5. Vessel spills less than 42,000 gallons

As indicated earlier, the ECO data is not applicable to smaller operational spills, many of which occur during transfer operations in harbors. Therefore, in obtaining insight on these spills, we will use the Coast Guard 1971 and 1972 data. In 1971 and 1972 the Coast Guard reported 624 vessel-related, crude spills occurring within harbors. During that period, the U.S. imported 1.412 billion barrels of crude. Under the assumptions used earler, that is, that we are dealing with a Poisson process in which the exposure variable is amount of oil landed whose intensity is a Gamma random variable about which we have no feelings prior to observing any data, likelihoods of the various possible numbers of spills are shown in Figures 5.1 , 5.2, and 5.3 for the small, medium, and large finds. In these figures, since we are dealing with much larger numbers of spills, instead of plotting the density itself, which would involve hundreds of arrows, we have shown the cumulatives of these densities. The cumulative is the probability for any given number of spills, n, that the actual number of spills will be less than or equal to $\bar{n}$. It is merely the sum of all the arrows up to and including n. A glance at these three figures will indicate that with respect to near-terminal spills based on the Coast Guard data, we are dealing with much larger numbers than we obtained when we used the ECO data. However, most of these spills are relatively speaking much smaller than the spills in the ECO data. Figure 5.4 shows the cumulative of the spill size

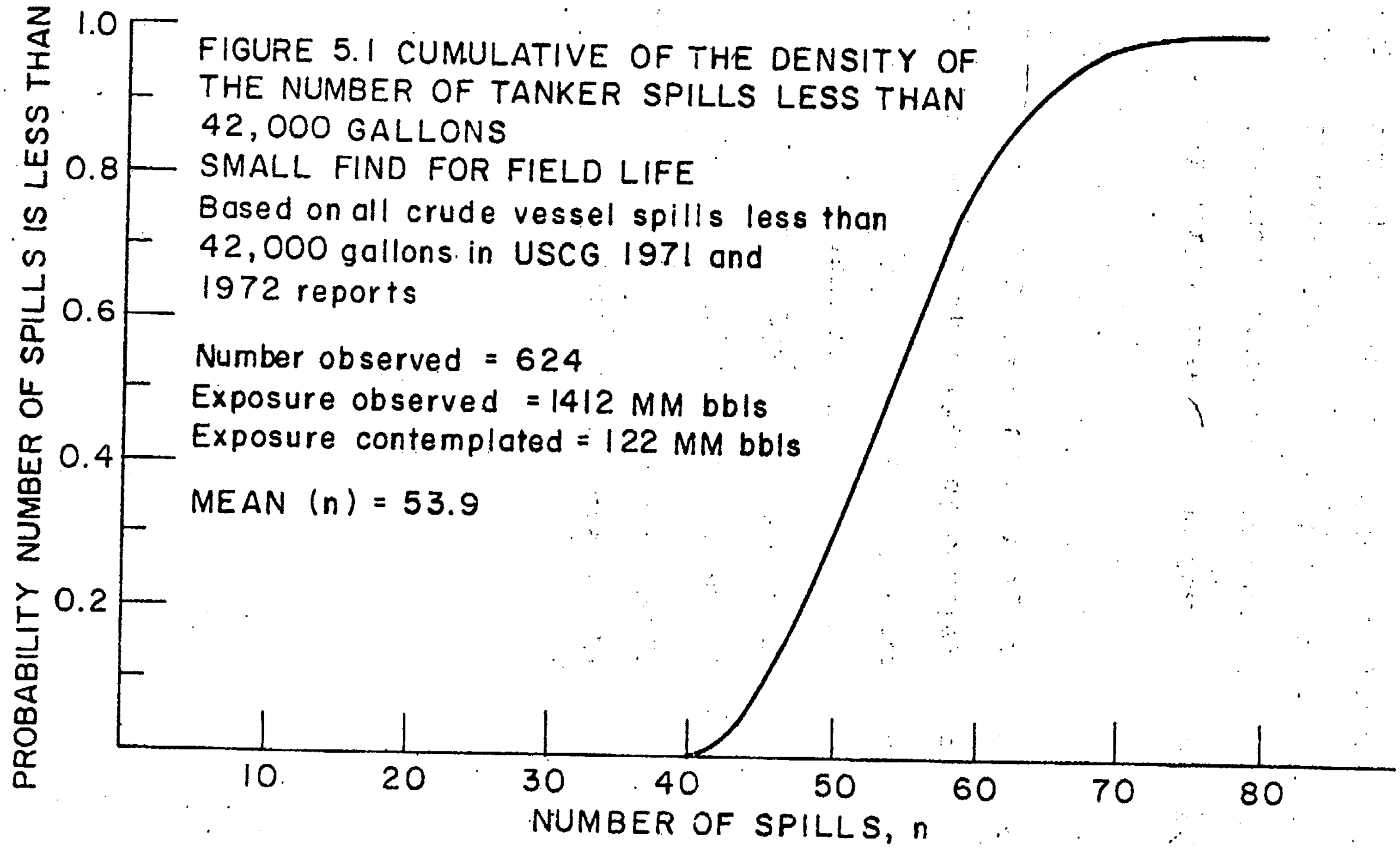

FIGURE 5.1 CUMULATIVE OF THE DENSITY OF THE NUMBER OF TANKER SPILLS LESS THAN 42,000 GALLONS
SMALL FIND FOR FIELD LIFE
Based on all crude vessel spills less than 42,000 gallons in USCG 1971 and 1972 reports

Number observed = 624
Exposure observed = 1412 MM bbls
Exposure contemplated = 122 MM bbls

