Hopenfeld

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

SEP 11 1992

MEMORANDUM FOR: E. Beckjord, Director

FROM: J. Hopenfeld, Reactor and Plant Safety Branch

SUBJECT: Addendum To March 27, 1992 Memo Regarding Degraded Steam Generator Tubes.

The subject memo concluded that stress corrosion cracking of steam generator tubes may increase core melt frequency. The attached document examines a different but a related subject: What is the effect of degraded tubes on risk from severe accidents.

In contrast to NUREG-1150 findings, the present brief study indicates that cracked tubes increase the risk of containment bypass in the TMLB' sequence.

The analysis suggests that a strong coupling exists between hot leg mass flow, SG tube leakage and crack propagation. If confirmed, such relation between system behavior and undetected tube defects may cause small leaks to quickly enlarge and result in a multiple tube rupture before the RCS is depressurized by failure of the surge line. The resultant containment bypass will increase the source term.

As the number of plants operating with degraded steam generator tubes increases, so does the risk of complete containment bypass following station blackout. A dedicated facility will be needed to generate the required data to examine the problem within the safety goal framework.

J. Hopenfeld
Reactor & Plant Safety Issues Branch
Division of Safety Issue Resolution, RES

EFFECT OF DEGRADED STEAM GENERATOR TUBES ON THE CONSEQUENCES OF SEVERE ACCIDENTS

PURPOSE

Reference 1 concluded that operation with degraded steam generated tubes could lead to a core melt following a MSLB that cannot be isolated. The purpose of the present study is to examine a different but a related case, i.e. how degraded tubes may effect the consequences of severe reactor accidents. The particular case examined is a core damage with the primary system held at high pressure (TMLB' sequence).

ANALYSIS

It is assumed that the temperature and the pressure at the outlet from the reactor vessel are kept at 2200 psi and 2800° F. Heat from the flowing superheated steam is transferred to the primary hot leg piping. The driving force for the flow of steam is by natural circulation and by forced convection when the cracks in the steam generator tubes are open. Two cases are considered: the secondary sides are held at 15 psi and 1050 psi, Cases A and B respectively. The term leakage as used below refers to primary steam and fission gases flowing through tube wall microcracks.

CASE A

From Table 1, SG tube temperatures reach 1400° F in 67 and 90 minutes for steam flow rates of 500 and 100 GPM respectively. The tensile strength of Inconel 600 at these temperatures is 27.5 kpsi, 1000 psi below the hoop stress (σ=pr/kt; p=2185 psi, r=0.35 in, t=0.040 in, k=0.6, factor for the allowable tube wall degradation.)

The time to rupture the degraded tubes with leakage can be compared with the time to fail the surge line with no leakage (i.e. non-cracked tubes). Figure 1 shows that for both flow rates the steam generator tube rupture occurs long before the surge line breaks.

CASE B

Figure 1 also shows that with zero leakage it takes 370 minutes to heat the SG tubes to 1400° F. However, since the pressure across the tubes is now only 1150 psi, material strength is 12.5 kpsi above tube stress and no tube rupture occurs. The SG tube temperature is about 800° F when the surge line fails.

DISCUSSION

The question of whether the hot leg piping or the degraded steam generator tubes fail first following core uncovery has been examined in NUREG-1150, Reference 2. Based on Expert opinion, it was concluded that the probability of defective tubes failing before a break in the RCS was 0.018.

In reaching the above conclusions, the Expert did consider the thermal hydraulic coupling between the hot leg, the surge line and the SG tubes with no primary to secondary leakage. The sensitivity of the SG temperature to flow, however, indicates that the problem is much more complex when leakage exists. Primary to secondary flow decreases the residence time of the steam in the hot leg with an accompanying increase in SG tube temperature which, in turn, increases crack propagation and thereby, most probably, leakage.

Although Case B above indicates that an early surge line break will prevent containment bypass, it raises more concern than Case A where failure of the secondary side relief valve triggers the leakage. Case B assumes that the tubes do not leak even though their temperature has increased from 600° to 1400° F. Based on theoretical consideration, however, microcrack propagation under oxidation, creep, and fatigue increases with temperature. Consequently, small through-the-wall or partially through-the-wall cracks which did not leak during normal operation may open up as the temperature increases and leak before surge line failure. As the leak increases, the temperature further increases, in turn causing further crack propagation. Since there is essentially no data on leakage through stress corrosion cracks in SG tubes in the above temperature range, quantitative predictions are not possible.

