Pulping Characteristics of Ten-Year Loblolly Pine Selected for Extreme Wood Specific Gravity

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(Received for publication December 15, 1967)

Introduction

The genetic improvement of wood and fiber properties has resulted in apprehension among wood, and pulp and paper technologists regarding the possible adverse influence that may result from attempts to produce trees having extremes in wood quality. In loblolly pine ***(Pinus taeda)*** pulpwood high specific gravity is associated with higher pulp yield per unit volume, higher cellulose production per acre at comparable growth rates, and more efficient use of pulping machinery. At the same time, therc is a loss of quality with respect to a number of strengt11 properties and printability.

VAN BUIJTENEN, ***et al.*** (1968) discussed the complex nature of wood specific gravity — pulp and paper property interrelationships and emphasized that specific gravity is the average result of a number of factors including the specific gravity of cell wall material, microporosity of cell walls, proportion of springwood and summerwood, wall thickness and fiber dimensions within the springwood and summerwood, and the level of extractives in the wood.

Excellent literature reviews on the influence of wood properties on pulp and papermaking properties were made by DADSWELL, ***et al.*** (1959), BESLEY (1959), and DINWOODIE (1965). General trends in wood property — pulp and paper property research emphasize that increases in wood specific gravity are accompanied by increases in tearing strength and reductions in bursting strength, breaking length, and fold endurance. Recent studies by BAREFOOT, ***et al.*** (1966) and WANGAARD, ***et al.*** (1966) demonstrated a strong influence of certain fiber dimensions on pulp and paper properties. The study described is a follow-up on an earlier study by VAN BUIJTENEN, ***et al.*** (1967) and was initiated to gain a greater understanding regarding the influence of wood specific gravity on pulp and paper properties. More specifically the objectives are to: (1) compare pulp and paper properties of selected high and low specific gravity loblolly pine clones, and (2) investigate the influence of a limited number of wood and fiber properties on pulp and paper characteristics.

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Materials and Methods

Materials

In an earlier study cited above, three loblolly pine clones selected for high specific gravity and three clones selected for low specific gravity were examined using 11 mm. increment core samples. In the present study a single tree from each of the six clones was cut and representative disk and chip samples obtained from the merchantable stem for use in further investigations on wood, pulp and paper property interrelationships. The trees being compared were grafted individuals and were approximately 10 years old. ***Table*** 1 summarizes the wood and fiber characteristics of the six clones. The values presented are average values based upon measurements made using increment core samples from four trees per clone. The packing density data presented in ***Table*** 1 are defined as the specific gravity of the cell wall and are calculated as the specific gravity divided by the percent cross-sectional area occupied by the cell walls.

Measurements on Wood

Measurements on wood included specific gravity, percent summerwood, fiber length, fiber diameter, cell wall thickness, percent lignin, alcohol-benzene extractives, and compression wood. For some characteristics, measurements were available from both breast height increment core (IC) [VAN BUIJTENEN, ***et al.*** (1967)] samples and whole tree (WT) samples based upon a series of disks taken at 0, 3, 5, 8, 10, and 13 feet along the stem. Specific gravity was determined using a water-displacement procedure and is the ovendry weight divided by the green volume, The compression wood values are based upon grid counts made on disks on which the compression wood areas had been outlined using a light box. Values for whole tree (WT) summerwood percent were obtained from disk samples by linear measurement of springwood and summerwood along two radii located approximately 180° from each other. Whole tree values for the above properties were calculated by weighting the disk data on a wood volume basis. Fiber length measurements were determined on unbeaten pulp samples by projecting the fibers on a ground-glass screen at a

Table 1. — Wood properties of loblolly pine clones determined from increment core samples.