MEAN (n) = 53.9

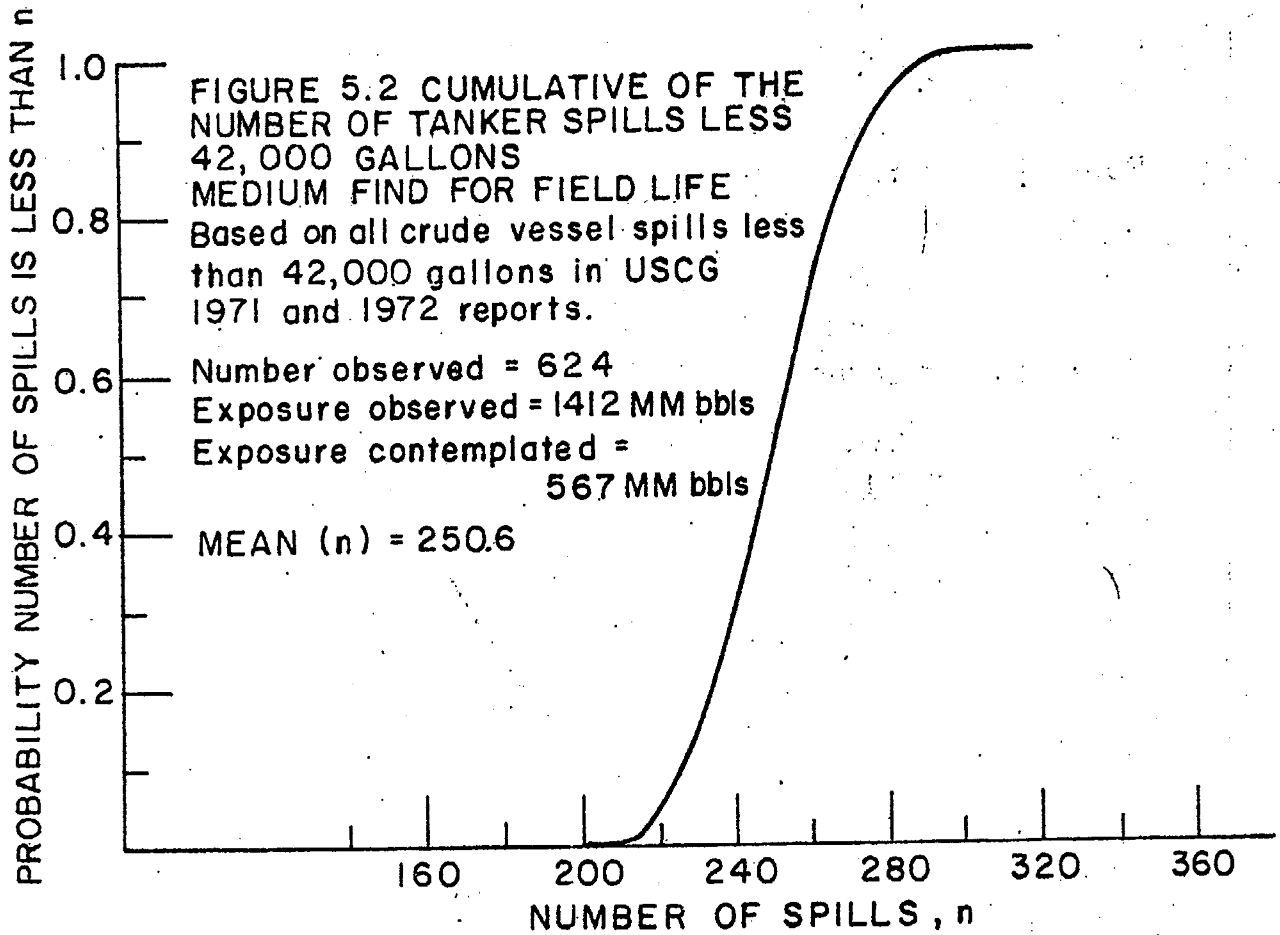

FIGURE 5.2 CUMULATIVE OF THE NUMBER OF TANKER SPILLS LESS 42,000 GALLONS
MEDIUM FIND FOR FIELD LIFE
Based on all crude vessel spills less than 42,000 gallons in USCG 1971 and 1972 reports.

Number observed = 624
Exposure observed = 1412 MM bbls
Exposure contemplated = 567 MM bbls

