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GENERAL REACTOR-ENGINEERING RESEARCH QUARTERLY PROGRESS REPORT FOR PERIOD ENDING AUGUST 31, 1950

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GENERAL REACTOR-ENGINEERING RESEARCH

QUARTERLY PROGRESS REPORT

for Period Ending August 31, 1950

Edited by

R. N. Lyon

DATE ISSUED

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PREFACE

The quarterly report of General Reactor-Engineering Research is issued in order to describe results on work which cannot be ascribed specifically to one reactor program. Miscellaneous corrosion testing, the development of new shielding materials, the testing of irradiated plastics, and general heat transfer investigations are examples of activities which are of simultaneous value in the development of more than one reactor or which are of value in providing facts on which long range reactor design considerations can be based. The results of such activities are contained in the following report. Engineering research and development motivated by specific reactor projects will be reported in the MTR, ANP and Homogeneous Reactor quarterly reports and will not be duplicated in this report.

[redacted]

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SUMMARY

It was found that MO concrete deteriorates on aging, particularly in wet or humid surroundings. This plus a lack of uniformity in the commercial ingredients has led to the decision not to initiate new studies on MO.

The compressive strength, thermal conductivity, specific heat, linear expansion and water absorption properties of barytes concrete were measured. In addition, the water absorption of ordinary concrete and of limonite concrete were measured.

Small sheets of boron carbide in plastisols exhibited superior physical properties to boron carbide in Tygon. A large 56½ in. × 66½ in. sheet of the latter was successfully fabricated.

A large Boral sheet, 52 in. × 92 in. × 3/16 in., was successfully rolled at a Republic Steel Company plant.

Boral was sprayed onto mild steels, but the bond with the base metal was weak and needs further development.

Ten service corrosion studies requested by various divisions of the Laboratory were completed or are in progress.

Mechanical properties of 34 plastics have been obtained as a function of total irradiation in the X-10 reactor. These are reported. Some data on other more resistant plastics have also been obtained as well as information on electrical properties and the effects of fast neutron and pure gamma irradiation. These latter data will be reported when the information is more complete.

[redacted]

INDIVIDUALS RESPONSIBLE FOR THE WORK REPORTED

Shielding Materials Development

A. S. Kitzes, Group Leader

Concrete Shielding Materials	R. B. Gallaher C. A. Gifford
Boral	V. L. McKinney
Plastics	A. S. Kitzes
Physical Properties	W. Q. Hullings

Miscellaneous Corrosion Studies

J. L. English, Group Leader

H. L. Barker	A. R. Olsen
J. W. Brown	S. H. Wheeler
L. L. Fairchild	

Irradiation Studies

O. Sisman, Group Leader

R. Battistella	W. K. Kirkland
C. D. Bopp	R. L. Towns

Note: Work performed by the above groups for specific reactor projects are reported in the several reactor progress reports.

SHIELDING MATERIALS DEVELOPMENT

MO CONCRETE
(Iron punchings in magnesium oxychloride cement)

Summary. Wide variations in the strength and curing time of duplicate specimens of magnesium oxychloride cement and concrete continued to be observed, and these are attributed to non-uniformity of the specially calcined MgO from which the cement is made. Commercially calcined MgO of uniform quality has not been obtainable.

While these inherent variations tended to mask the effects of different environments on MO concretes, all tests indicated a decreasing strength with age, and a serious deterioration when submerged in water. Irradiation in the X-10 reactor also appeared to reduce the strength of MO.

Because of the poor structural strength and aging characteristics of MO concrete, interest in MO at this site and other sites has diminished. Consequently, no new work on MO concrete is being initiated. The tests now in progress will be completed and a report will be issued as ORNL-709.

Variations in and Aging of Neat MO Concrete. Batches of neat MO cement for comparison tests have been made from three different shipments of commercial specially calcined magnesia. Some samples of these batches are being aged in a controlled atmosphere of 77°F and 50% relative humidity while others are being stored on the laboratory shelf where the average relative humidity is above 60%.

Setting time and compressive strength were not uniform from batch to batch, and this is attributed to variations in the commercial calcining process for the special magnesia, and also to chemical changes occurring in the stored magnesia after calcining.

It appears, on the average, that after eight weeks the cement in the controlled atmosphere has not lost as much compressive strength as has the cement stored in the laboratory. Until more data are obtained, a categorical statement cannot be made because of the wide variations in the properties of cement samples stored under identical conditions.

Aging Characteristics of MO Concrete. MO concrete was found to absorb moisture and to decrease in compressive strength with time. Samples were stored under a variety of conditions. Increased strength, resulting from the

use of sand blasted punchings, as opposed to rusty punchings, is indicated but has not been conclusively proven. In the laboratory atmosphere with an average temperature of about 77°F and relative humidity above 60% the initial strength of a number of samples varied from 2500-3200 psi, and after 24 days, the strength decreased to 1700-2200 psi. Upon examination of the broken specimens, it was evident that failure occurred at the bonds between the cement and the punchings. The relatively low strength of some of the "young" samples also indicated that the punchings may have been too rusty to make good concrete.

Effects of clean versus rusty punchings has not been definitely established since there is marked variation between the various batches of concrete. The data appear to indicate, however, that concrete made with clean punchings has a higher initial strength than concrete made with rusty punchings. In one experiment, the initial compressive strength of the concrete made with clean punchings averaged 2950 psi and decreased after four weeks storage to 2000 psi; whereas the concrete made with rusty punchings had an initial strength of 2100 psi which decreased to 1350 psi after four weeks storage.

Aging of concrete in a controlled atmosphere, with temperature 77°F, R.H. 50%, does not clearly show the effect of clean and rusty punchings on the compressive strength of samples to date. However, the data do indicate that the samples made with either clean or rusty punchings and stored in the controlled atmosphere have higher compressive strengths after the usual one week curing period than do the corresponding samples made from the same batches but stored in the laboratory atmosphere.

Comparisons are still in progress. To evaluate the effect of rusty versus clean punchings more precisely, a test procedure has been set up in which the variations in the magnesia from batch to batch will be kept to a minimum by blending four to five sacks of magnesia prior to mixing of the batches.

MO concrete cured or stored under water rapidly loses its strength. In most of the samples, the strength decreased below 1500 psi after one to two weeks soaking. Tygon paint reduced the rate of decrease in the compressive strength, but in a few weeks the strength of all submerged samples had dropped enough to render the concrete unsatisfactory.

Radiation Damage. MO was apparently weakened by an irradiation of over 10^{18} nvt in the X-10 reactor, but was not damaged seriously by a lower dosage. Earlier radiation damage experiments in the X-10 reactor did not give conclusive evidence as to the extent of the damage of MO. In one experiment,

there was a marked decrease in the compressive strength after two weeks exposure. Other experiments indicate no radiation damage after six weeks exposure. The poor aging characteristics and the inherent variation of MO are apparently masking the true effects of the radiation damage. A second series of samples is being irradiated in hole 19 in the X-10 pile. The control samples are being stored in the controlled atmosphere room at 77°F which is approximately the temperature of the samples in the pile. Results to date (Table I) indicate a marked decrease in compressive strength with a total irradiation of 1.2×10^{18} nvt, but no serious damage with 6×10^{17} nvt. The radiation damage tests are continuing.

TABLE I

	WEEKS OF EXPOSURE	TOTAL nvt	COMPRESSIVE STRENGTH (psi) EXPOSED	UNEXPOSED
Neat cement	1	6.3×10^{17}	6959	7310
Neat cement	2	1.21×10^{18}	4210	7455
Neat cement + 20% Fe	1	6.3×10^{17}	9623	9630
Neat cement + 20% Fe	2	1.21×10^{18}	5887	9647

MI CONCRETE
(Colemanite in magnesium oxychloride cement)

Blending dry colemanite and magnesia prior to the addition of the magnesium chloride solution shows promise of eliminating the cracking of samples during curing.

BARYTES CONCRETE

The physical properties of barytes concrete which have been determined so far are listed in Table II.

The ORNL chemical analysis and the petrographic analysis of the Bureau of Reclamation for the two-ton shipment of barytes from the Idaho Operations Area showed the aggregate to be unsuitable for use in the MTR Shield. The silica in the barytes was of the form which gave an alkali-aggregate reaction when mixed with cement. Consequently, all data reported in Table II were obtained by using Sweetwater, Tennessee, barytes.

TABLE II

Compressive strength	(psi)
10.1% P.C.	
7 day cure	3645
28 day cure	4667
9.5% P.C.	
7 day cure	3091
28 day cure	3607

Thermal conductivity at (Btu/hr-ft^2-°F/ft)	50°C	100°C	150°C	200°C	300°C	350°C
3 day old sample (no cure)	1.4	1.2	1.1	0.89	0.84	0.80
16 day old sample (7 day cure)	1.1	1.1	1.0	1.0	0.81	0.73

Specific heat at (Btu/lb-°F)	50°C	100°C	150°C	200°C
Sample cured for 28 days	0.123	0.133	0.141	0.150

Linear expansion or contraction on setting at 100°F

10.1% P.C.	+ 0.22 mils/in. after 6 days
	- 0.12 mils/in. after 14 days*
9.5% P.C.	+ 0.8 mils/in. after 2-3 days
	+ 0.5 mils/in. after 28 days

*This test was stopped after 14 days because of faulty relay controls and excessive building vibrations from nearby construction activities.

The water absorption properties of barytes concrete, Brookhaven cement (limonite), and ordinary concrete are shown in Table III The samples were cured under water and periodically weighed.

TABLE III

	WATER CONTENT (%)				
	WHEN POURED	1 Day	7 Days	14 Days	28 Days
Brookhaven (ρ = 2.6)	12.7	11.9	13.0	13.0	13.3
Ordinary Concrete (ρ = 2.3)	8.15	7.1	7.45	7.45	7.8
Barytes Concrete (ρ = 3.5)	5.61	5.07	5.59	5.54	5.69

SPECIAL CONCRETE

Formulation of mixes for limonite concrete (ρ = 3.5) using snagging scrap, cast iron borings, and a graded iron has begun for the limonite blocks to be used in the new Bulk Shielding Facility. Physical properties of the mix which is cheapest and most suitable for the facility will be determined.

SHIELDING PLASTICS

Results of initial experiments, in which a plastisol was substituted for Tygon paint as the binder, indicate that large tungsten carbide sheets can be fabricated which are more rigid and tougher than corresponding sheets made with Tygon paint. Small sheets were made, 4 in. × 4 in. × ½ in. These had a density of about 11, or about 75% of the theoretical density of the tungsten carbide used. The higher strength of the plastisols, and the fact that they are thermosetting and hence strong at temperatures above 300°F lead to the belief that for most applications tungsten carbide sheets of this material will be superior to sheets bonded with the weaker Tygon, which softens at about 170°F. A table is under construction for fabrication of large 56½ in. × 66½ in. sheets of the plastisol material.

The plastisol used in the initial tests was Unichrome 4032 supplied by the United Chromium, Inc., Carteret, N. J., and is a dispersion of finely divided vinyl chloride-acetate resin in which the entire dispersion medium consists of non-volatile liquid plasticizers. They are liquid pastes which

can be spread, dipped, injected, extruded or cast at room temperature and converted into tough vinyl resin products by heating at 350°F - 365°F. Since no volatiles are present, the problems of film shrinkage, drying, etc., are non-existent.

One sheet, 56½ in. × 66½ in. × ¼ in. of tungsten carbide and Tygon paint was fabricated to determine whether or not the sheet, when suspended from one edge, would support its own weight. The sheet weighs approximately 175 lbs. It supported its own weight and there was no evidence of creeping. However, it was possible that the center of the sheet would buckle when completely framed. To inhibit this buckling, a sheet may be made using tungsten powder instead of the carbide and then framed for use in the Lid Tank.

BORAL SHEETS

Boral, a mixture of boron carbide and aluminum with an exceptional ability to absorb thermal neutrons, was rolled into a sheet, 52 in. wide, 92 in. long and 3/16 in. thick at the South Division Plant of the Republic Steel Co., in Canton, Ohio. After a few more experimental rollings at Republic, Boral could be supplied commercially in sheets, 5 ft × 10 ft × 3/16 in., if the demand warrants commercial production.

Because of the small quantity required, Boral for the MTR will be rolled into sheets 24 in. wide, 84 in. long and either 1/8 in. or 1/4 in. thick in the X-10 rolling mill. Wider sheets will then be fabricated by joining several smaller ones. Boral ingots will be made at Y-12 and rolled by the Metallurgy Division at X-10. To make Boral available to the other installations, the Laboratory will accept small requests for urgent orders for 24 in. maximum width by 84 in. maximum length sheets.

Republic was chosen for commercial rolling experiments because it had hand-fed or "jobber" rolling mills which were more suited for the rolling of Boral. Two ingots, 23 in. × 14 in. × 2 in., and 50% B_4C by volume, were prepared and framed in aluminum according to the procedure outlined in ORNL-629. Two-inch frames and ½-in. covers were used.

At Republic, the ingots were heated to 1100°F in approximately three hours prior to rolling. Both ingots were reduced 50%, reheated to 1000°F, and rolled to 3/16 in., the minimum attainable thickness on the rolls which were being

used. Since 1/8 in. thick sheets were desired for some applications, E. C. Smith, chief metallurgist, suggested that he could hot-roll the 3/16-in.-thick sheet to 1/8 in. One sheet was reheated to 1000°F and hot-rolled unsuccessfully on rolls maintained at 600°F. The sheet stuck to the rolls causing considerable damage.

Results of the successful experimental rolling at Republic can be summarized as follows:

1. It is necessary to lubricate the rolls to prevent sticking of the aluminum to the steel.
2. Rolling should be done only on cold rolls.
3. Ingots should be heated to 1050°F - 1100°F, reduced 50% or until the temperature of the sheet falls to 600°F when measured with a tempelstik, reheated to 900°F - 1000°F and then rolled to the required thickness.

BORAL SPRAYING

Preliminary results indicate that Boral can be sprayed onto mild steels. However, the bond between the sprayed Boral and the base metal needs improvement. This development will be continued.

MISCELLANEOUS CORROSION STUDIES

Ten service corrosion studies requested by various divisions at the Laboratory have been completed or are in progress since the beginning of the quarter. Data on these projects are included below.

CORROSION RESISTANCE OF STELLITE L605

The corrosion resistance of a cobalt base alloy, Stellite L605, was determined in boiling 65% nitric acid solutions containing 0.01% - 75.0% hydrochloric acid by volume and in boiling 65% nitric acid containing 0.01% hydrochloric acid and 1.0% - 15.0% hydrogen peroxide by volume. The alloy was tested in both welded and non-welded conditions; exposures were made under total immersion and in the vapor phase. Temperature of the solutions averaged 110°C - 120°C. Corrosion resistance of the material was generally poor under all conditions of test. The best corrosion resistance, 12.8 mils/year, was observed on a non-welded specimen exposed to the vapor phase for 312 hours. A memorandum on this investigation was issued June 3, 1950, J. L. English to W. E. Unger, CF 50-6-208.

CORROSION RESISTANCE OF FUEL PLATES IN SIMULATED REACTOR COOLING WATER

The corrosion resistance of four groups of miniature fuel plates was determined in demineralized water containing 0.005 *M* hydrogen peroxide at 85°C. The four groups represented four different practices used in the fabrication of active fuel plate assemblies for the Materials Testing Reactor. Normal corrosion attack on all four groups of specimens was minor, 0.18 mil/year and less, but localized attack was very pronounced on several groups. Pit penetrations of 17.6 mils were observed on two groups of samples, resulting in a perforation of the protective 2S aluminum-72S aluminum cladding to the uranium-aluminum core material. Uranium was detected in the test solutions containing these particular groups of fuel plates. A final report, ORNL-824, is in the process of being issued.

