Image Resolution of Open Skies Acquisition Films

Part III

Prepared by DRAFT 2 (Nolan Tillman) Date: _____

REVISION 2

July 1998

Eastman Kodak Company
Commercial and Government Systems Division
Rochester, NY

Table of Contents

Section	Title	Page
1.	Introduction	1
2.	Procedures	2
3.	Results	2
3.1	3412 Film	4
3.2	3404 Film	5
3.3	SO-050 Film	5
4.	Conclusions	7
APPENDIX	Tables and Figures	8
A-I.	3412 Film	25
A-2.	3404 Film	42
A-3.	so-050 Film	58
A-4.	Conclusions	

1. Introduction

A comprehensive study by Eastman Kodak for the Open Skies Media Processing Facility (OSMPF) evaluated the resolution of the three US Open Skies acquisition films, SO-050, 3404 and 3412. This work originally considered the effect of processing and sensitometric contrast variation on tri-bar target resolution (Relationship Between Tri-Bar Resolution and Contrast *for* Open *Skies Acqquisition* Films). A subsequent revision included data on the effect of exposure variation on resolution *(Revision* #I), followed by additional work to simulate the effect of exposure variations on the resolution of aerial images of corn targets *(Image Resolution Study for Open Skies Acquisition Films, Revision #2).*

The present work extends this effort by evaluating resolution of tri-bar images as a function of tri-bar test object contrast (TOC) and exposure variation for 3412, 3404 and SO-050 acquisition films.

A *Procedures* section first outlines the experimental methods used. This is followed by a *Results* section which presents the data, with a considerable amount of supporting detail. The *Conclusions* section presents a concise overview of the most important results and conclusions arising from this work. For convenience, tables and figures are grouped as an Appendix, with sections organized by film type.

2. Procedures

Film samples were supplied by the OSMPF and exposed at Eastman Kodak to tri-bar resolution targets using the Advanced Microcamera (AM-I) at 99X reduction. After determining optimal focus, a series of exposures were made using eleven neutral density filters at steps of 0.20 density. Therefore, each target was imaged over an exposure range of 0 to 2 log relative E. Three repetitions of this series were made for tri-bar targets with the following test object contrasts (TOCs):

TOC	Log TOC
1000:1	3.00
6.45:1	0.81
3.24:1	0.51
2.14:1	0.33
1.7:1	0.23
1.15:1	0.06

After exposure, these films were sent to the OS lab for processing to the OS lab specification. The films were processed in a VERSAMAT 1140 using 641

developer. Processing conditions were: (a) 3412 at 89 °F/14 fpm/1 rack, (b) 3404 at 105 °F/30 fpm/2 racks, and (c) SO-050 at 104 °F/18.5 fpm/2 racks. Characteristic curves for each processed film are shown in figures 1, 15 and 29, found in the Appendix to this report. EAFS film speed averaged 35 for 3412, 150 for 3404, and and 636 for SO-050.

After processing, a microdensitometer was used at OSMPF to determine the large bar and space densities for each measurable target image. From the measured densities, the exposure (log H) was calculated from the sensitometric curves.

To minimize confusion, this report will use the term “log H” when referring to microdensitometer-measured absolute exposures (log lux-second), and “log relative E” when referring to relative exposures defined in terms of the exposure series used (eleven 0.20 ND steps over the range of 0 to 2).

The resolution of each tri-bar image was read at Kodak by five different readers. The overall average and standard deviation (S) was calculated for each tri-bar exposure from a total sample size of N = 3 repetitions X 5 readers = 15. Sample variance is reported as ± 2s = ± 2 standard deviations, or ± 2*sigma. ± 2s was chosen to represent variation since 4s was found, in general, to have about the same magnitude as the range (max - min).

3. **Results**

In the discussion that follows, the results for 3412 are reviewed in detail to show how the various tables and figures were derived from resolution and microdensitometry data. To avoid repetitiveness, only and overview of the highlights for 3404 and SO-050 is givne; however, the tables and figures are complete and are organized the same as for 3412.

3.1 3412 Film

Table 1 and Figure 2 (top) show the measured resolution values for 3412 film. The 1OOO1 and 1.7:1 targets are representative: peak resolutions were 285± 56 (average ± 2s) and 105 ± 45 c/mm, respectively. There was a consistent trend, with higher contrast targets showing higher resolutions.

These results are not significantly different from data reported earlier in the *Image Resolution Study,* which reports (see Table #4, Section A, Revision #2) peak resolution values of 286 ± 79 and 125 ± 21 c/mm for the 1000:1 andl.7:1 targets, respectively, for films processed by the OSMPF to an EAFS of 36.

Table 2 presents these same resolution results along with bar and space exposures (log H [lux-set]) determined by microdensitometry. A plot of resolution vs. log H is also given in Figure 2 (bottom).

In principle, the target images should show a contrast difference in microdensitometer-measured log H between the bars and spaces equal to the log TOC. (However, for the 1000:1 TOC targets the bar/space exposure range of 3 log E units exceeds the useful exposure scale of the film, so this rule is not expected to hold.) However, this relationship was only approximately observed. On average, measured exposure differences approximately equaled log TOC, but there were anomalies. Error tended to occur at low exposures below the toe of the sensitometry curve (< -1.5 log H), where small errors in density measurement result in large extrapolated exposure errors. There also appeared to be more error at high exposure (>-0.50 log H). In general, the theoretical bar/space exposure differences were most closely observed near the points of optimal film resolution. Lower contrast images presented fewer anomalies than higher contrast images.

The data in Table 2 was plotted against log H of the target image bars in Figures 3 to 5 for each contrast. Second-order polynomial curves are plotted with the experimental data. Variance is shown by the ± 2s points.

These polynomials were used to calculate (a) predicted peak resolutions and the corresponding exposures (bars) at peak resolution, and (b) predicted exposures corresponding to -20% loss in resolution. Exposures for the spaces were estimated by subtracting log TOC from the measured bar exposures.[1] The results of this process are collected in Table 3 and plotted in Figures 6 to 11. Note that since peak resolutions listed in Table 3 and the figures are calculated from the model fits, they differ slightly from the experimental values in Table 1 and Figure 2.

There is uncertainty in the exact exposures corresponding to peak resolution, due to the fact that the curve fits of resolution vs fog H for each film were flat around peak resolution. An examination of Figures 3 to 5 suggests that this uncertainty is on the order of ± 0.2 log H. However, flat plots also mean that there is a wide exposure lattitude within which there is not much decrease in resolution.

This data show peak resolution at somewhat higher developed densities than reported in the earlier image resolution studies. For example, Figure 10 shows peak resolution for the 1.7:1 TOC image at D = 1.5, compared with D = 0.6 under comparable processing conditions (EAFS = 36) in Appendix A of the *Image Resolufion Study (Revision #2).*

---

[1] Space exposures were estimated this way to minimize the errors discussed in a previous paragraph. Spaces frequently had low densities corresponding to the toe of the sensitometry curve, in which it is hard to accurately calculate exposures from measured densities, while bar exposures had higher densities on the straight line portion of the curve, from which more accurate exposure values can be calculated.

On the other hand, the loss of resolution as a function of relative exposure is in good agreement with the previous report. Figure 12 shows a graph, in similar format as found in Appendix A of the *Image Resolution Study (Revision #2),* of resolution decrease from peak vs log relative E at 1000: 1 and 1.7:1. The figure shows a -20% resolution loss at approximately ± 0.5 and ± 0.6 log relative E units from the optimum exposure for the 1000:l and 1.7:1 TOC targets, respectively. This compares with approximately ± 0.4 (1000: 1) and -0.4/+0.7 (1.7:1) log relative E units in the earlier report.

Maximum resolution occured with the highest contrast, 1OOO1 target, and generally decreased with lower contrast, particularily at TOC ≤ 2.14. This is shown in Figure 13.[2] Peak resolution was observed at log H = -0.59 for the 1OOO:l target and was within the range of -0.53 to -0.79 for the other targets (Table 3). The -20% resolution limits averaged +0.53 and -0.52 log H off of peak, with little variation with contrast.

Figure 14 provides a convenient plot of bar density vs log TOC with points for peak and -20% resolution. Second-order polynomial fits are graphed and and the equations are shown. Higher order polynomials, linear, power, logarithmic and exponential functions were also tried, but 2° polynomials gave the best fits (by comparing R^2) of any. Note, however, that 2° polynomials force the curve to have a parabolic shape. Since data were collected at the ends of the log TOC scale, this results in the "mounds" between log TOC = 0.81 (6.45:1) and 3.0 (1000:1) which are not significant. The true curve in this region is not accurately defined and is probably asymptotic like Figure 13. As a result, Figure 14 should be used to interpolate resolution only for low TOC values (e.g., < 1O:1). To better define the model, future work should therefore include intermediate contrast targets, with log TOC values between 0.81 (TOC = 6.45:1) and 3 (TOC = 1000:1).

3.2 3404 Film

The results for 3404 acquisition film are collected in Tables 4-6 and Figures 15-28. Peak resolution values (average ± 2s) were 97 ± 38 and 52 ± 21 c/mm for the 1000:l and 1.7:1 targets, respectively (see Table 4). These compare closely with values of 103 ± 20 and 53 ± 10 reported earlier in the *Image Resolution Study (Revision #2*). As with the 3412 results, bar densities measured by OSMPF at peak resolution are somewhat higher in this work than were reported earlier: 1.30 and 1.05 at 1OOO:1 and 1.7:1 (Figures 20 and 24), vs 0.60 to 0.80 in the earlier data.

As with the 3412 film, highest resoluion was obtained with the highest contrast target, with resolution falling off rapidly with TOC ≤ 2.14:1 (Figure 27). Plots of

[2] Error bars graphed are $\pm 2 \cdot S_{rel}$, where S_{rel} is the average relative standard deviation (2S = 32%).

bar density at peak and -20% resolution vs log TOC (Figure 28) are also similar to the 3412 film. The -20% resolution limits averaged -0.68 and +0.68 log H off of peak (Table 6), and like 3412 film, there was little change with tri-bar image contrast.

3.3 SO-050 *Film*

The results for SO-050 film are collected in Tables 7-9 and Figures 29-41. Peak resolution values (average ± 2s) were 59 ± 25 and 29 ± 9 c/mm for the 1000:1 and 1.7:1 targets, respectively (see Table 7), close to the values of 63± 12 and 29 ± 6 reported earlier in the *Image Resolution Study (Revision #2)*

Statistical models of resolution vs bar log H (Figures 31-33) were more asymmetric than found for 3412 and 3404, with a flatter decline at exposures greater than peak. As a result, 3° polynomials were required to get good statistical fits, which show a "tail" at higher exposures. In some cases, resolution didn't diminish by -20% until log H increased to the shoulder of the characteristic curve (see Figures 34-36). As a result, -20% resolution limits were asymmetric and averaged -0.55 and +1.O log H off of peak, with considerable sensitivity on the + side to tri-bar TOC.

As with the 3412 and 3404 films, highest resolution was obtained with the highest contrast target, with resolution falling off rapidly with TOC ≤ 2.14: 1 (Figure 40).

4. Conclusions

Table 10 summarizes key results for the three acquieistion films, showing predicted peak resolution, image bar density and bar log H (luxx-sec) at peak and -20% resolution.

Figure 42 plots peak resolution vs log TOC, and shows that for each film, maximum observed resolution was obtained at 1000:1 contrast. A 20% decrease in resolution from the 1000:1 TOC was observed at approximately 6.45:1 TOC for the 3412 and 3.24:1 TOC for the 3404 and SO-050 films. At ≤ 2.14:1 TOC, resolution decreased precipitously for all films.

The exposure lattitude corresponding to -20% loss in resolution from peak averaged approximately ± 0.5 log H for 3412, ± 0.7 log H for 3404, and -0.6/+1.0 log H for SO-050. In general, peak resolution at all contrasts was found near the middle to the upper middle of the linear portion of the sensitometric curves.

Resolution values, exposure lattitude, and the effect of contrast on resolution observed in this study is in good agreement with earlier results (in particular, *see* the *Image Resolution Study (Revision #2)*. That work established that

varying processing parameters did not increase resolution significantly beyond the optimal values obtained by OSMPF processing conditions. This current study finds that 1000:1 contrast yields the best estimate of maximum resolution for each acquisition film. Therefore, OSMPF processing of 1000:1 tri-bar images currently provides the best prediction of maximum resolution for each acquisition film.

A-1. Tables and Figures (3412 Film)

Table 1. Measured Average Resolving Power and Deviation (2s) vs Log Rel E for 3412 Film.

	1,000: 1 TOC		6.45:1 TOC		3.24:1 TOC	
Log Rel E	Average	2 Sigma Dev	Average	2 Sigma Dev	Average	2 Sigma Dev
0.00	56	31	32	16	27	25
0.20	115	61	71	36	64	33
0.40	158	71	103	43	86	34
0.60	213	44	149	54	138	66
0.80	244	44	174	59	170	65
1 .00	285	56	197	40	179	83
1.20	261	76	205	34	170	66
1.40	206	125	187	43	151	60
1.60	114	88	149	56	133	52
1.80	65	26	120	58	116	49
2.00	53	28	101	38	100	36

	2.14:1 TOC		1.7:1 TOC		1.15:1 TOC	
Log Rel E	Average	2 Sigma Dev	Average	2 Sigma Dev	Average	2 Sigma Dev
0.00	24	22	16	3		
0.20	67	55	40	36	23	15
0.40	87	47	58	34	31	21
0.60	120	62	77	31	41	26
0.80	134	54	91	32	40	29
1 .00	138	40	98	44	38	22
1.20	134	59	105	45	40	25
1.40	132	50	97	33	37	28
1.60	110	26	84	34	28	26
1.80	100	33	79	35	34	4
2.00	97	35	65	28		

Table 2. 3412 Film Resolving Power vs Log H

TOC	Bar Density	Bar Log H	Space Density	Space Log H	Resolution Average	Resolution 2* Std Dev
1,000:1	2.843	0.540	0.160	-1.723	53	28
1,000:1	2.730	0.443	0.153	-1.773	65	26
1,000:1	2.420	0.140	0.147	-1.807	114	88
1,000:1	2.093	-0.210	0.143	-1.817	206	125
1,000:1	1.727	-0.490	0.143	-1.827	261	76
1,000:1	1.503	-0.643	0.150	-1.810	285	56
1,000:1	1.017	-0.960	0.147	-1.797	244	44
1,000:1	0.723	-1.140	0.147	-1.803	213	44
1,000:1	0.517	-1.290	0.223	-1.683	158	71
1,000:1	0.353	-1.420	0.140	-1.880	115	61
1,000:1	0.210	-1.580	0.140	-1.820	56	31
6.45:1	2.640	0.333	1.163	-0.883	101	38
6.45:1	2.417	0.137	0.917	-1.013	120	58
6.45:1	2.190	-0.110	0.643	-1.190	149	56
6.45:1	1.863	-0.407	0.430	-1.357	187	43
6.45:1	1.480	-0.657	0.280	-1.483	205	34
6.45:1	1.263	-0.820	0.237	-1.537	197	40
6.45:1	0.790	-1.093	0.183	-1.650	174	59
6.45:1	0.570	-1.247	0.193	-1.633	149	54
6.45:1	0.420	-1.363	0.180	-1.663	103	43
6.45:1	0.303	-1.453	0.180	-1.670	71	36
6.45:1	0.213	-1.580	0.170	-1.687	32	16
3.24:1	2.570	0.014	1.490	-0.645	100	36
3.24:1	2.375	0.049	1.260	-0.820	116	49
3.24:1	2.120	0.021	0.955	-0.995	133	52
3.24:1	1.745	0.007	0.645	-1.195	151	60
3.24:1	1.420	-0.703	0.463	-1.333	170	66
3.24:1	1.203	-0.857	0.347	-1.410	179	83
3.24:1	0.773	-1.107	0.227	-1.553	170	65
3.24:1	0.550	-1.260	0.190	-1.640	138	66
3.24:1	0.397	-1.373	0.180	-1.667	86	34
3.24:1	0.300	-1.465	0.170	-1.690	64	33

CONTINUED

Table 2. 34 12 Film Resolving Power vs Log H (continued)

TOC	Bar Density	Bar LogH	Space Density	Space LogH	Resolution Average	Resolution 2* Std Dev
2.14:1	2.400	0.120	1.815	-0.440	97	35
2.14:1	2.220	-0.080	1.523	-0.623	100	33
2.14:1	1.990	-0.310	1.240	-0.833	110	26
2.14:l	1.590	-0.580	0.873	-1.040	132	50
2.14:l	1.307	-0.793	0.633	-1.200	134	59
2.14:l	1.123	-0.900	0.510	-1.297	138	40
2.14:l	0.690	-1.163	0.283	-1.480	134	54
2.14:1	0.500	-1.300	0.220	-1.563	120	62
2.14:1	0.340	-1.417	0.183	-1.660	87	47
2.14:l	0.253	-1.517	0.170	-1.697	67	55
1.7:1	2.150	-0.150	1.750	-0.470	65	28
1.7:1	2.047	-0.250	1.613	-0.563	79	35
1.7:1	1.743	-0.483	1.283	-0.793	84	34
1.7:1	1.387	-0.727	0.967	-0.993	97	33
1.7:1	1.133	-0.893	0.697	-1.157	105	45
1.7:1	0.880	-1.037	0.547	-1.267	98	44
1.7:1	0.583	-1.237	0.340	-1.417	91	32
1.7:1	0.423	-1.363	0.257	-1.513	77	31
1.7:1	0.307	-1.457	0.213	-1.577	58	34
1.7:l	0.260	-1.510	0.185	-1.645	40	36
1.15:1	1.890	-0.287	1.773	-0.393	40	25
1.15:1	1.650	-0.487	1.427	-0.633	38	22
1.15:l	0.760	-1.113	0.660	-1.183	40	29
1.15:1	0.577	-1.243	0.490	-1.307	41	26
1.15:1	0.483	-1.317	0.407	-1.367	31	21
1.15:l	0.363	-1.403	0.287	-1.480	23	15

Table 3. Predicted Resolution (Model Fit) vs Log H for 3412 Film.

TOC	Predicted PeakReso c/mm	Exposure, Log H: Peak Bar	Peak Space'	-20% Reso Bar 1	-20% Reso Space l*	-20% Reso Bar 2	-20% Reso Space 2'
1,000:l	257	-0.59	-3.59	-1.13	-4.13	-0.05	-3.05
6.45:1	202	-0.56	-1.37	-1.08	-1.89	-0.04	-0.85
3.24:1	185	-0.53	-1.04	-1.09	-1.60	0.02	-0.49
2.14:l	137	-0.69	-1.02	-1.27	-1.60	-0.11	-0.44
1.7:1	103	-0.79	-1.02	-1.24	-1.47	-0.33	-0.56
1.15:1	46	-0.75	-0.81	-1.20	-1.26	-0.30	-0.36

*Note: Space exposures are estimated from bar exposures by the formula log H (sp) = log H (bar) · log TOC.

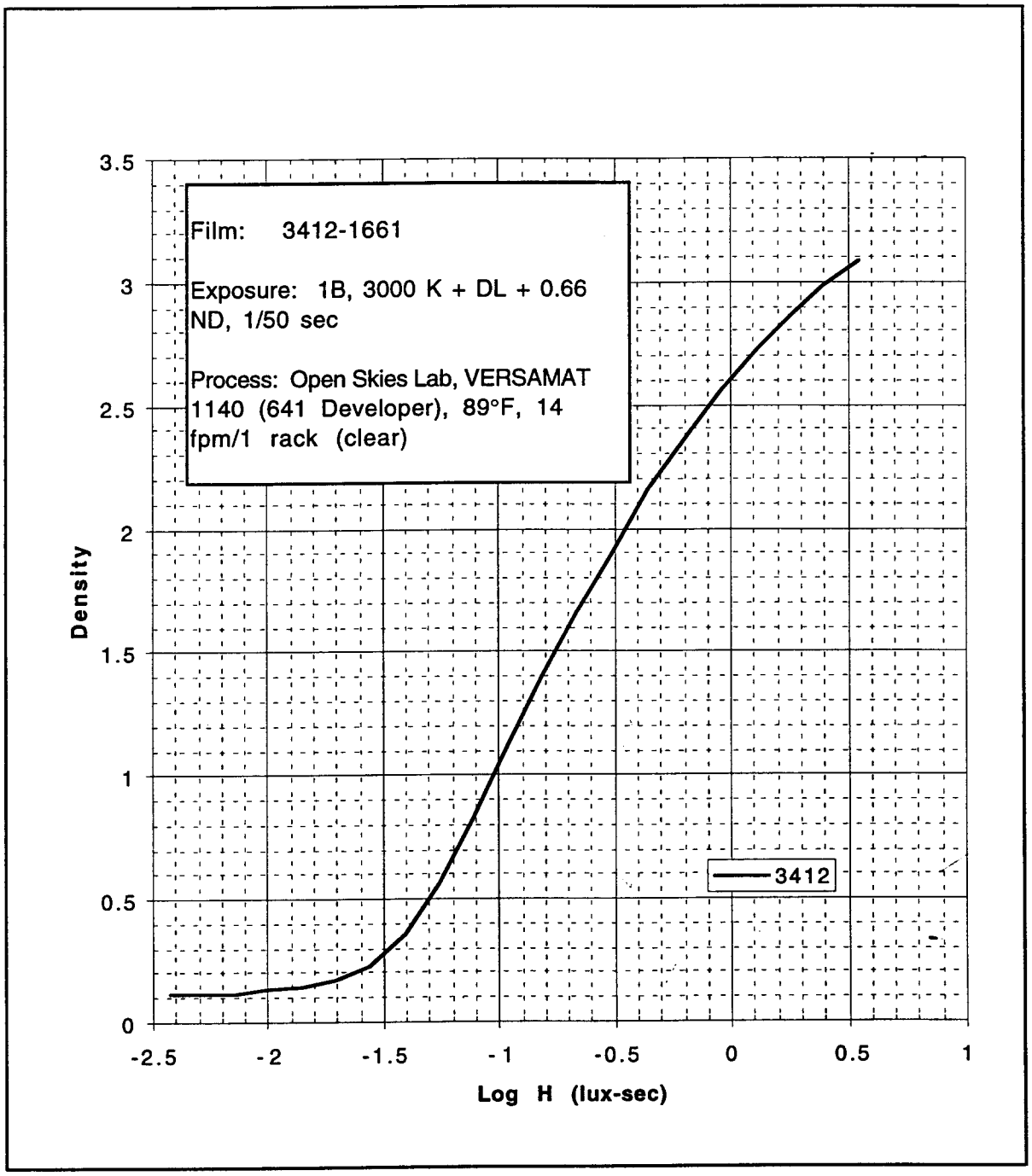


Figure 1. 3412 Film Sensitometry

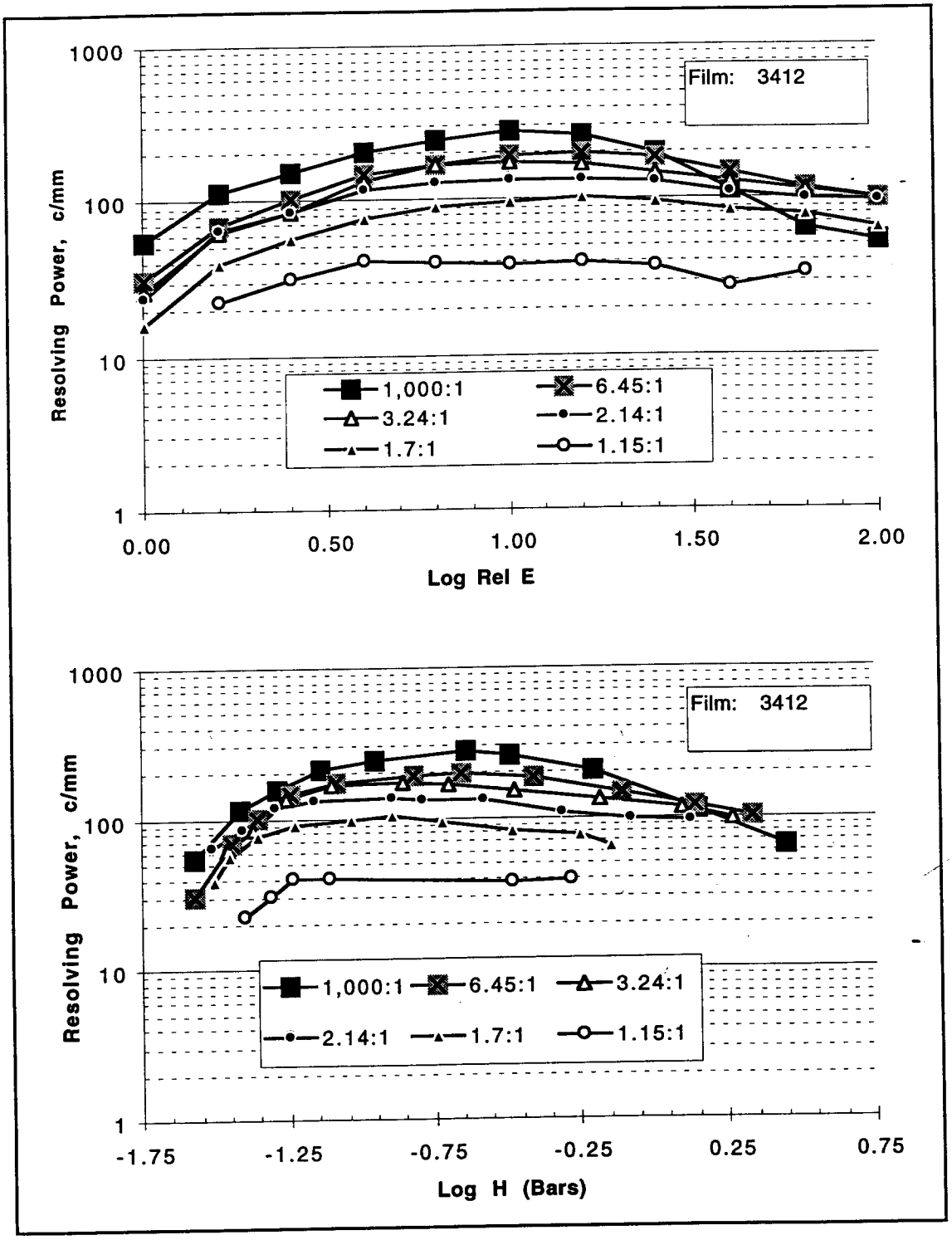


Figure 2. Resolution vs log Rel E (top) or Log H by Microdensitometry (bottom)