MEAN (n) = 250.6

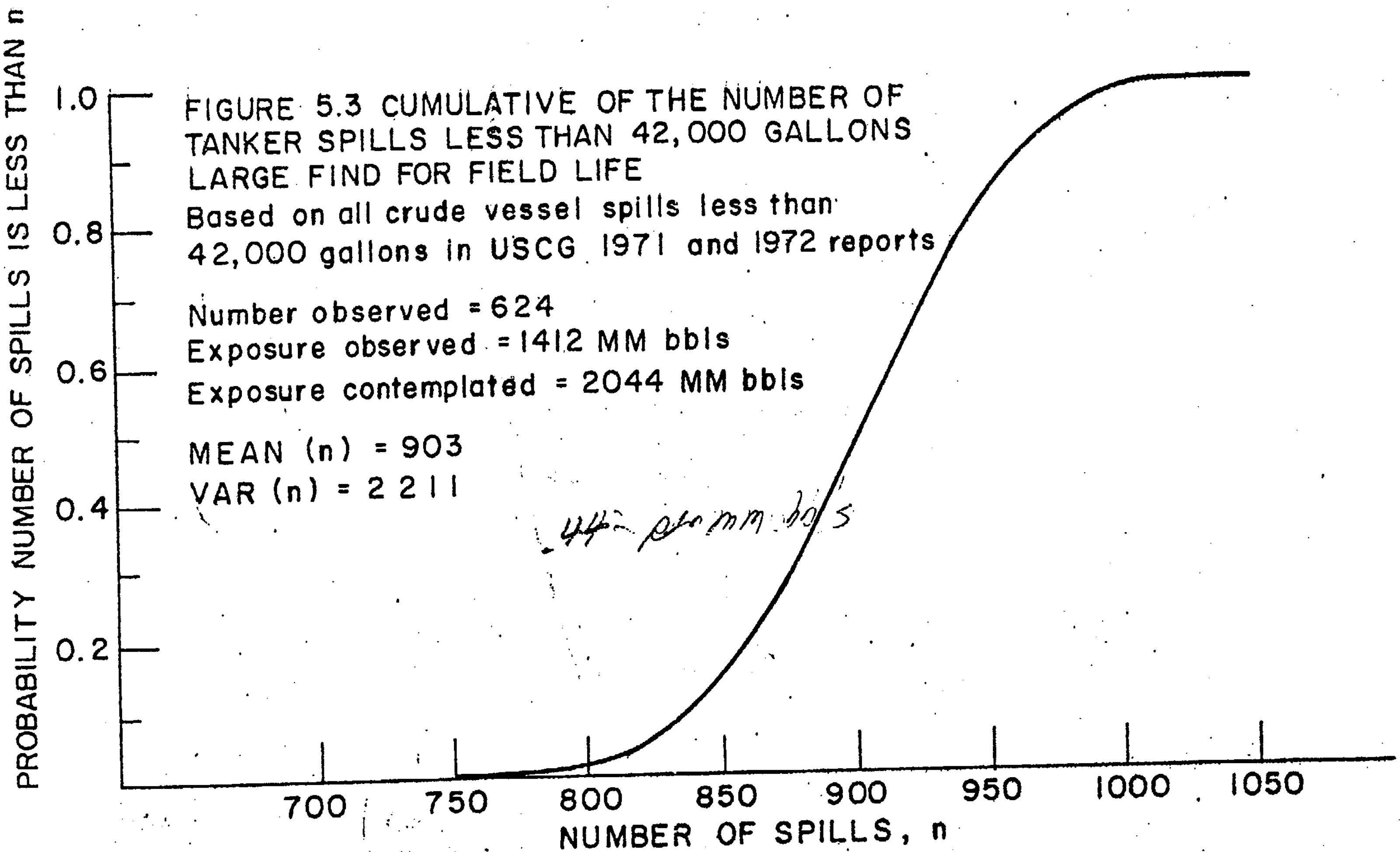

FIGURE 5.3 CUMULATIVE OF THE NUMBER OF TANKER SPILLS LESS THAN 42,000 GALLONS LARGE FIND FOR FIELD LIFE

Based on all crude vessel spills less than 42,000 gallons in USCG 1971 and 1972 reports

Number observed = 624
Exposure observed = 1412 MM bbls
Exposure contemplated = 2044 MM bbls

MEAN (n) = 903
VAR (n) = 2211

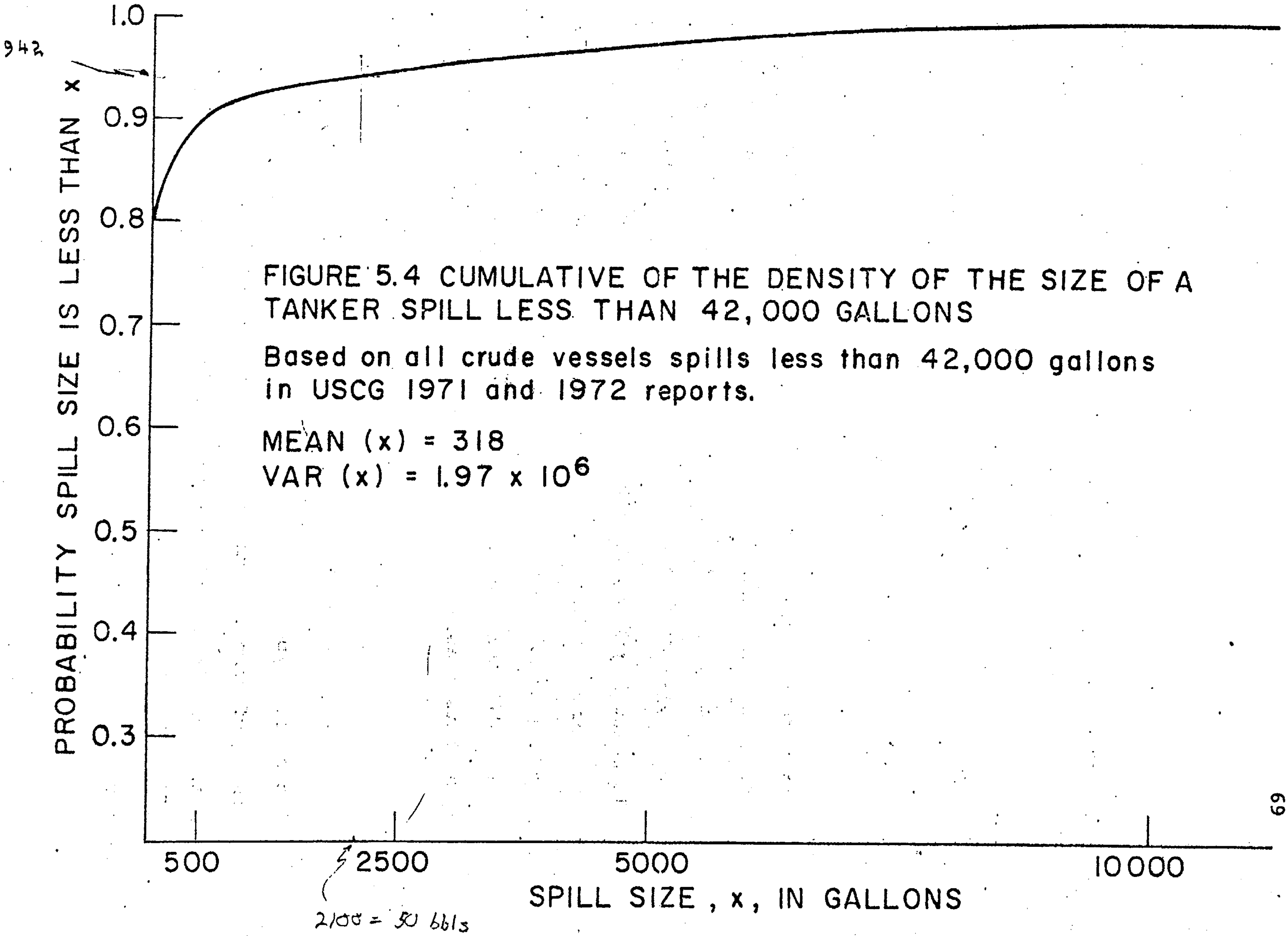

FIGURE 5.4 CUMULATIVE OF THE DENSITY OF THE SIZE OF A TANKER SPILL LESS THAN 42,000 GALLONS

Based on all crude vessels spills less than 42,000 gallons in USCG 1971 and 1972 reports.