CORROSION RESISTANCE OF CARBON IN NITRIC ACID

A carbon piston intended for use in a positive displacement type of metering instrument for nitric acid was tested in cold, 70% nitric acid with aeration for 581 hours. The sample exhibited a weight gain of 12.4 $mg/dm^2/day$ and a dimensional expansion of 20 mils across the diameter. No flaking or softening of the material was observed after the test. A memorandum was issued May 15, 1950, J. L. English to R. P. Milford, CF 50-5-191.

CORROSION RESISTANCE OF GLASS COATED STAINLESS STEEL

A sample of glass coated Type 347 stainless steel was tested in boiling 70% nitric acid containing 0.01% hydrochloric acid at 116°C for 480 hours. The average thickness of the coating was 15 mils. The specimen lost 7.61 gm during the test which included the loss in weight of the glass coating and the weight loss of stainless steel by corrosion attack. Corrosion attack was pronounced and was initiated on an area surrounding the hole used for specimen support in the test solution. The glass coating at this point was extremely thin and probably cracked, thus permitting solution contact with the base metal. The evolution of gases from the corrosion reaction resulted in a progressive disintegration of the glass coating down the length of the test specimen. A memorandum was issued June 27, 1950, J. L. English to E. Wischhusen, CF 50-6-209.

CORROSION RESISTANCE OF STAINLESS STEELS IN VARIOUS ACIDS CONTAINING AMMONIUM BIFLUORIDE

Corrosion tests were conducted with Hastelloy C, Carpenter 20, 309 stainless steel (welded and non-welded), and 316 stainless steel in 2.51 *M* ammonium bifluoride solutions containing 5, 20, and 35% nitric acid and in 2.51 *M* ammonium bifluoride solutions containing 5, 12.5, 20% hydrochloric acid. Tests were conducted at room temperature for one week with vigorous aeration. Carpenter 20 exhibited the best corrosion resistance to all solutions, 0.01 - 11.0 mils/year. Hastelloy C exhibited the next best corrosion resistance to all solutions, 0.1 - 12.6 mils/year. Type 309 stainless steel, welded or non-welded, exhibited the best corrosion resistance to the nitric acid solutions

only, 0.03 - 0.1 mil/year. The best corrosion resistance to the hydrochloric acid solutions was shown by Hastelloy C, 0.1 - 6.1 mils/year. A memorandum was issued March 9, 1950, J. L. English to D. T. Jones, CF 50-3-216.

CORROSION RESISTANCE OF STAINLESS STEELS IN RaLa PURIFICATION PROCESS SOLUTIONS

The corrosion resistance of 304, 309, 316, 316 ELC, and 347 stainless steels in feed solutions for the RaLa purification process was determined. Tests were run for 30 days at room temperature. The highest corrosion rate, 0.05 mil/year, was obtained on the 304 stainless steel; all other materials showed corrosion rates of 0.01 - 0.02 mil/year. A memorandum was issued on September 1, 1950, A. R. Olsen to W. E. Unger, CF 50-9-133.

CORROSION RESISTANCE OF STAINLESS STEELS FOR USE IN AN EVAPORATION AND DISTILLATION SYSTEM

Types 309, 316, and 347 stainless steel are being tested to determine their corrosion resistance in an evaporation and distillation system for the recovery of nitric acid from waste solutions. These steels are tested in a welded and non-welded condition at boiling temperatures. The test solution is composed of sodium sulfate, sodium triphosphate, sodium nitrate, nitric acid, and small traces of sodium chloride. The stainless steel samples are tested under conditions of total immersion, exposure to the vapor phase, and exposure to the liquid-vapor phase to study liquid level attack. A report, ORNL-848, is in the process of being issued.

CORROSION RESISTANCE OF ALUMINUM ALLOYS IN FILTERED WATER

The corrosion resistance of 2S aluminum, with and without protective coatings, in filtered water is being determined for the shielding reactor program. Tests are conducted at room temperature. Thus far, the addition of 60 ppm of sodium chromate to the filtered water has successfully inhibited the formation of pitting attack. Anodized aluminum samples have withstood localized attack also. Unprotected 2S aluminum and 2S-72S aluminum clad samples have exhibited definite tendencies to pit in this water. A memorandum was issued, A. R. Olsen to W. M. Breazeale, on September 5, 1950, CF 50-9-134.

CORROSION OF THORIUM AND THORIUM ALLOYS

The resistance of thorium and thorium alloys, processed by the Metallurgy Division, in distilled water at 98°C is being checked. This program is in its initial phase and to date there are only 20 samples representing seven alloys and four metallurgical treatments in test. The results of this investigation will be reported periodically as the tests are completed.

THE CORROSION RESISTANCE OF VARIOUS STAINLESS STEELS IN AQUEOUS SOLUTIONS CONTAINING DOWEX 50 RESIN

Tests were made to determine the comparative corrosion resistance of stainless steel Types 304, 309, 316, 347, 410 and 430, when exposed to Dowex No. 50 Resin saturated with distilled water, 6 *M* HNO_3 and 5% oxalic acid for two and four months periods.

Results indicate that Type 304 and Type 347 should be used for unwelded and welded containers, respectively. The penetration rates for these steels are less than 0.12 mil per year. A report, ORNL-804, has been issued by A. R. Olsen.

IRRADIATION STUDIES

ENGINEERING PROPERTIES OF IRRADIATED PLASTICS

Polystyrene plastics were found to be resistant to more than 1500 times as much pile irradiation as cellulose base plastics, lucite, fluorothene, teflon or saran, judging from changes in mechanical properties. Investigation of the more resistant plastics has yet to be completed. Changes in electrical properties have also been observed and will be reported when all of the data have been accumulated.

Studies have been initiated to investigate the effect of screening the thermal neutrons away from the test specimens during irradiation by means of a cadmium jacket.

Equipment for subjecting materials to gamma radiation from Au^{198} has been designed and is now in the shop for fabrication.

Tests to determine the effect of the presence of oxygen during the irradiation of organic materials are now in progress. This is prompted by the observation that in some cases where X-10 reactor irradiation of plastics took place in air, the greatest damage appeared to be on the surface of the plastic.

In Figs. 1 through 26, the tensile, shear and impact strengths, and the Rockwell Hardness of various plastics are indicated as function of total nvt due to irradiation in hole 19 of the X-10 reactor. The scales are different for the various graphs. This was found necessary to show clearly the changes which occur in a given plastic. In general, plastics with similar radiation resistance are presented on the same plot.

It will be seen from the graphs that in addition to polystyrene, the following materials are probably useable at 15×10^{18} nv/cm^2:

Phenol formaldehyde impregnated graphite (Karbate)
Polyvinyl carbazole (Palectron)
Phenol formaldehyde impregnated asbestos (Haveg)
Furfural alcohol polymer with graphite asbestos filler (Duron)
Nylon (FM 3003)
Nylon (FM 10,001)
Polyethylene

[redacted]

It will also be seen that such materials as cellulose nitrate are seriously affected by an irradiation of 10^{16} nv/cm^2.

Specimens were sealed in aluminum cans and the cans were cooled by flowing water through the pile hole. In this hole, the flux with an energy between 1 ev and 1 Mev is about 50% as large as the thermal flux, while the flux above 1 Mev is about 3% as large as the thermal flux. (See ORNL-525 for details of the determination of the fast and epithermal flux in hole 19.) The gamma flux is estimated to be about equal to the thermal neutron flux.

Tests on the mechanical properties were made according to the ASTM specifications for plastics. To determine the zero irradiation point, an average was taken for a number of tests. The results indicated for irradiated specimens, in most cases, represent individual tests. This was necessary because limited pile space prevented the exposure of more specimens.

Recheck tests were made on unirradiated specimens which were stored in a controlled atmosphere at the same temperature as the irradiated specimens. The data shown in the figures have been adjusted slightly in some cases to correct for changes attributable to storage rather than to radiation.

All specimens of a given plastic were cut from the same sheet of material to minimize discrepancies due to non-uniformity of manufacture. A few test results have been discarded where faulty specimens were indicated by wide deviations from the other results.

INDUCED ACTIVITY IN ENGINEERING MATERIALS

Data are being accumulated on the activity induced in engineering materials by irradiation in the ORNL reactor. They will be listed in later reports.

RADIATION STABILITY OF RUBBERS AND CERAMICS

Work on irradiation stability of rubber is in the planning stage.

Study of the radiation stability of ceramics has been suspended to divert manpower to other work.

[redacted]

[redacted]