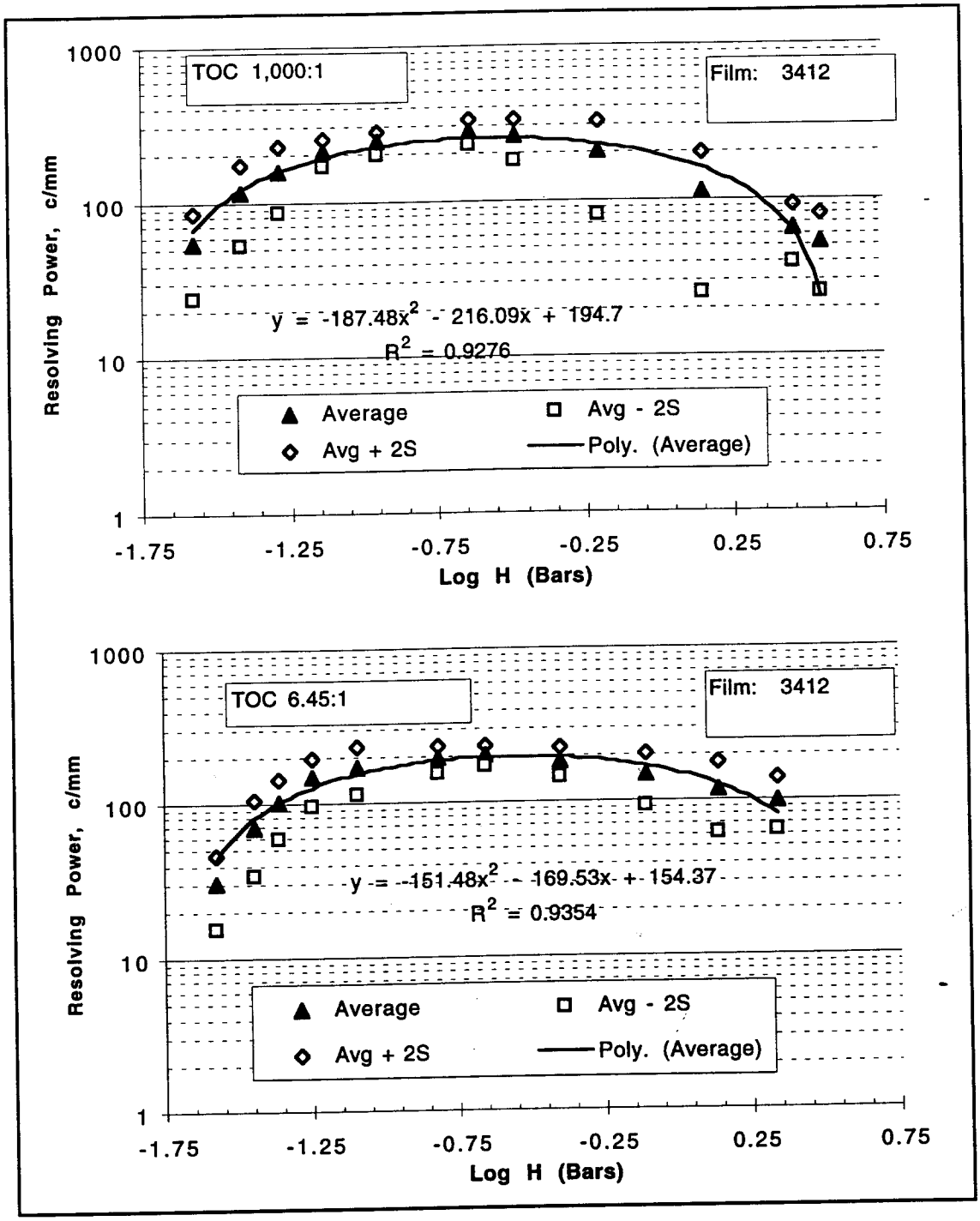


Figure 3. Resolution vs Log H for 1,000:1 (top) and 6.45:1 Targets (bottom).

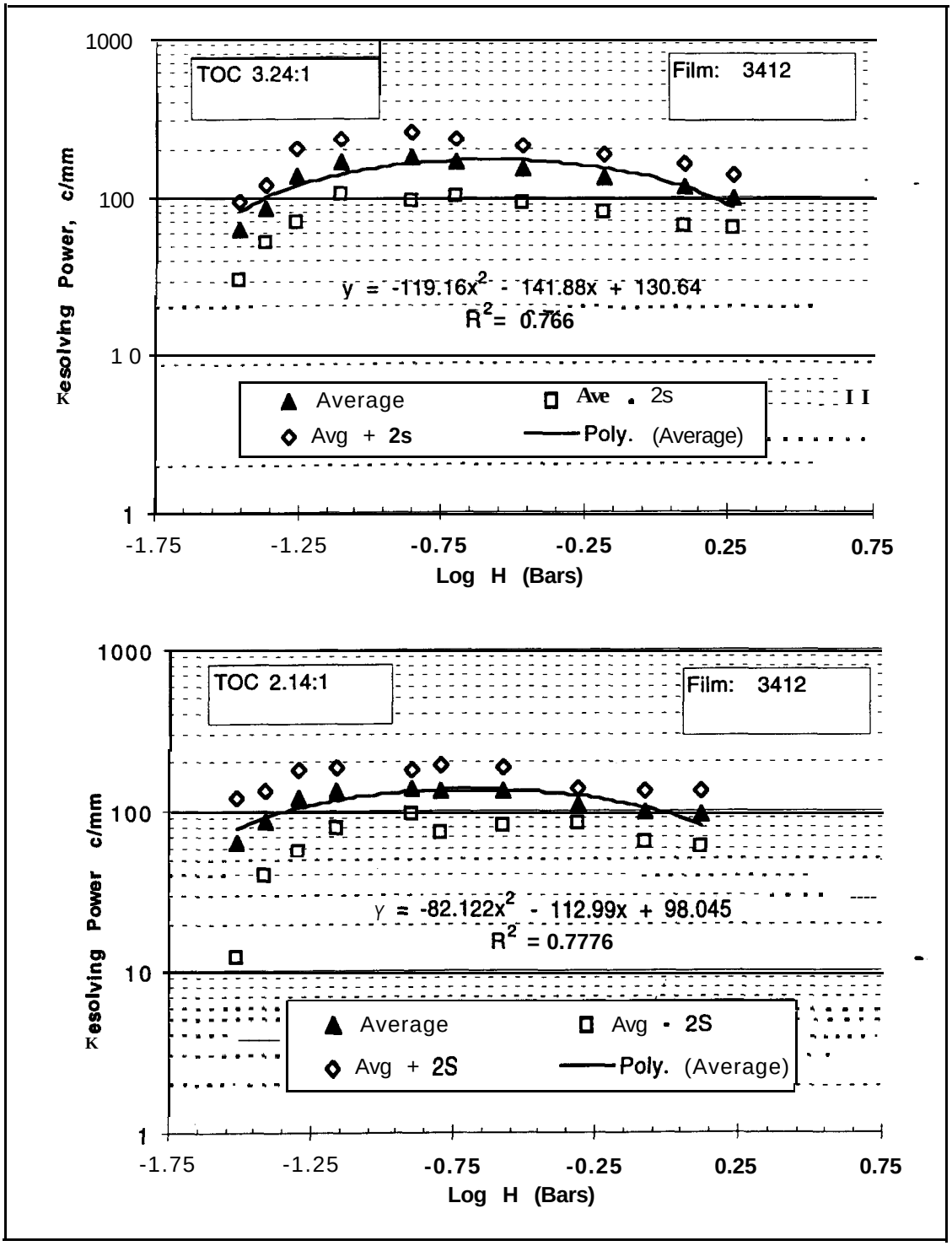


Figure 4. Resolution vs Log H for 3.24:1 (top) and Targets (bottom)

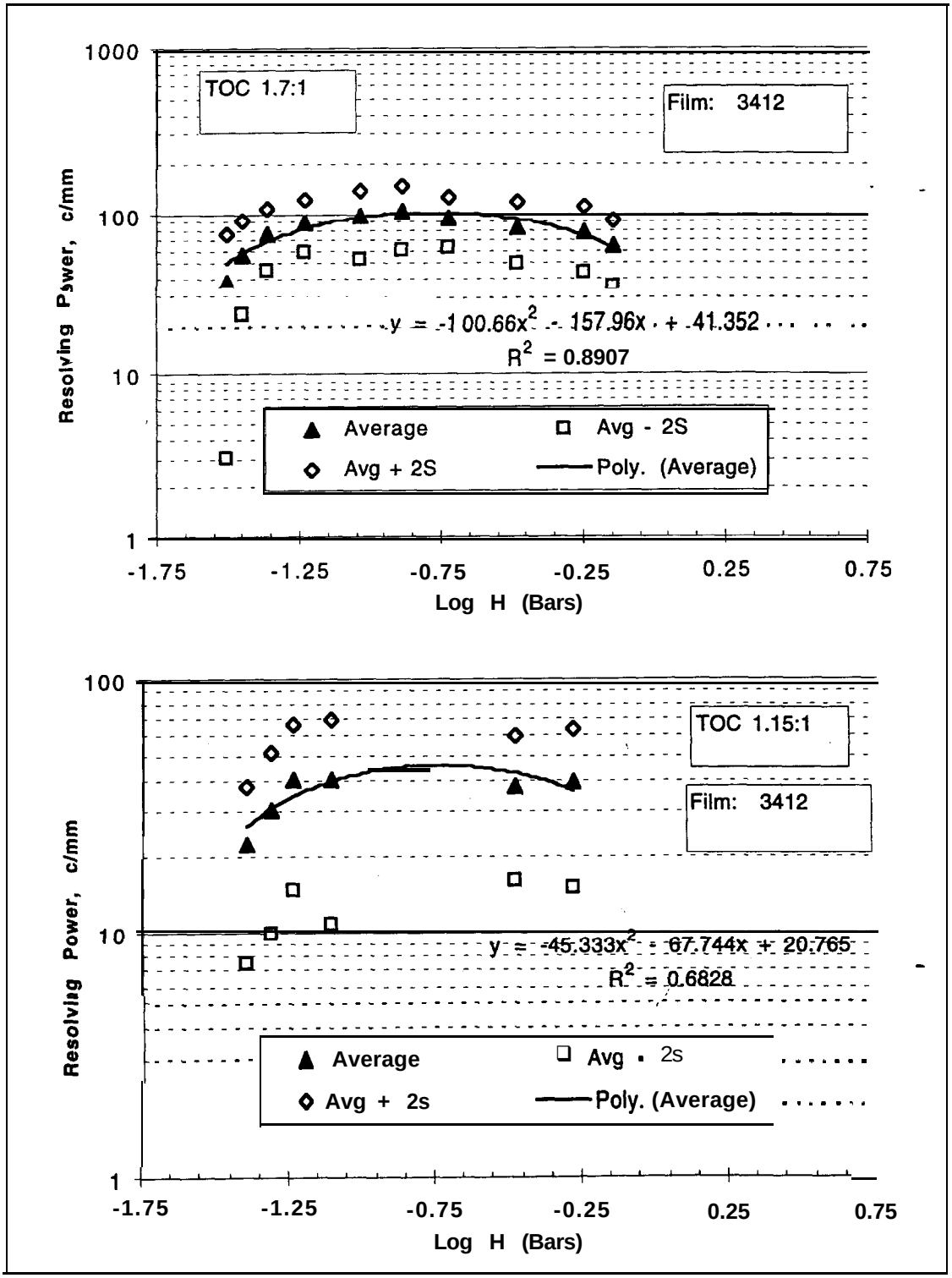
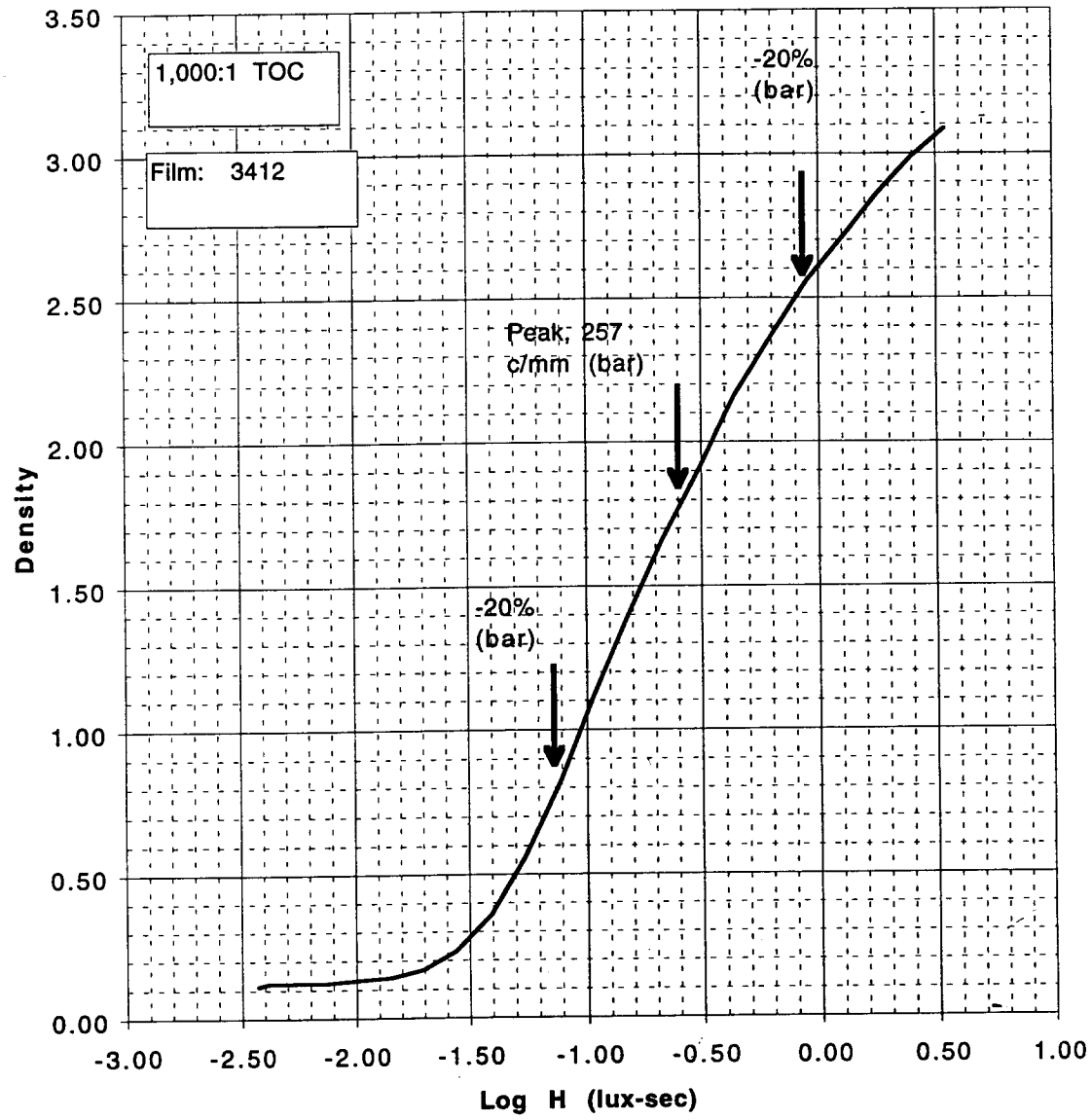
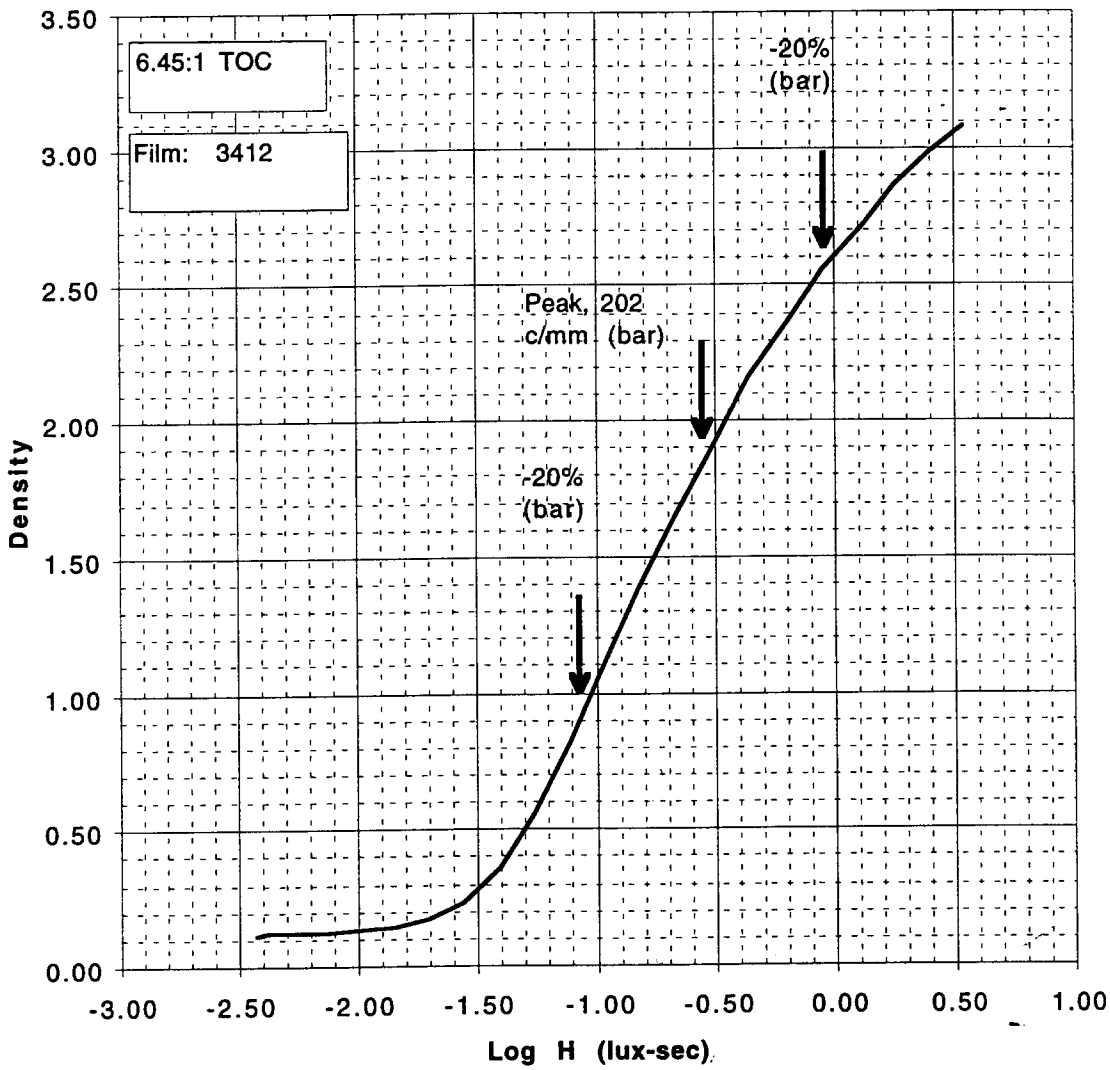


Figure 5. Resolution vs Log H for 7.7: 7 (top) and 7.75: 7 Targets (bottom)



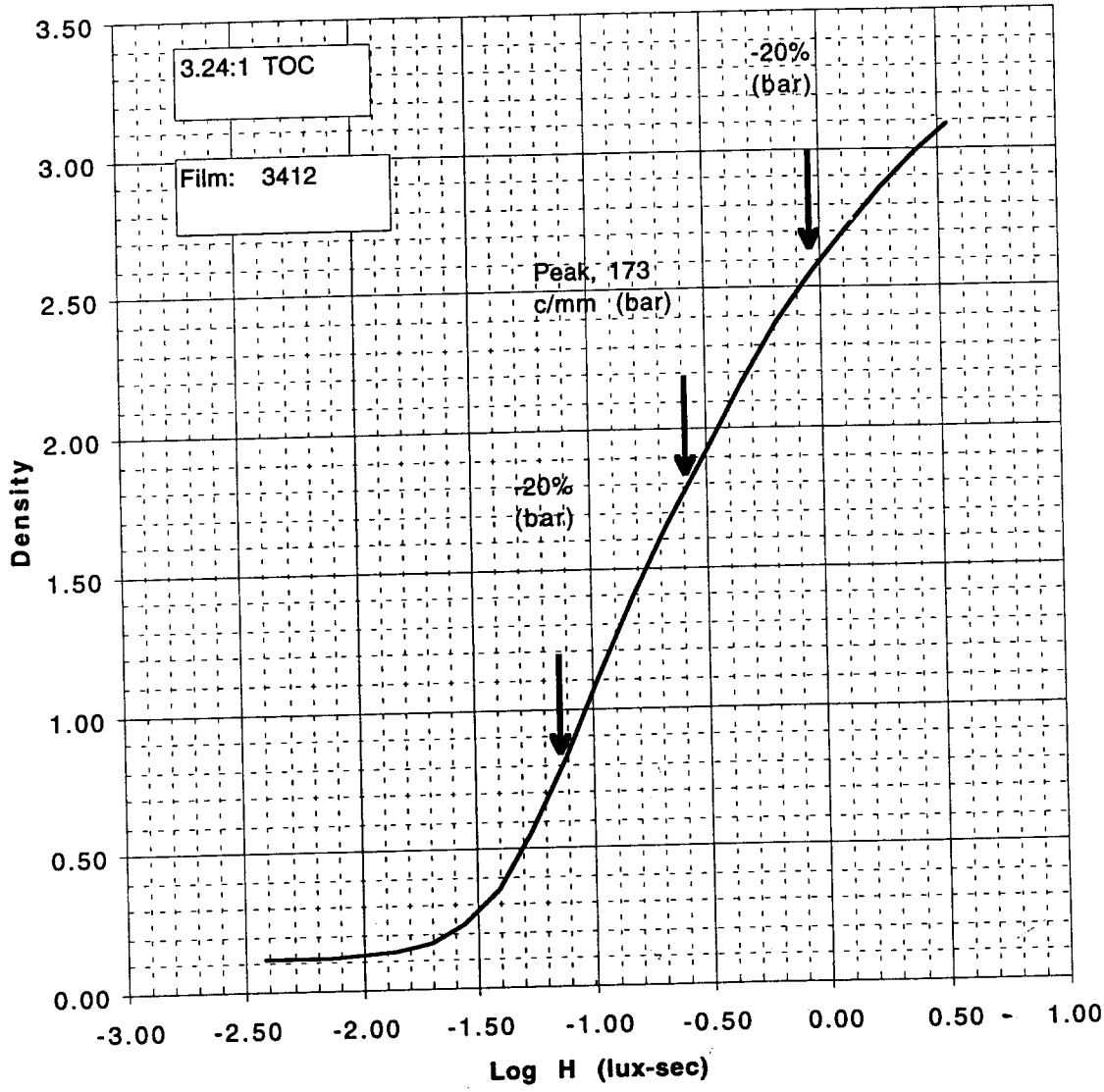
Peak Reso	Peak Bar	Peak Space (est)	Exposure Lower Limit -20% (bar)	Exposure Lower Limit -20% (space)	Exposure Upper Limit -20% (bar)	Exposure Upper Limit -20% (space)
257	-0.59	-3.59	-1.13	-4.13	-0.05	-3.05

Figure 6. Resolution vs Exposure. 1000:1 TOC.