If the assumption (Case B) that leakage is not triggered during the 600 to 800° F increase cannot be validated by experiments, then the failure of the relief valve (Case A) may not be a required precondition for containment bypass.

Until data on microcrack propagation shows that leakage does not develop in the subject environment, the possibility that degraded tubes will lead to a complete containmert bypass cannot be dismissed.

References

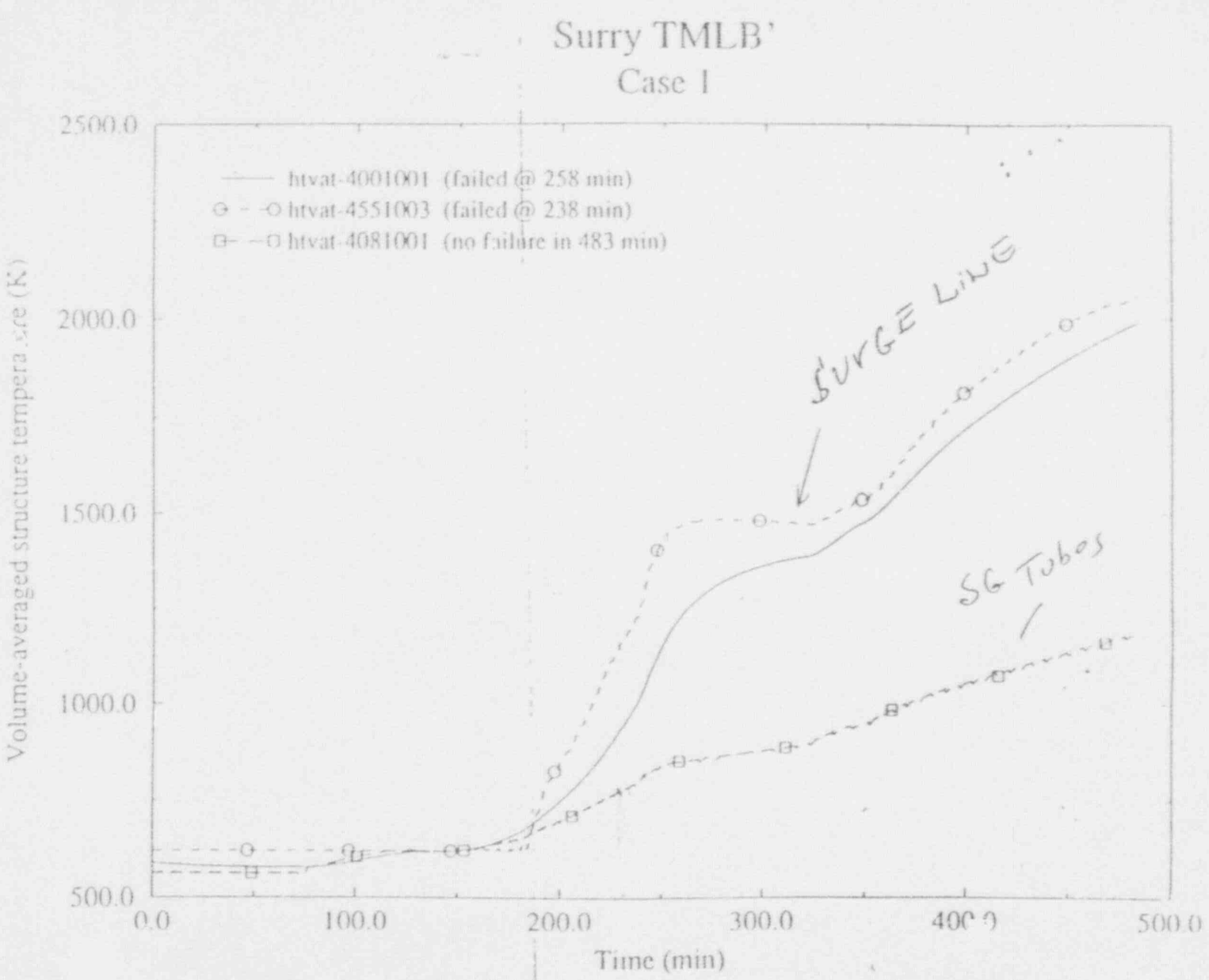
1. J. Hopenfeld to E. Beckjord
"A New Generic Issue: "Multiple Steam Generation Leakage"
March 27, 1992