DWG. 9828

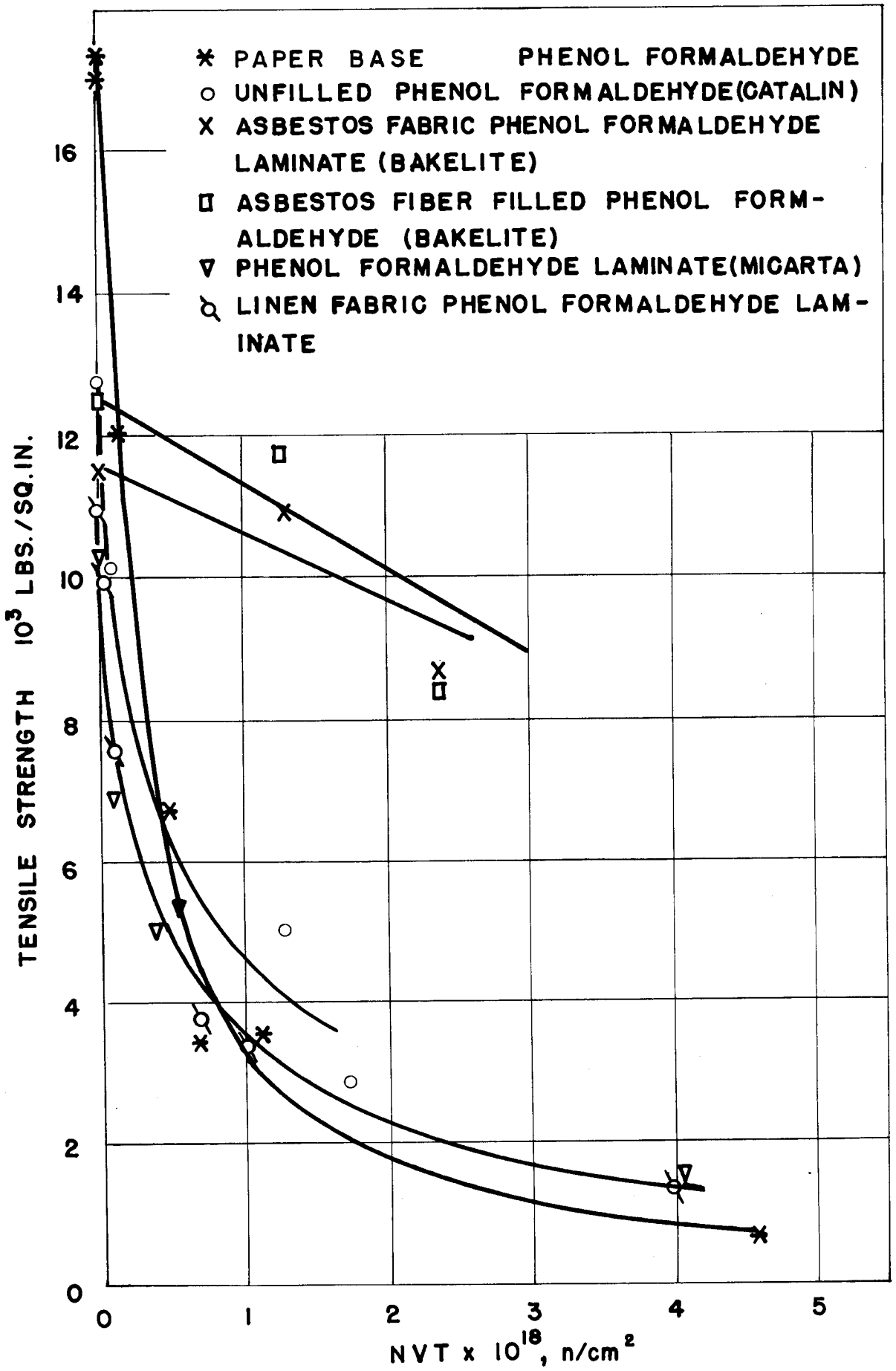

FIGURE 1 TENSILE STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9829

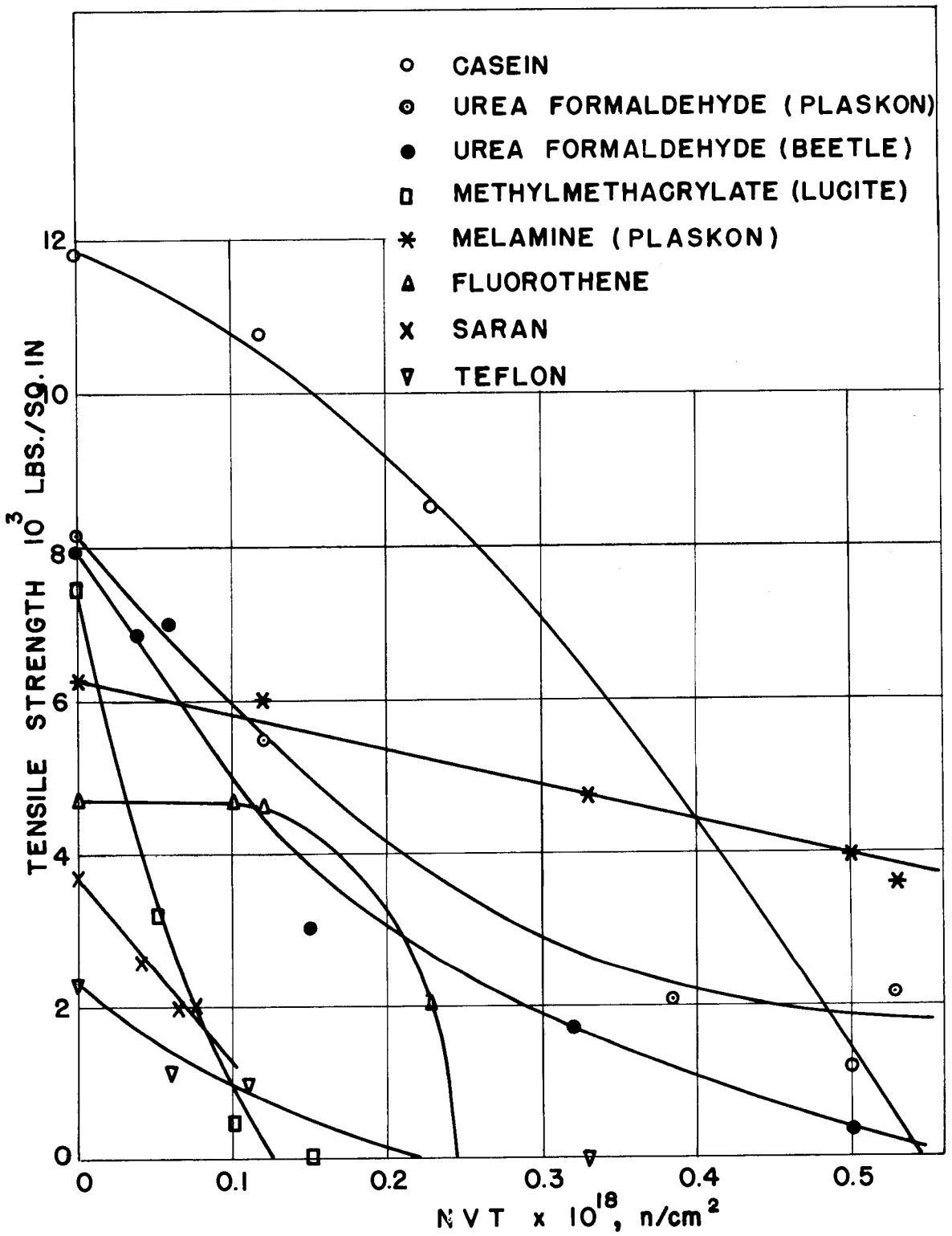

FIGURE 2 TENSILE STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9830

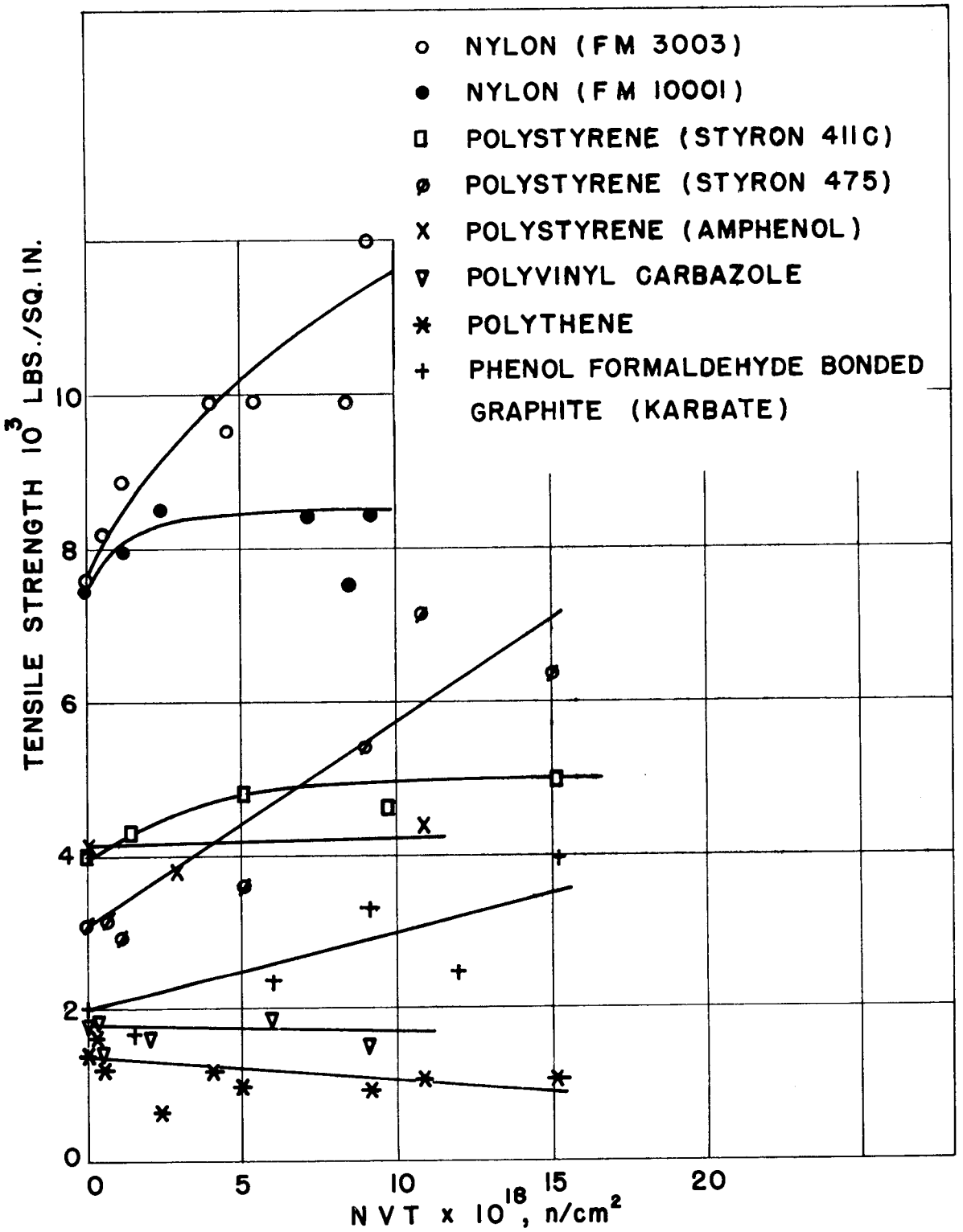

FIGURE 3 TENSILE STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9831

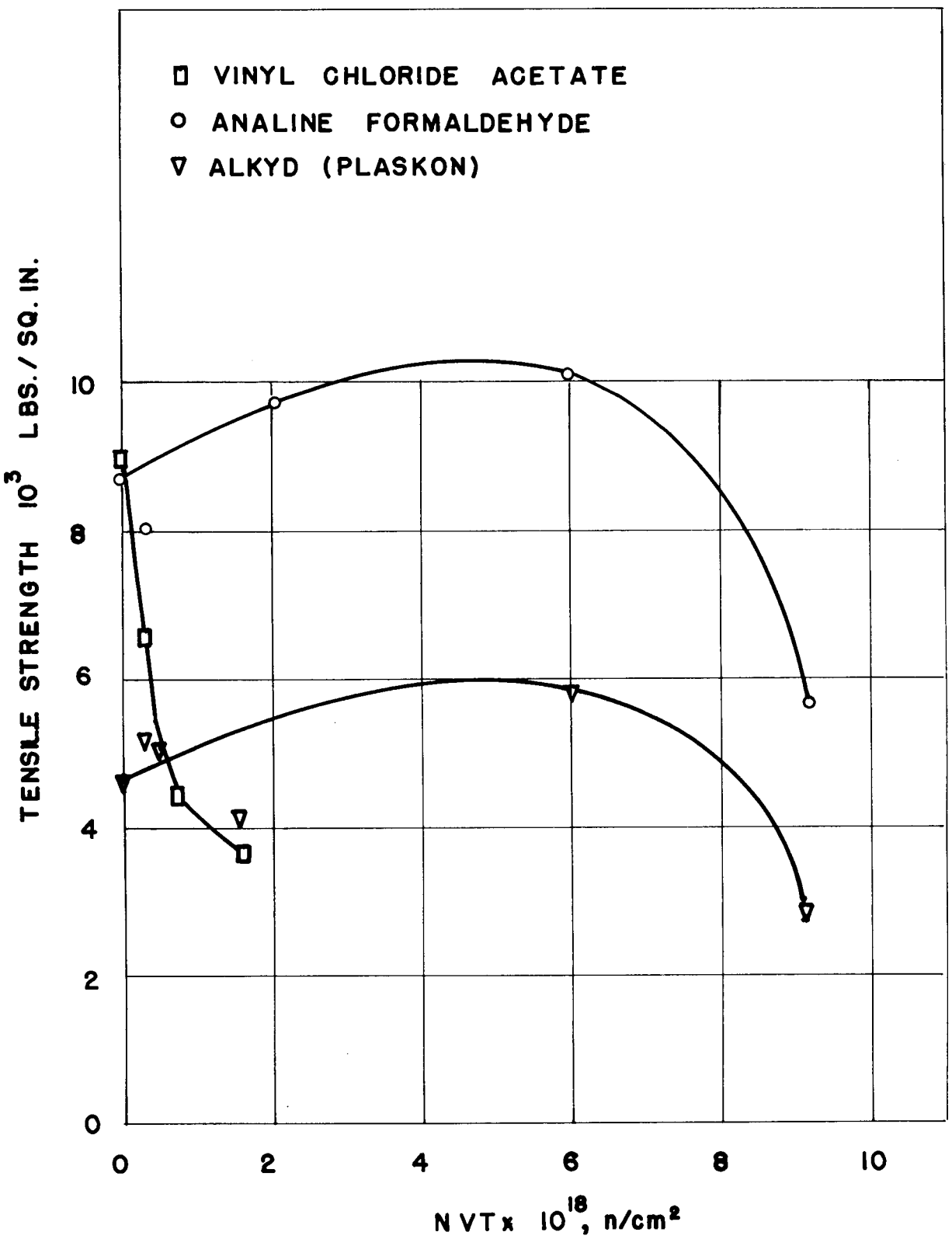

FIGURE 4 TENSILE STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9832