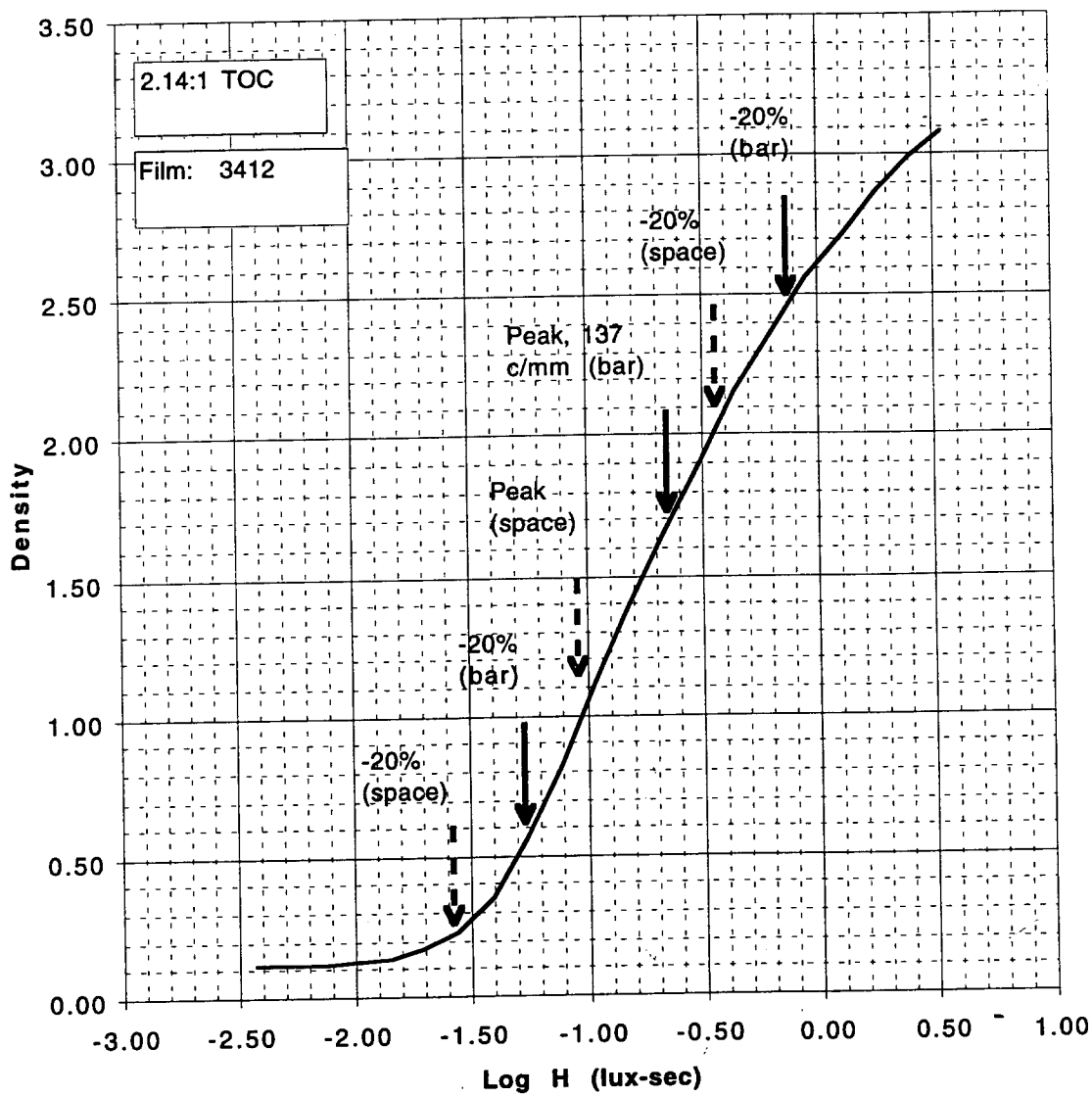
Peak Reso	Peak Bar	Peak Space (est)	Exposure Lower Limit -20% (bar)	Exposure Lower Limit -20% (space)	Exposure Upper Limit -20% (bar)	Exposure Upper Limit -20% (space)
202	-0.56	-1.37	-1.08	-1.89	-0.04	-0.85

Figure 7. Resolution vs Exposure. 6.45:1 TOC.



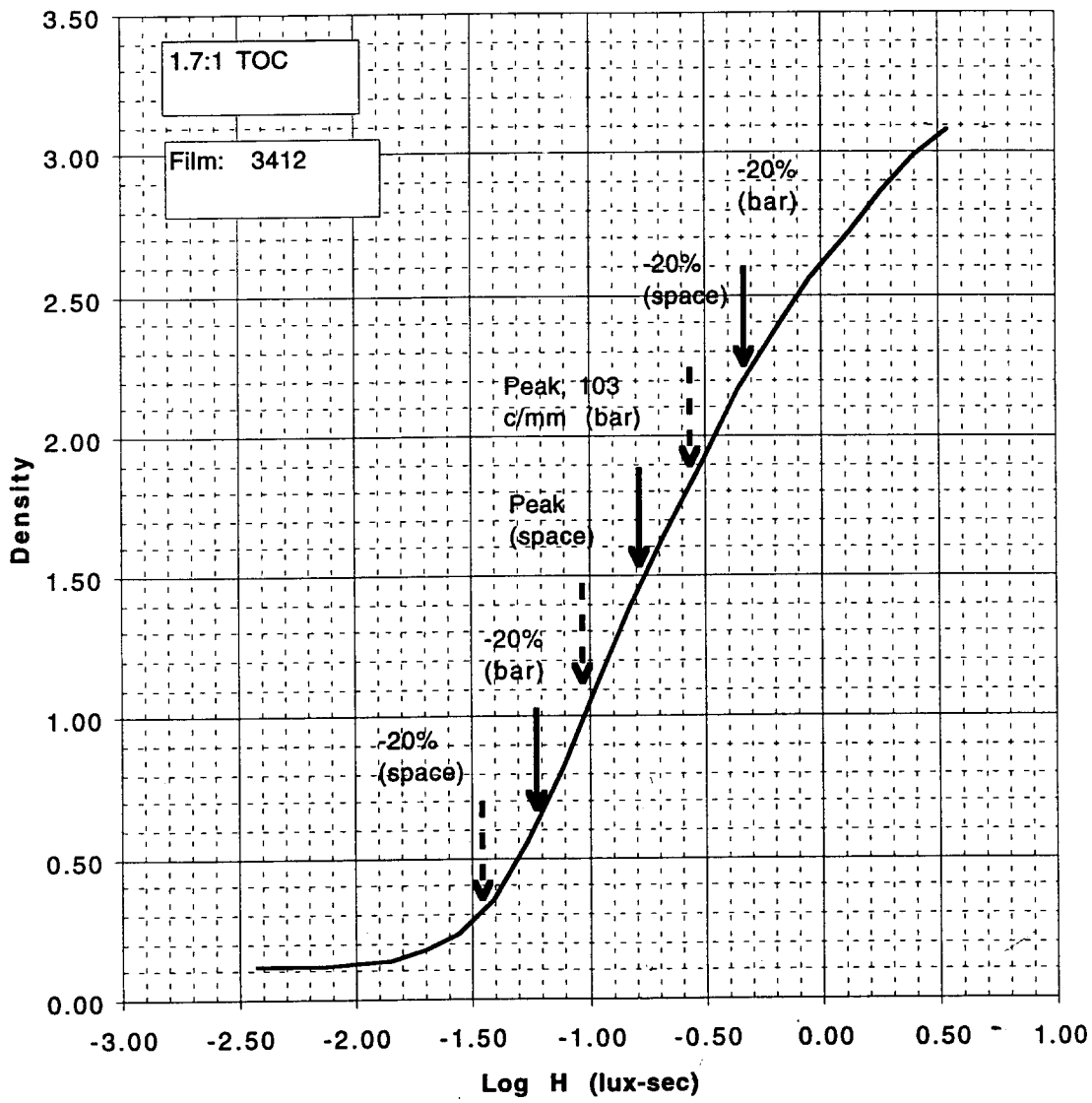
Peak Reso	Peak Bar	Peak Space (est)	Exposure Lower Limit -20% (bar)	Exposure Lower Limit -20% (space)	Exposure Upper Limit -20% (bar)	Exposure Upper Limit -20% (space)
173	-0.60	-1.11	-1.13	-1.64	-0.06	-0.57

Figure 8. Resolution vs Exposure. 3.24:1 TOC.



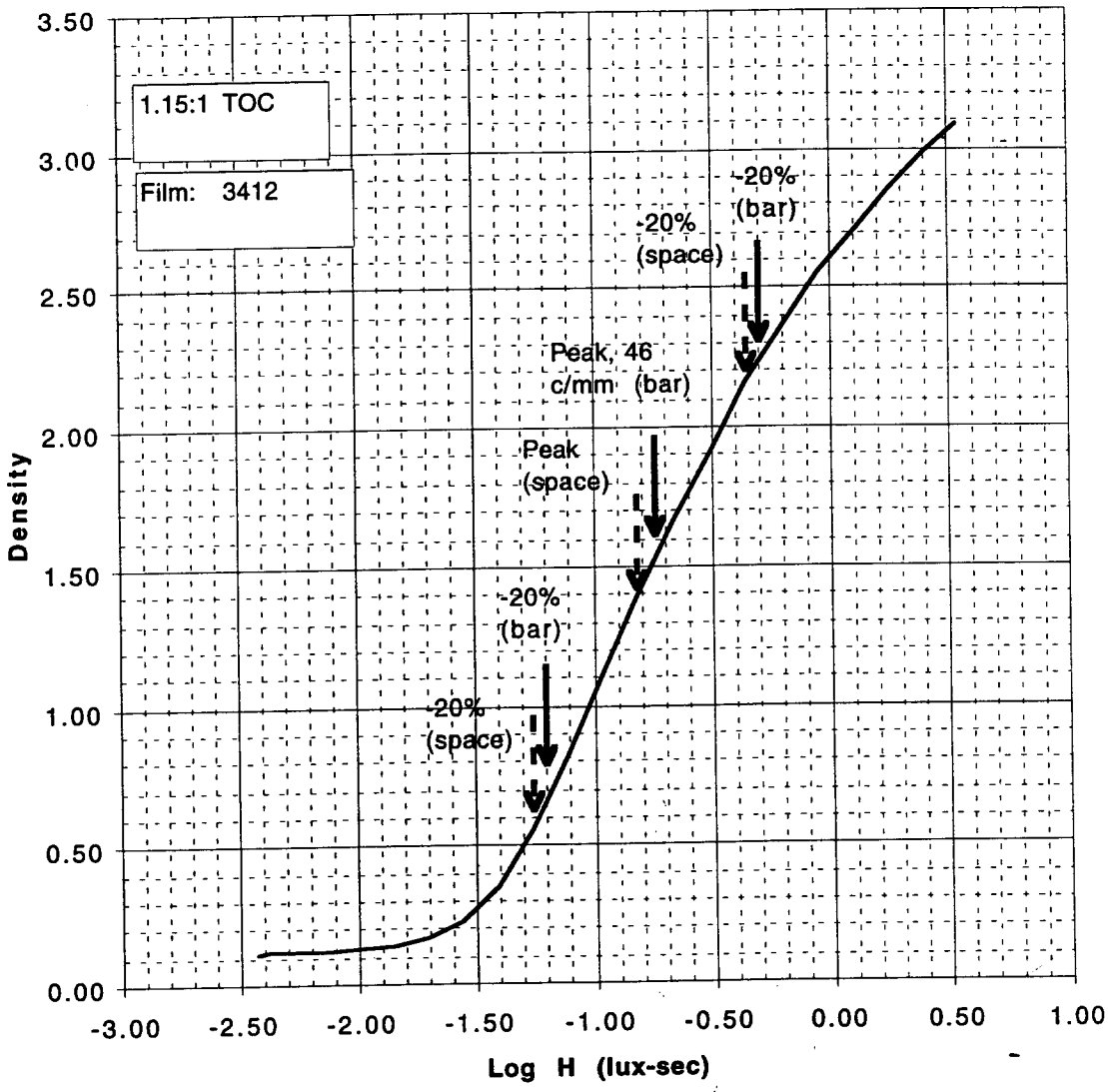
Peak Reso	Peak Bar	Peak Space (est)	Exposure Lower Limit -20% (bar)	Exposure Lower Limit -20% (space)	Exposure Upper Limit -20% (bar)	Exposure Upper Limit -20% (space)
137	-0.69	-1.02	-1.27	-1.60	-0.11	-0.44

Figure 9. Resolution vs Exposure. 2.14:1 TOC



Peak Reso	Peak Bar	Peak Space (est)	Exposure Lower Limit -20% (bar)	Exposure Lower Limit -20% (space)	Exposure Upper Limit -20% (bar)	Exposure Upper Limit -20% (space)
103	-0.79	-1.02	-1.24	-1.47	-0.33	-0.56

Figure 10. Resolution vs Exposure. 1.7:1 TOC.



Peak Reso	Peak Bar	Peak Space (est)	Exposure Lower Limit -20% (bar)	Exposure Lower Limit -20% (space)	Exposure Upper Limit -20% (bar)	Exposure Upper Limit -20% (space)
46	-0.75	-0.81	-1.20	-1.26	-0.30	-0.36

Figure 11. Resolution vs Exposure. 1.15:1 TOC.

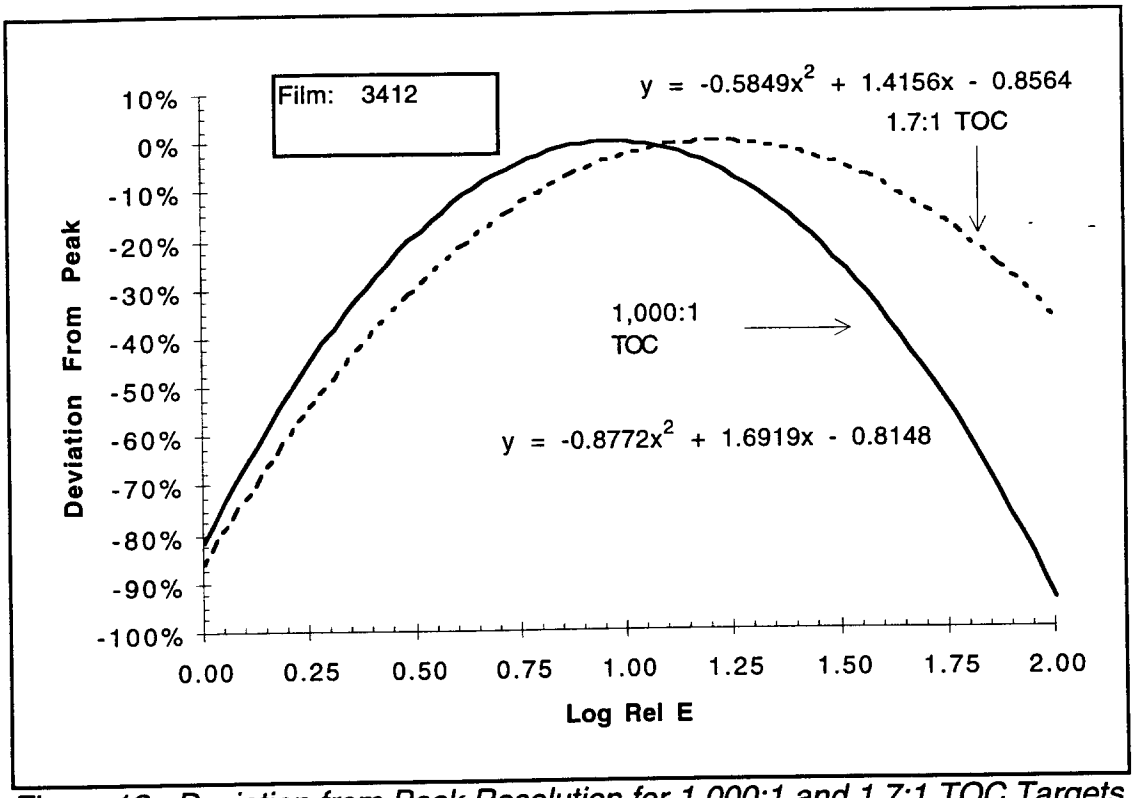


Figure 12. Deviation from Peak Resolution for 1,000;1 and 1.7:1 TOC Targets

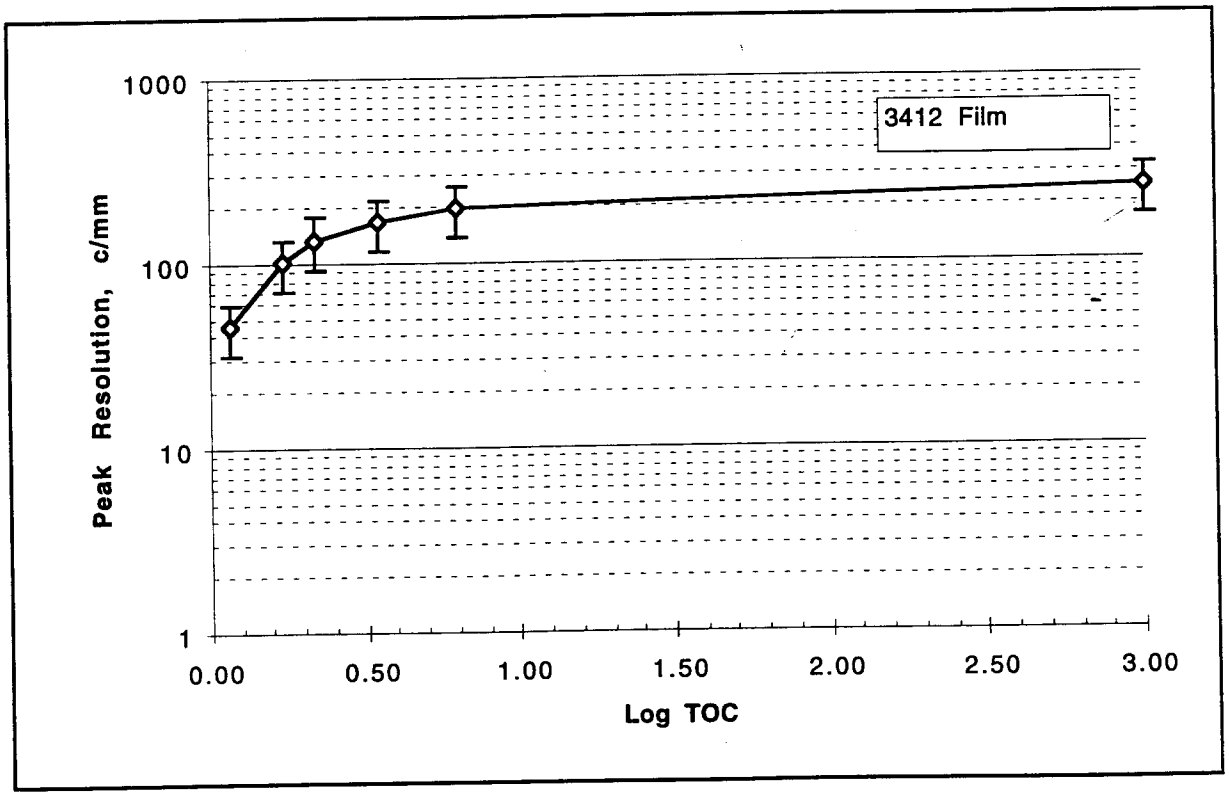


Figure 13. Peak Resolution vs Log Test Object Contrast (TOC)

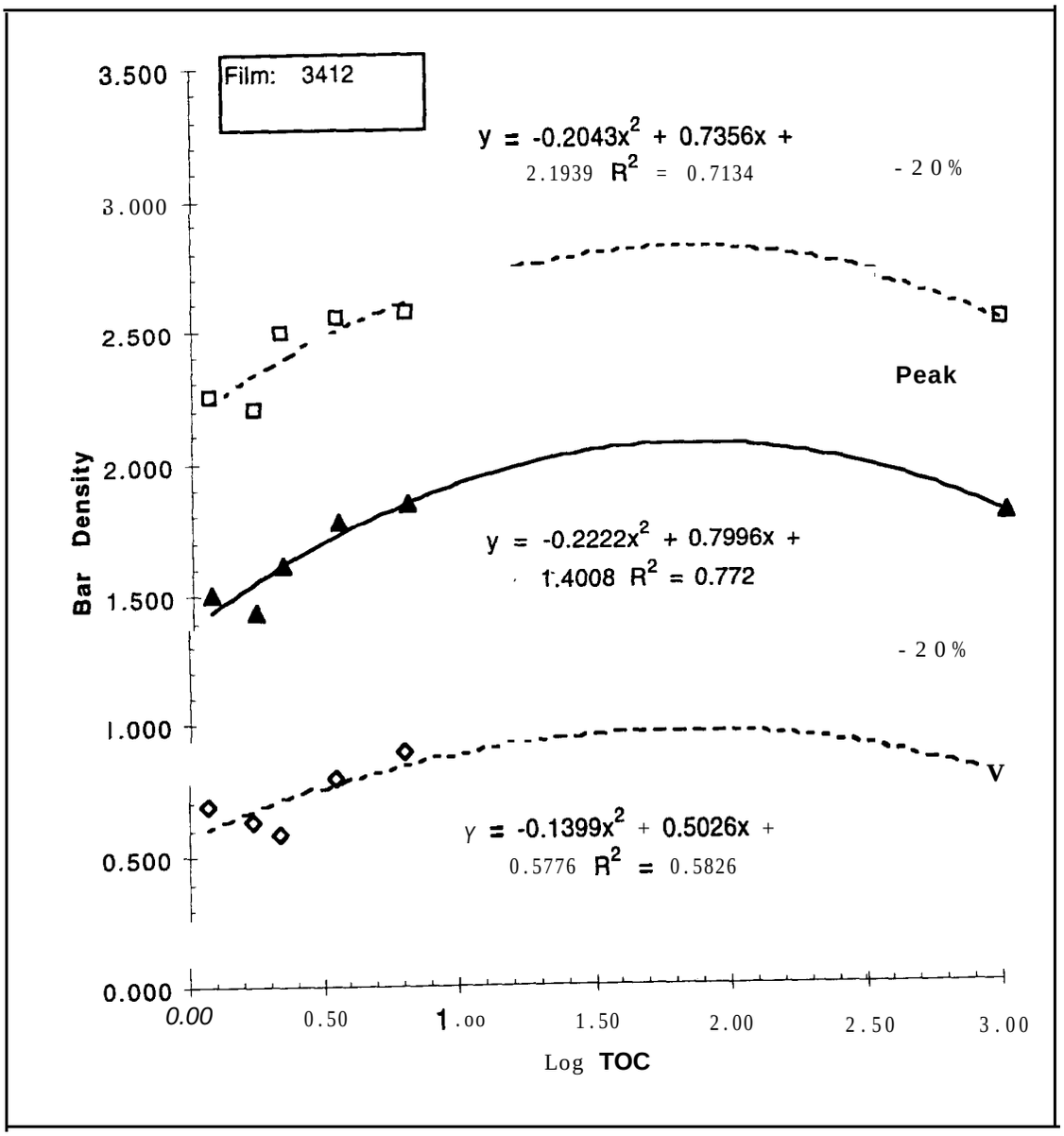


Figure 14. Bar Density vs Log TOC. Polynomial Curve Fits.