MEAN (x) = 318
VAR (x) = 1.97×10^6

density. The mean of this density is 318 gallons while the variance is close to 2 million gallons squared. The ratio of the variance to the mean squared is close to 20, an extremely widely dispersed density. The only way the Gamma has of handling these extreme combinations of low mean and high variance is to place a great deal of the probability at the very low end, counterbalancing this by a very small amount of probability placed very far out in the rightward tail.* Hence the form of the cumulative shown in Figure 5.4, where the probability that the critical spill size will be less than the mean is about .87. This extreme skew may be trying to tell us that we should be modeling spill sizes by a multi-model density, for it does appear somewhat strange to place a significant amount of probability (about .05) in spills below 1 gallon, despite the fact that in the 624 tanker spills reported, no volumes less than 1 gallon were reported. This problem also shows up in numerical problems associated with the integration in the expression on the bottom of page 30. For this reason, in Figure 5.4 we have approximated the cumulative by a Gamma with the same mean and variance as the actual densities. The differences involved are not large.

The foregoing analysis was based on all tanker-barge spills of all types within harbors in the Coast Guard data. An issue of some importance in the context of Atlantic-Gulf of Alaska oil is the difference in spillage characteristics

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*The same thing is true of any other unimodal density over the interval $(0,\infty)$.

of single buoy moorings and fixed berths. To obtain some insight into this area, MIT and ECO Inc. undertook to obtain what data they could on SBM spillage. Unfortunately, data on past SBM spillage is hard to come by. There are no U.S. SBM installations. The excellent cooperation we have received from the industry in other areas simply has not been exhibited with respect to SBM spillage.

We have essentially three sets of data:

1. A sample of some 55 spills collected by ECO Inc. These spills are shown in Table 5.1.
2. A sample of some 200 spills made available to us by the Anglesey Defence Action Group. This is Shell Oil data which purports to cover all the spillage from Shell Oil SBM instllations through October 1971.* The data is summarized in Tables 5.2 and 5.3. The spillage reported in these tables is taken from submittals by Shell to the House of Lords during hearings concerning the large SBM installation which Shell is constructing off Anglesey [5]. During these hearings, Shell witnesses claimed these records are complete and that any spillage (defined to be oil reaching water) is fully recorded.

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*We asked for this data direct from Shell but received no response. We also made repeated requests to the SBM Forum, an industry organization to promote the transfer of information on single buoy mooring installations among users, to no avail.

TABLE 5.1

OFFSHORE TERMINAL SPILLS OBTAINED FROM SBM FORUM

Year Installed	Port	Type	Maximum Tanker Size	Spill Size, Gallons	Report Period	Cause
62	Brega	Fixed	100	33,600	62-72	Unloading arm
62	Brega	Fixed	100	21,000	62-72	Unloading arm
62	Brega	Fixed	100	8,400	62-72	Unloading arm
62	Brega	Fixed	100	16,800	62-72	Unloading arm
62	Brega	Fixed	100	4,200	62-72	
69	Brega	SALM	300	2,100	69-72	Hoses
70	Singapore	CALM	250		70-71	
71	Nakagusaku	SALM	250		71-72	
72	Botany Bay	SBM	80	1,260	72-72	Expansion piece
67	Huelva Bay	SBM	100	25,200	71-72	Mooring line and hose
67	Huelva Bay	SBM	100	420	71-72	Hoses
67	Huelva Bay	SBM	100	840	71-72	Hoses
67	Koshiba	SBM	100	21,000	67-72	Fishing vessel tore hoses
67	Koshiba	SBM	100	840	67-72	Hoses
67	Koshiba	SBM	100	420	67-72	Hoses
71	Tetney	SBM	210	25,200	71-72	Tanker hit buoy
71	Tetney	SBM	210	200	71-72	Hoses
71	Tetney	SBM	210	400	71-72	Hoses
70	Durban	SBM	220	8,400	71-72	Underbuoy hose
70	Durban	SBM	220	1,680	71-72	Hoses
70	Durban	SBM	220	420	71-72	Hoses
68	Wulsan	SBM	200	420	71-72	Hoses
68	Wulsan	SBM	200	630	71-72	Hoses
65	Gamba	SBM	90	420	67-72	Hoses
65	Gamba	SBM	90	6,300	67-72	Underbuoy hose
65	Gamba	SBM	90	200	67-72	Hoses
72	Porto Baleo	SBM	100		72-72	
72	Porto Baleo	SBM	250		72-72	
66	Wulsan	SBM	75	840	70-72	Hoses
66	Wulsan	SBM	75	600	70-72	Hoses

TABLE 5.1--Continued.

Year Installed	Port	Type	Maximum Tanker Size	Spill Size, Gallons	Report Period	Cause
65	Chiba	SBM	120	2,520	70-72	Buoy chain
65	Chiba	SBM	120	400	70-72	Hoses
65	Chiba	SBM	120	600	70-72	Hoses
68	Kawasaki	SBM	260	2,100	70-72	Buoy hit by vessel
68	Kawasaki	SBM	260	840	70-72	Hoses
68	Kawasaki	SBM	260	200	70-72	Hoses
71	Java	SBM	80	1,050	71-72	Swivel seals
71	Java	SBM	80	400	71-72	Swivel seals
72	Java	SBM	140		72-72	
63	Port Dickson	SBM	100	7,140	70-72	Hoses
63	Port Dickson	SBM	100	400	70-72	Hoses
63	Port Dickson	SBM	100	200	70-72	Hoses
63	Port Dickson	SBM	100	800	70-72	Hoses
64	Miri	SBM	65	400	70-72	SBM hose connection
64	Miri	SBM	65	600	70-72	Hoses
71	Seria	SBM	250		71-72	
67	Subic Bay	SBM	108	400	70-72	Valves
67	Subic Bay	SBM	108	1,000	70-72	Hoses
70	Saint John	SBM	350	200	70-72	Chafed underbuoy hose
70	Saint John	SBM	350	400	70-72	Chafed underbuoy hose
70	Saint John	SBM	350	200	70-72	Chafed underbuoy hose

