.12	0.10	−0.02
sugar	7.58	7.55	−0.03	5.52	5.90	+0.38
IU/100 g						
carotene	4285	4460	+175	2819	3480	+661
mg/100 g						
ascorbic acid	89.61	91.89	+2.28	68.96	72.63	+3.67
riboflavin	0.031	0.034	+0.003	0.02	0.03	+0.01
niacin	0.77	0.51	−0.26	0.33	0.31	−0.02
thiamin	0.04	0.03	−0.01	0.03	0.02	−0.01
calcium	34.75	36.03	+1.28	27.05	35.15	+8.10
phosphorus	10.05	9.50	−0.55	7.50	8.20	+0.70
iron	0.18	0.21	+0.03	0.43	0.38	−0.05
sodium	2.31	2.09	−0.22	5.81	6.52	+0.71
potassium	40.52	37.34	−3.18	105.10	95.00	−10.10

culated from values obtained from unirradiated samples of each of the cultivars of the four fruits examined. Check runs were performed during each harvest. Each run consisted of two fruit samplings. No limits could be calculated for calcium and potassium since the values of the individual samplings were not supplied by the analysts concerned with these analyses.

RESULTS

The results of the compositional analyses of mangoes, papayas, strawberries, and litchis are given in Tables II, III, IV, and V, respectively. These tables are summarized in Table VI, which shows the mean values for all mango, papaya, and strawberry cultivars and the mean values for litchis.

Statistical Analyses. *Differences in the Constituents of the Control and Irradiated Fruits of Each Cultivar.* Block analyses of variance ($P = 0.01$) of the results shown in Table II indicate significant differences between the water content of unirradiated and irradiated Kent mangoes and the acidity of treated and untreated Zill and Peach mangoes. No significant differences could be detected in the concentrations of any of the other components of the four mango cultivars, nor could significant differences be found between the constituents of the control and irradiated fruits tabulated in Tables III to V for papayas, strawberries, and litchis. The differences between the individual cultivars disappear when the mean values of each of the four fruits shown in Table VI are analyzed statistically.

Differences between Cultivars. It may be seen from Table VII that there are ten, or 59%, of the chemical components where no significant differences occur between the four mango cultivars. Hortus Gold and Papino papayas differ significantly from each other only in their sodium content. Water and acidity are significantly different in Selekta and Parfait strawberries.

Significant Variations between the Four Fruits. Table VIII contains the results of the statistical analyses of the component differences between mangoes, papayas, strawberries, and litchis. To prove chemical similarity between papayas and strawberries, which are recommended for unconditional clearance for human consumption, and mangoes, commissioned for limited feeding studies, and litchis, for which no feeding studies are contemplated, points of nonsignificance were sought.

Table IV. Strawberry Composition (c = Control, γ = 2.00 kGy)

	Selekta			Parfait		
	c	γ	γ-c	c	γ	γ-c
g/100 g						
water	89.25	89.80	+0.55	91.70	90.60	−1.10
fat	0.15	0.13	−0.02	0.20	0.22	+0.02
ash	0.50	0.48	−0.02	0.40	0.43	+0.03
acidity	0.75	0.76	+0.01	0.60	0.64	+0.04
protein	0.84	0.79	−0.05	0.70	0.72	+0.02
starch						
sugar	6.05	4.95	−1.10	4.90	4.90	0
IU/100 g						
carotene	382	368	−14	326	616	+290
mg/100 g						
ascorbic acid	59.80	57.30	−2.50	57.80	52.70	−5.10
riboflavin	0.03	0.03	0	0.03	0.03	0
niacin	0.47	0.49	+0.02	0.63	0.52	−0.11
thiamin	0.02	0.02	0	0.02	0.02	0
calcium	13.27	13.63	+0.36	4.25	4.35	+0.10
phosphorus	17.85	18.20	+0.35	12.50	13.40	+0.90
iron	0.54	0.72	+0.18	0.84	0.92	+0.08
sodium	0.60	0.55	−0.05	0.66	0.82	+0.16
potassium	84.73	82.98	−1.75	116.65	118.00	+1.35

Table V. Litchi Composition (c = Control, γ = 2.00 kGy)

	c	γ	γ-c
g/100 g			
water	80.35	80.55	+0.20
fat	0.10	0.11	+0.01
ash	0.42	0.44	+0.02
acidity	0.25	0.29	+0.04
protein	0.76	0.74	−0.02
starch			
sugar	16.24	15.15	−1.09
IU/100 g			
carotene	0	0	0
mg/100 g			
ascorbic acid	39.15	39.38	+0.23
riboflavin	0.08	0.08	0
niacin	0.31	0.29	−0.02
thiamin	0.006	0.004	−0.002
calcium	3.77	3.80	+0.03
phosphorus	24.90	25.15	+0.25
iron	0.27	0.25	−0.02
sodium	0.35	0.37	−0.02
potassium	121.80	112.60	−9.20

Counts of nonsignificance expressed as a percentage of the number of constituents investigated are as follows: papaya, mango, 17.6%; papaya, litchi, 33.3%; strawberry, mango, 25%; strawberry, litchi, 40%.