A-2. Tables and Figures (3404)

Table 4. Average Resolving Power and Deviation (2s) vs Log Rel E, 3404 Film.

	1,000:1 TOC		6.45:1 TOC		3.24:1 TOC	
Log Rel E	Average	2 Sigma Dev	Average	2 Sigma Dev	Average	2 Sigma Dev
0.00	40	19	24	24	19	13
0.20	75	33	54	20	50	16
0.40	83	33	64	26	58	11
0.60	92	36	75	28	73	36
0.80	97	38	83	31	79	33
1 .00	92	27	83	25	78	37
1.20	87	23	85	34	77	34
1.40	77	27	85	45	75	40
1.60	66	25	74	32	68	32
1.80	59	21	64	22	61	23
2.00	52	20	63	25	54	19

	2.14:1 TOC		1.7:1 TOC		1.15:1 TOC	
Log Rel E	Average	2 Sigma Dev	Average	2 Sigma Dev	Average	2 Sigma Dev
0.00	19	11	15	11		
0.20	41	15	30	19	14	13
0.40	59	30	38	15	15	10
0.60	62	15	43	16	17	15
0.80	65	17	52	22	17	15
1 .00	70	21	52	21	19	14
1.20	70	25	51	20	20	10
1.40	63	30	48	17	13	4
1.60	62	30	42	24		
1.80	54	27	32	18		
2.00	49	32	31	16		

Table 5. 3404 Film Resolving Power vs Log H.

	Bar		Space		Resolution	
TOC	Density	Log H	Density	Log H	Average	2 Sigma Dev
1,000:1	2.250	-0.050	0.133	-2.303	52	20
1,000:1	2.173	-0.070	0.087	-2.470	59	21
1,000:1	2.010	-0.247	0.063	-2.757	66	25
1,000:1	1.840	-0.463	0.060	-2.917	77	27
1,000:1	1.630	-0.717	0.060	-2.880	87	23
1,000:1	1.487	-0.883	0.060	-3.010	92	27
1,000:1	1.150	-1.247	0.060	-3.010	97	38
1,000:1	0.910	-1.460	0.060	-3.010	92	36
1,000:1	0.680	-1.673	0.060	-2.900	83	33
1,000:1	0.510	-1.847	0.060	-3.010	75	33
1,000:1	0.180	-2.217	0.060	-3.010	40	19
6.45:1	2.013	-0.247	1.177	-1.220	63	25
6.45:1	1.907	-0.377	0.937	-1.440	64	22
6.45:1	1.757	-0.570	0.760	-1.590	74	32
6.45:1	1.567	-0.793	0.473	-1.883	85	45
6.45:1	1.373	-1.010	0.273	-2.080	85	34
6.45:1	1.237	-1.160	0.193	-2.193	83	25
6.45:1	0.910	-1.460	0.120	-2.347	83	31
6.45:1	0.680	-1.677	0.073	-2.537	75	28
6.45:1	0.460	-1.893	0.073	-2.680	64	26
6.45:1	0.307	-2.033	0.063	-2.740	54	20
3.24:1	1.863	-0.433	1.243	-1.150	54	19
3.24:1	1.743	-0.590	0.973	-1.410	61	23
3.24:1	1.530	-0.833	0.737	-1.617	68	32
3.24:1	1.317	-1.080	0.537	-1.820	75	40
3.24:1	1.193	-1.207	0.377	-1.963	77	34
3.24:1	0.847	-1.510	0.160	-2.253	78	37
3.24:1	0.633	-1.727	0.093	-2.433	79	33
3.24:1	0.450	-1.903	0.067	-2.613	73	36
3.24:1	0.300	-2.047	0.063	-2.863	58	11
3.24:1	0.080	-2.480	0.060	-3.010	50	16

CONTINUED

Table 5. 3404 Film Resolving Power vs Log H (Continued)

TOC	Bar Density	Bar Log H	Space Density	Space Log H	Resolution Average	Resolution 2 Sigma Dev
2.14:1	1.893	-0.393	1.473	-0.897	54	27
2.14:1	1.710	-0.633	1.263	-1.133	62	30
2.14:1	1.480	-0.893	0.990	-1.400	63	30
2.14:1	1.250	-1.150	0.733	-1.620	70	25
2.14:1	1.117	-1.273	0.607	-1.743	70	21
2.14:1	0.780	-1.573	0.330	-2.010	65	17
2.14:1	0.597	-1.760	0.173	-2.233	62	15
2.14:1	0.383	-1.957	0.123	-2.330	59	30
2.14:1	0.270	-2.080	0.133	-2.360	41	15
						2s
1.7:1	1.623	-0.733	1.343	-1.047	42	24
1.7:1	1.403	-0.980	1.043	-1.347	48	17
1.7:1	1.170	-1.227	0.830	-1.527	51	20
1.7:1	1.053	-1.337	0.713	-1.640	52	21
1.7:1	0.730	-1.620	0.397	-1.953	52	22
1.7:1	0.517	-1.837	0.233	-2.137	43	16
1.7:1	0.327	-2.017	0.130	-2.313	38	15
1.7:1	0.203	-2.177	0.093	-2.437	30	19
1.15	0.955	-1.425	0.870	-1.495	17	15
1.15	0.727	-1.623	0.620	-1.737	17	15
1.15	0.527	-1.827	0.427	-1.923	15	10
1.15	0.425	-1.925	0.320	-2.020	14	13

Table 6. Predicted Resolution (Model Fit) vs AM-1 Exposure for 3404 Film.

TOC	Predicted PeakReso c/mm	Exposure, Log H: Peak Bar	Peak Space*	-20% Reso Bar 1	Space 1'	Bar 2	Space 2'
1,000:l	96	-1.08	-4.08	-1.77	-4.77	-0.40	-3.40
6.45:l	85	-1.10	-1.91	-1.80	-2.61	-0.40	-1.21
3.24:l	79	-1.35	-1.89	-2.06	-2.59	-0.65	-1.18
2.14:l	70	-1.18	-1.51	-1.89	-2.22	-0.47	-0.80
1.7:1	52	-1.33	-1.56	-1.91	-2.14	-0.75	-0.98
1.15:1	17	-1.55	-1.61	-1.95	-2.01	-1.15	-1.21

*Note: Space exposures are estimated from bar exposures by the formula log H (sp) = log H (bar) - log TOC.

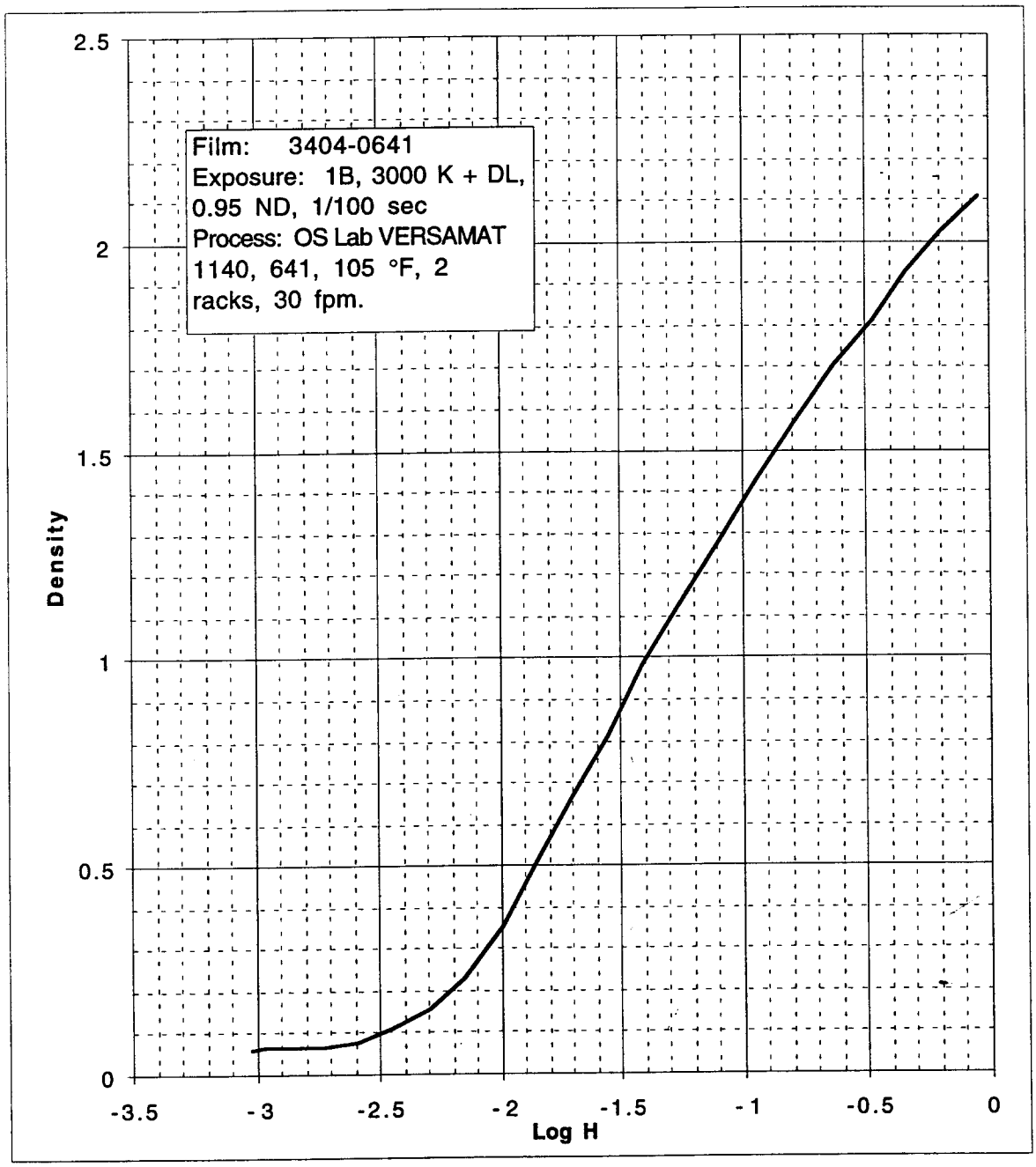


Figure 15. 3404 Processed Film Sensitometry

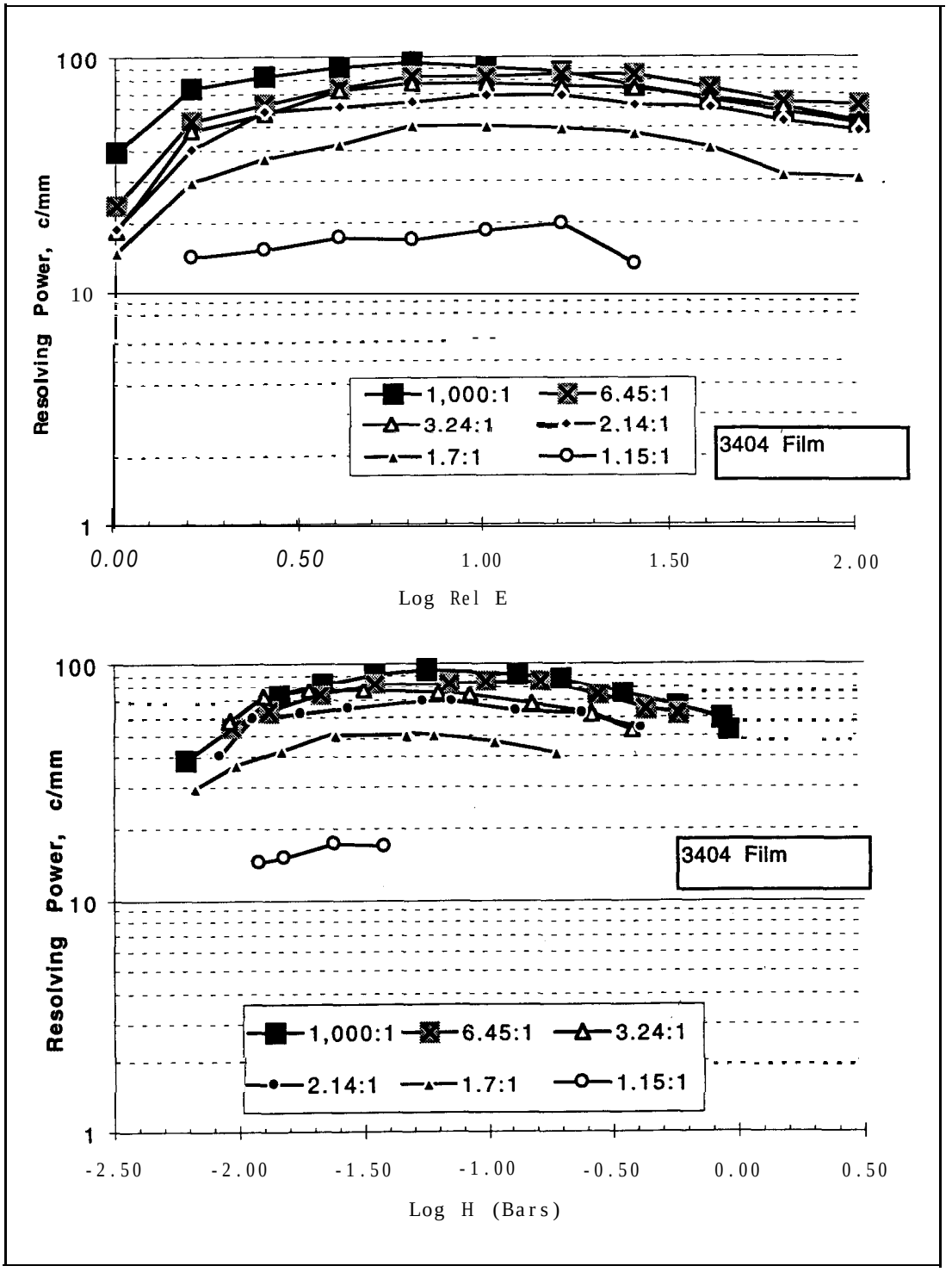


Figure 16. Resolution vs log Rel E (top) or Log H by Microdensitometry (bottom)

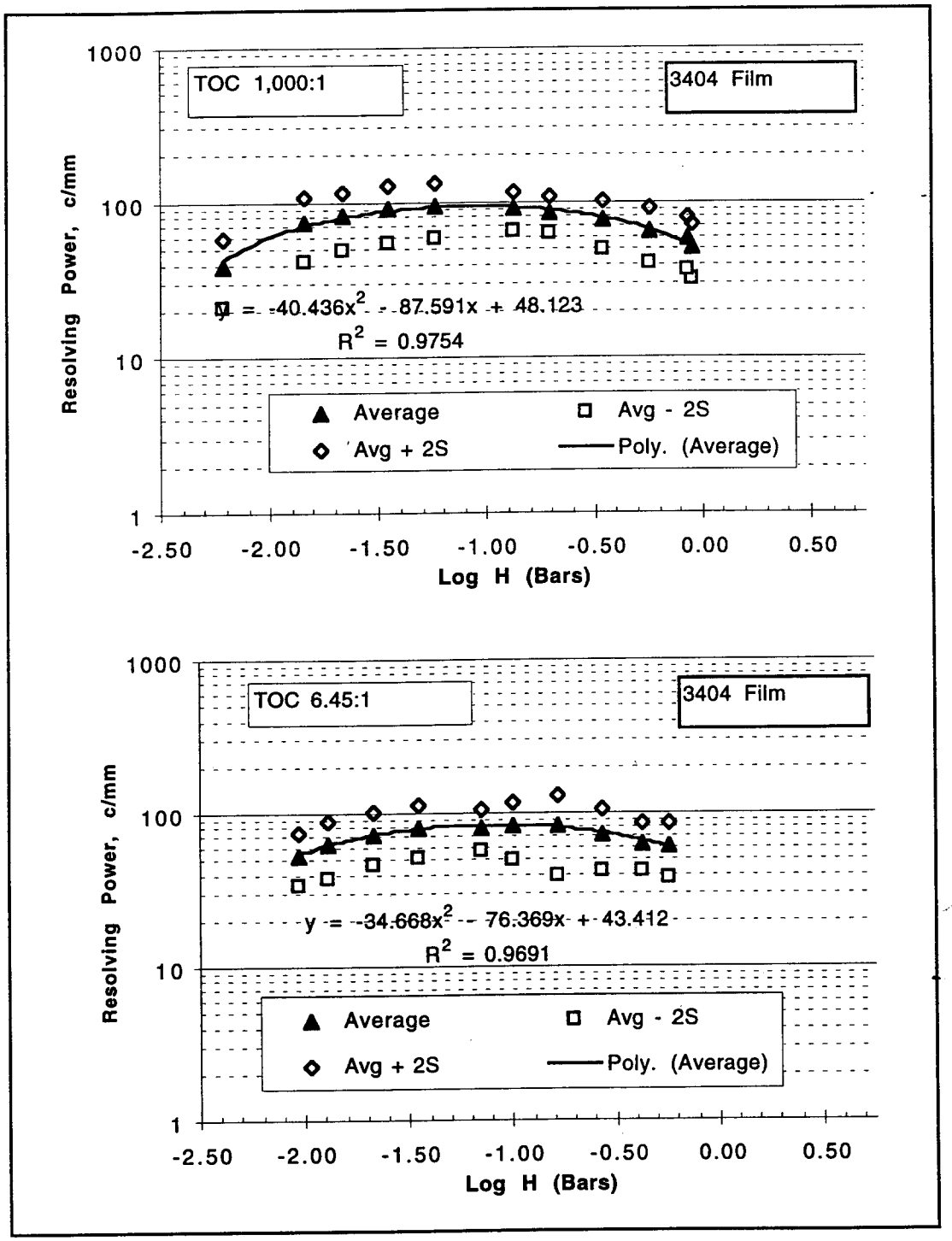


Figure 17. Resolution vs Log H for 1,000:1 (top) and 6.45:1 Targets (bottom)

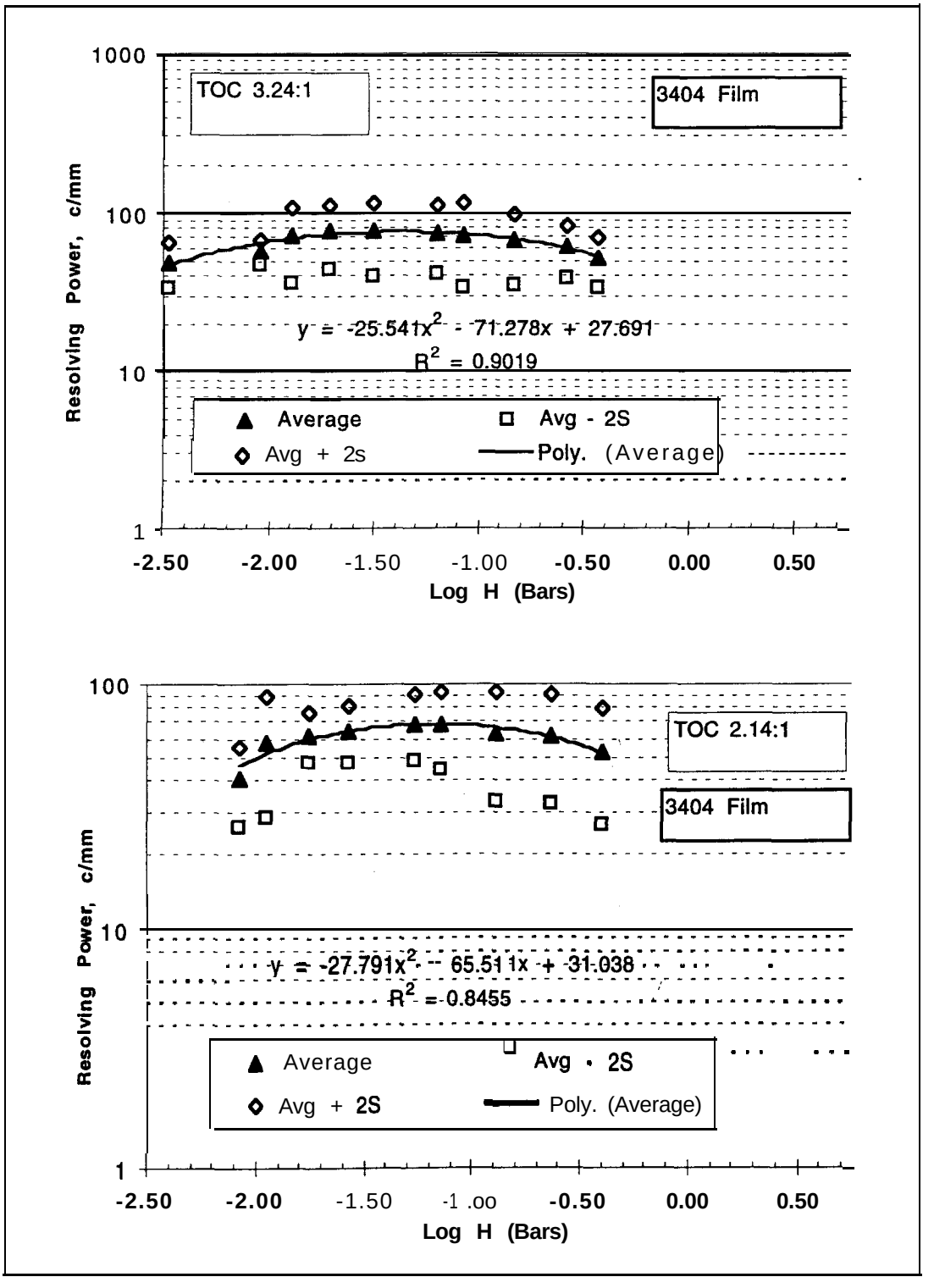


Figure 18. Resolution vs Log H for 3.24:1 (top) and 2.14:1 Targets (bottom)