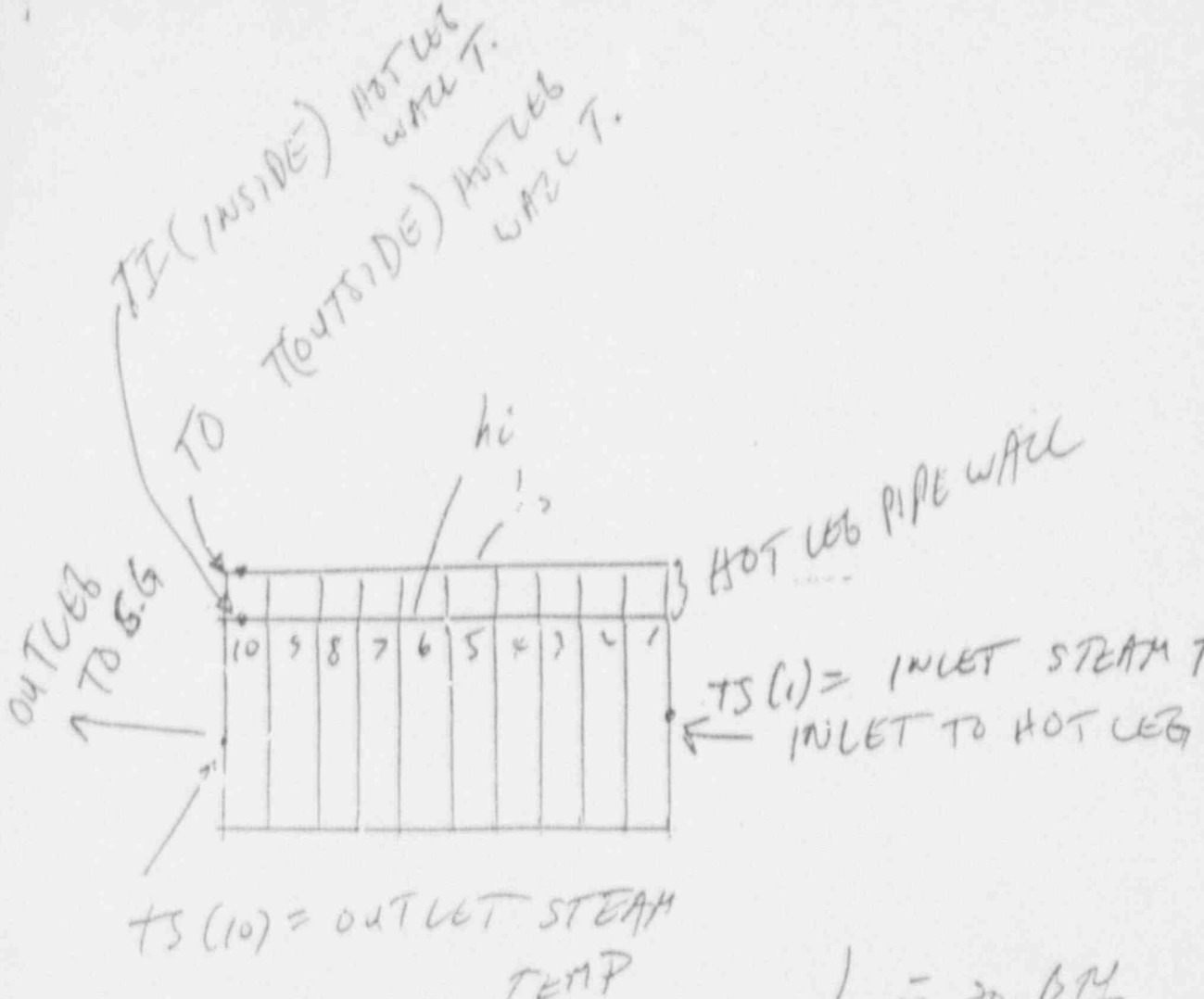
2. Letter, D.L. Knudson, INEL to F. Odar
SCDAP/RELAP5/MOD3 DATA
From Surry TMLB' calculations
DLK-7-92. June 27, 1992.