Clone	Wood specific gravity, g./cm.^{3}	Percent Summerwood	Diameter of springwood tracheids, µ	Wall thickness of springwood tracheids, µ	Diameter of summerwood tracheids, µ	Wall thickness of summerwood tracheids, µ	Packing density,[1]) g./cm.^{3}	Fiber length: Arithmetic average, mm.	Fiber length: Weighted average, mm.
B	0.362	17.0	32.6	4.94	25.3	9.6	0.782	1.95	2.36
C	0.361	17.9	35.3	5.14	25.5	9.4	0.792	1.87	2.25
D	0.417	23.3	35.7	5.83	28.5	10.1	0.826	2.07	2.49
X	0.330	16.2	35.6	4.53	27.1	8.7	0.795	2.04	2.45
Y	0.522	13.9	37.4	5.04	26.7	9.1	0.756	2.11	2.49
Z	0.315	7.4	35.0	5.22	27.0	8.9	0.734	2.06	2.49

[1]) Packing density is defined as the specific gravity of the cell walls and is calculated as the wood specific gravity divided by the percent cross-sectional area occupied by the cell walls.

magnification of 50× and measuring the fiber length using a semiautomatic, planimeter-type fiber-measuring device. Measurements were based upon 1400—1500 fibers and included not only intact but cut and broken fibers as well. Both arithmetic and weighted average fiber length are presented.

Pulp and Papermaking Procedures

Representative chip samples for each tree were prepared from three 36-inch bolts located at 0 to 3, 5 to 8, and 10 to 13 feet along the stem. Following chipping in the Carthage chipper, the fines were removed from the chips by screening on a four-mesh wire cloth, and knots, slivers, and discolored chips were removed by manual sorting. Representative chip samples were removed and reduced to 40-mesh wood flour in a micropulverizer. This material was used to determine the extractive and lignin content of the wood. TAPPI standards T 6 m-59 and T 13 m-54 were used in determining extractives and lignin.

A stainless steel, vertical, stationary digester was used to pulp the wood chips. This vessel has a capacity of about 60 liters and is fitted for circulation of the cooking liquor through a steam heat exchanger. Conditions used in the pulping and the product variables are shown in *Table 2*. The digester was blown at the end of the cook into a muslin-covered washbox and the pulp washed using warm water. The washed pulp was screened on a Valley flat screen fitted with 0.10-in. cut plate. The screening rejects were oven dried, weighed and the weight recorded. The accepted stock was dewatered using a modified laundry centrifuge. The dewatered pulp was broken into crumbs in a mechanical mixer and packaged in a polyethylene bag for storage. Representative samples taken at this time were used to determine the moisture-free fiber content and the permanganate number[2]) of the pulp.

Table 2. — Cooking conditions and product variables whole tree pulping study.

Wood sample	B	C	D	X	Y	Z
Digester charge, g.	9000	9000	9000	9000	9000	9000
Digester charge, g.[1])	4162	4104	4661	3780	3452	3895
Unscreened yield, %[1])	39.9	40.9	43.7	42.1	40.4	41.2
Screened yield, %[1])	39.8	40.8	43.6	42.1	40.4	41.1
Permanganate no.[2])	18.6	18.2	18.6	17.5	20.1	18.8

Constant Conditions:	
Liquor ratio, ml./g.[1])	5.0
Active alkali as NaOH, %[1])	25
Sulfidity, %	25
Maximum temperature, °C	170
Time to max. temp., min.	105
Time at max. temp., min.	135
Time to relieve to 85 p.s.i., min.	5
Relief to 0 p.s.i. at 100° C	

[1]) Basis moisture-free wood.
[2]) TAPPI Method T 214 m-50, 40-ml. basis.

Single beater evaluations were performed as described in TAPPI T 200 ts-61. Handsheets were prepared as specified in TAPPI T 205 m-56. In addition to the standard sheets tested for caliper, density, tearing, bursting, and tensile strength and formation, a single sheet having approximately 85% of the weight of a standard sheet was formed. This sheet was used to measure the zero-span tensile strength of the pulp.

[2]) Permanganate number determined by TAPPI T 214 m-50, 40-ml. basis.

Results and Discussion

The measurements of whole tree wood properties were carried out using a series of disks and the values presented are based on disk measurements that have been weighted on a volume basis. *Table 3* summarizes the whole tree wood property measurements. *Table 4* summarizes the

Table 3. — Wood properties determined on whole trees.

Tree no.	Wood specific gravity,[1]) grams/cc.	Compression wood, %[1])	Summerwood, [1]) %	Fiber Length [2])	
				Arithmetic average, mm.	Weighted average, mm.
B-1	0.382	6	15	1.40	2.05
C-1	0.373	7	13	1.48	1.98
D-1	0.421	9	17	1.68	2.34
X-3	0.340	6	15	1.64	2.10
Y-4	0.340	5	14	1.44	2.01
Z-1	0.318	4	9	1.52	2.12

[1]) Values based upon a series of six disks taken at 0, 3, 5, 8, 10, and 13 feet along each stem. Values were weighted on a volume basis.
[2]) Measurements made on unbeaten pulp samples.