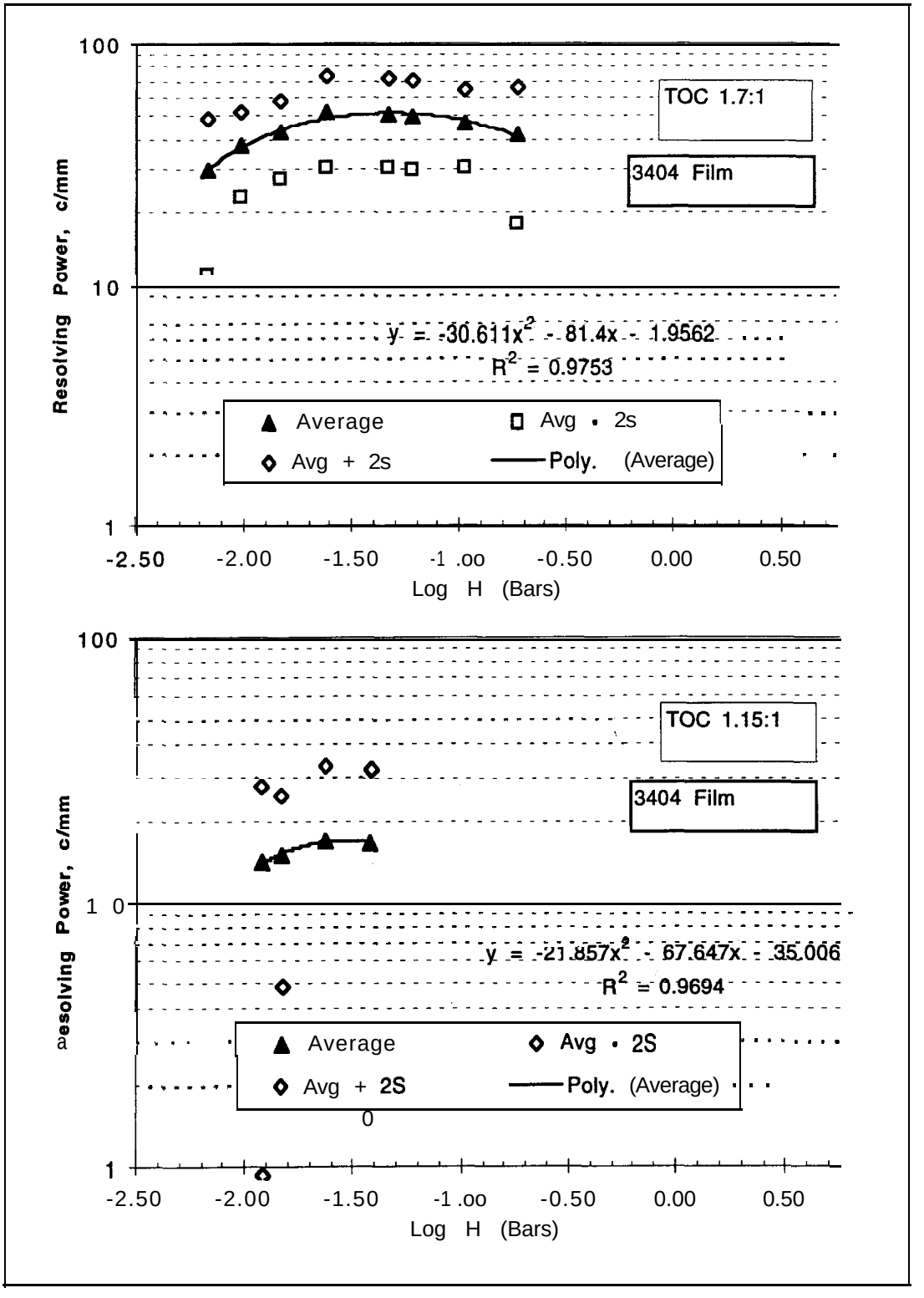
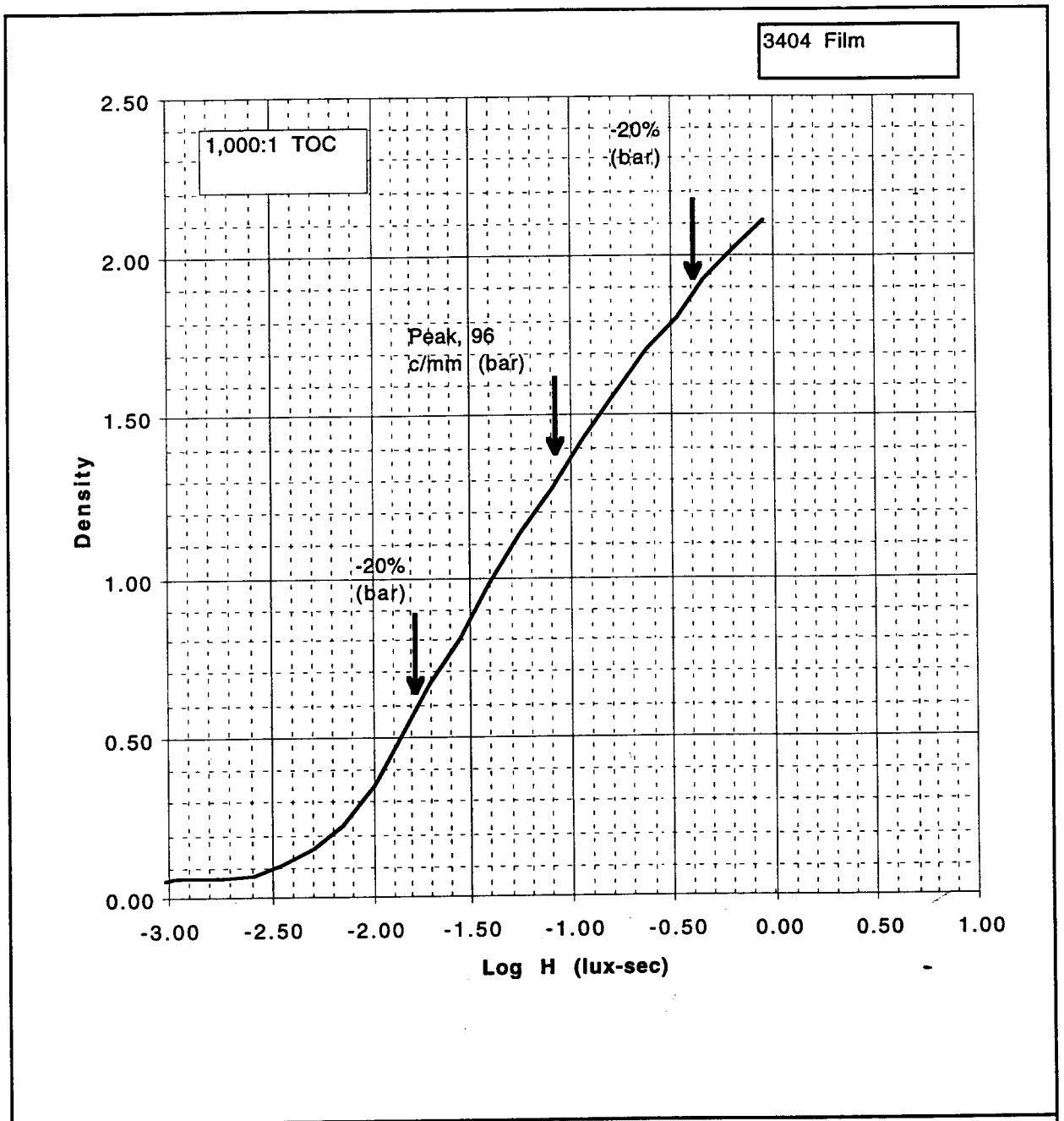
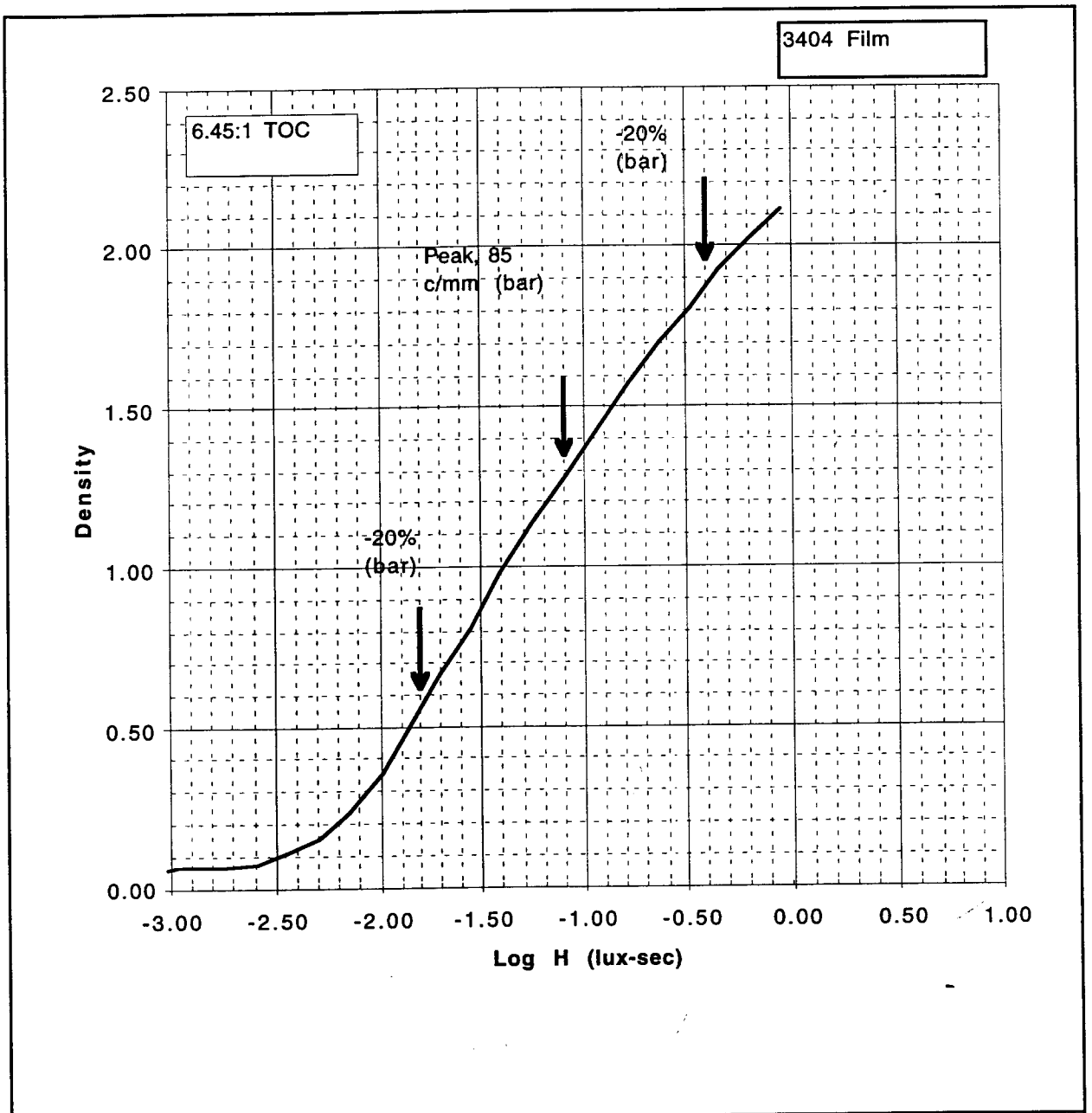


Figure 19. Resolution vs Log H for 1.7:1 (top) and 1.15: 1 Targets (bottom)



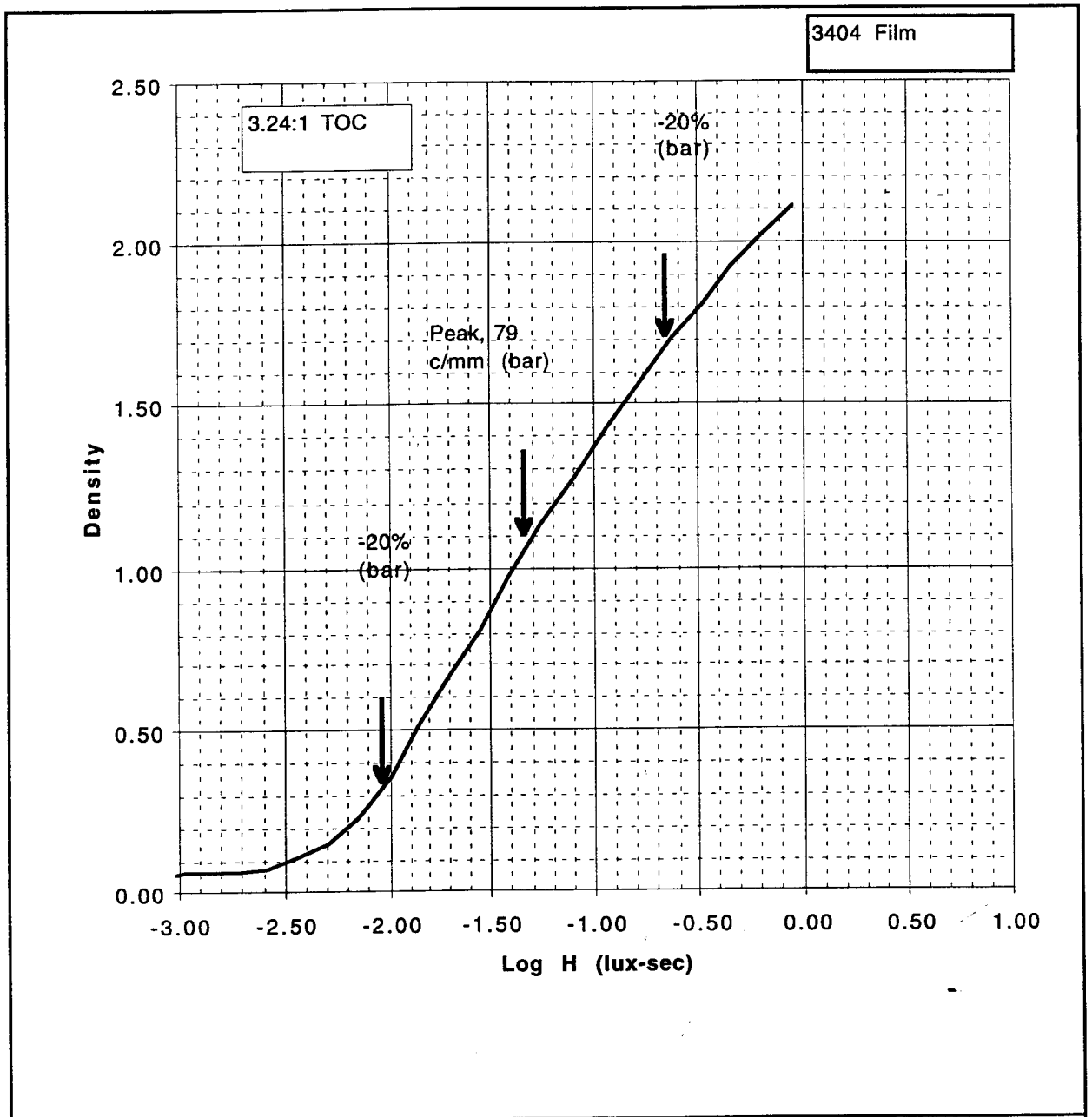
Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
96	-1.08	-4.08	-1.77	-4.77	-0.40	-3.40

Figure 20. Resolution vs Exposure. 1000:1 TOC.



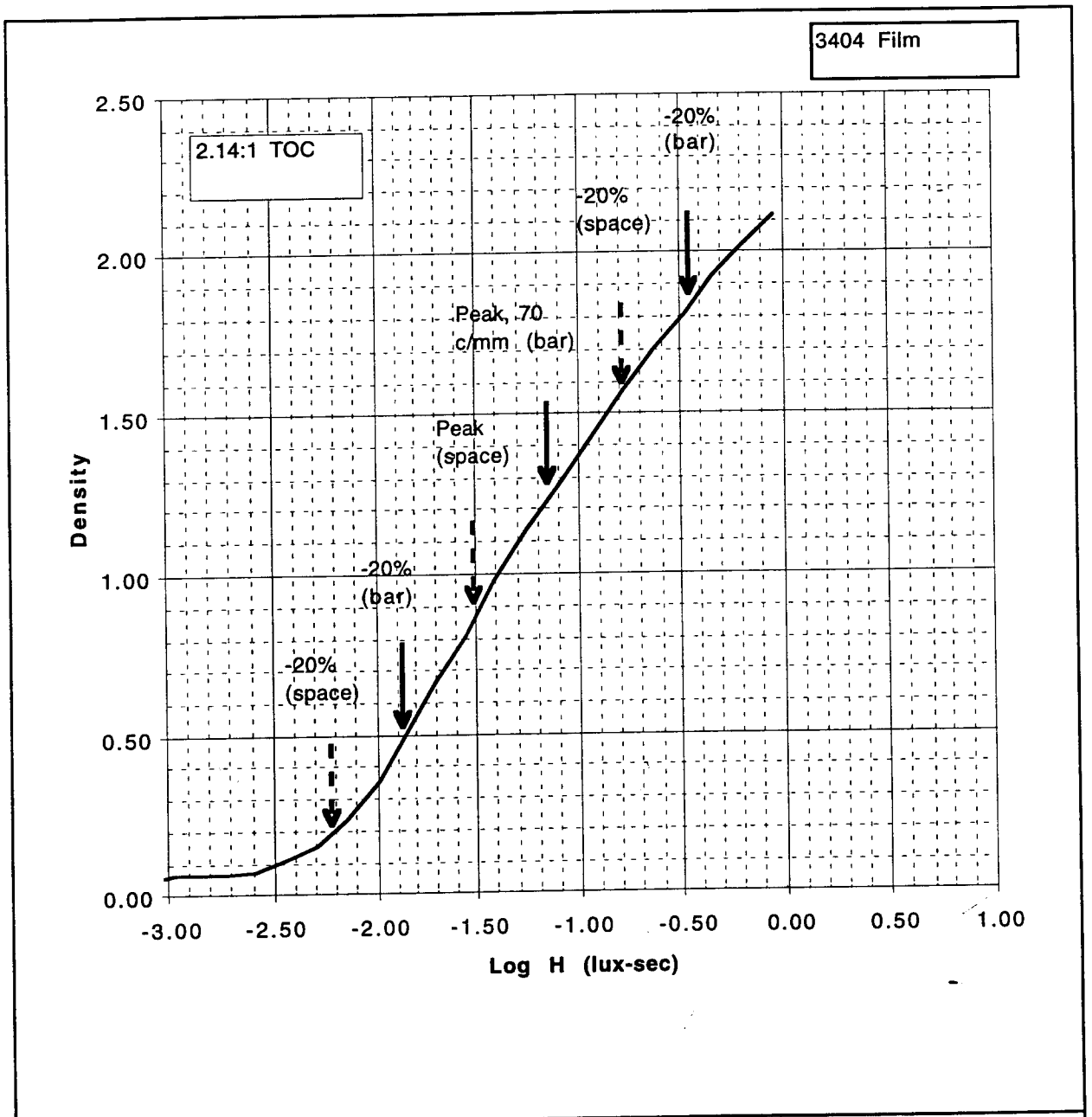
Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
85	-1.10	-1.91	-1.80	-2.61	-0.40	-1.21

Figure 21. Resolution vs Exposure. 6.45:1 TOC.



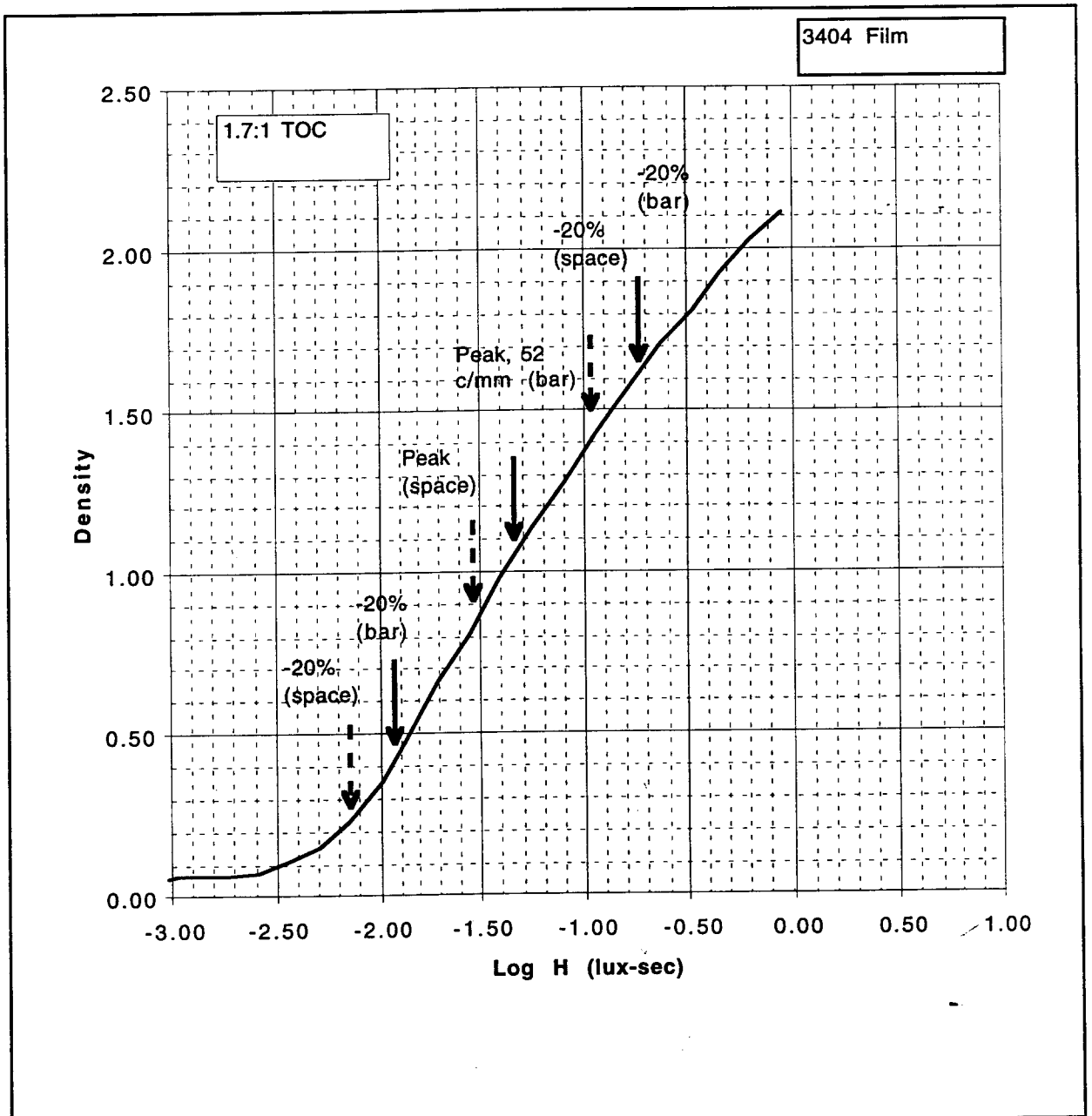
Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
79	-1.35	-1.89	-2.06	-2.59	-0.65	-1.18

Figure 22. Resolution vs Exposure. 3.24:1 TOC.



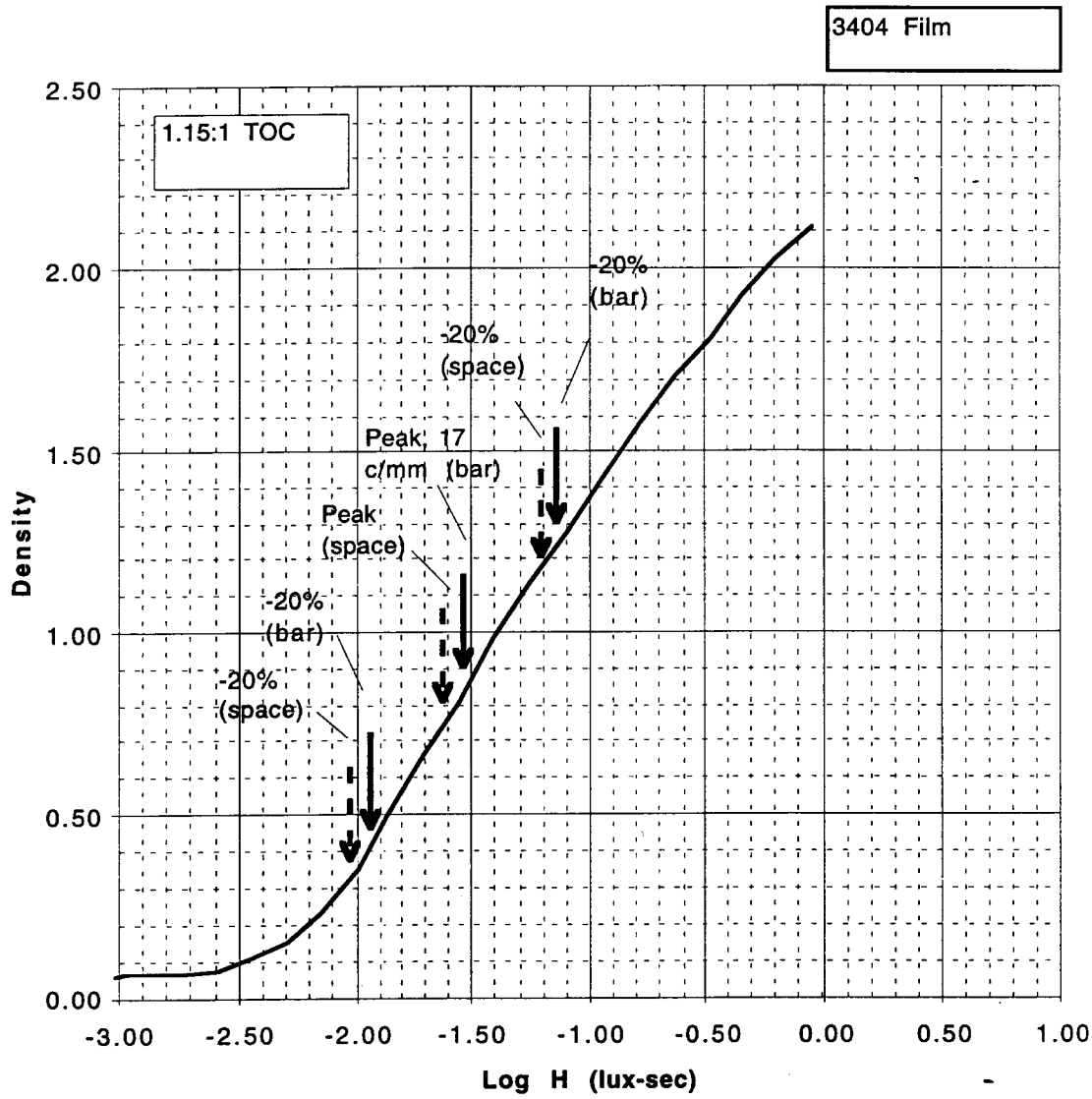
Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
70	-1.18	-1.51	-1.89	-2.22	-0.47	-0.80

Figure 23. Resolution vs Exposure. 2.14:1 TOC.



Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
52	-1.33	-1.56	-1.91	-2.14	-0.75	-0.98

Figure 24. Resolution vs Exposure. 1.7:1 TOC.



Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
17	-1.55	-1.61	-1.95	-2.01	-1.15	-1.21

Figure 25. Resolution vs Exposure. 1.15:1 TOC.

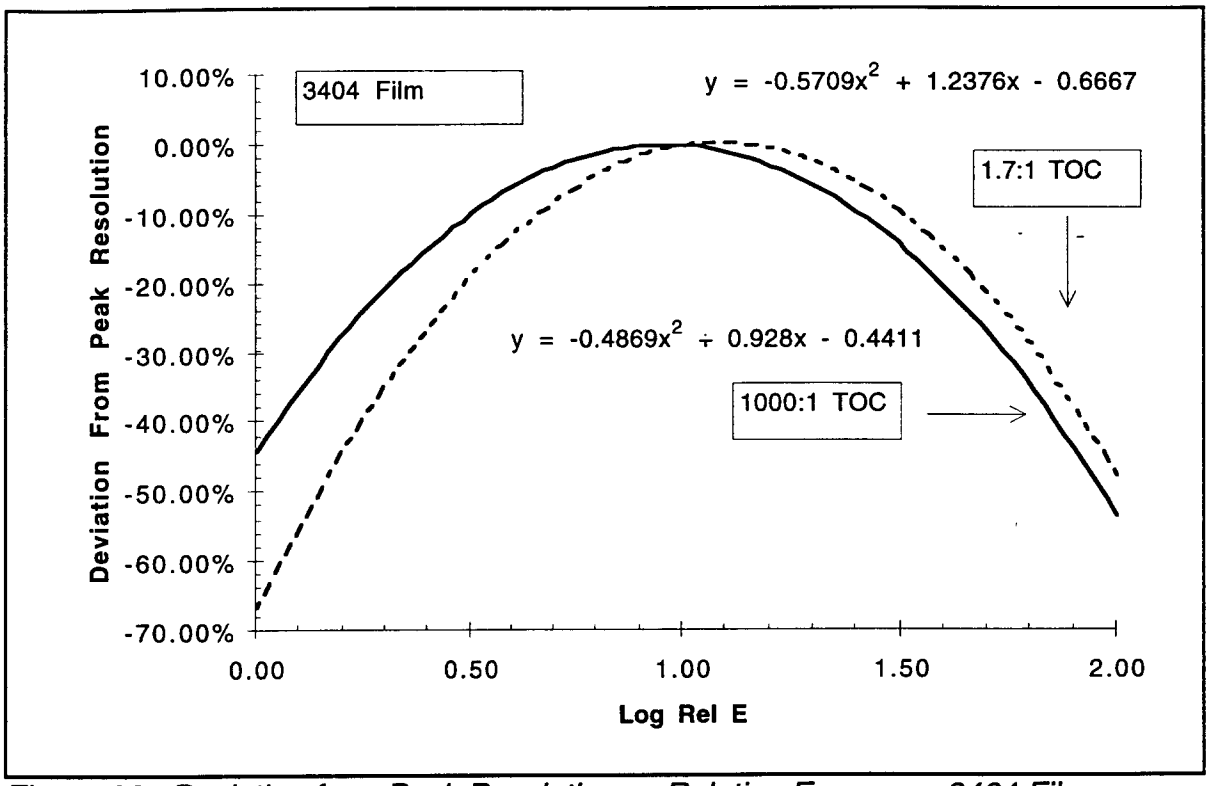


Figure 26. Deviation from Peak Resolution vs Relative Exposure, 3404 Film.

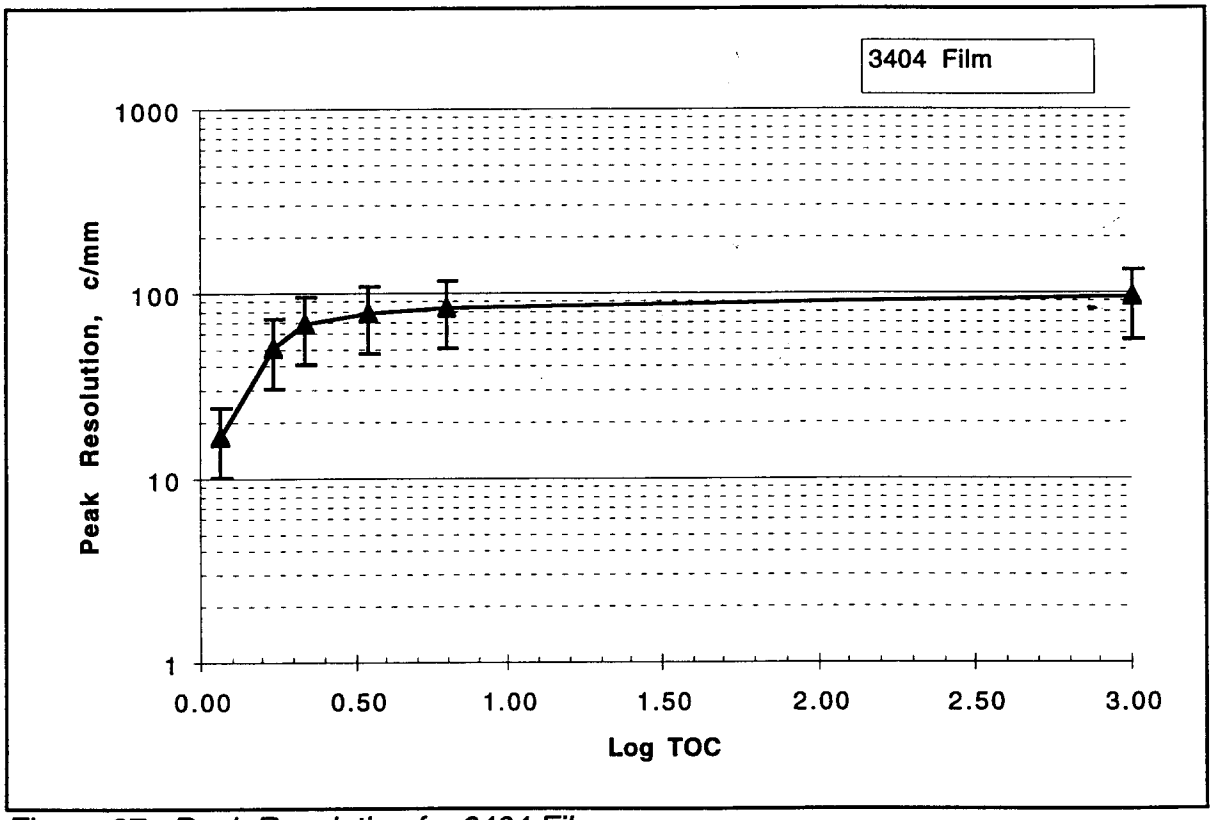


Figure 27. Peak Resolution for 3404 Film

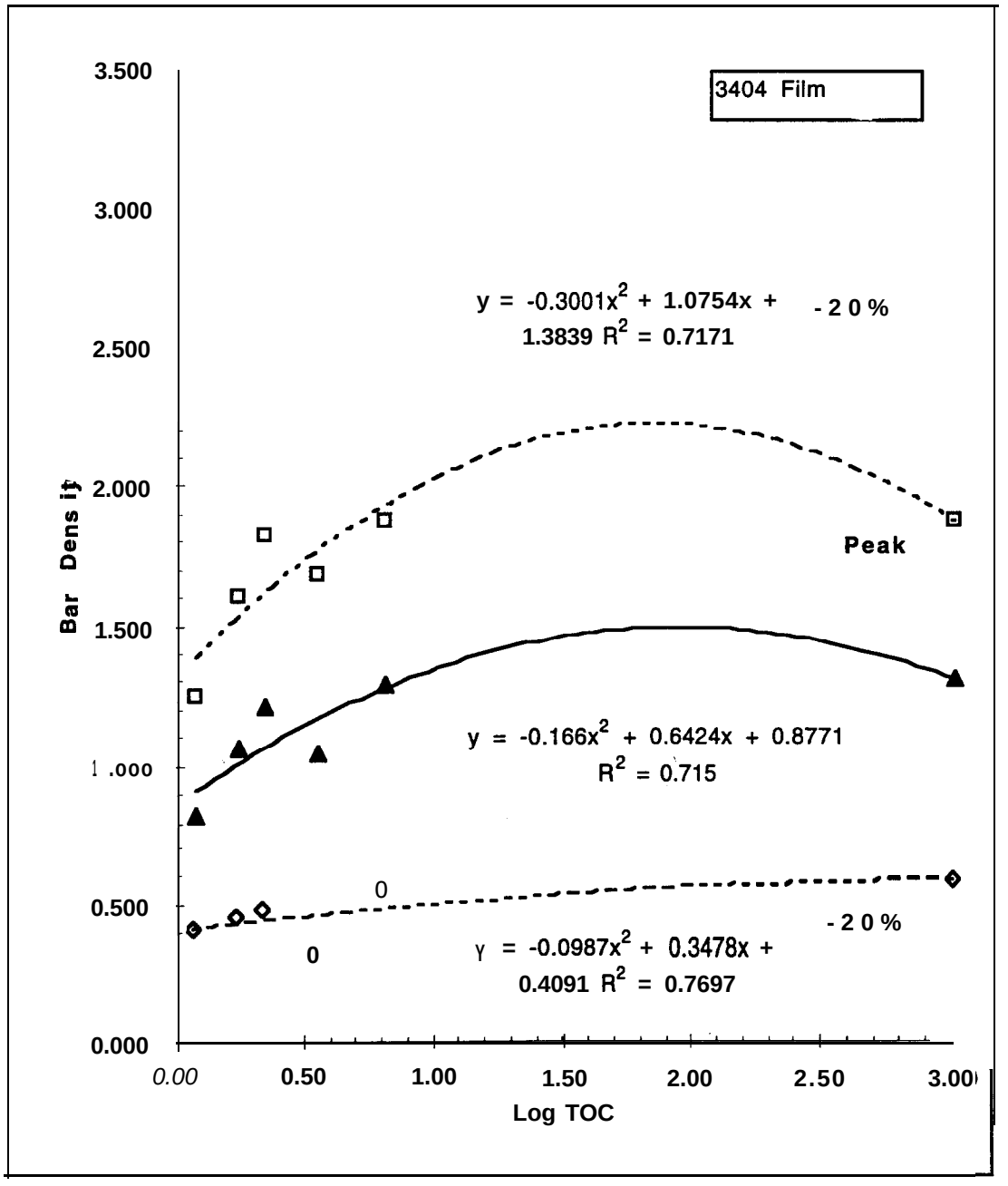


Figure 28. Peak Resolution vs Bar Density for 3404 Film

A-3. Tables and Figures (SO-050)

Table 7. Average Resolving Power and Deviation (2 sigma) vs Log Rel E, SO-050 Film.

	1,000:1 TOC		6.45:1 TOC		3.24:1 TOC	
Log Rel E	Average	2 Sigma Dev	Average	2 Sigma Dev	Average	2 Sigma Dev
0.00	19	6	14	4	14	5
0.20	48	l a	29	14	26	16
0.40	57	28	41	17	36	21
0.60	59	25	53	20	46	22
0.80	59	17	57	22	46	17
1 .oo	52	15	52	10	46	20
1.20	48	12	52	20	45	l a
1.40	44	18	47	l a	42	13
1.60	36	14	45	14	36	14
1 .80	32	9	40	18	32	9
2.00	29	9	37	14	30	12

	2.14:1 TOC		1.7:1 TOC		1.15:1 TOC	
Log Rel E	Average	2 Sigma Dev	Average	2 Sigma Dev	Average	2 Sigma Dev
0.00					NOT	
0.20	24	16	15	6	RESOLVABLE	
0.40	30	16	19	9	INSUFFICIENT	
0.60	37	15	25	10	CONTRAST	
0.80	38	16	28	9		
1 .oo	36	13	27	12		
1.20	35	16	25	9		
1.40	31	15	23	14		
1.60	26	13	19	11		
1.80	22	16	l a	9		
2.00	19	a	17	9		

Table 8. SO-050 Film Resolving Power vs Log H.

TOC	Bar Density	Bar Log H	Space Density	Space Log H	Resolution Average	Resolution 2 Sigma Dev
1,000:l	2.37	-0.41	0.20	-3.18	29	9
1,000:l	2.33	-0.43	0.25	-3.01	32	9
1,000:l	2.37	-0.38	0.17	-3.25	36	14
1,000:l	2.14	-0.71	0.18	-3.24	44	18
1,000:l	1.95	-1.05	0.21	-3.11	48	12
1,000:l	1.86	-1.17	0.22	-3.11	52	15
1,000:l	1.54	-1.58	0.18	-3.17	59	17
1,000:l	1.30	-1.84	0.18	-3.22	59	25
1,000:l	1.02	-2.12	0.20	-3.16	57	28
1,000:l	0.83	-2.29	0.15	-3.28	48	18
1,000:l	0.51	-2.60	0.17	-3.20	19	8
6.45:1	2.26	-0.47	0.26	-2.94	37	14
6.45:1	2.23	-0.52	0.14	-3.28	40	la
6.45:1	1.98	-1.02	0.16	-3.21	45	14
6.45:1	1.83	-1.24	0.19	-3.24	47	la
6.45:1	1.65	-1.44	0.20	-3.17	52	20
6.45:1	1.53	-1.60	0.22	-3.06	52	10
6.45:1	1.22	-1.94	0.17	-3.26,	57	22
6.45:1	0.99	-2.16	0.14	-3.28	53	20
6.45:1	0.65	-2.45	0.19	-3.15	41	17
6.45:1	0.56	-2.54	0.21	-3.15	29	14
6.45:1	0.34	-2.81	0.20	-3.16	14	4
3.24:1	2.11	-0.79	1.48	-1.66‘	32	9
3.24:1	2.07	-0.86	1.28	-1.88	36	14
3.24:1	1.88	-1.19	1.00	-2.15	42	13
3.24:1	1.57	-1.54	0.72	-2.38	45	18
3.24:1	1.40	-1.74	0.58	-2.52	46	20
3.24:1	1.15	-2.00	0.41	-2.72	46	17
3.24:1	0.99	-2.15	0.31	-2.85	46	22
3.24:1	0.74	-2.36	0.38	-2.76	36	21
	0.68	-2.42	0.30	-2.90	26	16

CONTINUED

Table 8. SO-050 Film Resolving Power vs Log H (Continued).

TOC	Bar Density	Bar Log H	Space Density	Space Log H	Resolution Average	Resolution 2 Sigma Dev
2.14:1	1.98	-1.02	1.61	-1.49	26	1-3
2.14:l	1.84	-1.19	1.27	-1.88	31	15
2.14:1	1.52	-1.60	1.06	-2.08	35	16
2.14:1	1.44	-1.69	0.94	-2.19	36	13
2.14:1	1.28	-1.87	0.58	-2.52	38	16
2.14:1	0.94	-2.19	0.41	-2.71	37	15
2.14:1	0.72	-2.38	0.29	-2.89	30	16
2.14:1	0.56	-2.54	0.27	-2.91	24	16
1.7:1	1.84	-1.22	1.60	-1.51	19	11
1.7:1	1.58	-1.53	1.24	-1.91	23	14
1.7:1	1.48	-1.65	1.20	-1.95	25	9
1.7:1	1.34	-1.81	1.02	-2.12	27	12
1.7:1	1.04	-2.11	0.69	-2.41	28	9
1.7:1	0.80	-2.31	0.57	-2.53	25	10
1.7:1	0.58	-2.51	0.41	-2.72	19	9
1.7:1	0.47	-2.65	0.38	-2.75	15	6
1.15:1	NOT RESOLVABLE					

Table 9. Predicted Resolution (Model Fit) vs AM- 1 Exposure for SO-050 Film.

TOC	Predicted Peak Reso c/mm	Exposure, Log H: Peak Bar	Peak Space*	-20% Reso Bar 1	Space 1*	Bar 2
1,000:1	71	-1.78	-4.50	-2.27	-5.27	-0.40
6.45:1	62	-1.86	-2.28	-2.38	-3.19	-0.62
3.24: 1	58	-1.87	-2.21	-2.31	-2.85	-0.76
2.14:1	43	-1.82	-2.15	-2.53	-2.86	-1.11
1.7:1	32	-1.87	-2.10	-2.43	-2.66	-1.32
1.15:1	NOT RESOLVABLE					

'Note: Space exposures are estimated from bar exposures by the formula log H (sp) = log H (bar) - log TOC.

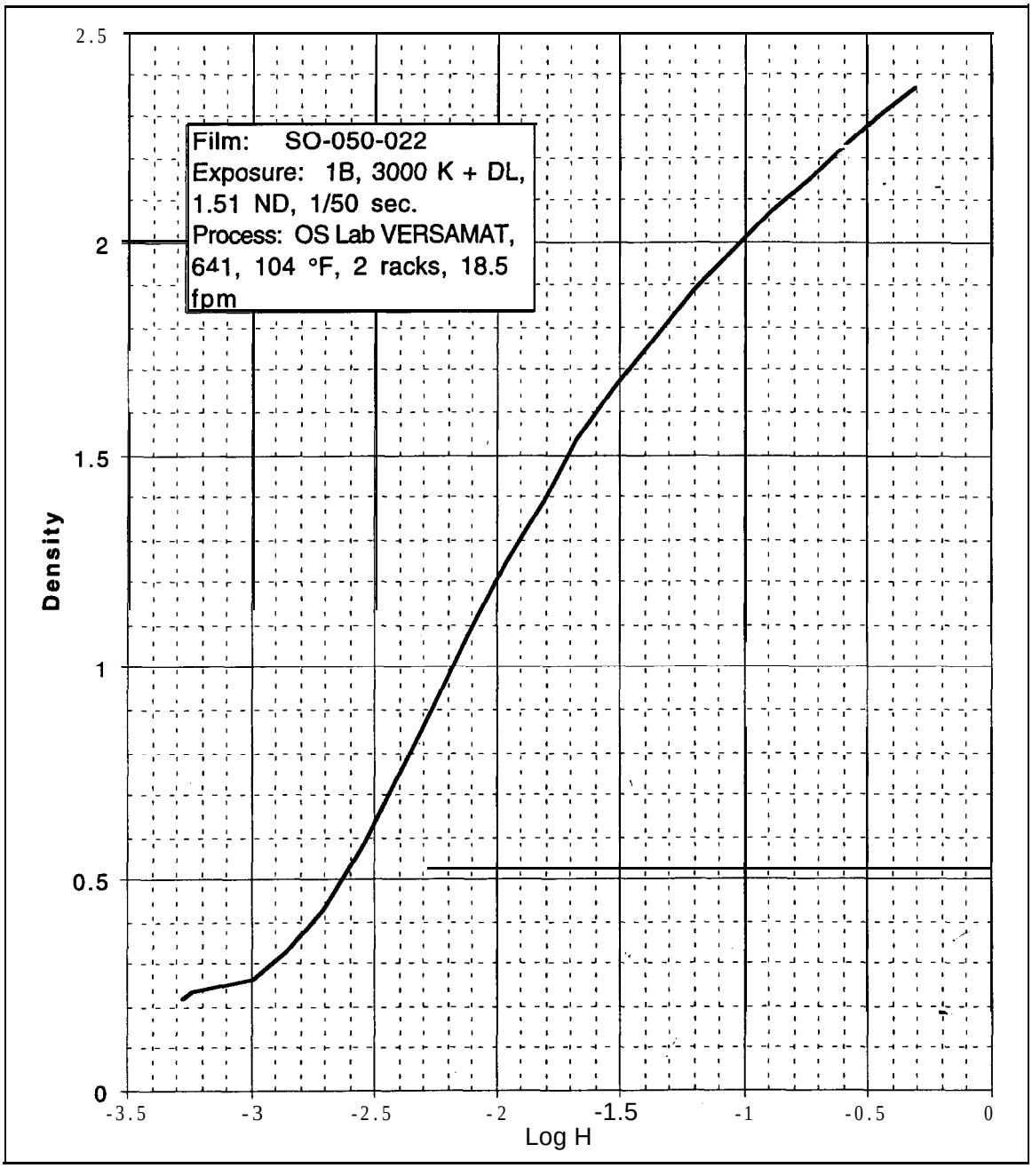


Figure 29. SO-050 Processed Film Sensitometty

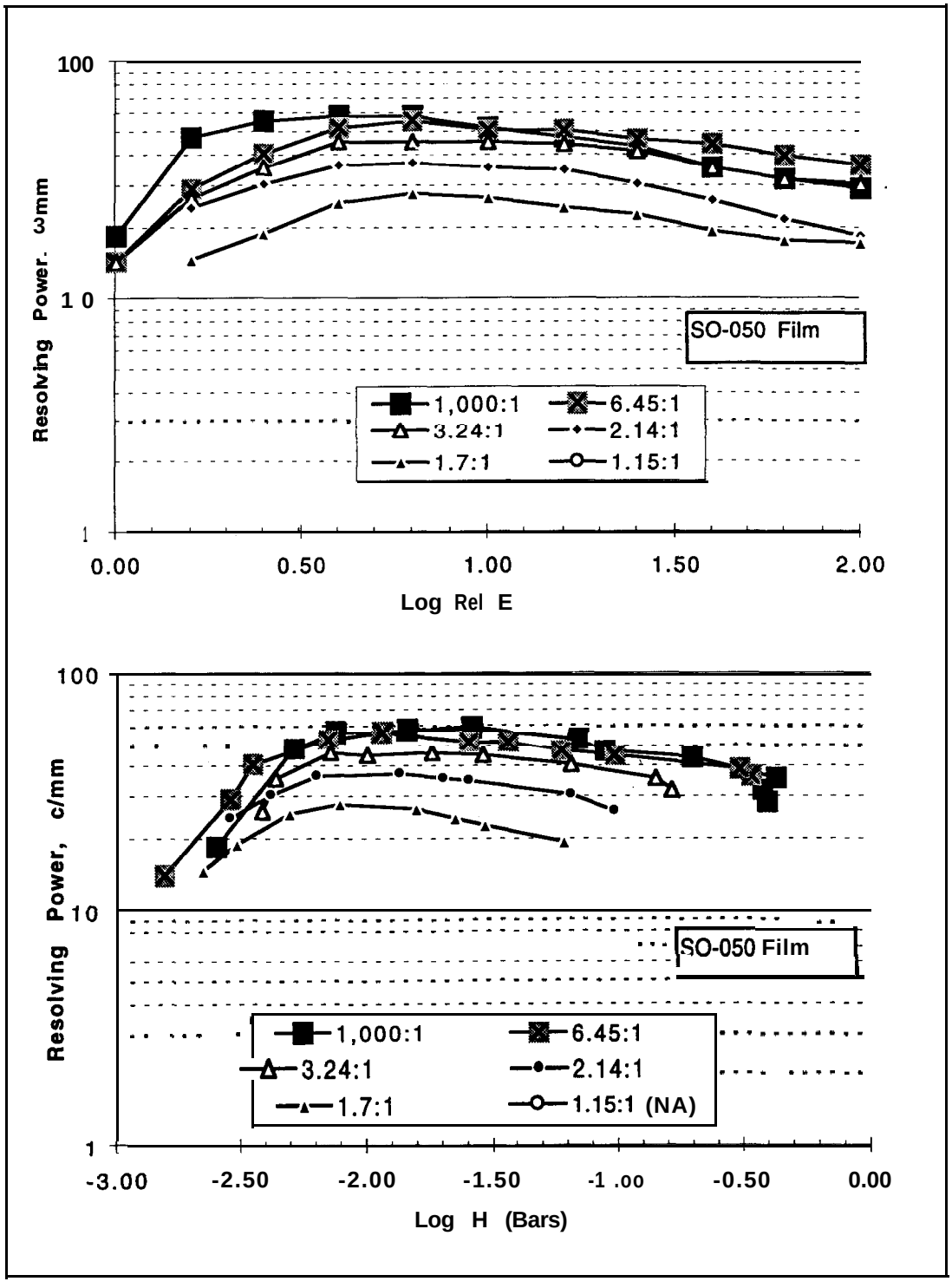


Figure 30. Resolution vs log Rel E (top) or Log H by Microdensitometry (bottom)