3. Evaluation of Severe Accident Risks: NUREG/CR-9451

APPENDIX

Steam Generator Tube Temperature With And Without Primary To Secondary Leakage Following Core Melt


Surry TMLB'
Case 1
htvat-4001001 (failed @ 258 min)
htvat-4551003 (failed @ 238 min)
htvat-4081001 (no failure in 483 min)
SURGE LINE
SG Tubes
Volume-averaged structure temperature (K)
2500.0
2000.0
1500.0
1000.0
500.0
0.0
100.0
200.0
300.0
400.0
500.0
Time (min)



$h_i = 20 \frac{BTU}{HR\,FT^2\,°F}$

$h_o = 1.0 \frac{BTU}{HR\,FT^2\,°F}$

TWO CASES (1) 500 GPM SG TUBE LEAK $\Rightarrow$ 10 lb/sec

(2) 100 GPM " " $\Rightarrow$ 1 lb/sec

(CASE 1)

MASS FLOW = 10.0 kg/sec

TABLE 1

ME= 0.000000

T(I)	TS(I)
500.000000	
500.000000	
500.000000	
500.000000	
500.000000	
500.000000	
500.000000	
500.000000	
500.000000	
500.000000	

ME= 0.500000

TO(I)	TI(I)	TS(I)	Q(I)
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000
499.958955	500.000000	500.000000	0.000000

ME= 200.000000

TO(I)	TI(I)	TS(I)	Q(I)
497.527813	502.800105	549.875000	-2.562743
496.619025	498.917351	502.800105	-0.211074
496.568124	498.639244	498.917351	-0.030241
496.568096	498.639057	498.914460	-0.029950
496.568069	498.638873	498.911597	-0.029661
496.568042	498.638691	498.908761	-0.029375
496.568015	498.638510	498.905953	-0.029092
496.567989	498.638331	498.903171	-0.028812
496.567963	498.638154	498.900417	-0.028534
496.567937	498.637978	498.897689	-0.028259

ME= 400.000000

TO(I)	TI(I)	TS(I)	Q(I)
499.957637	508.953732	599.875000	-4.965271
494.962430	497.827409	508.953732	-0.604462
494.526305	496.668222	497.827409	-0.125304
494.525945	496.667111	497.815430	-0.124132
494.525590	496.666010	497.803562	-0.122970
494.525237	496.664920	497.791806	-0.121820
494.524888	496.663839	497.780160	-0.120680
494.524543	496.662770	497.768623	-0.119551
494.524201	496.661710	497.757193	-0.118432
494.523862	496.660660	497.745871	-0.117324

ME= 600.000000

TO(I)	TI(I)	TS(I)	Q(I)
505.990767	518.436345	649.875000	-7.204623
493.955755	497.589414	518.436345	-1.132777
492.583512	494.838403	497.589414	-0.297063
492.582062	494.835108	497.561014	-0.294354
492.580626	494.831845	497.532873	-0.291669
492.579204	494.828611	497.504989	-0.289009
492.577795	494.825408	497.477359	-0.286373
492.576399	494.822234	497.449981	-0.283761
492.575016	494.819089	497.422853	-0.281173
492.573646	494.815973	497.395972	-0.278608

ME= 800.000000

TO(I)	TI(I)	TS(I)	Q(I)
515.334366	530.983906	699.875000	-9.297426
493.789875	498.372254	530.983906	-1.773074
490.792096	493.226060	498.372254	-0.555544
490.788209	493.218776	498.319143	-0.550596

682.635161	726.016920	1214.883015	-59.551373
671.025834	714.552749	1205.681636	-59.618944
660.721717	704.292558	1196.425799	-59.545252
651.235107	694.786404	1187.135683	-59.384416
642.287023	685.776939	1177.823244	-59.167363
633.706685	677.106616	1168.495691	-58.912961

ME= 3200.000000

TO(I)	TI(I)	TS(I)	Q(I)
807.201288	847.970664	1299.875000	-57.102124
774.888342	817.385688	1291.385382	-59.481778
751.270441	794.830063	1282.509872	-60.860922
734.081444	778.207484	1273.394162	-61.518050
720.654924	765.057607	1264.143848	-61.757818
709.278163	753.799540	1254.819857	-61.772576
699.097807	743.645783	1245.454727	-61.657994
689.666836	734.183920	1236.066838	-61.464206
680.729573	725.178097	1226.667121	-61.219860
672.129499	716.483927	1217.262219	-60.942434

ME= 3400.000000

TO(I)	TI(I)	TS(I)	Q(I)
841.684930	883.794174	1349.875000	-59.891115
811.310540	854.984684	1341.136374	-62.039350
788.913481	833.543417	1332.054185	-63.260729
772.411051	81[illegible]42883	1322.761252	-63.814069
759.358906	804.727601	1313.353738	-63.981845
748.186462	793.647842	1303.887108	-63.942467
738.111346	783.581590	1294.390969	-63.784650
728.723821	774.150815	1284.882043	-63.554869
719.789565	765.139358	1275.370279	-63.279670
711.165127	756.414886	1265.861738	-62.975243