TABLE 5.2

SHELL DATA: DISCHARGE SBM'S
1 OCTOBER 1971

Location	No of SBM's	Yrs	<150 Gal.	150-1500 Gal.	1500-9000 Gal.	>9000 Gal.	Reported Total Gallons	No of Ship Calls	Tons Handled x 10^{-6}
Yokkaichi	2	6	8	0	0	0	-	514	50.5
Niigata	1	5	15	0	0	0	210	104	6.6
Port Dickson	1	8	0	2	1	0	9,750	583	24.5
Kawasaki	1	3	24	0	0	0	-	194	21.9
Durban	1	1	13	5	5	0	-	91	7.4
Durban (thru 3/72)			16	5	5	0	17,100	111	9.3
Totals thru 10/71			60	12	11	0	27,060	1,486	111.1

TABLE 5.3

SHELL DATA: LOADING SBM'S
1 OCTOBER 1971

Location	No of SBM's	Yrs.	<150 Gal.	150-1500 Gal.	1500-9000 Gal.	>9000 Gal.	Reported Total Gallons	No of Ship Calls	Tons Handled x 10^{-6}
Gamba	1	4-7/12	0	12	3	8	1,856,000	303	11.4
Forcados	2	2	0	0	7	16	269,700	533	36.1
Mina-al-Fahal, Muscat	3	4	4	3	1	1	18,560	1,676	63.4
Halul Island, Qatar	1	9-7/12	7	0	2	0	11,600	816	43.7
Miri, Sarawak	3	10	15	11	8	10	335,530	2,250	36.1
Totals thru 10/71			26	26	21	35	2,491,000	5,578	196.7

3. A submittal from Exxon covering four of their installations. This data is summarized in Table 5.4.

The Exxon data suffers from the fact that spill incidence is not reported. The ECO data is incomplete, as can be seen by comparing the ECO Durban spills with the Shell data. Therefore, it appears that the best data we have is the Shell information received via Anglesey.

Shell witnesses at the House of Lords hearings maintained that the data for the loading ports is not relevant to unloading ports. Loading ports generally employ higher pressures (200-500 psi vs. 120-150 psi). Also, there's less valving in ship-to-shore operations due to the larger reception tank sizes. Valve operations onshore are usually more highly automated than those on board ships. Finally, tank overflows in ship-to-shore operations are much more easily contained than in operations where the vessel is the receptor. And the data indicates that loading installations do have rather different characteristics than unloading. From the point of view of volume, the record of the loading terminals is much worse than that of the discharge terminals. Gamba has the worst record. The largest spill was 3,400 tons which flowed for 4.5 hours.

At Forcados, the three largest spills were put at 350, 300, and 281 tons respectively. This terminal is 12 miles offshore and Shell blames communications problems from ship

TABLE 5.4

EXXON SUBMITTAL ON OFFSHORE TERMINAL SPILLS

Year Installed	Country	Type	Port	Maximum Vessel Size (DWT)	Total Tankers Handled	Total Throughput (Bbls)	Reported Spills (Gals)
1962	Libya	Fixed	Brega	100,000	$2,300^{+}$	1,100,000,000	Approx. 84,000
1969	Libya	SALM	Brega	300,000			
1970	Singapore	CALM	Singapore	250,000	57	66,000,000	None reported*
1971	Okinawa	SALM	Nakagusuku Bay	250,000	19	23,000,000	None reported*
TOTALS					$2,376^{+}$	1,189,000,000	Approx. 84,000

Data collected through 31 January 1973.

*Spills over 42 gallons would be reported.

to shore for these spills. At Mina-Al-Fahal in Muscat, the largest spill is placed at 36 tons. This was due to pumping to an unoccupied SBM and blowing out the hose. The next two spills are 20 tons (failure of an SBM bellowspiece), and 8 tons. At Halul Island off Qatar, the two largest spills are placed at 20 tons each. There is some conflict here within the testimony. One witness puts the total number of spills at Halul at 34, while the table says 9. At Miri, Sarawak, the largest spills were put at 375, 231, 183, 179, 75, 53, and 51 tons. They were all blamed on corrosion of pre-war-laid underwater pipeline.

The reported totals are 108 spills and 8,600 tons out of 5,578 calls and 196 million tons handled, or 1 spill for every 50 ships and an average reported spillage rate of 4.3×10^{-5}.

Interestingly enough, despite all the reasons why one would expect spillage to be more frequent in shore-to-ship operations than ship-to-shore, the discharge ports report a considerably higher frequency of spills than the loading ports. (Most loading ports are in countries where there is little or no non-company monitoring of spillage.) The totals for the discharge terminals are 89 tons and 99 spills out of 111 million tons landed and 1,486 calls, or about 1 spill every 15 ship calls and a reported average spillage rate of 8.9×10^{-7}. All the spill sizes in the discharge table were estimated from the slick size and thus are subject to a number of errors and biases.

The worst record is Durban, South Africa, which through 1971 reported about 1 spill every 5 ship calls and a reported average spillage rate of 5.9×10^{-6}. Shell claims Durban is a special case due to an unusually sharp vertical current gradient and generally rough water. Nonetheless, it is of interest to study the Durban spills in some detail (see Table 5.5). The largest spill, estimated at 4,400 gal, was caused by a deck line being blown out of an expansion point when a butterfly valve used to control hose drips during disconnect closed during pumping. The next largest, 3,000 gal, was caused by mooring lines parting during a squall, breaking the hoses. Another 3,000 gallon spill was caused by a collision with the buoy. A large number of the other spills are blamed on manufacturing defects in the hoses. It may be possible to eliminate some of these causes. Shell claims that redesign of the buoy makes penetration of the tanker hull in a collision much more unlikely. Several manufacturers now offer self-sealing disconnect devices. Nonetheless, it appears that an upper bound on discharge buoy operations is the Durban experience--1 spill every 5 ship calls with spill sizes ranging up to about 3,000 gal. A lower bound, using 1970-1971 technology, can be obtained by accepting the non-Durban data at face value, which would indicate a mean rate of 1 spill every 30 ship calls.