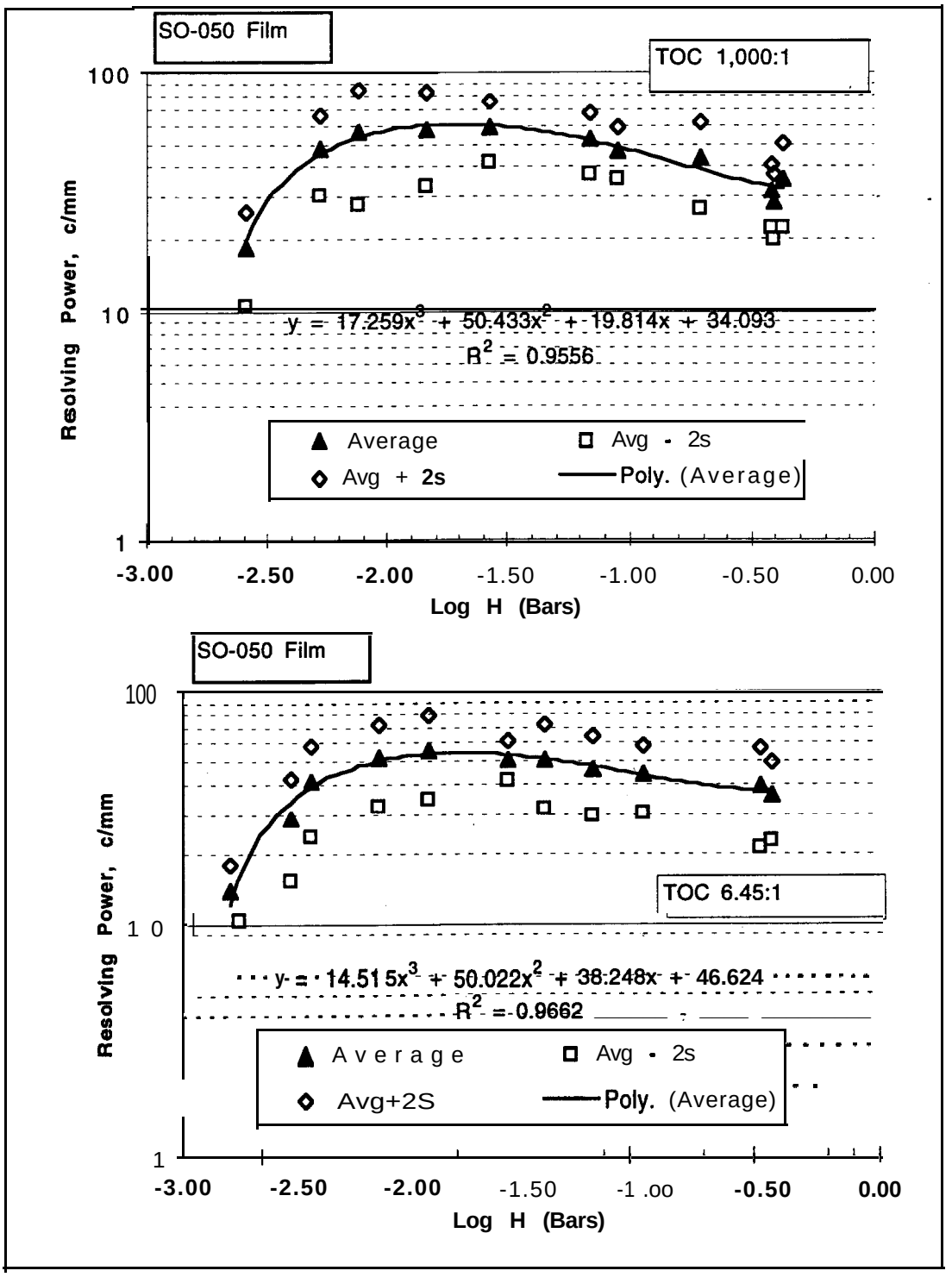


Figure 31. Resolution vs Log H for 1,OOO:1 (top) and 6.45:1 Targets (bottom)

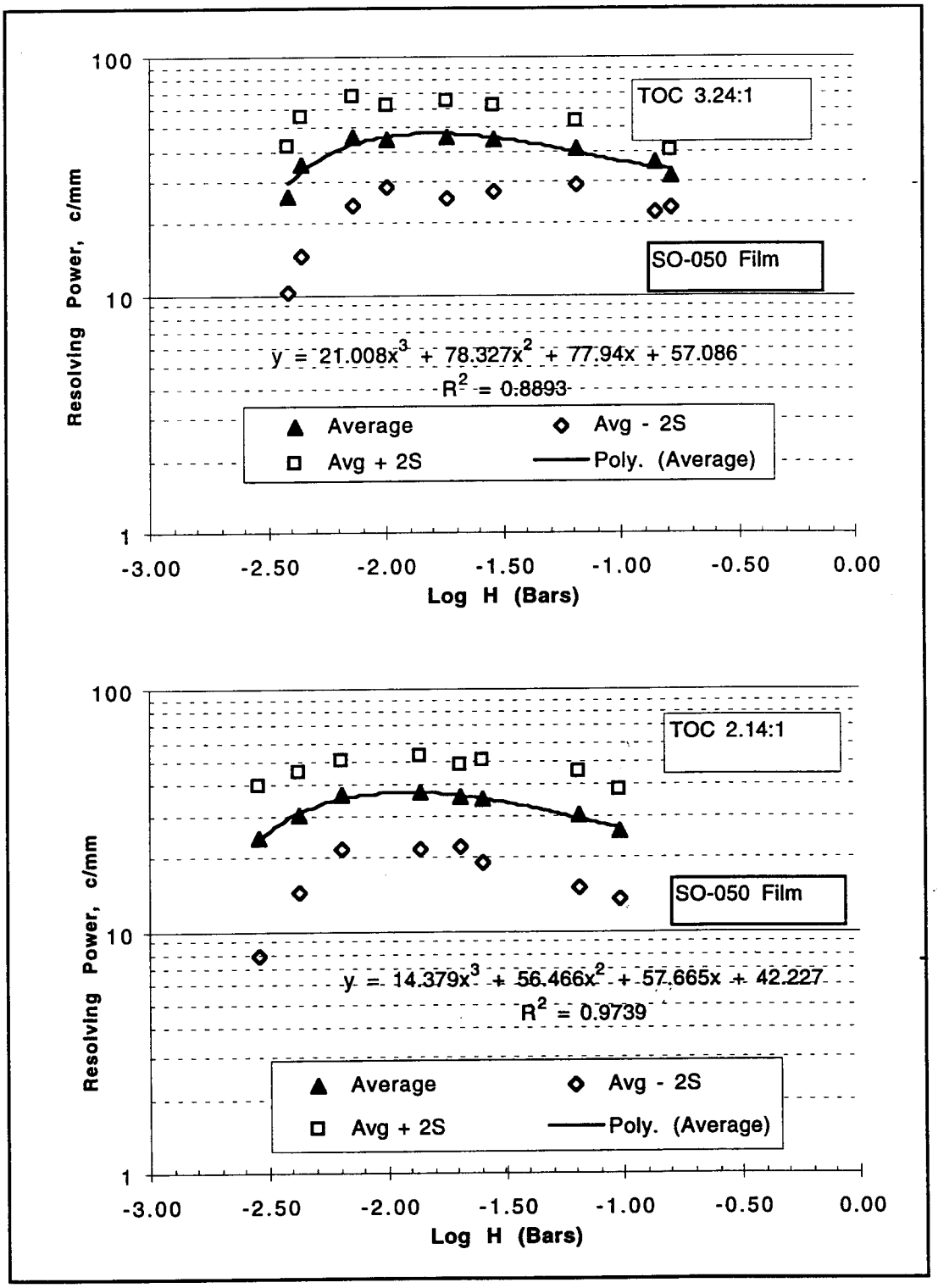


Figure 32. Resolution vs Log H for 3.24:1 (top) and 2.14:1 Targets (bottom)

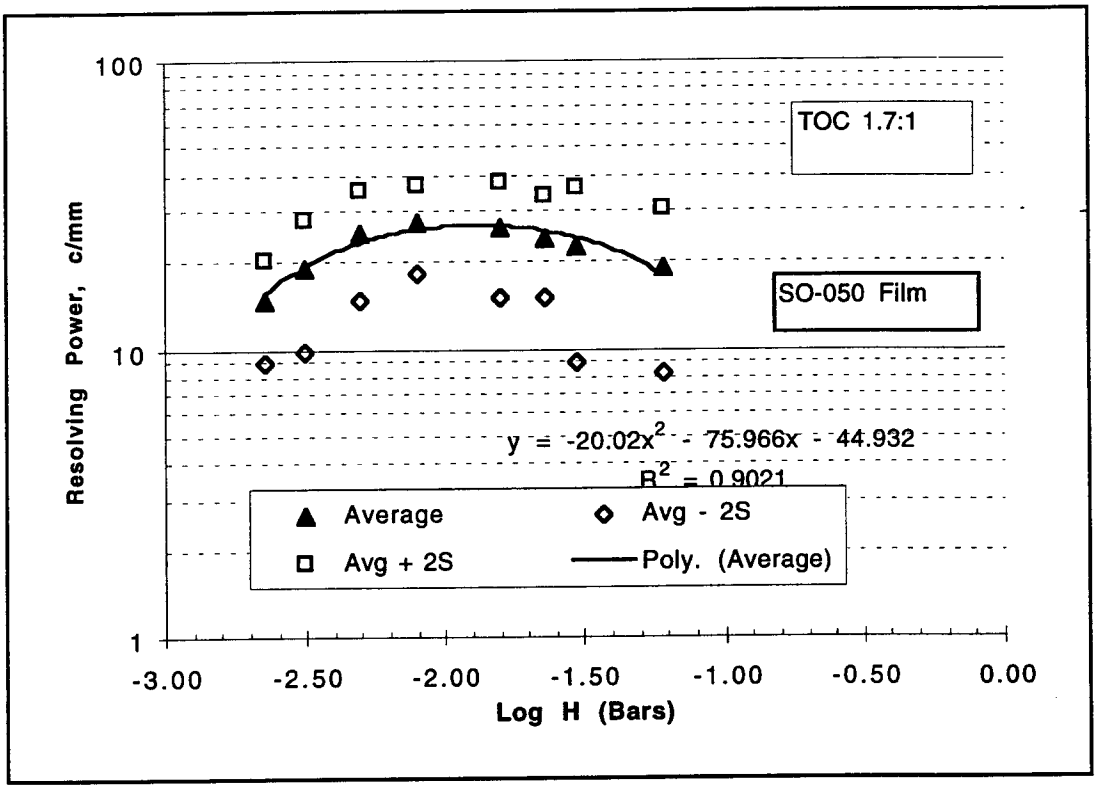
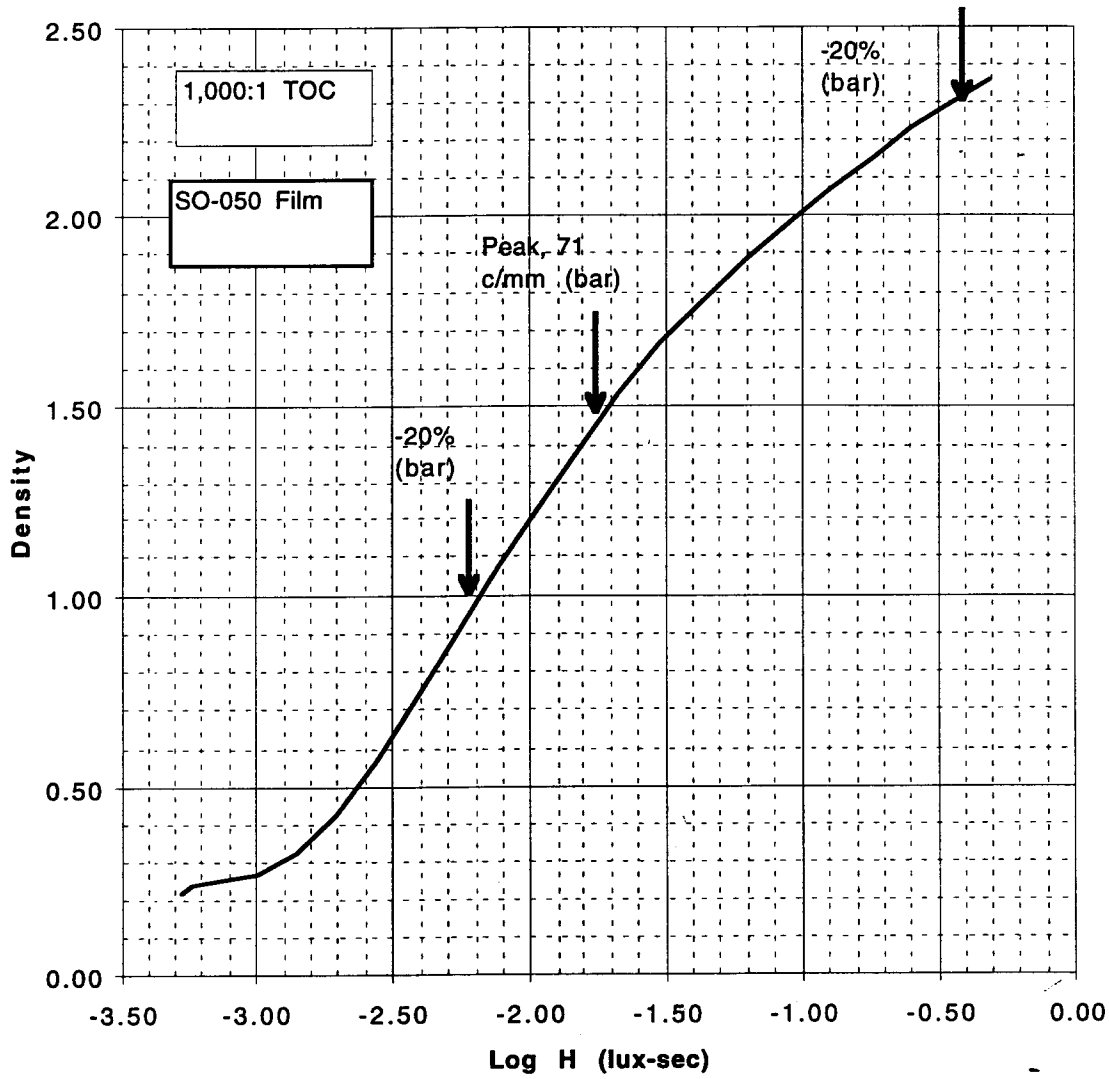
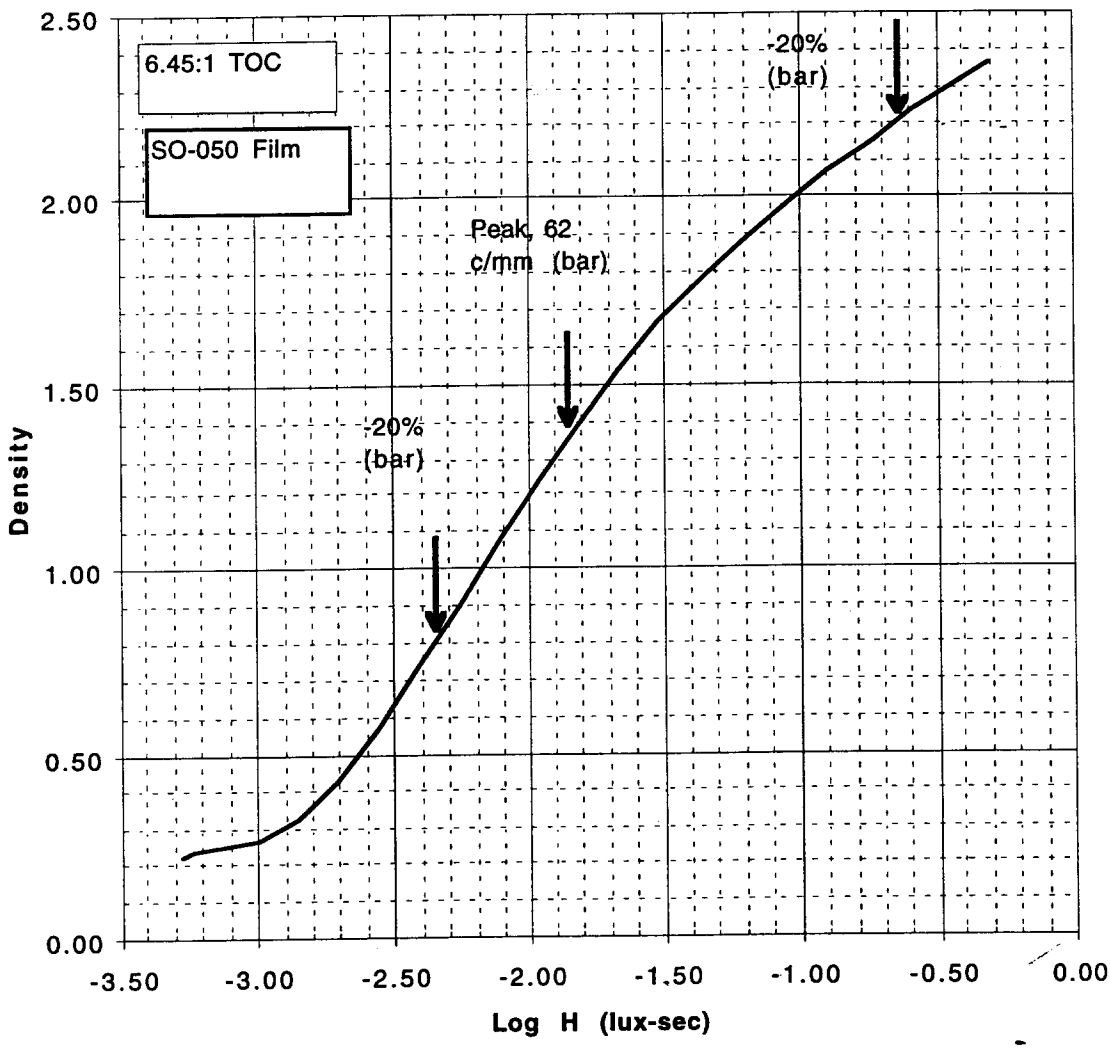


Figure 33. Resolution vs Log H for 1.7:1 Target



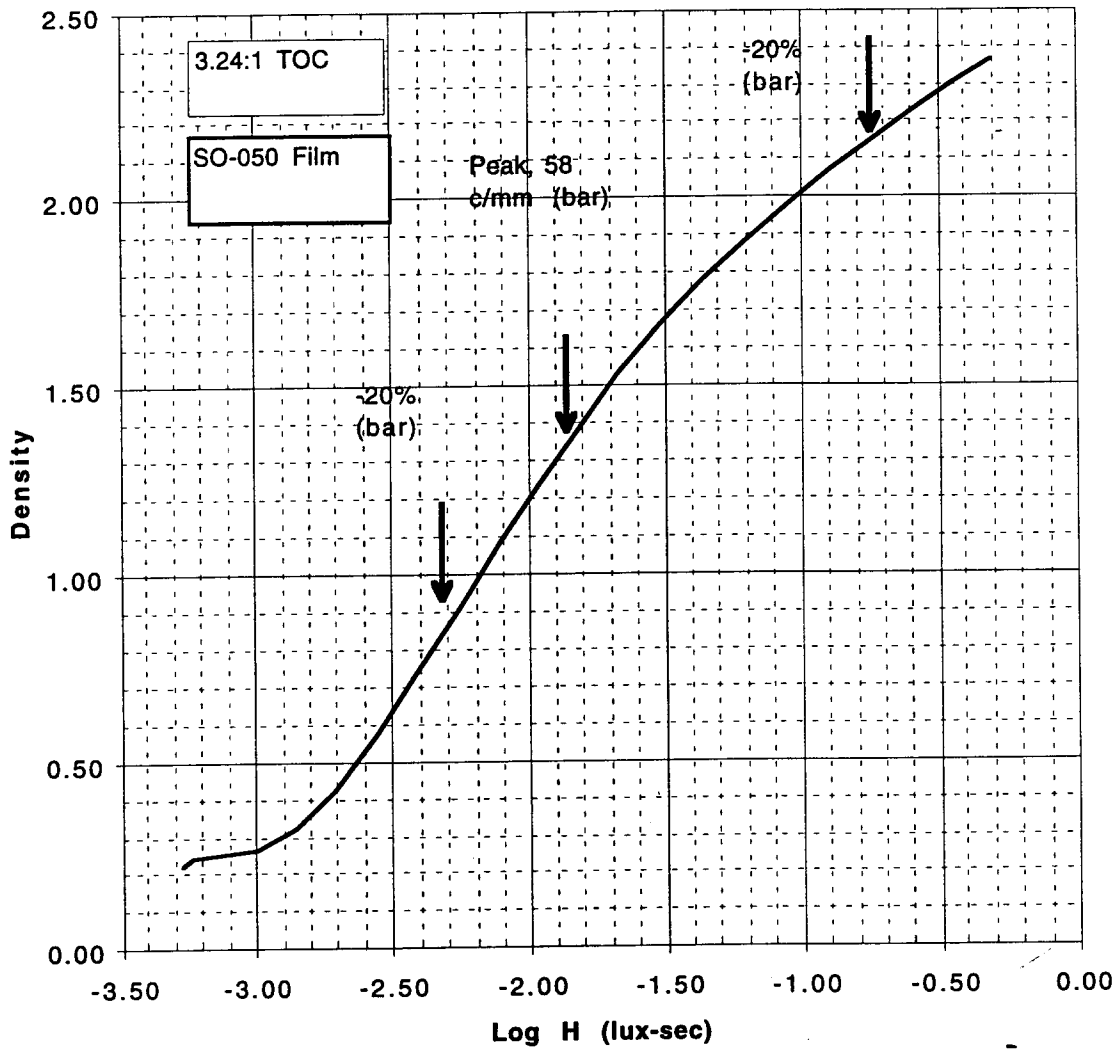
Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
71	-1.78	-4.50	-2.27	-5.27	-0.40	-3.40

Figure 34. Resolution vs Exposure. 1000:1 TOC.