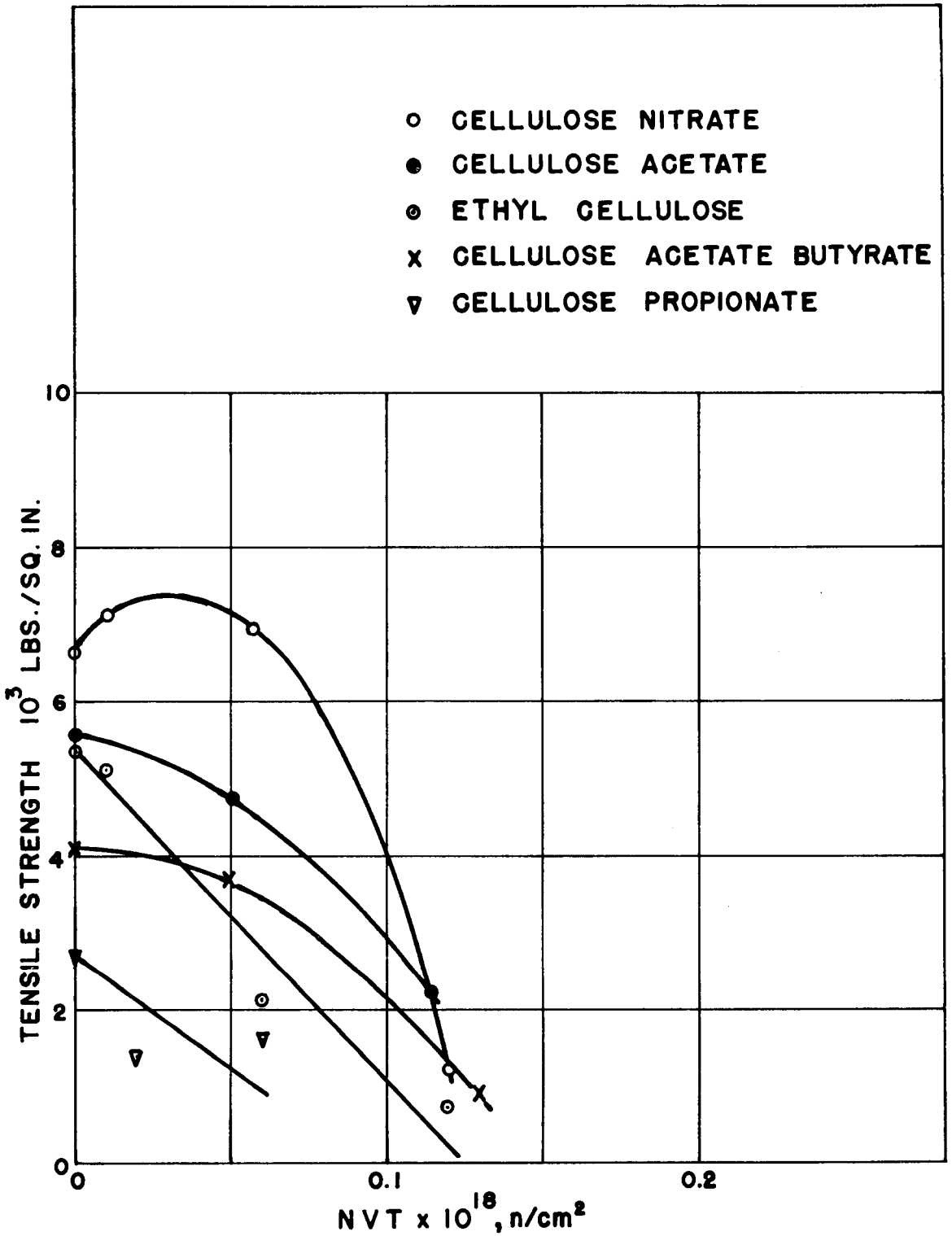

FIGURE 5 TENSILE STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9833

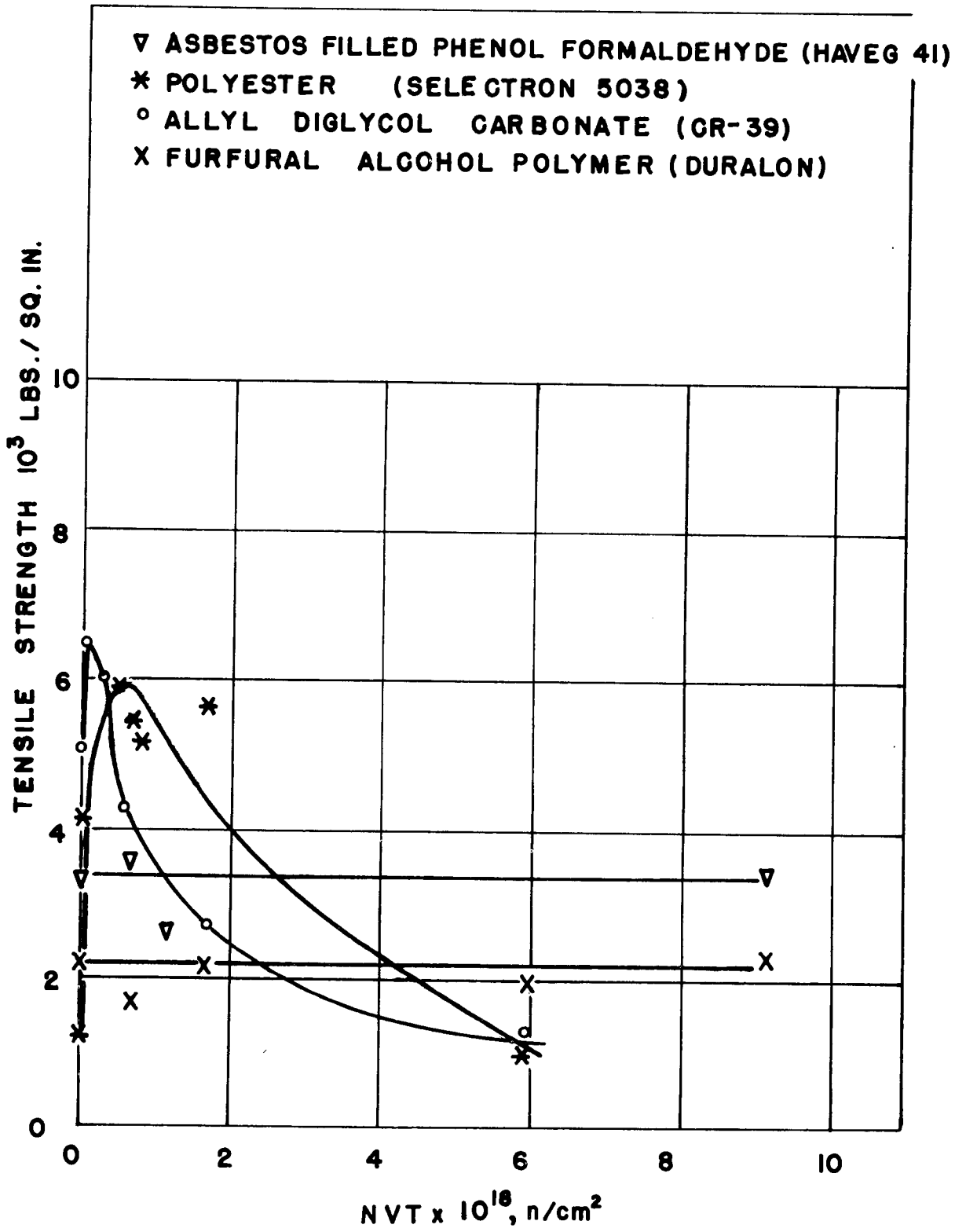

FIGURE 6 TENSILE STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9834

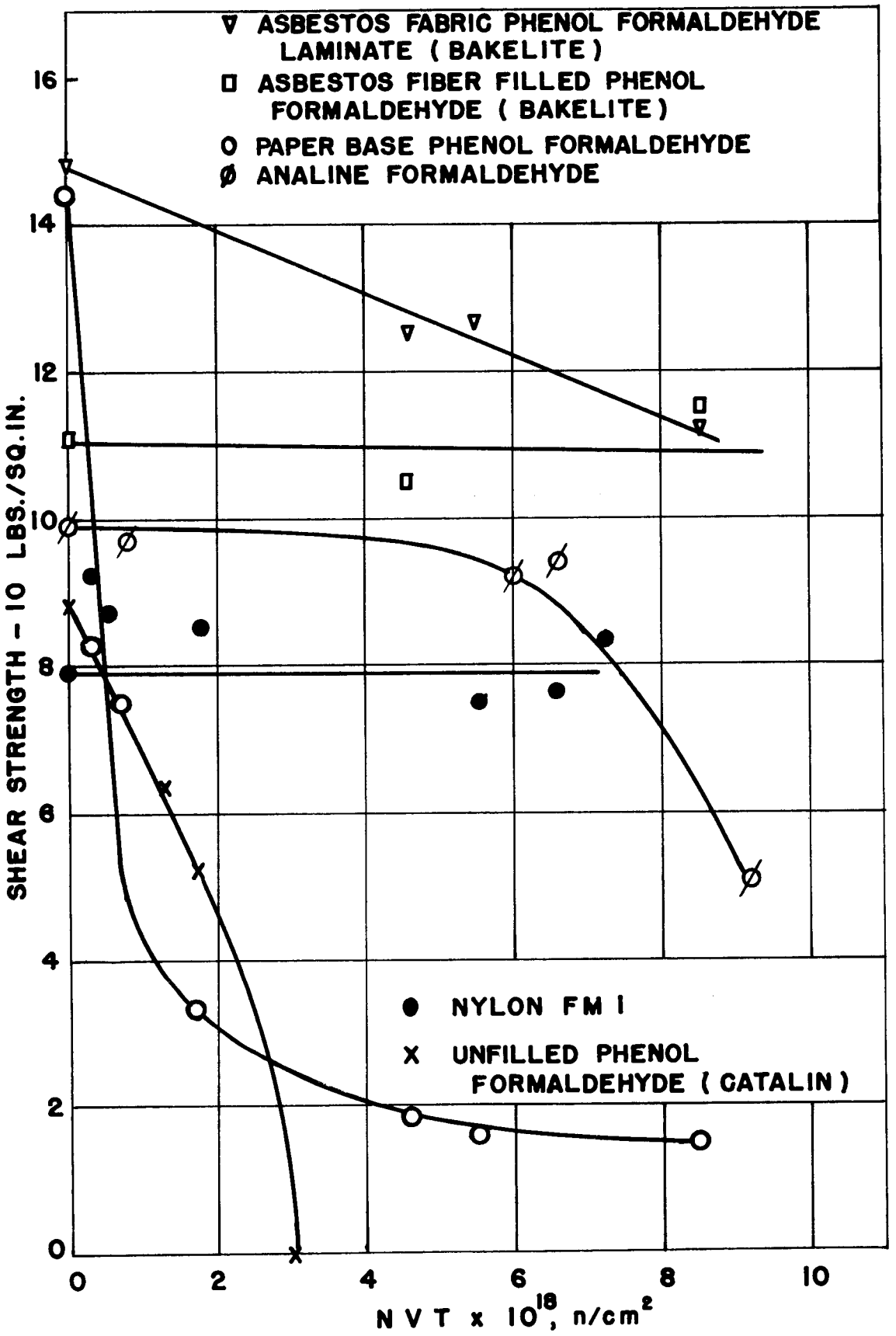

FIGURE 7 SHEAR STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9835

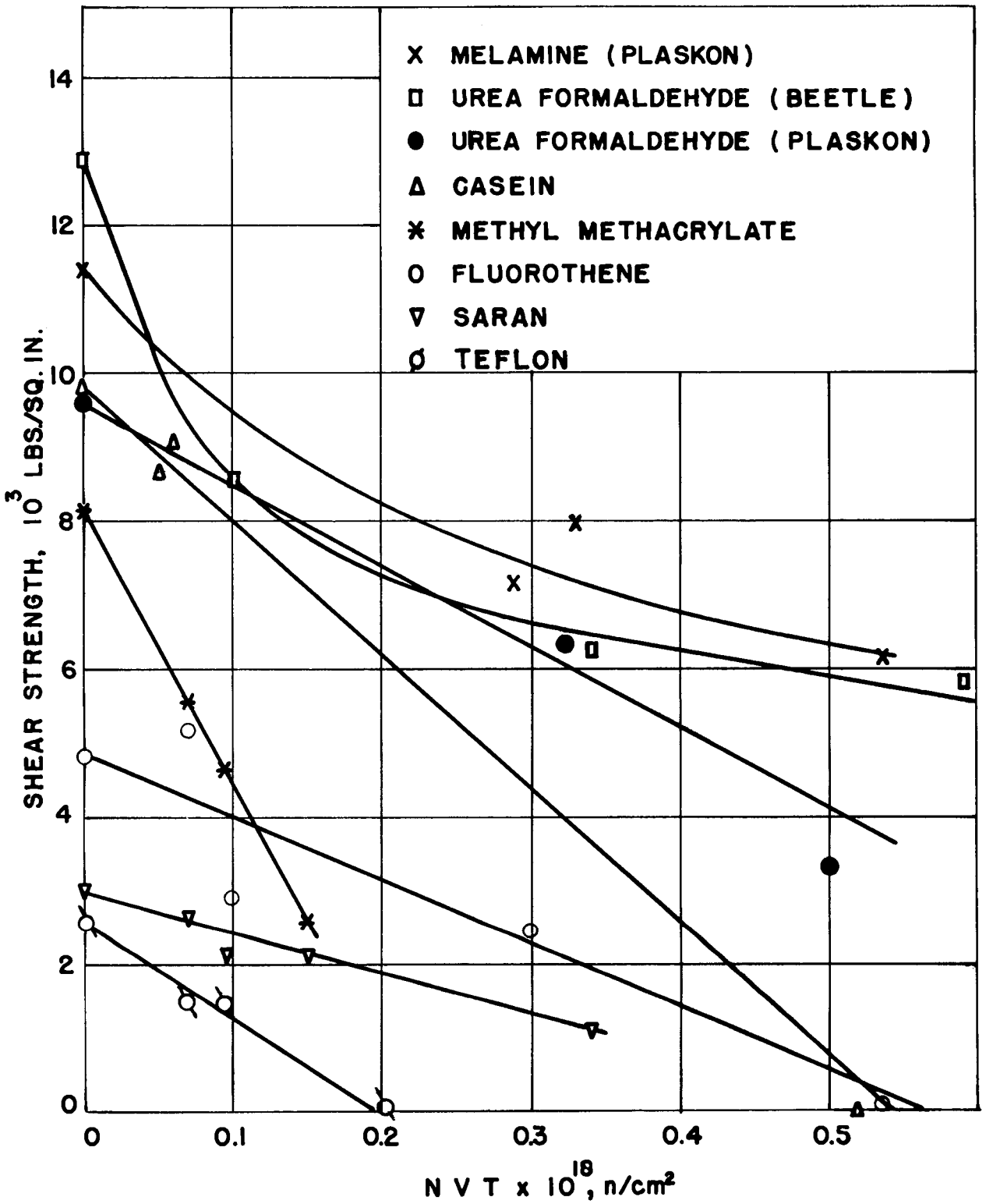

FIGURE 8 SHEAR STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9836

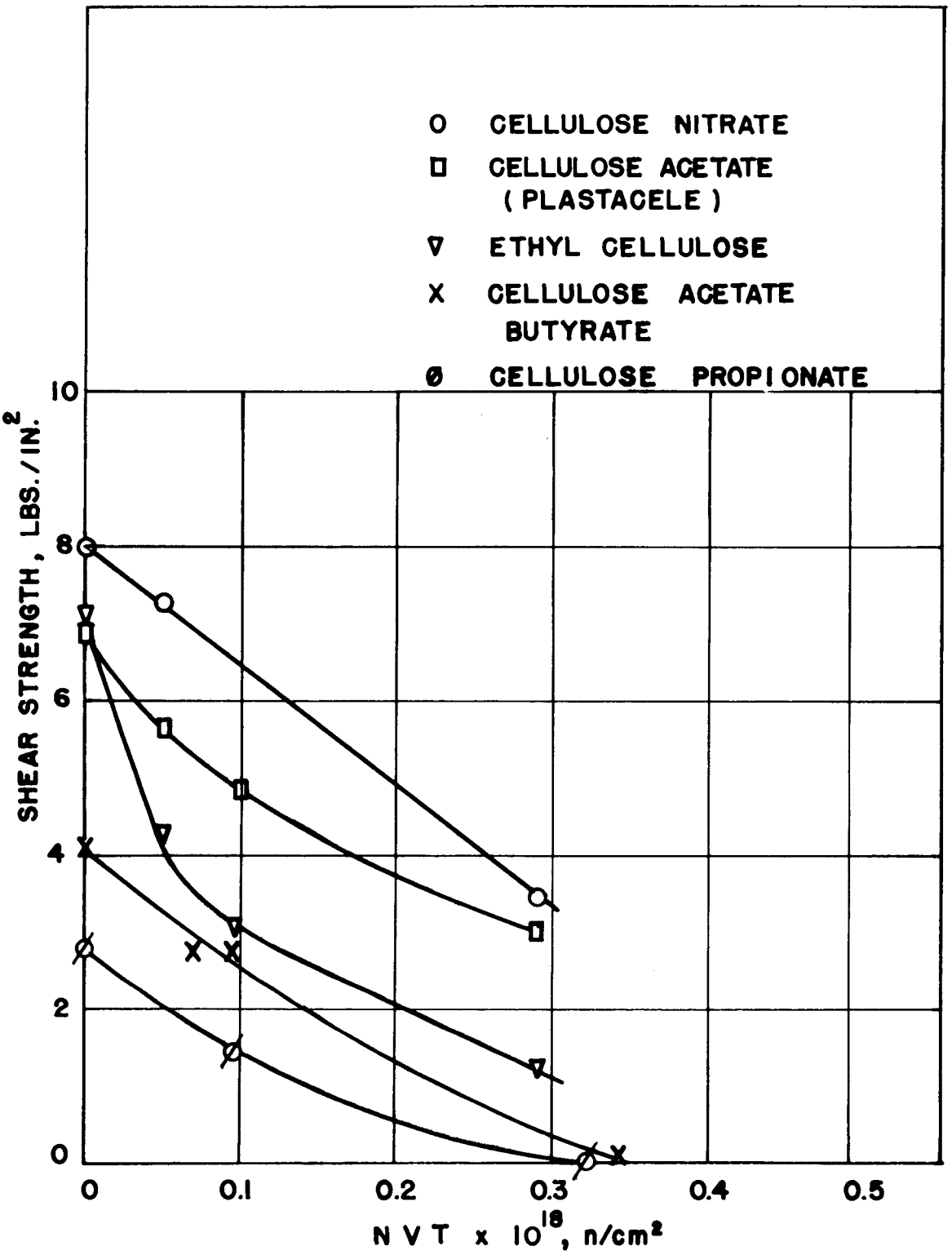