It is of some interest to compare this experience with shoreline fixed berth history. Our best data in this regard is the Milford Haven experience. Milford Haven is a modern, well-run, large-volume fixed berth complex in whose reporting

TAB.).5

LISTING OF FIRST 23 DURBAN SPILLS

	Date	Amount	Time to Discovery (minutes)	Cause
1	21.9.70	20	10	Bolts on 16" blind flange loosened
2	29.9.70	250	nil	Tanker hull leak, no. 5 port wing tank
3	30.9.70	85	5	Underwater hose leak, manufacturer's defect
4	4.10.70	6	nil	Spill from hose end during connect operation
5	10.10.70	1	nil	Underwater hose leak, manufacturer's defect
6	11.10.70	20	nil	Tanker ballast discharge valve leaking
7	18.11.70	1,470	nil	Floating hose rupture at buoy, manufacturer's defect
8	12.12.70	2,940	nil	Hull leak due to contact with SBM ballast box
9	22.12.70	42	nil	Underwater hose nipple, manufacturer's defect
10	3.1.71	24	5	Tanker "World Friendship" overboard discharge
11	31.1.71	85	5	Tanker "World Friendship" overboard discharge
12	6.2.71	4,410	nil	Butterfly valve shut against ship pumps blowing 24" deckline out of expansion joint
13	16.2.71	2,940	nil	Both end hoses parted when mooring lines broke in 40 knot squall, light condition
14	17.2.71	20	nil	During repair due to spill 13
15	18.2.71	20	nil	During repair due to spill 13
16	27.3.71	20	nil	Hose connection during heavy rain
17	31.3.71	880	nil	Floating hose nipple blew during discharge
18	6.5.71	1	5	Tanker hull leak, no. 2 port wing tank
19	15.5.71	20	5	Main sea valve leak, port pumproom
20	22.5.71	1,470	2	Main sea valve leak
21	14.6.71	620	nil	Tanker overflow from no. 3 starboard tank during discharge
22	11.7.71	72	nil	Tanker overflow from no. 1 port wing tank during discharge
23	24.10.71	600	nil	Floating hose rupture, ship end. Manufacturer's defect

we have some confidence. Milford Haven had been averaging one spill for about every 60 ship calls and an average spillage rate through 1972 of 1.8×10^{-6}.

In general, one would expect more small operational spills from an SBM operation than a shoreside fixed berth operation. The SBM has essentially all the operational causes that a fixed berth has plus ship motion, two sets of flexible hoses subject to wave action, and the possible loss of mooring. Therefore, as a beginning point, it might be reasonable to assume that you will have something better than twice the number of small operational spills from an SBM as from a fixed berth for the same number of ship calls.

From the data, theredoesn't appear to be much difference in the size of operational SBM spills and fixed berth spills. The average of the Milford Haven spills is in the neighborhood of 300 gallons, the average of the Shell discharge spills, about 300 gallons. We are more than a bit leery of comparing reported small spill volumes, and the same factors that tend to cause more small spills would seem to also tend to make these spills somewhat larger, but from the data it is impossible to distinguish any significant differences in small spill size.

In summary, with respect to operational unloading spills and based on data which on the SBM side is uncomfortably scarce and possibly lacking in quality, the number of small spills can be expected to be several times that of a well-run fixed berth, but we are unable from the data to say that the resulting spills will be significantly different in size from those at a fixed berth.

Statements about loading operations are much more difficult to make. Accepting the Shell arguments, it appears that their loading data does not include a very large portion of smaller spills. It may well include most of the volume. However, most of the volume appears to have been caused by what could easily be termed gross negligence and we would expect better performance at an installation off the U.S. coast. A ballpark estimate of the spillage might be to use the Durban data. Under this assumption and once again reverting to the assumption that the relevant exposure variable is volume handled, the densities of the number of spills at SBM's for the small, medium, and large finds are shown in Figures 5.5, 5.6, and 5.7. They imply fairly large numbers of spills. However, these densities should not be given much weight. The simple truth is that we have no trustworthy data on SBM loading terminals operating under conditions comparable to the U.S. continental shelf.

With respect to large spills associated with ramming, grounding or collision, the SBM <u>may</u> have a distinct advantage over an equivalent shoreside facility. Ramming (hitting a berth) appears to be a very unlikely cause of large spills. No spills over 1000 barrels in the ECO data are attributed to ramming. Nonetheless, it is to the SBM's credit that it is possible to ram the berth with little or no spillage. At the Anglesey Hearings, a Shell witness stated that the Humber SBM had been rammed by a tanker on approach, with substantial damage to the buoy in mooring system, but no oil spillage, due in part to the hoses had been filled with sea water as far as the subsurface check valve.