Papaya and strawberry contents are nonsignificant in 31.3% of instances while the best agreement occurs between mango and litchi, i.e., 46%.

CONCLUSION

The constituents of four mango, two papaya, one litchi, and two strawberry cultivars were determined on irradiated and unirradiated fruit.

We have come to the conclusion that changes wrought by γ irradiation are not significant and that the nutritional value of the fruits is not affected; no significantly detrimental changes were observed in any of the radiation-sensitive vitamins. Far greater variation is noted in the cultivar differences of mangoes. Seasonal variations which are not isolated from the bulk of the results, also exhibited marked fluctuations. Therefore, cultivar differences, seasonal variations, method of analysis, and the analyst concerned have a greater influence on the results reported than irradiation.

It is not clear how far the chemical composition of new fruits considered for radiation treatment must agree with that of fruits which have been studied in detail in order that limited feeding studies be sufficient. For evaluating

Table VI. Representative Composition of Irradiated and Nonirradiated Mangoes, Papayas, Strawberries, and Litchis

	mangoes			papayas			strawberries			litchis		
	c	γ	γ-c	c	γ	γ-c	c	γ	γ-c	c	γ	γ-c
g/100 g												
water	80.78	80.47	−0.31	86.98	86.95	−0.03	90.48	90.20	−0.28	80.35	80.55	+0.20
fat	0.07	0.08	+0.01	0.09	0.07	−0.02	0.18	0.18	0	0.10	0.11	+0.01
ash	0.36	0.36	0	0.45	0.46	+0.01	0.45	0.46	+0.01	0.42	0.44	+0.02
acidity	0.30	0.34	+0.04	0.10	0.12	+0.02	0.68	0.70	+0.02	0.25	0.29	+0.04
protein	0.44	0.45	+0.01	0.60	0.62	+0.02	0.77	0.76	+0.01	0.76	0.74	−0.02
starch	1.07	1.26	+0.19	0.102	0.075	−0.027						
sugar	9.07	8.64	−0.43	6.55	6.73	+0.18	5.48	4.93	−0.55	16.24	15.15	−1.09
IU/100 g												
carotene	6727	7017	+290	3552	3970	+418	354	492	+138	0	0	
mg/100 g												
ascorbic acid	12.23	11.70	−0.53	79.29	82.26	+2.97	58.80	55.00	−3.80	39.15	39.38	+0.23
riboflavin	0.07	0.06	−0.01	0.03	0.03	0	0.03	0.03	0	0.08	0.08	0
niacin	0.72	0.74	+0.02	0.55	0.41	+2.01	0.55	0.51	−0.04	0.31	0.29	−0.02
thiamin	0.07	0.06	−0.01	0.04	0.03	−0.01	0.02	0.02	0	0.006	0.004	−0.002
calcium	13.11	11.67	−1.44	30.90	35.59	+4.69	8.76	8.99	+0.23	3.77	3.80	+0.03
phosphorus	12.17	12.90	+0.73	8.78	8.85	+0.07	15.18	15.80	+0.62	24.90	25.15	+0.25
iron	0.29	0.28	−0.01	0.31	0.30	−0.01	0.69	0.82	+0.13	0.27	0.25	−0.02
sodium	0.66	0.58	−0.08	4.06	4.31	+0.25	0.63	0.69	+0.06	0.35	0.37	+0.02
potassium	87.54	91.69	+4.15	72.81	66.62	−6.19	100.69	100.49	+0.20	121.80	112.60	−9.20

Table VII. Analysis of Variance of the Four Mango Cultivars[a]

	significant difference		significant difference
water	NS[b]	riboflavin	NS
fat	NS	niacin	Peach, Kent, Zill
ash	NS		
acidity	Kent, Zill, Haden, Peach	thiamin	Peach, Kent, Zill
		calcium	NS
protein	Haden, Kent, Zill, Peach	phosphorus	Haden, Kent, Peach, Zill
starch	NS		
		iron	NS
sugar	NS		
		sodium	NS
carotene	Haden, Kent, Peach, Zill	potassium	NS
ascorbic acid	Haden, Zill, Peach, Kent		

[a] Vertical rules indicate groups of cultivars with no significant difference in chemical composition. [b] NS, no significant difference between cultivars.