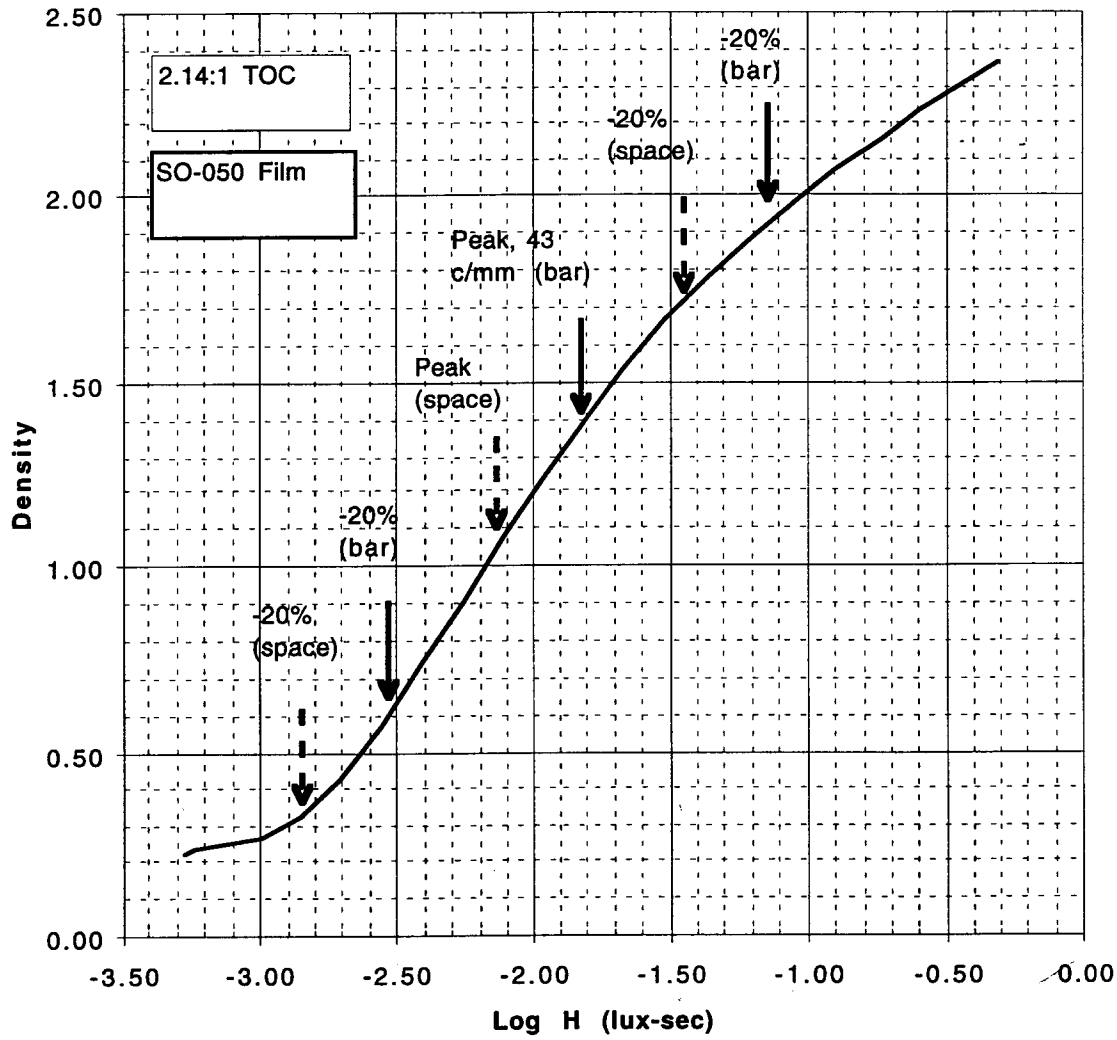
Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
62	-1.86	-2.28	-2.38	-3.19	-0.62	-1.43

Figure 35. Resolution vs Exposure. 6.45:1 TOC.



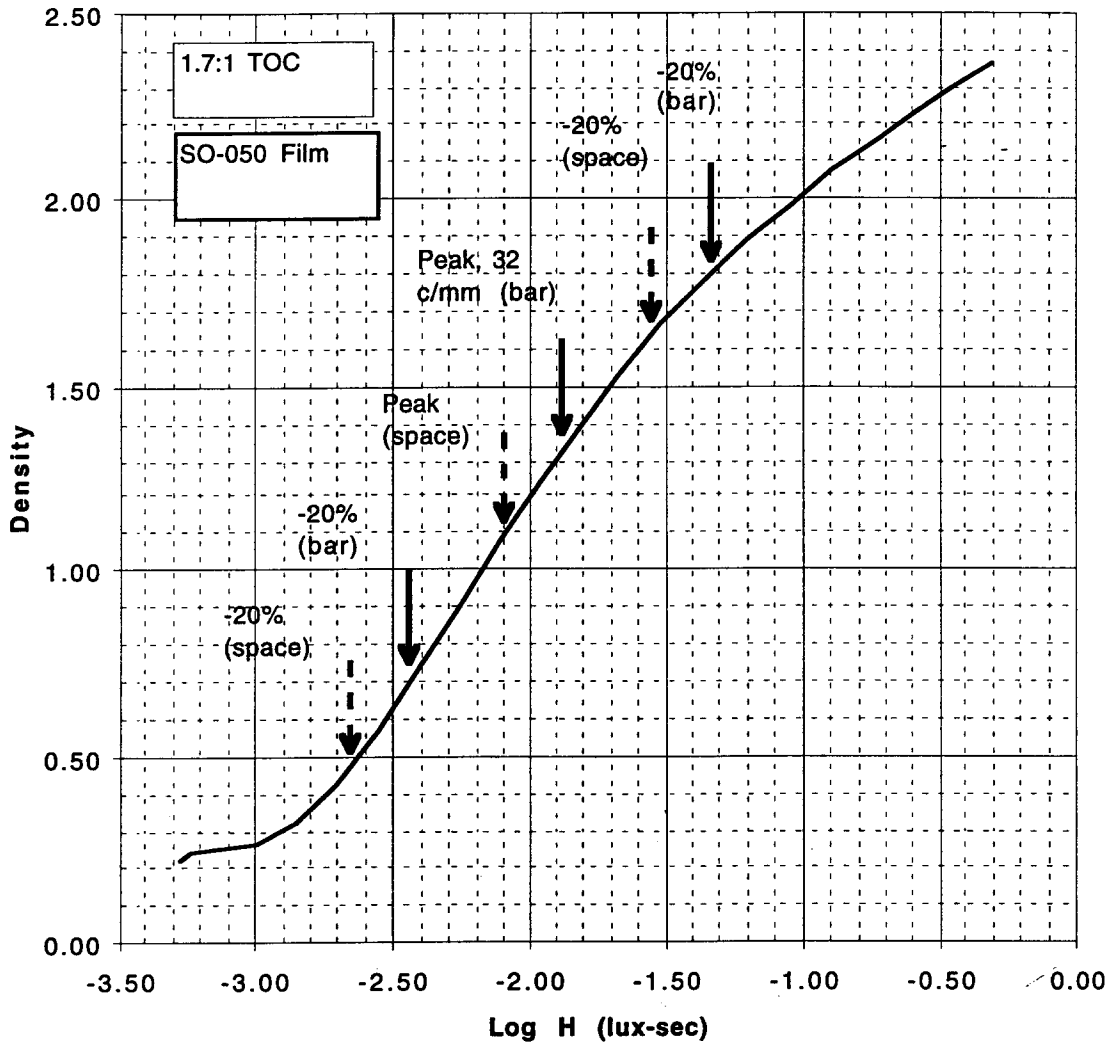
Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
58	-1.87	-2.21	-2.31	-2.85	-0.76	-1.30

Figure 36. Resolution vs Exposure. 3.24:1 TOC.



Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
43	-1.82	-2.15	-2.53	-2.86	-1.11	-1.44

Figure 37. Resolution vs Exposure. 2.14:1 TOC.



Peak Reso	Peak (bar)	Peak (sp, est)	Lower Limit -20% (bar)	Lower Limit -20% (space)	Upper Limit -20% (bar)	Upper Limit -20% (space)
32	-1.87	-2.10	-2.43	-2.66	-1.32	-1.55

Figure 38. Resolution vs Exposure. 1.7:1 TOC.

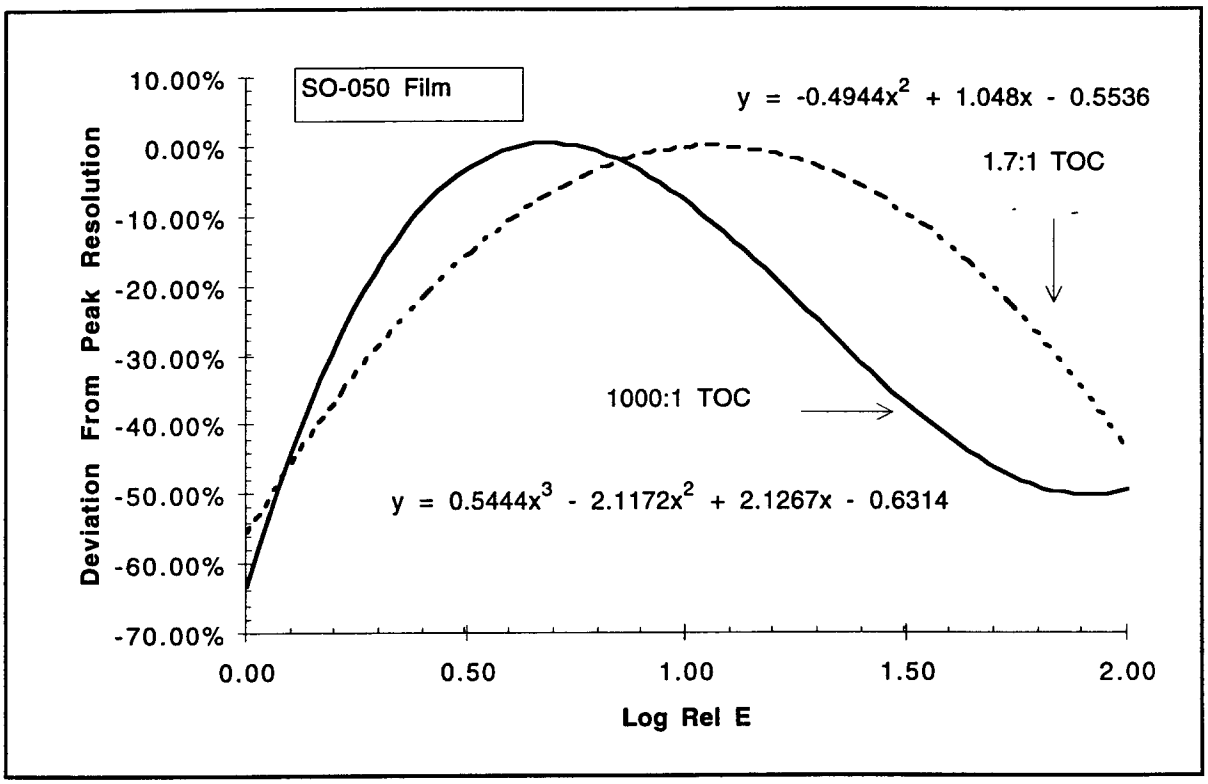


Figure 39. Deviation from Peak Resolution vs Relative Exposure for SO-050 Film

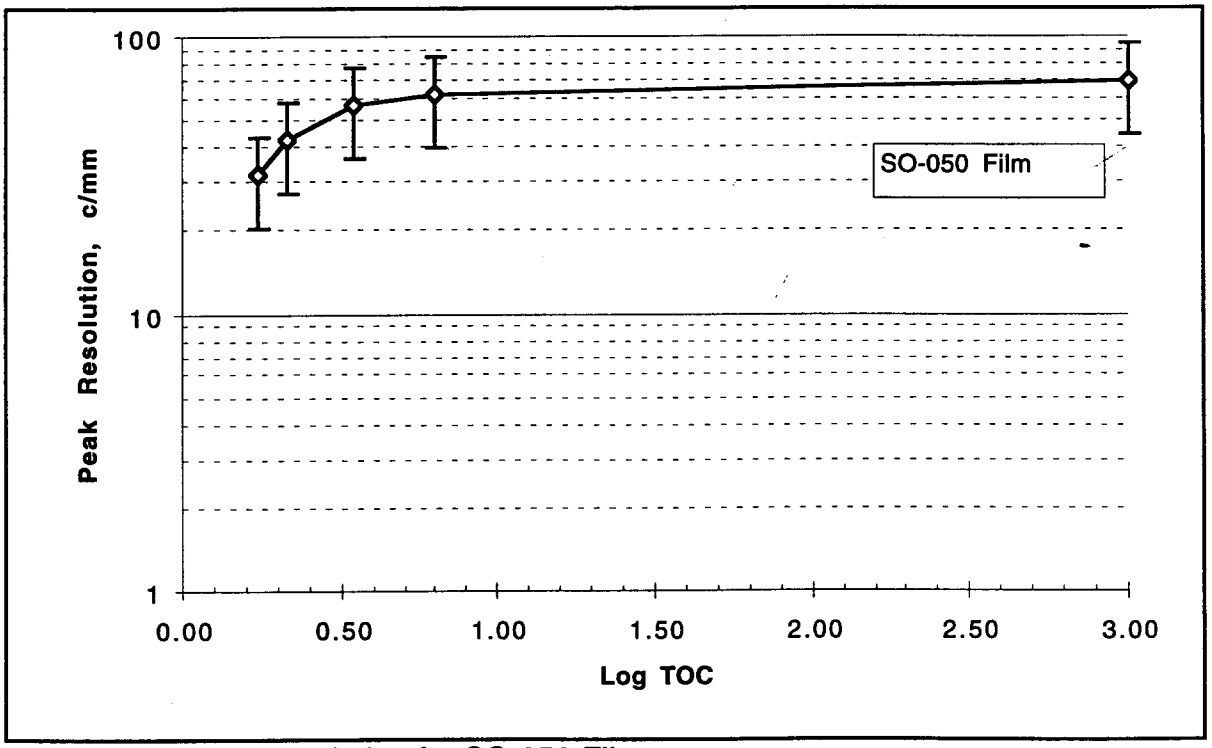


Figure 40. Peak Resolution for SO-050 Film

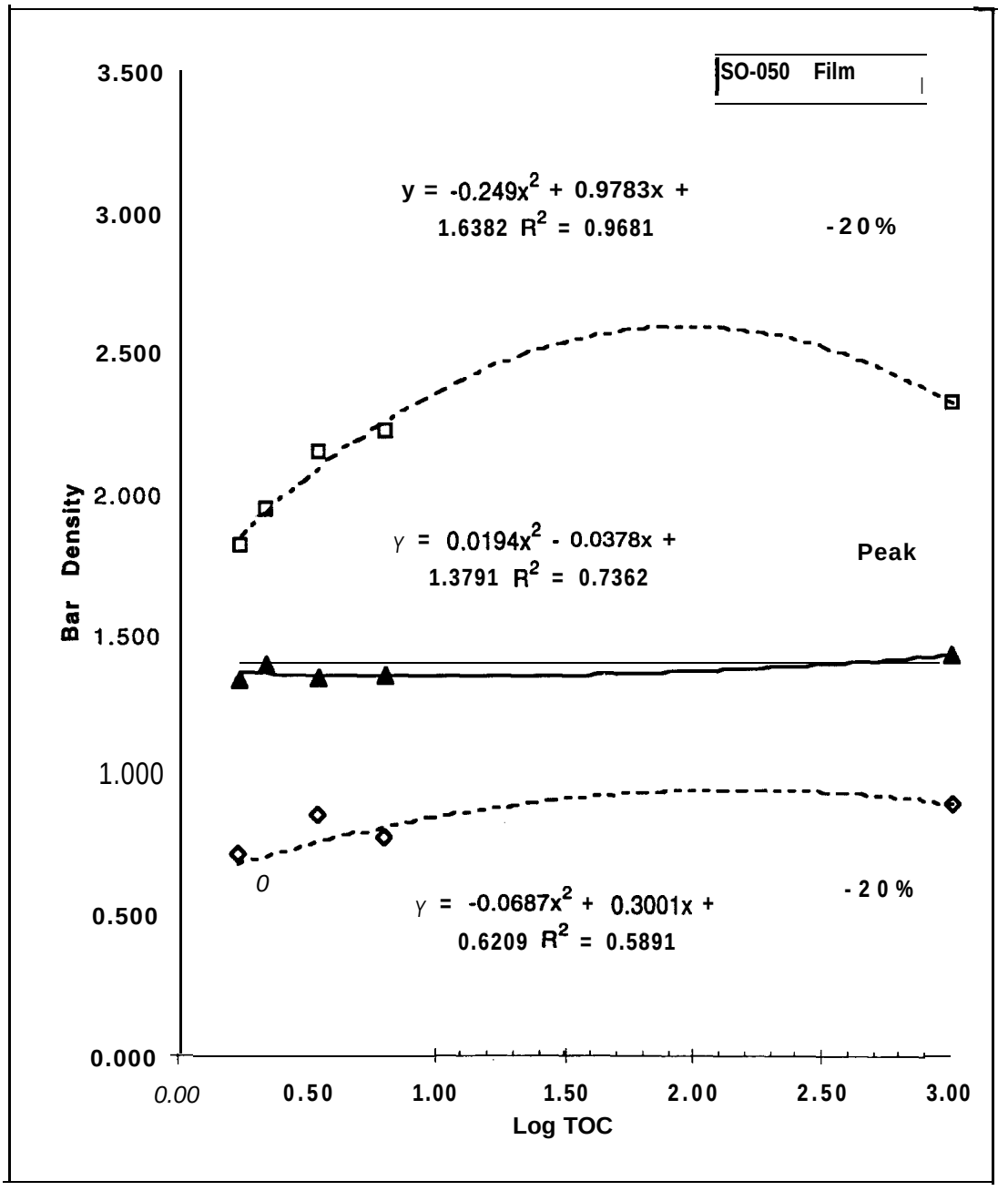


Figure 41. Peak Resolution vs Bar Density for SO-050 Film

A-4. Tables and Figures (Summary and Conclusions)

Table 10. Peak and -20% Resolution, Bar Density and Bar Exposures for Open Skies Acquisition Films.

TOC	Peak Reso, c/mm*	Bar Density* -20%	Peak	-20%	Bar Exposure, Log H (lux-sec)* -20%	Peak	-20%
3412 Film							
1,000:1	257	0.82	1.80	2.56	-1.13	-0.59	-0.05
6.45:1	202	0.90	1.85	2.57	-1.08	-0.56	-0.04
3.24:1	173	0.81	1.79	2.56	-1.13	-0.60	-0.06
2.14:1	137	0.59	1.62	2.50	-1.27	-0.69	-0.11
1.7:1	103	0.64	1.45	2.21	-1.24	-0.79	-0.33
1.15:1	46	0.70	1.51	2.26	-1.20	-0.75	-0.30
3404 Film							
1,000:1	96	0.59	1.31	1.88	-1.77	-1.08	-0.40
6.45:1	85	0.56	1.30	1.88	-1.80	-1.10	-0.40
3.24:1	79	0.32	1.05	1.69	-2.06	-1.35	-0.65
2.14:1	70	0.48	1.22	1.83	-1.89	-1.18	-0.47
1.7:1	52	0.45	1.07	1.61	-1.91	-1.33	-0.75
1.15:1	17	0.42	0.83	1.25	-1.95	-1.55	-1.15
SO-050 Film							
1,000:1	71	0.90	1.44	2.33	-2.27	-1.78	-0.40
6.45:1	62	0.78	1.36	2.22	-2.38	-1.86	-0.62
3.24:1	58	0.86	1.35	2.15	-2.31	-1.87	-0.76
2.14:1	43	0.62	1.40	1.95	-2.53	-1.82	-1.11
1.7:1	32	0.72	1.35	1.82	-2.43	-1.87	-1.32
1.15:1	NOTREADABLE		NOTREADABLE			NOTREADABLE	

*Note: Resolution, density and exposure values are predicted from statistical model fits.

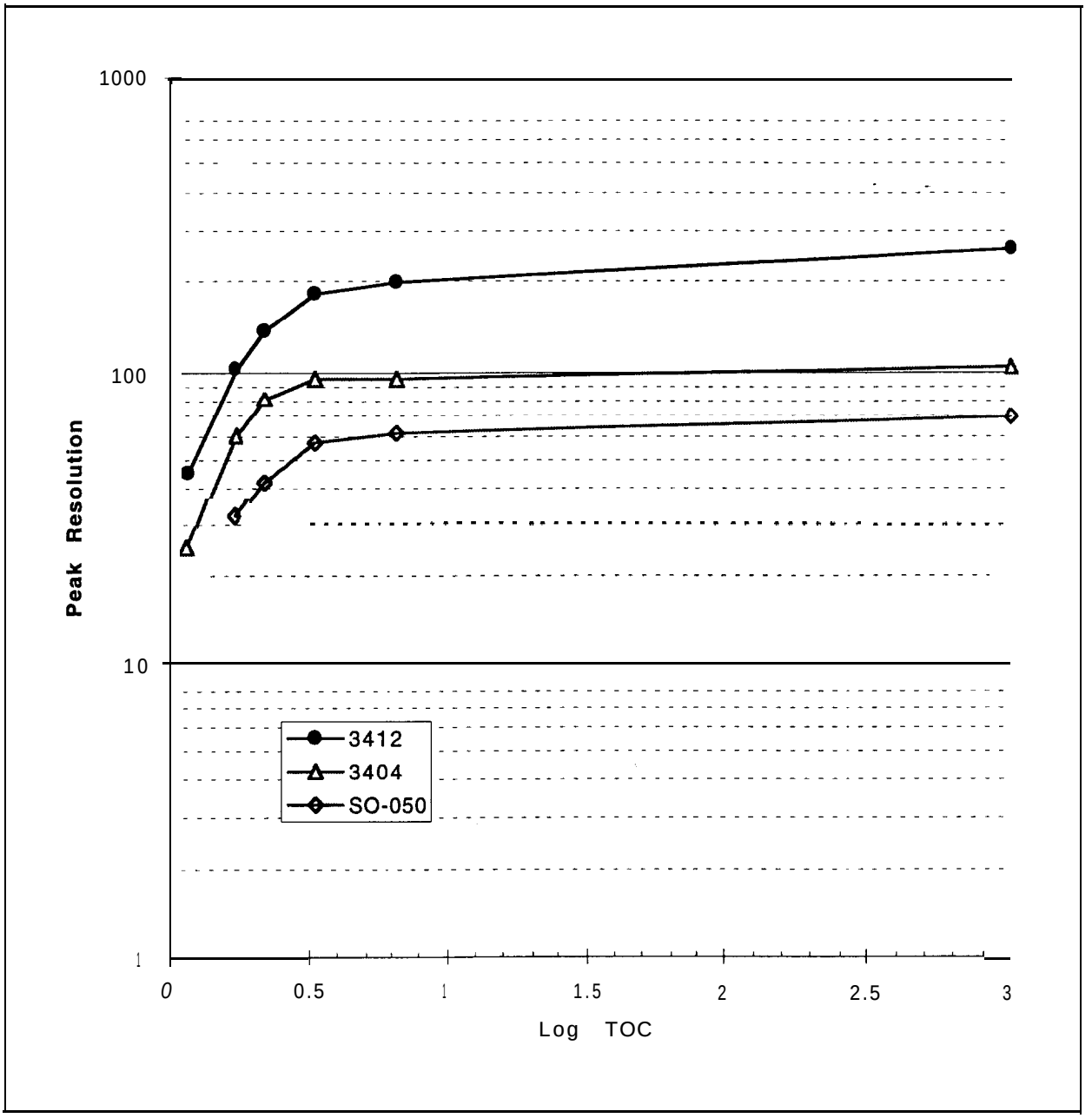


Figure 42. Peak Resolution vs Log TOC for 3472, 3404 and SO-050