Table 4. — Comparison of physical properties of whole tree pulps at two freeness levels.

Tree	B	C	D	X	Y	Z
Properties at 800-cc. S.-R. freeness						
Beating time, min.	26	21	26	22	20	21
Apparent density	14.5	14.2	13.9	14.7	14.8	15.1
Bursting strength, pt./100 lb.	139	137	143	144	138	148
Tear factor	1.30	1.09	1.22	1.10	0.91	0.82
Tensile strength, lb./in.[1])	34.3	36.5	35.2	37.6	37.2	39.8
Zero-span tensile strength, lb./in.[1])	58.2	61.0	60.8	60.0	61.2	63.5
Properties at 500-cc. S.-R. freeness						
Beating time, min.	61	46	53	57	51	63
Apparent density	15.5	15.4	15.0	15.9	15.8	16.3
Bursting strength, pt./100 lb.	149	153	153	163	160	169
Tear factor	1.12	0.98	1.11	0.94	0.88	0.74
Tensile strength, lb./in.[1])	38.2	40.3	38.5	40.0	40.7	40.9
Zero-span tensile strength, lb./in.[1])	59.5	64.0	63.5	61.8	63.4	65.7

[1]) Basis 45-lb. sheet.

whole tree pulp and paper properties obtained by pulping representative chip samples and running a standard TAPPI beater evaluation on the pulps obtained. The data are presented at 500 and 800-cc. Schopper-Riegler freeness level. The test handsheet produced from the high specific gravity trees in general had lower apparent density, lower bursting strength, lower tensile strength, lower zero-span tensile strength, and higher tearing strength. Statistical comparisons between the high and low specific gravity clones revealed the differences obtained were significant for apparent density at 500 and 800-cc. freeness, bursting strength and tear factor at 500-cc. freeness and tensile strength at 800-cc. freeness. Zero-span tensile strength differences were not significant.

Table 5 summarizes the significant simple correlations obtained when the whole tree wood and fiber property data were compared with the whole tree pulp and paper properties and with clonal average increment core measurements. *Table 6* summarizes similar types of comparison between wood and fiber properties measured on increment core samples (using average values for clones) and whole tree pulp and paper properties. In both tables significant pulp property relationships have been omitted.[3])

The simple correlations between specific gravity and pulp properties confirmed the observations of earlier workers which suggested that increasing specific gravity is accompanied by increases in tearing strength and decreases in apparent density and bursting and tensile strength. *Tables 5 and 6* present a number of additional interesting relationships including the positive correlation between specific gravity and percent summerwood, and specific gravity and percent compression wood. Also of interest is the influence of specific gravity, percent summerwood, and percent compression wood on the apparent density of handsheets at 500 and 800-cc. freeness and at zero beating interval. The wall thickness of summerwood fibers (tracheids) and the packing density were also related to the apparent density of the handsheets. Summerwood tracheids apparently do not collapse and tend to give bulky open-textured sheets with low apparent density. The results obtained are in agreement with the work of WATSON

Table 5. — Selected significant simple correlations between whole tree wood and fiber properties and whole tree pulping and increment core wood property data.

Variables		r values[3])
Specific gravity (WT)[1])	Compression wood, % (WT)	0.93
	Apparent density, 500-cc. freeness	—0.97
	Burst, 500-cc. freeness	—0.84
	Tear, 500-cc. freeness	0.90
	Tensile, 500-cc. freeness	—0.83
	Apparent density, 800-cc. freeness	—0.95
	Tear, 800-cc. freeness	0.82
	Tensile, 800-cc. freeness	—0.85
	Summerwood + compression wood, % (WT)	0.87
	Apparent density, zero beating	—0.95
	Specific gravity (IC)[2])	0.98
	Summerwood, % (IC)	0.92
	Wall thickness, summerwood fibers (IC)	0.94
	Packing density (IC)	0.85
Summerwood, % (WT)	Tear, 500-cc. freeness	0.86
	Tensile, 800-cc. freeness	—0.81
	Extractives (IC)	—0.84
	Summerwood, % (IC)	0.91
	zero-span (IC)	—0.82
	Packing density (IC)	0.86
Compression wood, % (WT)	Apparent density, 500-cc. freeness	—0.94
	Apparent density, 800-cc. freeness	—0.98
	Apparent density, zero beating	—0.95
	Extractives (WT)	—0.85
	Extractives (IC)	—0.84
	Specific gravity (IC)	0.95
	Summerwood, % (IC)	0.96
	Packing density (IC)	0.96
Fiber length, arithmetic (WT)	Unscreened yield (WT)	0.96
	Lignin (WT)	—0.99
	Diameter, summerwood fibers (IC)	0.84
Fiber length, weighted average (WT)	Unscreened yield (WT)	0.88
	Lignin, % (WT)	—0.87
	Lignin, % (IC)	—0.97
	Diameter, summerwood fibers (IC)	0.86