FIGURE 9 SHEAR STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9837

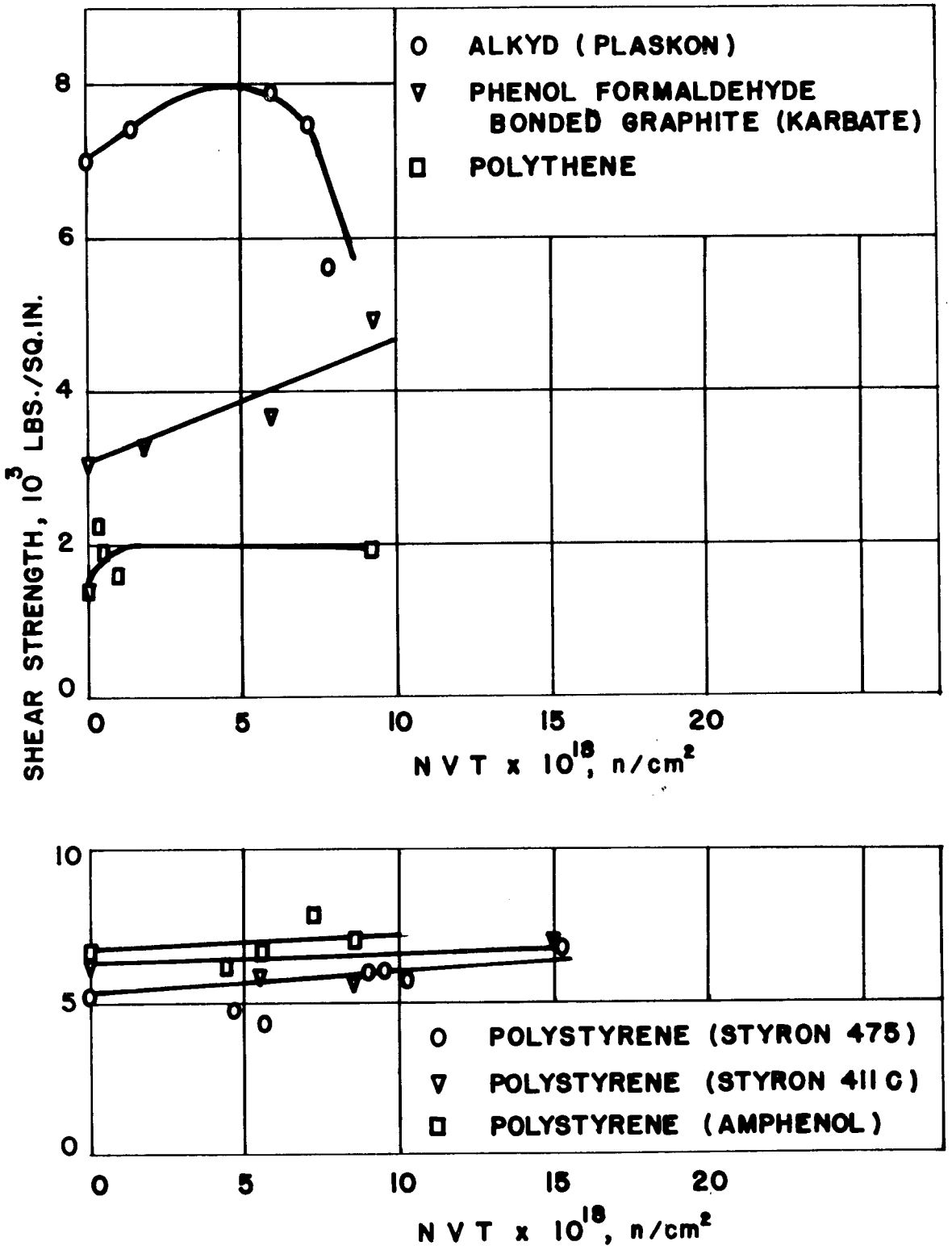

FIGURE 10 SHEAR STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9838

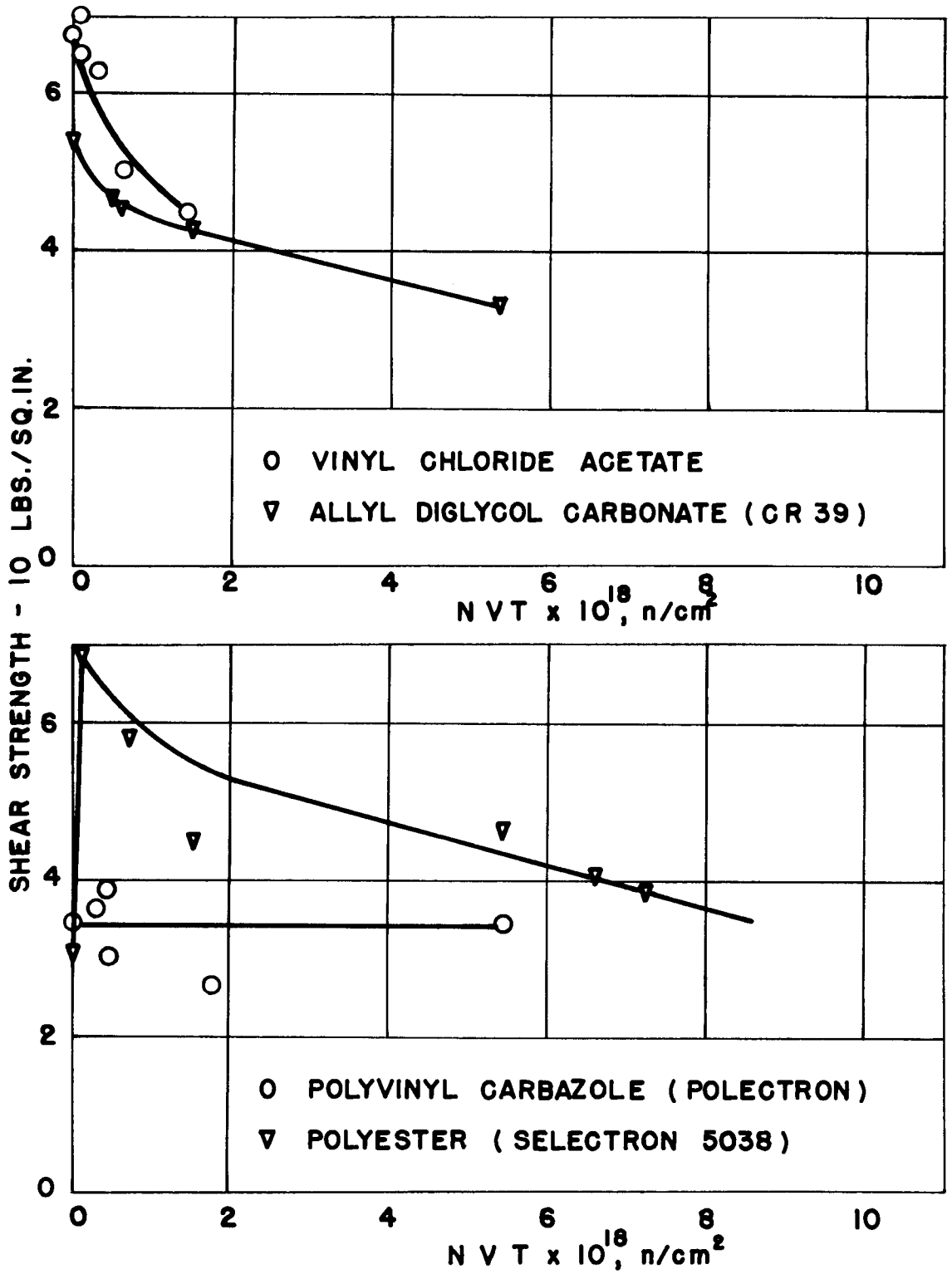

FIGURE 11 SHEAR STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9839

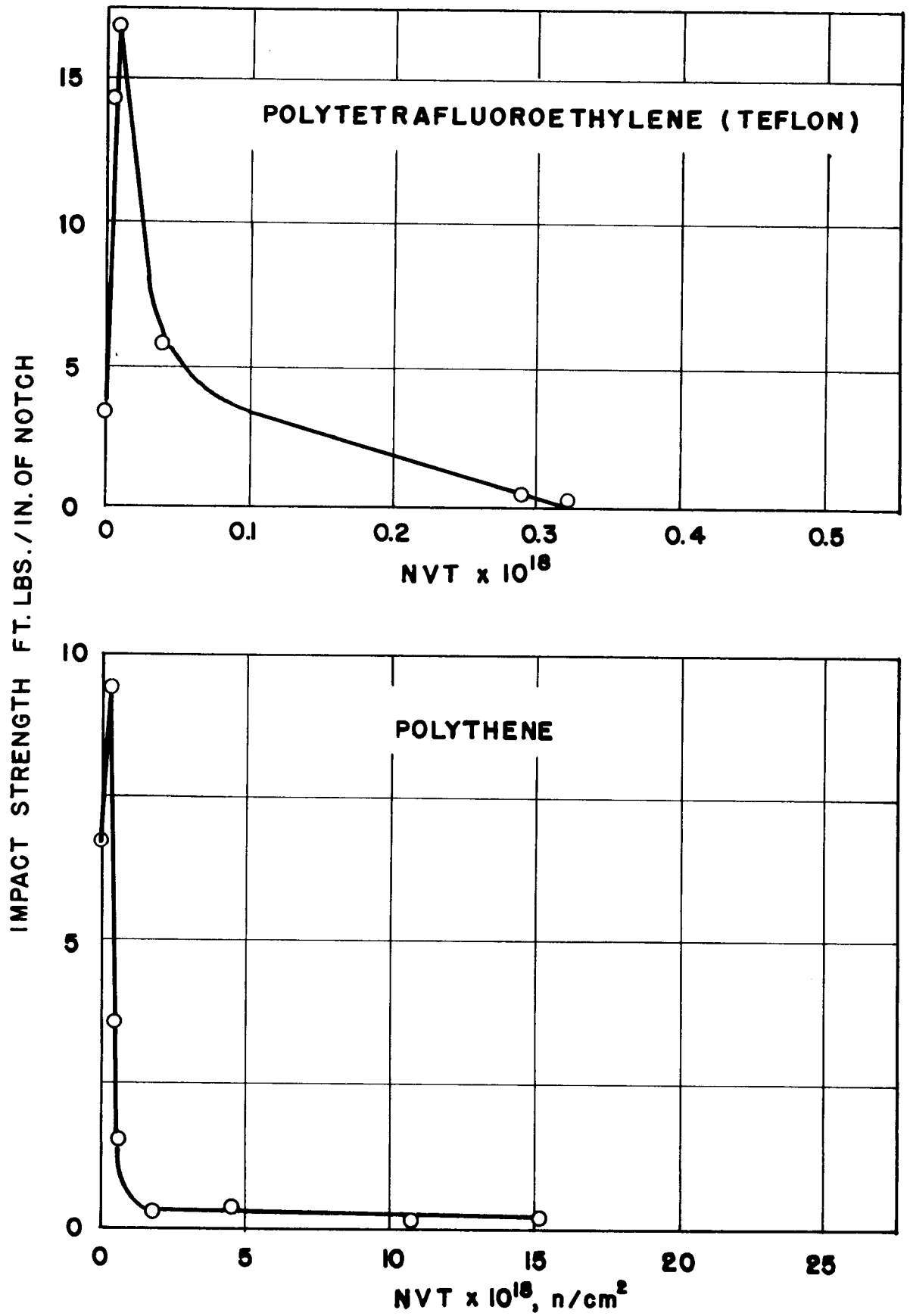

FIGURE 12 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9840

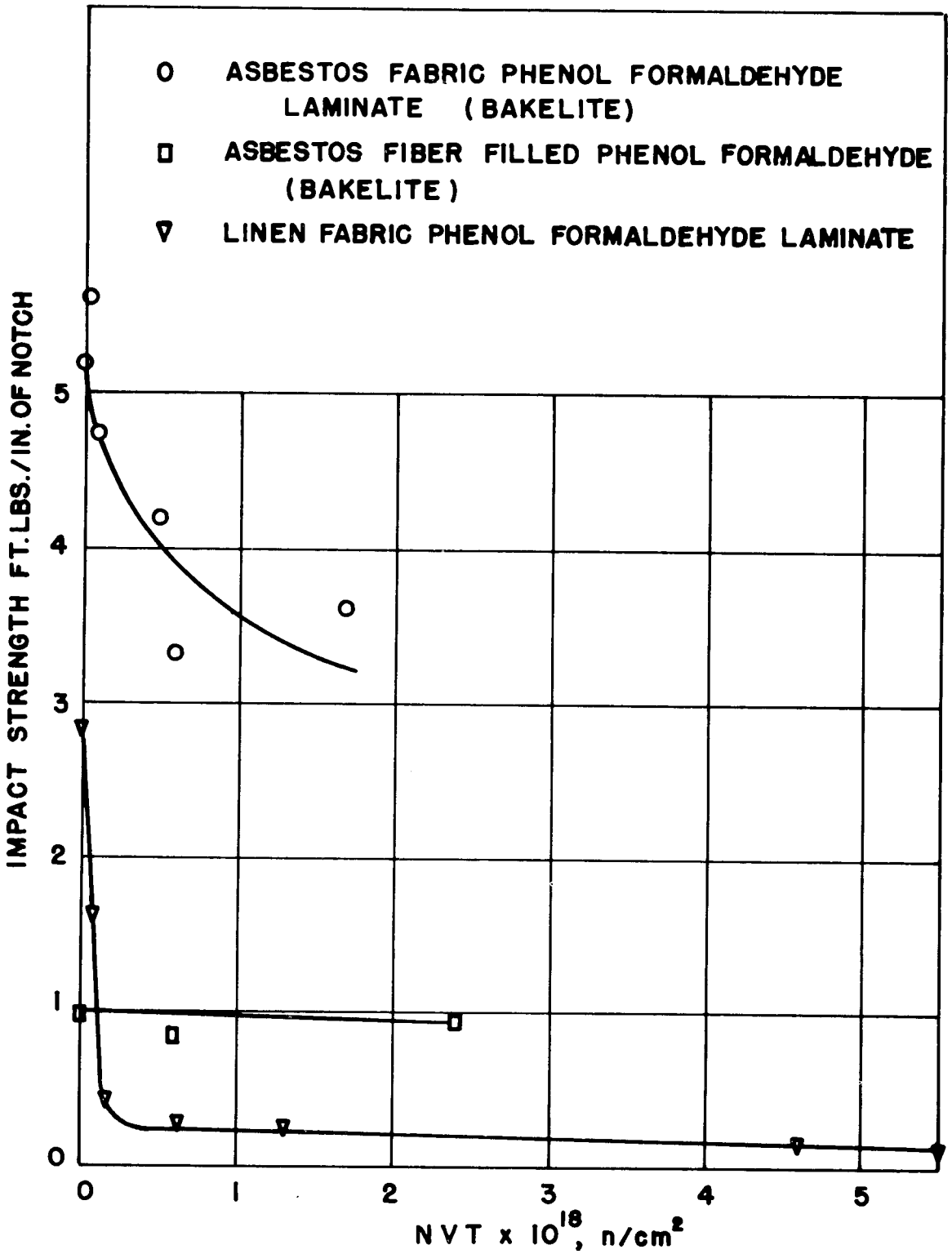

FIGURE 13 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9841