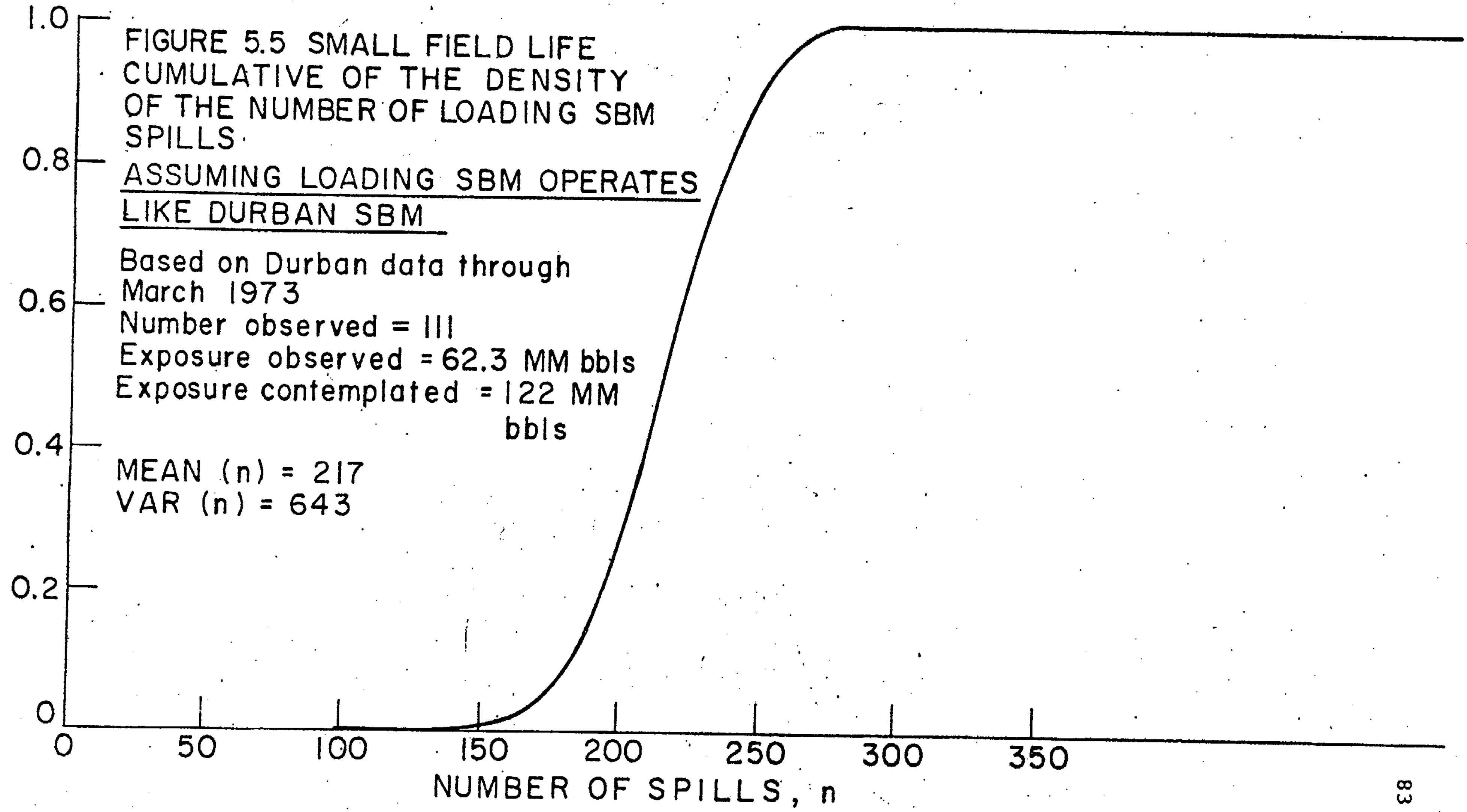

FIGURE 5.5 SMALL FIELD LIFE CUMULATIVE OF THE DENSITY OF THE NUMBER OF LOADING SBM SPILLS

ASSUMING LOADING SBM OPERATES LIKE DURBAN SBM

Based on Durban data through March 1973
Number observed = 111
Exposure observed = 62.3 MM bbls
Exposure contemplated = 122 MM bbls

MEAN (n) = 217
VAR (n) = 643

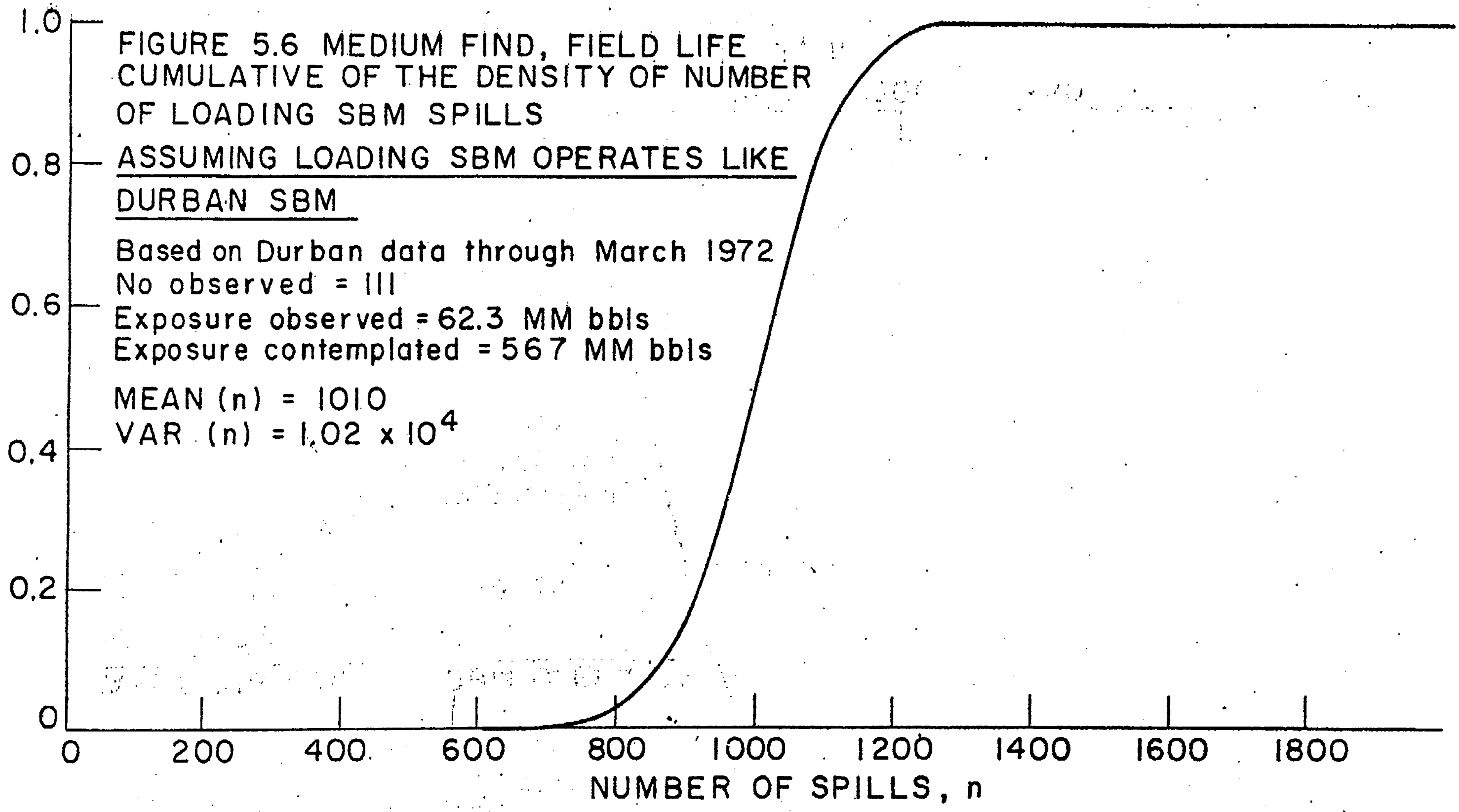
FIGURE 5.6 MEDIUM FIND, FIELD LIFE
CUMULATIVE OF THE DENSITY OF NUMBER
OF LOADING SBM SPILLS
ASSUMING LOADING SBM OPERATES LIKE
DURBAN SBM
Based on Durban data through March 1972
No observed = 111
Exposure observed = 62.3 MM bbls
Exposure contemplated = 567 MM bbls
MEAN (n) = 1010
VAR (n) = 1.02 x 10^4
1.0
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
1200
1400
1600
1800
NUMBER OF SPILLS, n