Table VIII. Analysis of Variance: Differences in Composition of Mangoes, Papayas, Strawberries, and Litchis ($P = 0.01$)[a]

	significant difference		significant difference
water	mango, litchi, papaya, strawberry	riboflavin	papaya, strawberry, mango, litchi
fat	mango, papaya, litchi, strawberry	niacin	litchi, papaya, strawberry, mango
ash	mango, litchi, papaya, strawberry	thiamin	litchi, strawberry, papaya, mango
acidity	papaya, litchi, mango, strawberry	calcium	litchi, strawberry, mango, papaya
protein	mango, papaya, strawberry, litchi	phosphorus	papaya, mango, strawberry, litchi
starch	papaya, mango	iron	litchi, mango, papaya, strawberry
sugar	strawberry, papaya, mango, litchi	sodium	strawberry, mango, litchi, papaya
carotene	strawberry, papaya, mango	potassium	papaya, mango, strawberry, litchi
ascorbic acid	mango, litchi, strawberry, papaya		

[a] Vertical rules indicate groups of fruits with no significant difference in chemical composition.

the safety of the fruits in question, however, we feel that a sufficient degree of similarity has been established to justify inclusion of mangoes and litchis in the same diet class as papayas and strawberries.

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Supplementary Material Available: Four tables of the literature values of the components determined in the four species of fruit are given. References additional to those cited in the main body of the text are quoted (5 pages). Ordering information is given on any current masthead page.

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γ Irradiation of Subtropical Fruits. 2. Volatile Components, Lipids, and Amino Acids of Mango, Papaya, and Strawberry Pulp

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An investigation of volatile components, amino acids, and fatty acids in irradiated and nonirradiated mango, papaya, and strawberry pulp samples was made. Capillary gas chromatographic analyses of sample extracts have revealed at least 137 mango volatiles, 85 papaya volatiles, and 124 strawberry volatiles. Examination of the gas chromatography profiles and peak ratios from integration data of samples at the same degree of ripeness show similar patterns, and no significant difference between the volatile profiles of irradiated and nontreated samples were established by peak-by-peak analyses of variance. It was further found that the free amino acid and total amino acid content of mango, papaya, and strawberry pulp remained unchanged by irradiation. The fatty acid composition of mango, papaya, and strawberry samples was similar in irradiated and control samples. It was also noted that the organoleptic qualities, volatile profiles, and lipid content of these fruits were highly dependent on the degree of maturity. This factor must be carefully considered in future comparative studies.

Irradiated papayas and strawberries were given recommendation for unconditional clearances for human consumption by an Expert Committee Meeting convened by FAO/IAEA/WHO ("Wholesomeness of Irradiated Food", 1977). Since mangoes have an apparent chemical similarity to strawberries and papayas, only limited feeding studies on mangoes have been commissioned by the International Food Irradiation Project (IFIP). However, it was recommended that these feeding studies be supplemented by analysis confirming chemical similarity between mangoes and the two fruits studied in detail.

Samples of irradiated and nonirradiated mango, papaya, and strawberry pulp were submitted to this Institute for study by the South African Atomic Energy Board, Pelindaba. The purpose of this investigation was to determine if irradiation of the pulp caused significant differences in the lipid fraction, amino acid fraction, or in the total profile of volatile components of the various fruits. This study complements the compositional tables on irradiated and nonirradiated mangoes, papayas, strawberries, and litchis compiled by the South African Atomic Energy Board (Beyers et al., 1978).

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EXPERIMENTAL SECTION

Cultivars. Mangoes (*Mangifera indica* Linn.) Kent variety; papayas (*Carica papaya* Linn.) Papino variety (a type similar to the "Solo" variety grown in Hawaii); strawberries (*Fragaria ananassa* Linn.) Selekta variety.

Source of Fruit. Mangoes and papayas were supplied by the Letaba Co-operative, Tzaneen, Transvaal, while strawberries were supplied by the Glenwood Farm, Hartebeespoort, Transvaal.

Irradiation. The research "loop" of the commercial ^{60}Co package irradiator (AECL, Ltd) at Pelindaba operating at a dose rate of ca. 0.80 kGy/h was used for all

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