[1]) WT — whole tree data based upon disk or chip samples.
[2]) IC — increment core data based upon clone average values.
[3]) Correlation coefficients (*r*) are significant at the 5% level if they exceed 0.81 and significant at the 1% level if they are greater than 0.92.

Table 6. — Selected significant simple correlations between wood and fiber properties measured on increment core samples and whole tree pulping data.

Variables		r values[3])
Specific gravity (IC)[1])	Apparent density, 500-cc. freeness	—0.94
	Tear, 500-cc. freeness	0.83
	Apparent density, 800-cc. freeness	—0.94
	Apparent density, zero beating	—0.96
Summerwood, % (IC)	Apparent density, 500-cc. freeness	—0.95
	Tear, 500-cc. freeness	0.89
	Apparent density, 800-cc. freeness	—0.95
	Tear, 800-cc. freeness	0.81
	Tensile, 800-cc. freeness	—0.82
	Apparent density, zero beating	—0.89
	Extractives, % (WT)[2])	—0.81
	Extractives, % (IC)	—0.90
Diameter, springwood fibers (IC)	No significant correlations	
Wall thickness, springwood fibers (IC)	No significant correlations	
Diameter, summerwood fibers (IC)	Unscreened yield (WT)	0.88
	Lignin, % (WT)	—0.86
	Lignin, % (IC)	—0.93
Wall thickness, summerwood fibers (IC)	Apparent density, 500-cc. freeness	—0.90
	Apparent density, 800-cc. freeness	—0.84
	Apparent density, zero beating	—0.86
Fiber length, arithmetic (IC)	No significant correlations	
Fiber length, weighted (IC)	No significant correlations	
Zero-span (IC)	Tear, 500-cc. freeness	—0.85
	Zero-span, 500-cc. freeness	0.92
	Tear, 800-cc. freeness	—0.84
	Tensile, 800-cc. freeness	0.89
	Zero-span, 800-cc. freeness	0.98
Packing density (IC)	Apparent density, 500-cc. freeness	—0.87
	Tear, 500-cc. freeness	0.83
	Apparent density, 800-cc. freeness	—0.91
	Summerwood + compression wood, % (WT)	0.95
	Apparent density, zero beating	—0.88
	Extractives (WT)	—0.86
	Extractives (IC)	—0.89

[1]) IC — increment core data based upon clone average values.
[2]) WT — whole tree data based upon disk or chip samples.
[3]) Correlation coefficients (*r*) are significant at the 5% level if they exceed 0.81 and significant at the 1% level if they are greater than 0.92.

and DADSWELL (1962) in which they studied the influence of early-wood and late-wood morphology on paper properties.

Another interesting relationship is the negative correlation between fiber length and percent lignin and the positive correlation between fiber length and pulp yield. Longer fibers could result in fewer end walls per given weight of wood and would consequently result in less lignin (and less pectin compounds) and a higher pulp yield. Since fiber length and diameter are highly correlated *(Table 7)*, it is also possible that the relative proportion of the cell wall layers is changed due to the general increase in cell size. Whatever the case may be, the relationship needs further investigation to confirm its occurrence and establish its cause.

Multiple regressions were run to investigate more closely the interrelationships of selected wood properties on pulp and paper properties. Because of a limited number of data

[3]) In an effort to conserve space significant simple correlations between such properties as tear, burst, tensile strength, etc. have been omitted.