ME= 3600.000000

TO(I)	TI(I)	TS(I)	(I)
877.193609	920.566716	1399.875000	-64.683583
848.583089	893.370586	1390.882480	-64.613998
827.292995	872.937495	1381.584318	-65.685063
811.408369	857.494346	1372.101848	-66.137634
798.688407	844.973437	1362.522804	-66.233849
787.692837	834.045295	1352.897753	-66.139322
777.704344	824.047931	1343.253649	-65.936381
768.347353	814.634824	1333.605687	-65.668136
759.407110	805.607858	1323.962889	-65.359196
750.752139	796.845741	1314.330738	-65.024565

ME= 3800.000000

TO(I)	TI(I)	TS(I)	Q(J)
913.64498[illegible]	958.212055	1449.875000	-65.491360
886.637314	932.479845	1440.623981	-67.216155
866.348764	912.956674	1431.101635	-68.143558
851.017790	898.010668	1421.419013	-68.498029
838.590151	885.746253	1411.656280	-68.523034
827.745049	874.944222	1401.859589	-68.372434
817.824806	864.997608	1392.053486	-68.122689
808.485153	855.588764	1382.251761	-67.813809
799.529259	846.536099	1372.462565	-67.468624
790.836617	837.728435	1362.690819	-67.101036

ME= 4000.000000

TO(I)	TI(I)	TS(I)	Q(I)
950.963330	996.660080	1499.875000	-68.325590
925.410070	972.253978	1490.360555	-69.855581
906.025492	953.549775	1480.606130	-70.645143
891.188376	939.044777	1470.713522	-70.[illegible]03733
879.015492	927.001202	1460.756082	-70.857675
868.295591	916.300953	1450.775969	-70.650021
858.425660	906.387500	1440.795534	-70.351833
849.090114	896.969651	1430.827272	-70.000271
840.108542	887.880953	1420.878515	-69.616518
831.370484	879.019487	1410.953644	-69.213460

(CASE 2) MASS FLOW = 1 lb/sec

IME= 0.000000

I	T(I)	TS(I)
*	500.000000	
*	500.000000	
*	500.000000	
*	500.000000	
*	500.000000	
*	500.000000	
*	500.000000	
*	500.000000	
*	500.000000	
*	500.000000	

IME= 0.500000

I	TO(I)	TI(I)	TS(I)	Q(I)
1	499.958955	500.000000	500.000000	0.000000
2	499.958955	500.000000	500.000000	0.000000
3	499.958955	500.000000	500.000000	0.000000
4	499.958955	500.000000	500.000000	0.000000
5	499.958955	500.000000	500.000000	0.000000
6	499.958955	500.000000	500.000000	0.000000
7	499.958955	500.000000	500.000000	0.000000
8	499.958955	500.000000	500.000000	0.000000
9	499.958955	500.000000	500.000000	0.000000
0	499.958955	500.000000	500.000000	0.000000

IME= 200.000000

I	TO(I)	TI(I)	TS(I)	Q(I)
1	497.527813	502.800105	549.875000	-2.562743
2	496.619025	498.917351	502.800105	-0.211074
3	496.568124	498.639244	498.917351	-0.029632
4	496.567989	498.638332	498.903187	-0.028233
5	496.567861	498.637464	498.889691	-0.026900
6	496.567738	498.636636	498.876833	-0.025629
7	496.567622	498.635848	498.864582	-0.024419
8	496.567511	498.635098	498.852909	-0.023266
9	496.567405	498.634383	498.841788	-0.022167
0	496.567305	498.633702	498.831192	-0.021120

IME= 400.000000

I	TO(I)	TI(I)	TS(I)	Q(I)
1	499.957637	508.953732	599.875000	-4.965271
2	494.962430	497.827409	508.953732	-0.604462
3	494.526305	496.668222	497.827409	-0.122775
4	494.524545	496.662778	497.768721	-0.117147
5	494.522868	496.657585	497.712724	-0.111778
6	494.521270	496.652633	497.659293	-0.106654
7	494.519746	496.647909	497.608311	-0.101765
8	494.518294	496.643404	497.559666	-0.097100
9	494.516909	496.639107	497.513251	-0.092648
0	494.515590	496.635009	497.468964	-0.088401