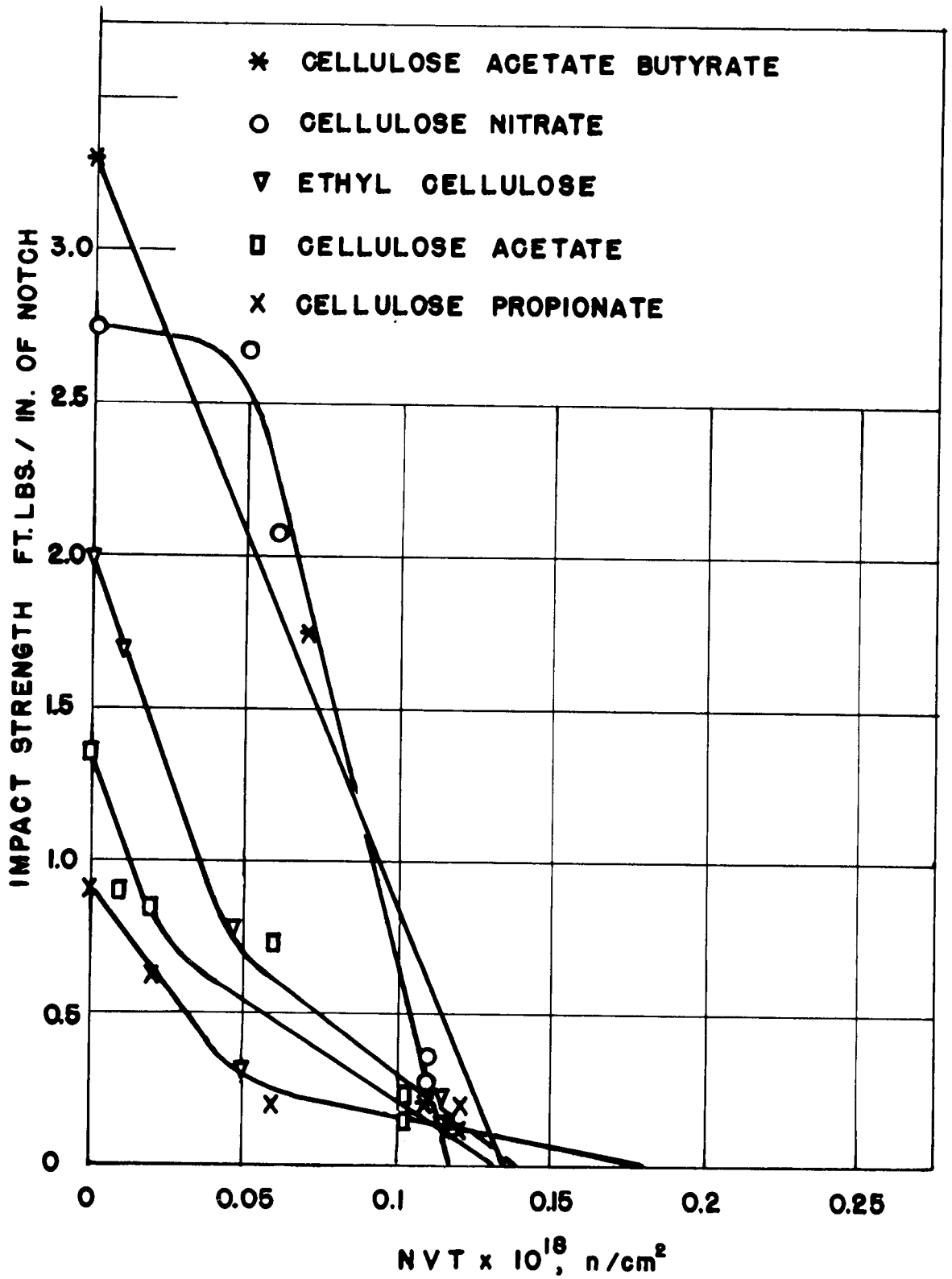

FIGURE 14 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9842

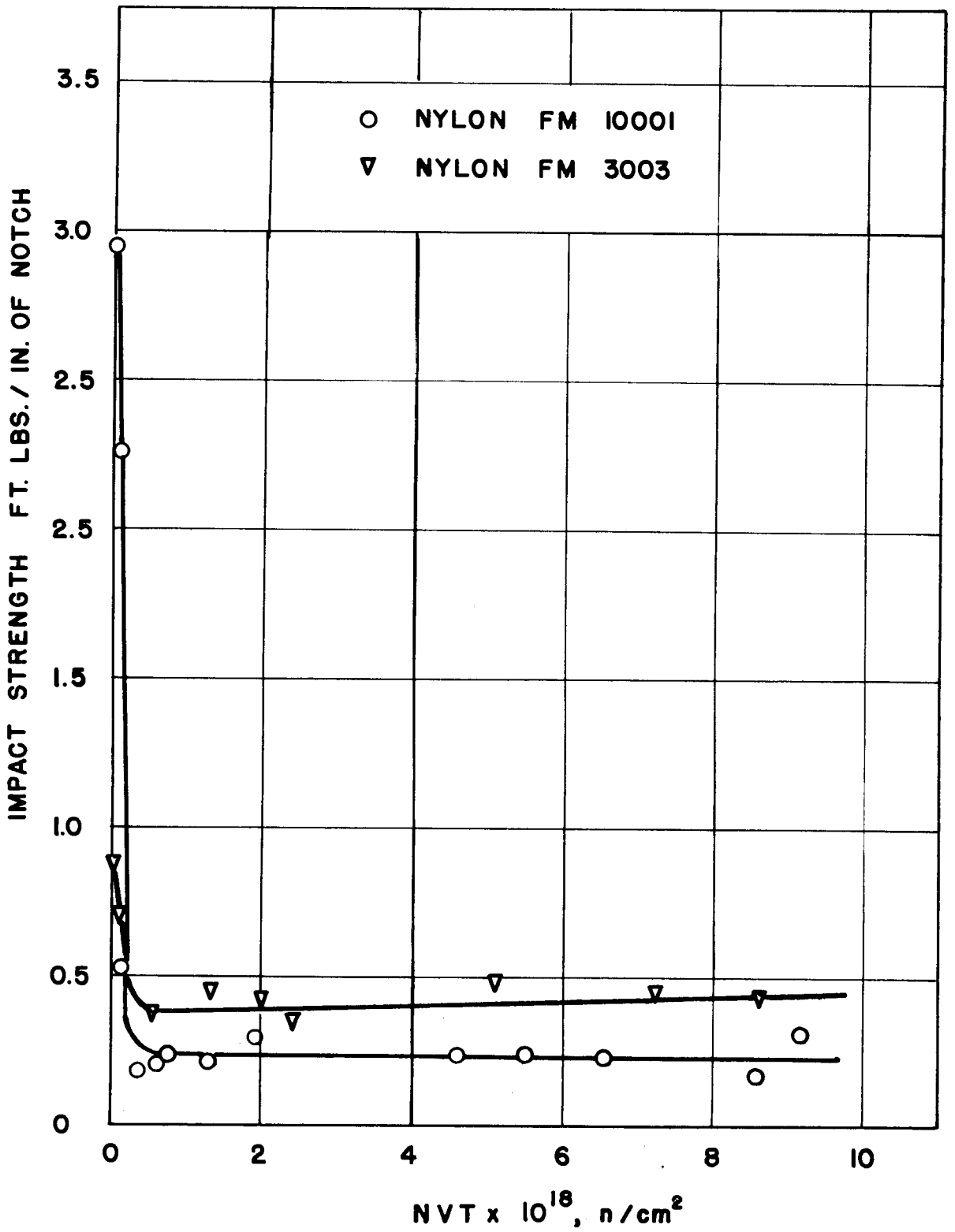

FIGURE 15 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9843

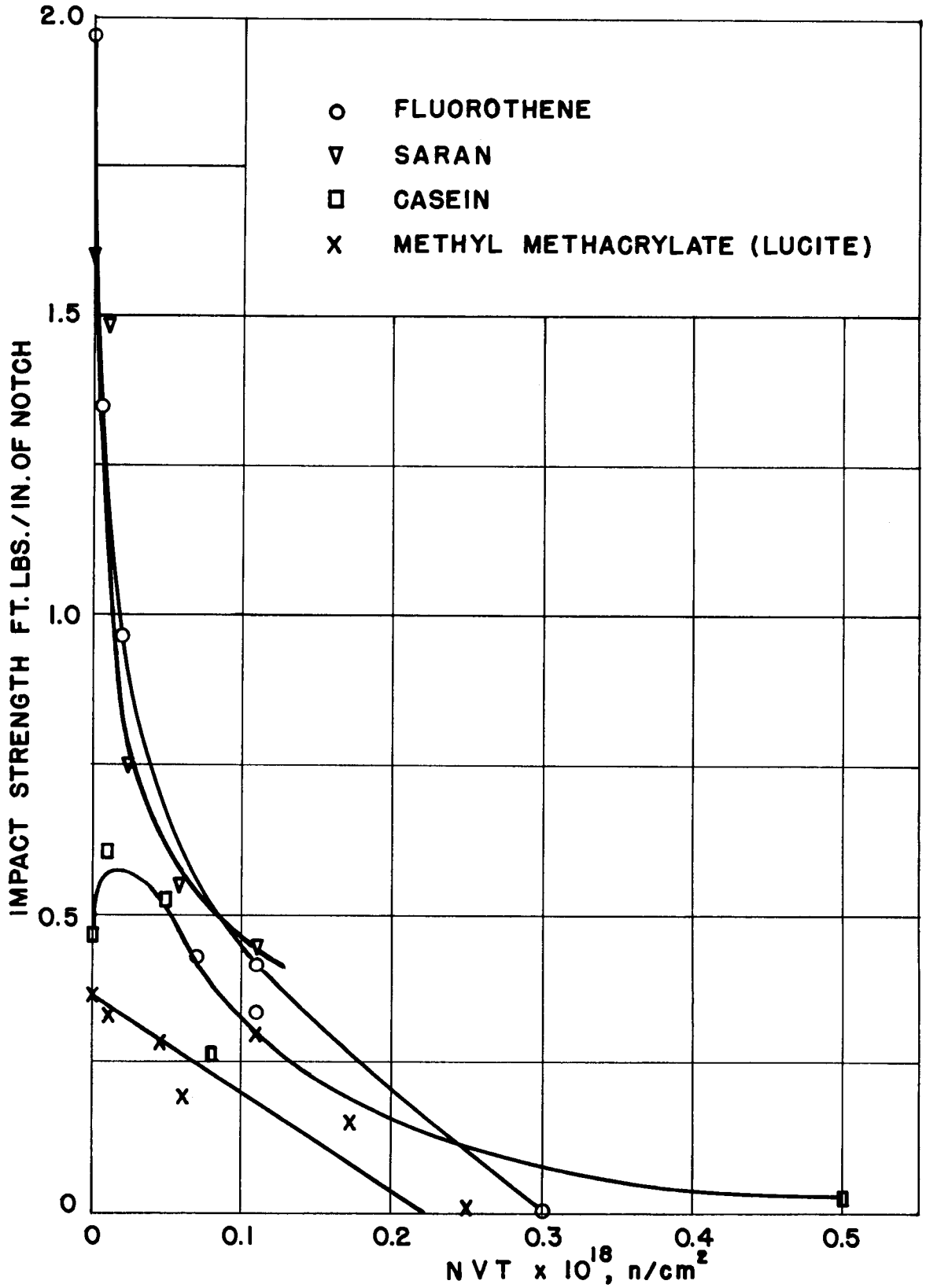

FIGURE 16 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9844

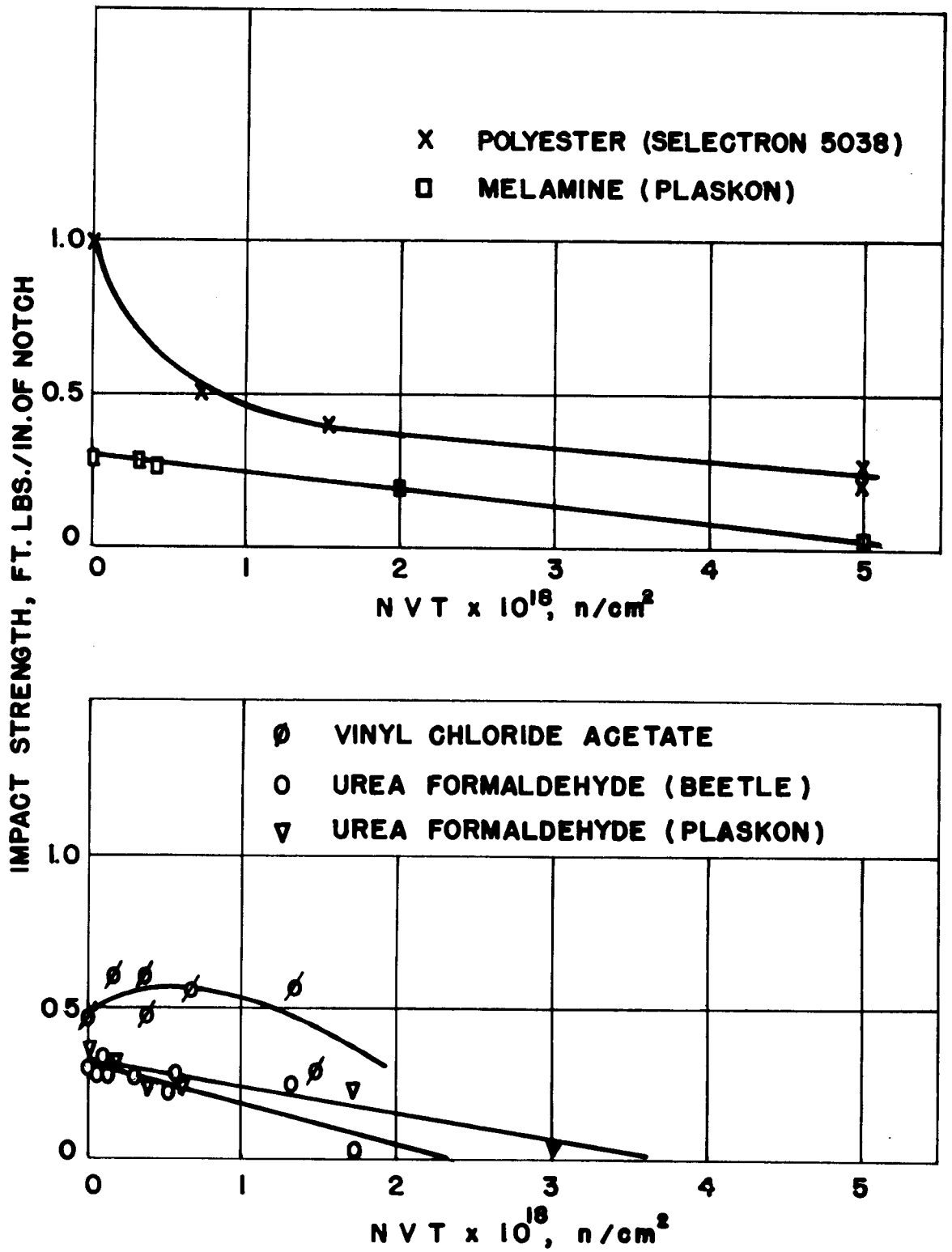

FIGURE 17 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9845

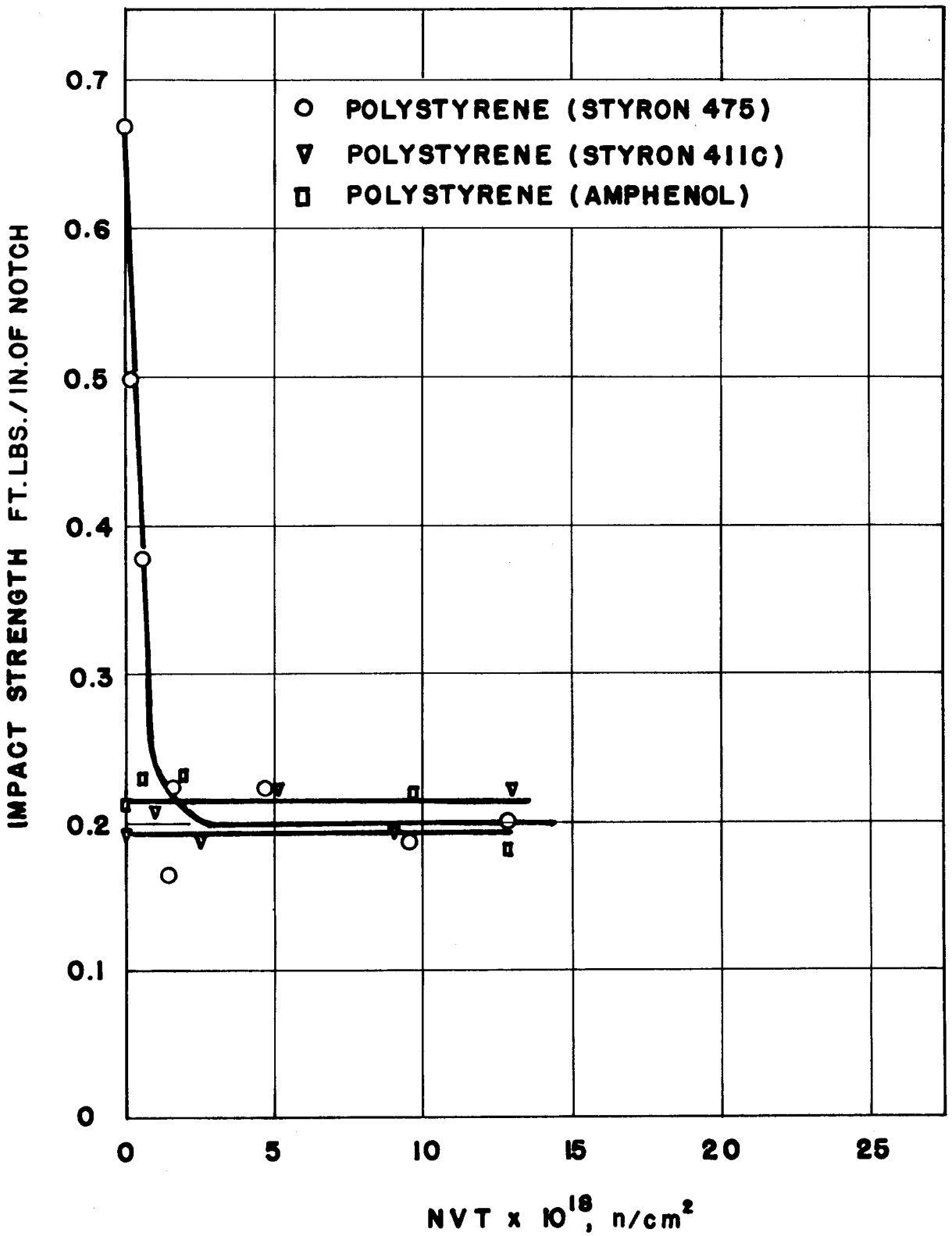