Table 7. — Relationship between fiber length and fiber diameter.

Dependent variable	Independent variable	Regression coefficient	t	R	R^2
Fiber length, arithmetic (WT)	Constant	—0.578			
	diameter, summerwood fibers (IC)	0.0788	0.959	0.801	0.690
Fiber length, weighted (WT)	Constant	0.363			
	diameter, springwood fibers (IC)	—0.0462	0.959		
	Diameter, summerwood fibers (IC)	0.126	0.994	0.972	0.944

points, all independent variables could not be handled at one time. As a result, a series of multiple correlations were run using three independent variables at a time and various combinations of appropriate variables. The results are presented in *Table 8*. Only statistically significant relationships are shown. Generally speaking, tensile and tear were related to zero span, specific gravity, percent summerwood, wall thickness of springwood, and wall thickness of summerwood fibers. Bursting strength was related to specific gravity and fiber length.

Tear factor was found to be significantly related to the percent summerwood, the diameter of the springwood tracheids, and the wall thickness of the springwood and summerwood tracheids. Similarly, tensile strength was significantly related to the percent summerwood, the wall thickness of the springwood tracheids and the wall thickness of the summerwood tracheids. Burst factor appears to be less influenced by the wood properties considered and fiber length was the only property that was significantly correlated with burst. Wall thickness of the summerwood tracheids and wall thickness of the springwood tracheids were the two fiber dimensions that influenced the greatest number of pulp and paper properties. This is in agreement with the findings of Barefoot, *et al.* (1966). The fact that the trees used were selected for extremes in specific gravity may have influenced this relationship.

Summary and Conclusions

The pulp and paper properties of six clones, three selected for high specific gravity and three selected for low

Table 8. — Multiple regression equations of pulp and papermaking properties on various wood and fiber properties.[1])

Dependent variable	Independent variable	Regression coefficient	t	R	R^2
Unscreened yield, % (WT)	Constant	99.8			
	Lignin, % (IC)	—1.81	0.985		
	Extractives, % (IC)	0.66	0.955	0.967	0.936
Unscreened yield, % (WT)	Constant	109.3			
	Lignin, % (WT)	—2.32	0.999	0.976	0.952
Burst, 800-cc. freeness	Constant	107.9			
	Specific gravity (WT)	—103.1	0.965		
	Fiber length, weighted (WT)	33.8	0.975	0.934	0.872
Tear, 800-cc. freeness	Constant	407.8			
	Zero-span, 800-cc. freeness	—6.43	0.972		
	Specific gravity (WT)	249.8	0.955	0.973	0.947
Tear, 800-cc. freeness	Constant	289.7			
	Summerwood, % (IC)	2.77	0.995		
	Diameter, summerwood fibers (IC)	—6.41	0.986	0.982	0.965
Tear, 800-cc. freeness	Constant	—152.5			
	Wall thickness, springwood fibers (IC)	—45.1	0.958		
	Wall thickness, summerwood fibers (IC)	52.6	0.983	0.941	0.885
Tensile, 800-cc. freeness	Constant	9.71			
	Zero-span, 800-cc. freeness	0.623	0.973		
	Specific gravity (WT)	—29.9	0.976	0.979	0.958
Tensile, 800-cc. freeness	Constant	68.2			
	Wall thickness, springwood fibers (IC)	4.45	0.997		
	Wall thickness, summerwood fibers (IC)	—5.81	0.999	0.993	0.987
Burst, 500-cc. freeness	Constant	168.8			
	Specific gravity (WT)	—235.4	0.997		
	Fiber length, weighted (WT)	35.4	0.982	0.982	0.965
Burst, 500-cc. freeness	Constant	280.0			
	Wall thickness, springwood fibers (IC)	16.0	0.981		
	Wall thickness, summerwood fibers (IC)	—21.9	0.995	0.976	0.953
Tear, 500-cc. freeness	Constant	183.3			
	Zero-span, 500-cc. freeness	—3.06	0.998		
	Specific gravity (WT)	291.7	1.000	0.997	0.994
Tear, 500-cc. freeness	Constant	187.9			
	Summerwood, % (IC)	2.42	0.995		
	Diameter, springwood fibers (IC)	—3.69	0.957	0.979	0.958
Tear, 500-cc. freeness	Constant	—137.2			
	Wall thickness, springwood fibers (IC)	—31.1	0.978		
	Wall thickness, summerwood fibers (IC)	42.1	0.994	0.973	0.947