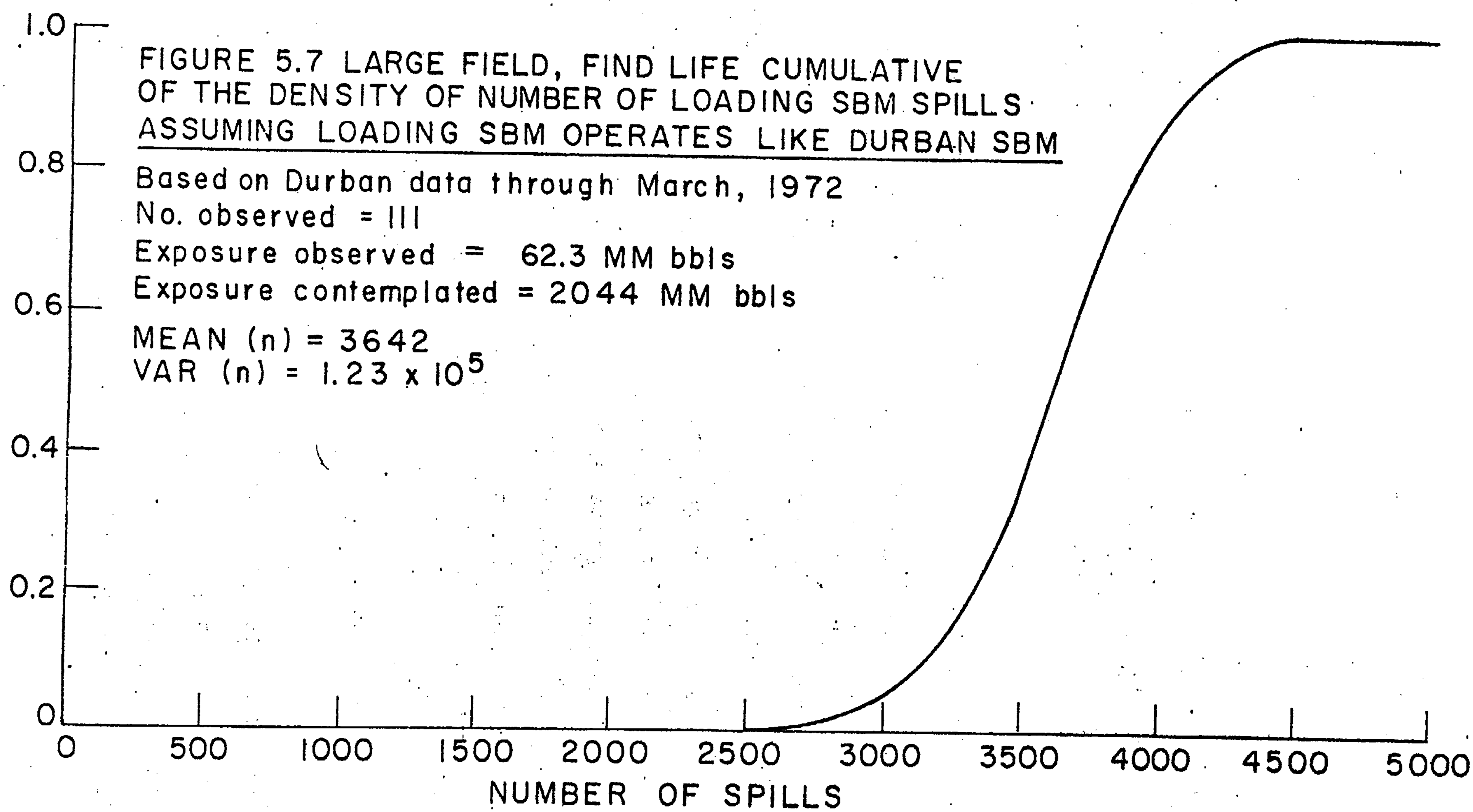

FIGURE 5.7 LARGE FIELD, FIND LIFE CUMULATIVE OF THE DENSITY OF NUMBER OF LOADING SBM SPILLS ASSUMING LOADING SBM OPERATES LIKE DURBAN SBM

Of more importance to the SBM is the possible reduction of large tanker spills associated with grounding, and possibly very nearshore collisions. In the ECO data, groundings accounted for 28% of all the spills and about 25% of all the spillage. Almost all this grounding spillage was put in the harbor or entranceway category, that is, inside the sea buoy. Of this grounding spillage, 19%, or 5% overall, took place within the harbor, the remainder in the approaches. Depending on location, an SBM might be expected to reduce the probabilities of a portion of this spillage relative to those associated with an equivalent shoreside facility, either through reduction of the number of landfalls or through the fact that the tankers need not approach closer to land than the SBM's.

Obviously, any such reduction in spillage would be extremely site-dependent; witness the Conoco Brittania spill in which a tanker overshot the Humber SBM, dropped an anchor in an attempt to check its process, went aground, overriding the anchor which holed a tank, resulting in a large spill. But an offshore SBM might be expected to reduce the mean frequency of large spills by 5% to 25% over that of equivalent shoreside facilities, depending on location.

In summary, SBM's appear to have considerably higher incidence of small operational spills than well-run fixed berths in protected waters per ship call. However, it is quite possible the SBM may decrease the total volume spilled relative to fixed shoreside berths by decreasing the number of ship calls and increasing the minimum distance to shore.

Finally, our spill-tracking analysis [9] indicates that at least in certain locations, e.g. middle of Delaware Bay, SBM terminal spills would require a day or more to reach land, which has some advantages both biologically and with respect to the response time available to containment and cleanup systems.

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