FIGURE 18 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9846

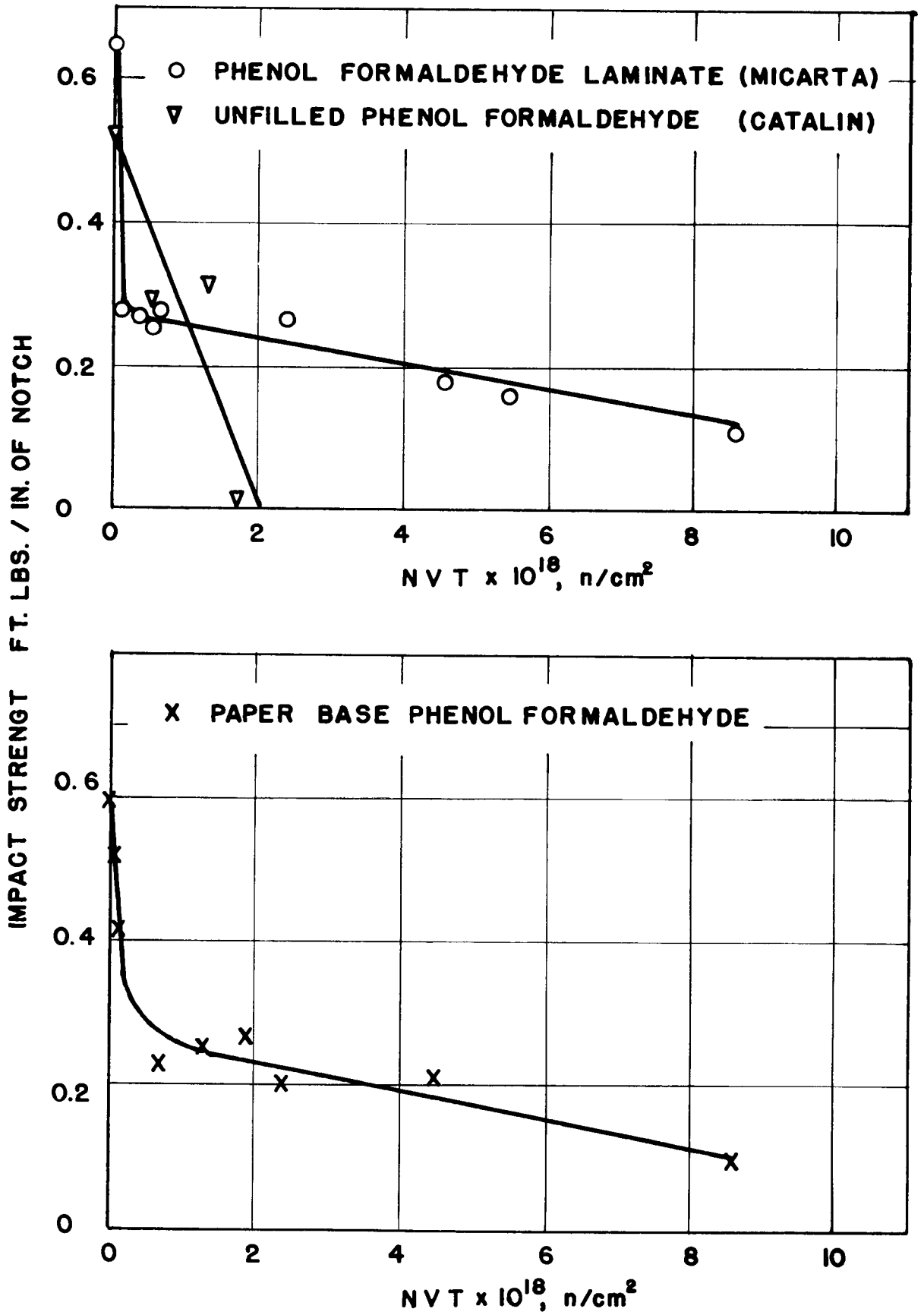

FIGURE 19 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9847

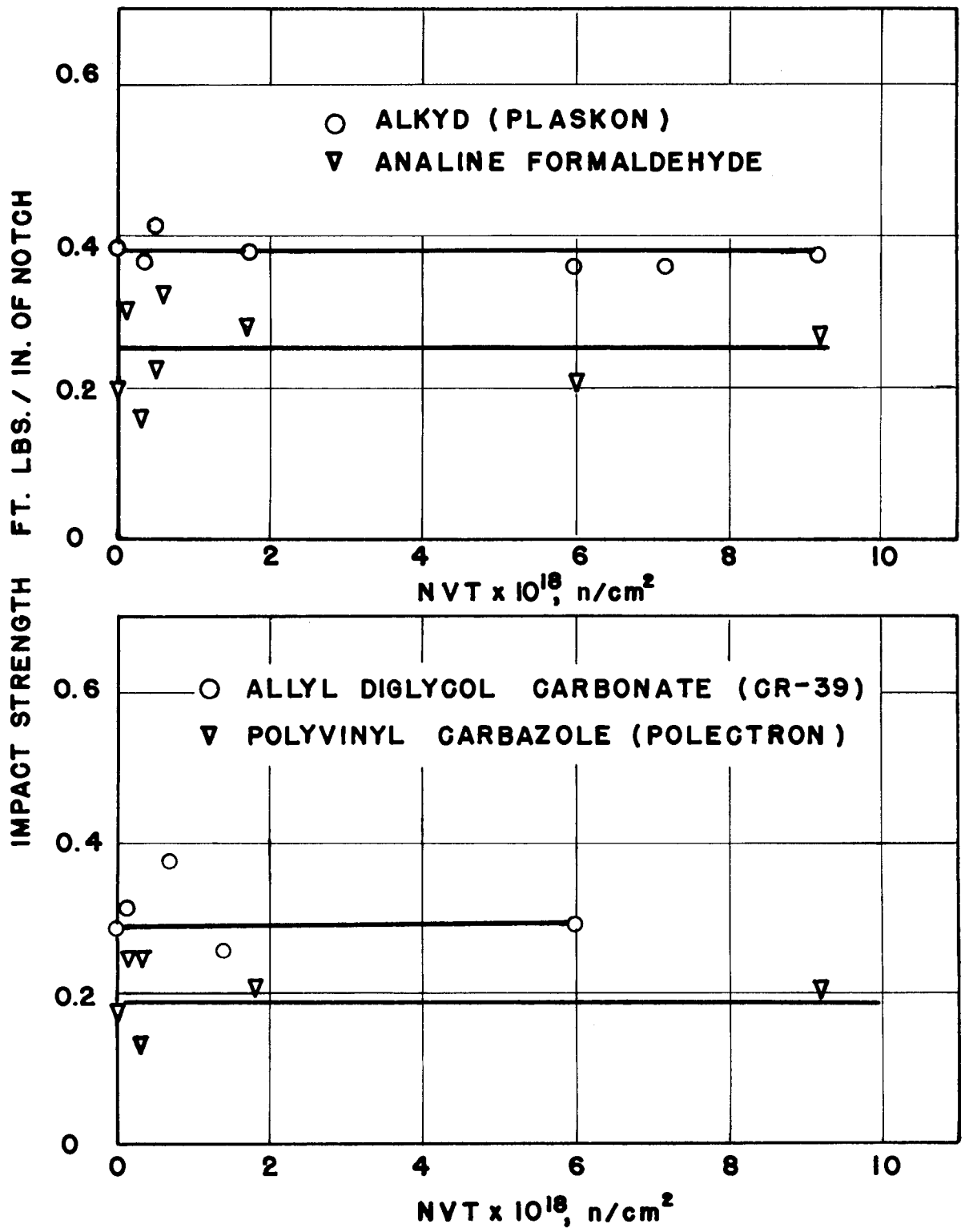

FIGURE 20 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9848

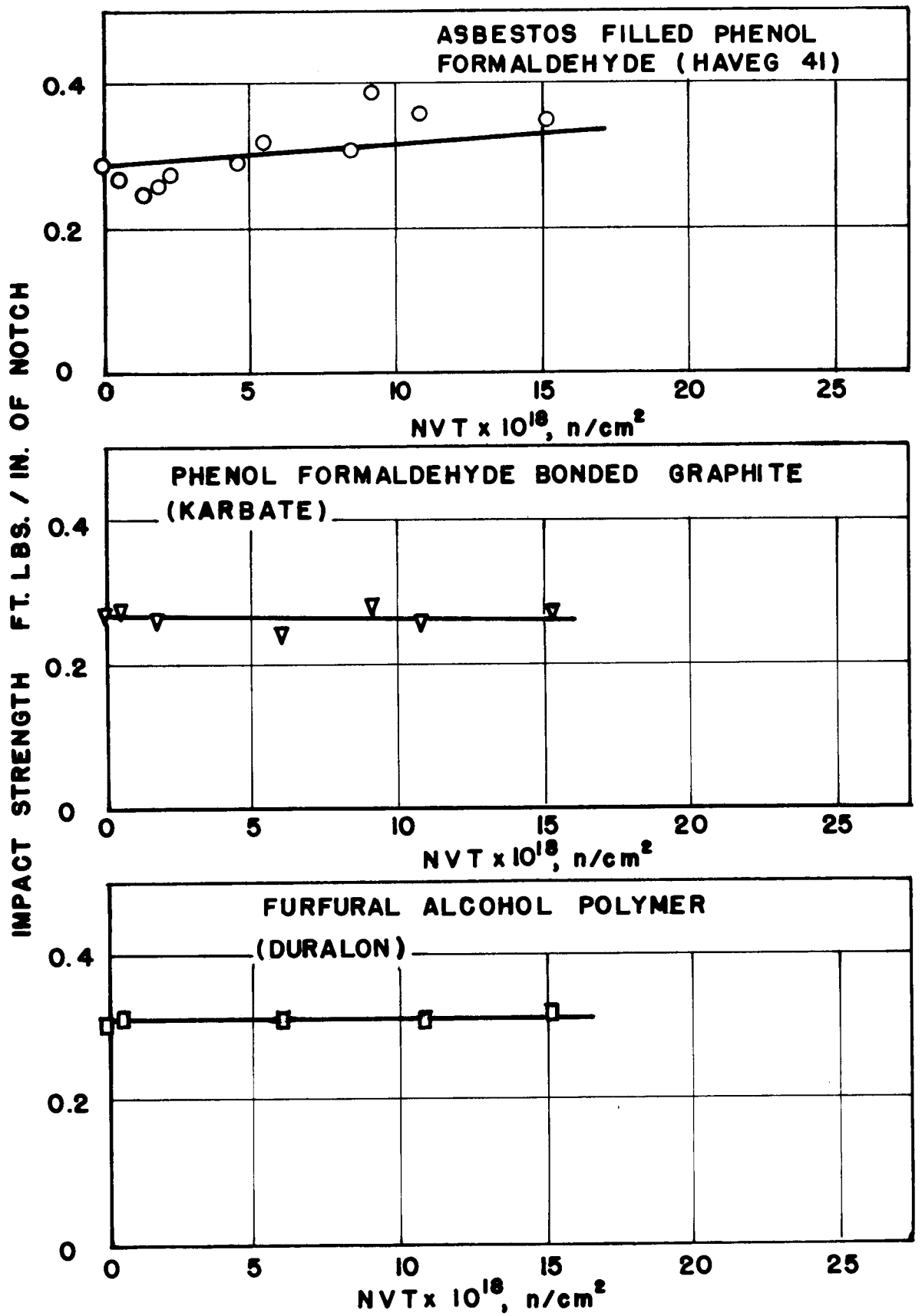

FIGURE 21 IMPACT STRENGTH OF IRRADIATED PLASTICS

[redacted]

DWG. 9849

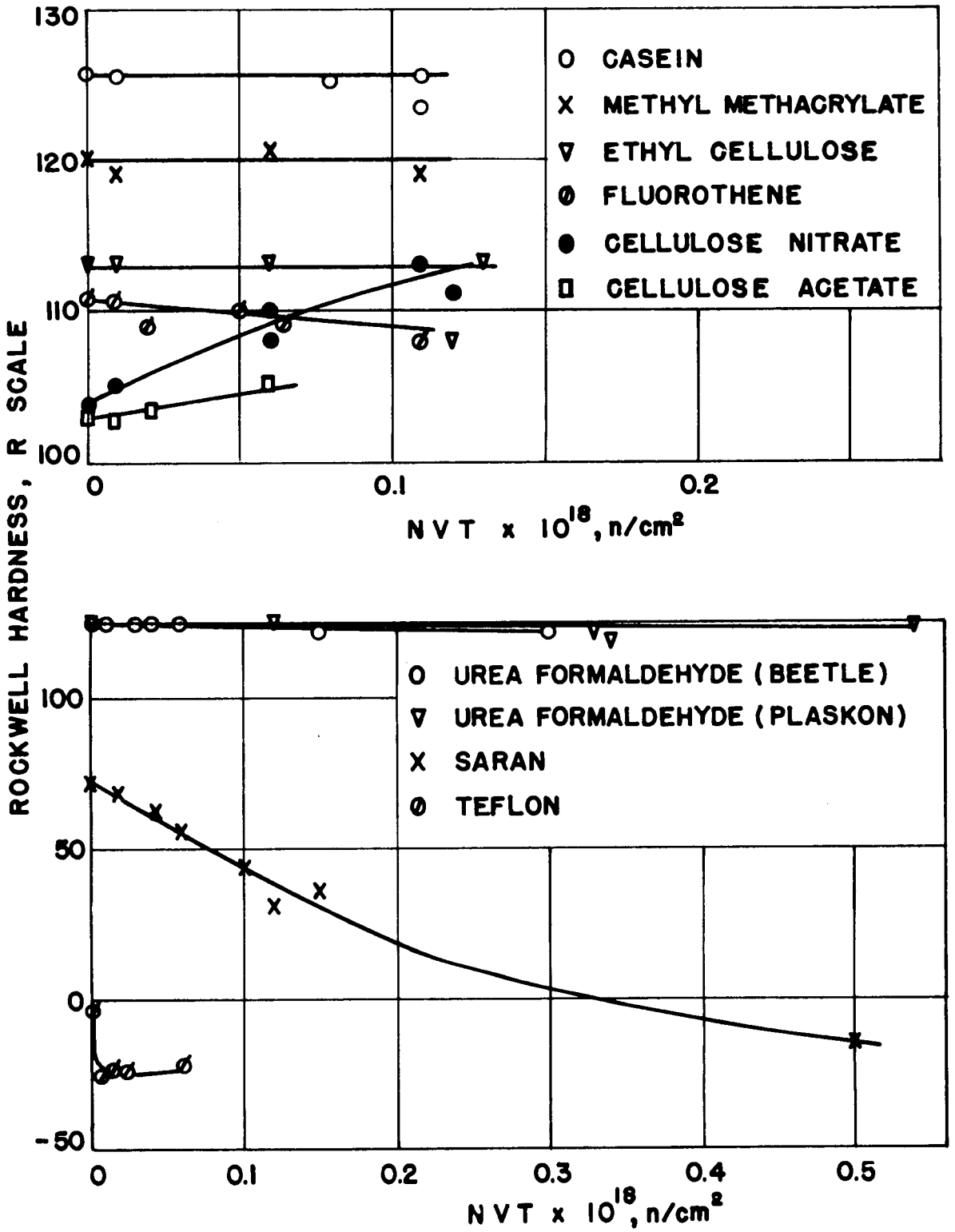

FIGURE 22 HARDNESS OF IRRADIATED PLASTICS

[redacted]