[1]) Zero-span tensile strength was included as an indication of fiber strength.

specific gravity, were compared by pulping and running standard beater evaluations on representative chip samples from single trees from each clone. The results obtained were compared with wood and fiber properties obtained from disk samples and earlier evaluated increment core samples. The trees evaluated were approximately ten years old and the wood was primarily juvenile wood. Because the trees were selected for extremes in specific gravity, considerable variation existed in specific gravity and related fiber morphology. In evaluation of the results, the selection procedure used should be kept in mind.

Simple correlations demonstrated that specific gravity was correlated with the percent summerwood, the percent compression wood, and the wall thickness of the summerwood fibers. Increases in specific gravity were accompanied by increases in tearing strength and reductions in burst and tensile strength. Handsheets made from the high specific gravity trees had lower apparent density indicating the thick-walled summerwood and compression wood fibers were not collapsing with the result that open textured, bulky sheets of low apparent density were produced. Highly significant correlations were obtained between pulp yield and percent lignin ($r = —.98$) and pulp yield and the arithmetic average fiber length ($r = .96$).

Multiple regression analysis revealed that tensile strength was significantly related to the percent summerwood, and the wall thickness of springwood and summerwood tracheids. Tearing strength was related to the above factors and, in addition, was significantly correlated with the diameter of the springwood tracheids. Bursting strength was less influenced by fiber and wood properties and only fiber length was found to be significantly related to bursting strength.

There is considerable evidence in the literature that indicates wood specific gravity is under moderate to strong genetic control. Specific gravity and associated fiber morphology appeared to have considerable influence on pulp and paper properties. The desirability of the use of forest genetic techniques to increase specific gravity of the southern pines is influenced by a number of factors. The importance of increased pulp yield and higher tearing strength *versus* lower apparent density, lower burst and lower tensile strength must be considered. Also worthy of consideration are the possibilities of technologically modifying fiber properties as well as the possible use of silvicultural techniques (fertilization, irrigation, spacing, and length of rotation) to influence specific gravity and fiber morphology.

Acknowledgement

The authors are indebted to Mrs. M. M. Mohammed for many hours of painstaking work in obtaining the wood property data. Appreciation is also expressed to members of the Technology Section for their contribution to the pulping phases of the program and to W. A. Wink and members of the Paper Evaluation Section for making the paper property measurements.

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Male Bud and Pollen Radiosensitivity in Selected Conifer Species[1])

By G. R. Stairs and V. Troendle[2])

(Received for publication December 15, 1967)

Introduction

Mutation induction in forest trees may be accomplished by using ionizing or particulate radiation, chemical mutagens, or by other physical treatments. Definitive comparisons of these various techniques in forest tree materials have not been made and much remains to be learned about the relative advantages of each. Prior to such comparisons, the usefulness of each separate approach must be defined for the broad spectrum of available materials. The study herein reported was conducted to provide data for planning mutation breeding programs in conifers, using gamma radiation of male buds or pollen as the mutagen treatment. It is expected that subsequent breeding studies would provide a basis of comparison to other induced mutation methods.

Reviews of radiation experiments conducted in forest tree material are included in recent publications by Ericksson *et al.* (1966) and Lynn (1967). From these listings it is apparent that the majority of studies thus far have dealt with the irradiation of seeds or other somatic materials. Despite the preponderant use of somatic tissues, certain theoretical advantages of gametic irradiation are obvious. In particular, gamete treatment avoids the disadvantages of chimeral cell populations that often result from somatic radiation. The problems of dominance or recessive mutant gene character are not necessarily made easier, although the question of meiotic screening for chromosomal irregularities in individuals following radiation is expected to be more consistent than with chimeral tissues.

The question why one should desire mutation induction in already heterozygous forest tree material ignores much of the biological potential of the technique. A previous discussion of the usefulness of irradiated pollen has been published by Stairs and Mergen (1964). In that article the authors pointed to the possibilities of producing germinable

[1]) This study was supported by a grant from the U. S. Atomic Energy Commission, Division of Biology and Medicine, Biology Branch, Contract No. AT (30-1) 3571, NYO 3571-6.

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