IME= 600.000000

I	TO(I)	TI(I)	TS(I)	Q(I)
1	505.990767	518.436345	649.875000	-7.204623
2	493.955755	497.589414	518.436345	-1.132777
3	492.583512	494.838403	497.589414	-0.291063
4	492.576411	494.822265	497.450283	-0.278058
5	492.569636	494.806857	497.317368	-0.265634
6	492.563170	494.792146	497.190392	-0.253764
7	492.557001	494.778101	497.069090	-0.242424
8	492.551115	494.764691	496.953209	-0.231590
9	492.545498	494.751888	496.842506	-0.221240
0	492.540138	494.739664	496.736751	-0.211352

IME= 800.000000

I	TO(I)	TI(I)	TS(I)	Q(I)
1	515.334366	530.983906	699.875000	-9.297426
2	493.789875	498.372254	530.983906	-1.773074
3	490.792096	493.226060	498.372254	-0.544315
4	490.773446	493.190374	498.112065	-0.520568

1017.467003	1065.462673	1591.914095	-71.045403
978.676621	1025.769811	1543.278136	-68.480857
940.675161	986.897221	1495.812981	-66.097614
903.279149	948.666105	1449.402291	-63.887356
866.365563	910.953540	1403.929256	-61.836544
829.840728	873.663841	1359.278458	-59.930120

ME= 5400.000000

TO(I)	TI(I)	TS(I)	Q(I)
1231.268105	1283.458129	1849.875000	-85.661989
1184.034534	1235.405080	1794.273049	-82.360571
1139.703617	1190.172170	1740.288045	-79.127679
1097.629981	1147.149721	1687.881281	-76.023163
1057.152528	1105.720370	1636.979099	-73.097998
1017.775272	1065.416949	1587.475277	-70.377381
979.213773	1025.966625	1539.245227	-67.860119
941.290323	987.195106	1492.161673	-65.534150
903.882820	948.979783	1446.100531	-63.383464
866.896301	911.223480	1400.942235	-61.391413

ME= 5600.000000

TO(I)	TI(I)	TS(I)	Q(I)
1273.432682	1326.393045	1899.875000	-88.807963
1225.742934	1277.795208	1842.690208	-85.155179
1180.857852	1231.944345	1787.349703	-81.637999
1138.170898	1188.263287	1733.770178	-78.301090
1097.068047	1146.175629	1681.844010	-75.182126
1057.084772	1105.241455	1631.440547	-72.296837
1017.949802	1065.198791	1582.417849	-69.637978
979.489880	1025.876512	1534.636121	-67.189424
941.583179	987.151591	1487.962383	-64.932377
904.133212	948.925006	1442.271166	-62.848263

ME= 5800.000000

TO(I)	TI(I)	TS(I)	Q(I)
1316.005292	1369.705739	1949.875000	-92.040991
1267.774942	1320.479477	1891.035902	-88.019388
1222.276567	1273.951448	1834.281734	-84.203384
1178.935928	1229.570741	1779.481891	-80.611815
1137.179683	1186.795839	1726.492656	-77.298695
1096.570365	1145.209851	1675.157123	-74.239968
1056.847468	1104.559317	1625.314274	-71.431981
1017.840861	1064.674927	1576.810240	-68.854215
979.428274	1025.432455	1529.501638	-66.484763
941.511350	986.730587	1483.255559	-64.302815

ME= 6000.000000

TO(I)	TI(I)	TS(I)	Q(I)
1358.953159	1413.365865	1999.875000	-95.366389
1310.099043	1363.428153	1939.302958	-90.956267
1263.928523	1316.163638	1881.072283	-86.825496
1219.893425	1271.041634	1825.001589	-82.986161
1177.455054	1227.549726	1770.908480	-79.448071
1136.198800	1185.290003	1718.607589	-76.206943
1095.872594	1144.015211	1667.917043	-73.242304
1056.308087	1103.556493	1618.667281	-70.528872
1017.381793	1063.787591	1570.703066	-68.041304
978.993054	1024.604393	1523.882657	-65.756258

ME= 6200.000000

TO(I)	TI(I)	TS(I)	Q(I)
1402.246138	1457.345515	2049.875000	-98.789078
1352.685710	1406.613324	1987.483977	-93.968406
1305.784087	1358.552534	1927.709201	-89.505488
1261.013158	1312.646800	1870.314142	-85.394434
1217.863112	1268.407234	1815.074550	-81.630097
1175.938173	1225.450989	1761.774151	-78.197401
1134.992417	1183.534744	1710.208174	-75.068571
1094.857923	1142.488710	1660.189700	-72.213152
1055.409169	1102.183729	1611.550195	-69.602026
1016.542691	1062.512316	1564.137775	-67.209021