DWG. 9850

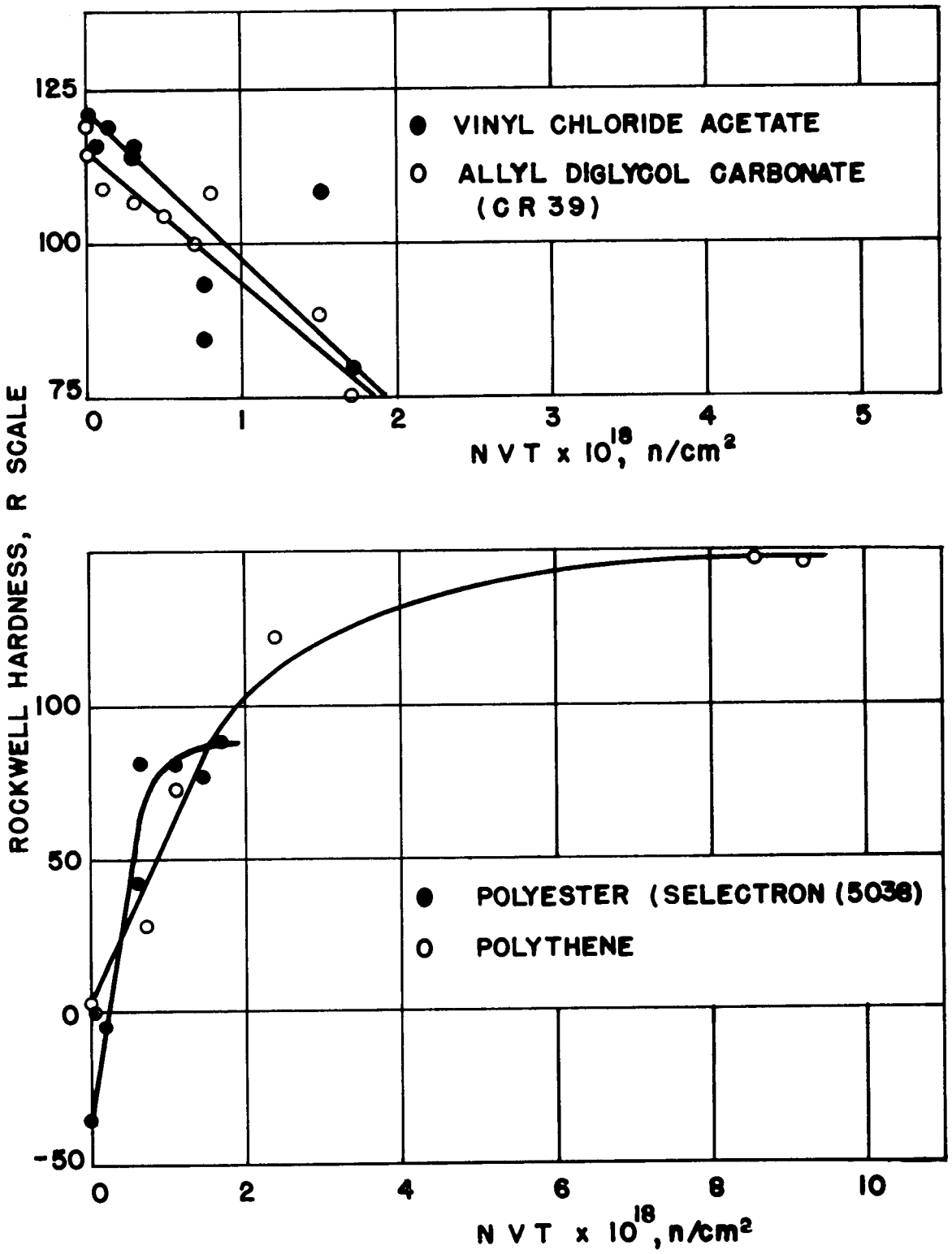

FIGURE 23 HARDNESS OF IRRADIATED PLASTICS

[redacted]

DWG. 9851

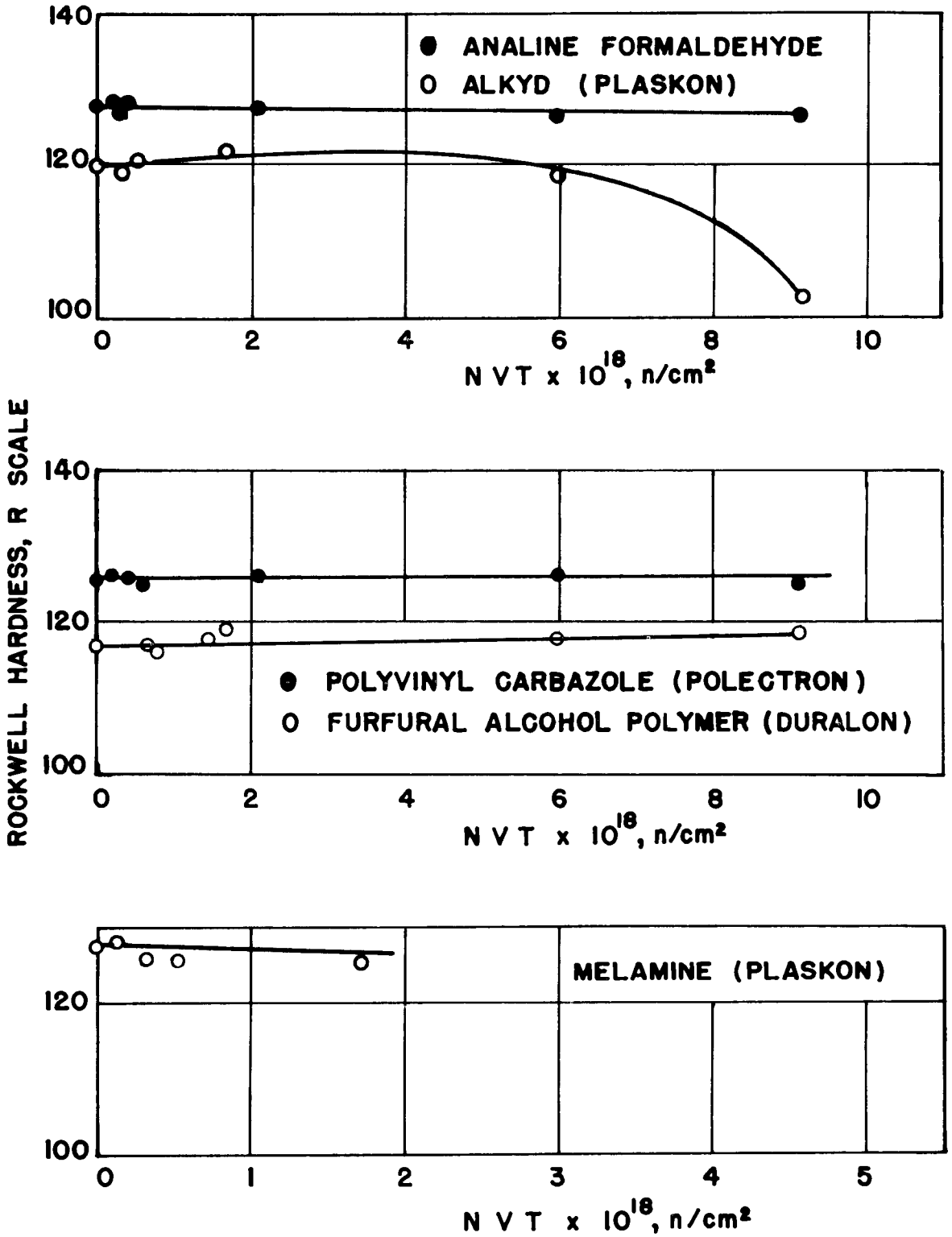

FIGURE 24 HARDNESS OF IRRADIATED PLASTICS

[redacted]

DWG. 9852

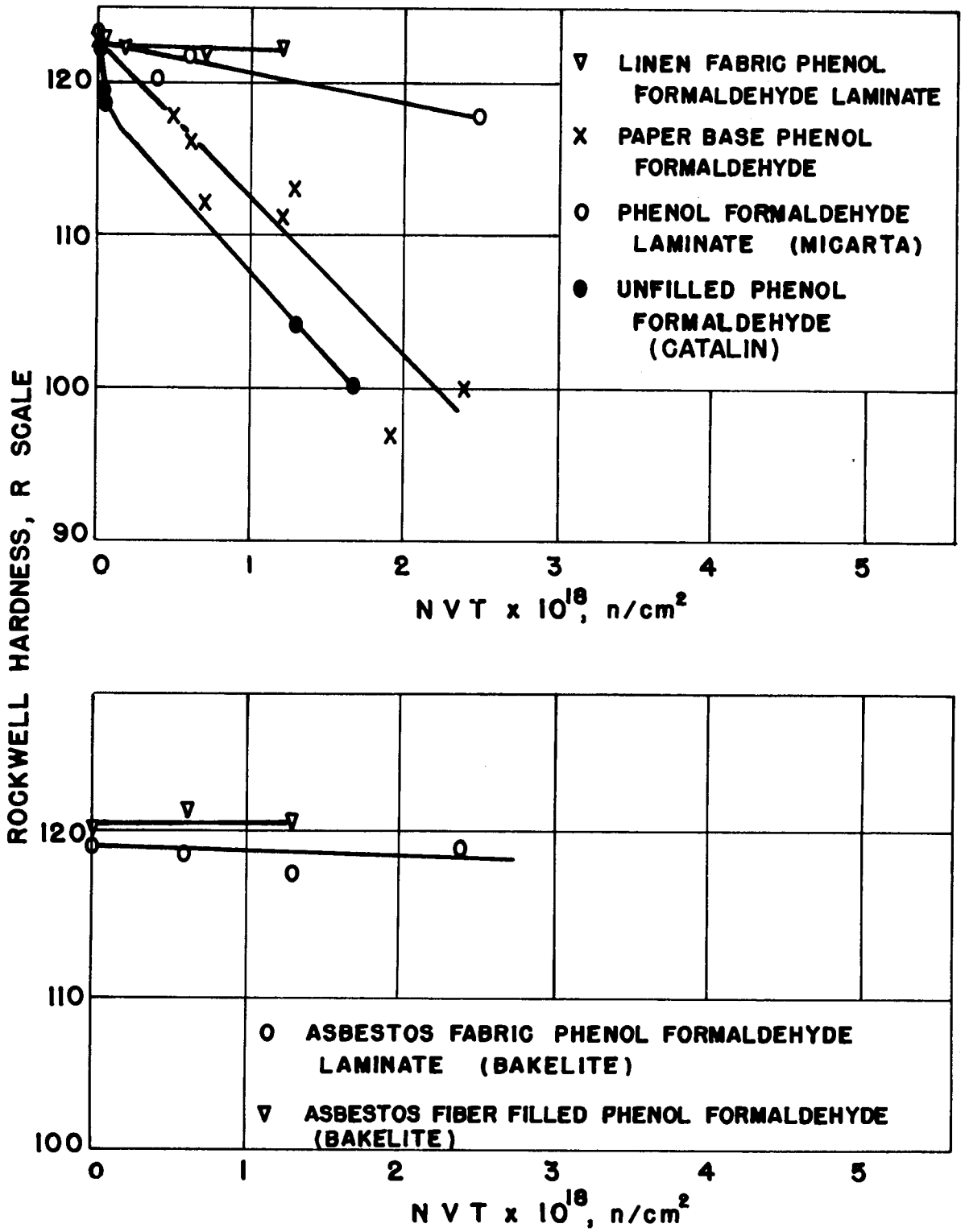

FIGURE 25 ROCKWELL HARDNESS OF IRRADIATED PLASTICS

[redacted]

DWG. 9853

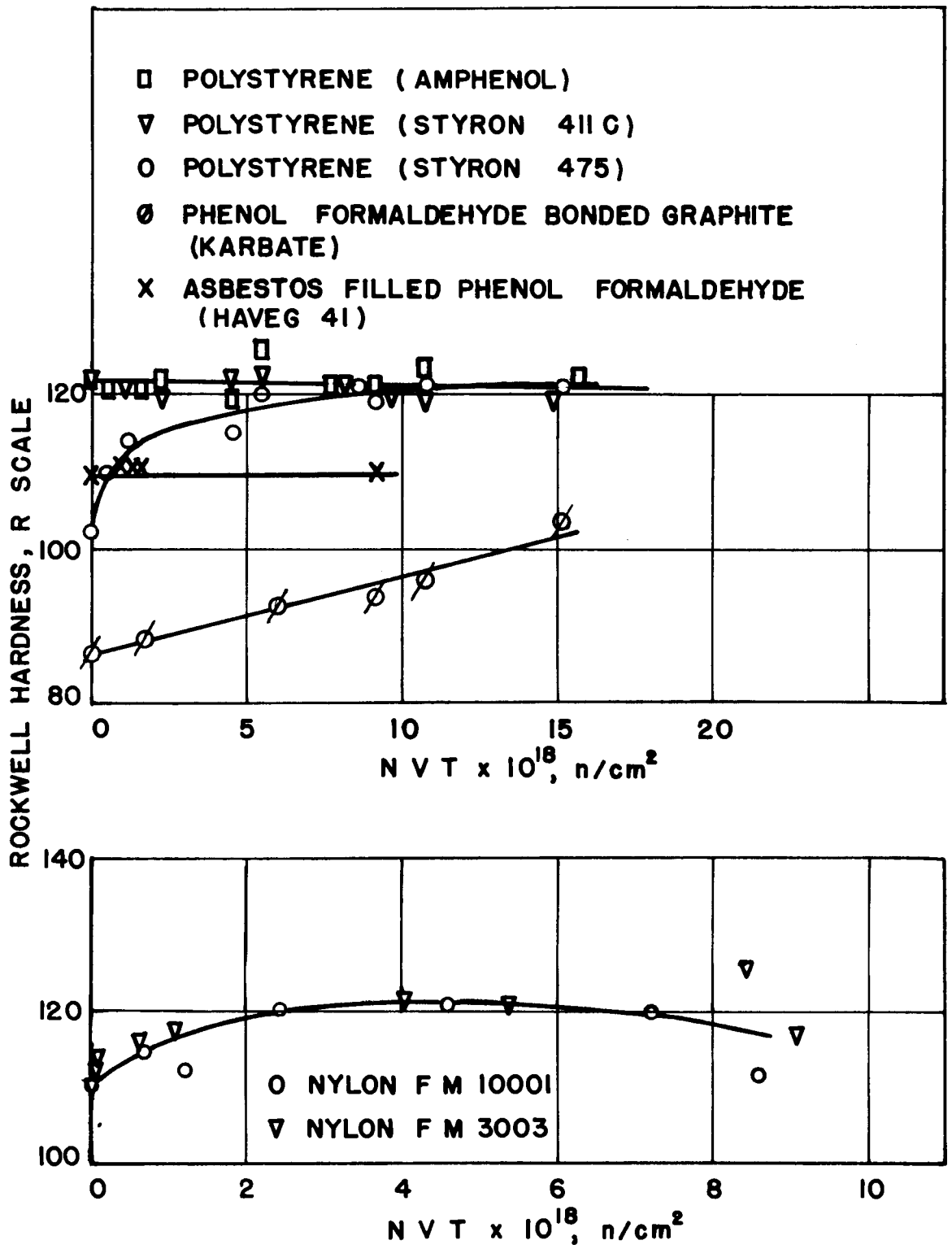

FIGURE 26 ROCKWELL HARDNESS OF IRRADIATED PLASTICS