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Alfonso Pujol, Jr., Major Professor

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Date June 10, 1985

COMPUTER GENERATION OF TWO-DIMENSIONAL PSEUDOCOLOR IMAGES OF MONTE CARLO INPUT/OUTPUT DATA

A Thesis

Presented for the

Master of Science

Degree

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Calvin D. Prather

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ABSTRACT

Graphic display of radiation dose distribution is one of the most effective means of communicating the influence of radiographic technique on the risk of diagnostic x-ray exposure. Isodose contours have been used extensively for this purpose. However, a major problem has been the simultaneous display of these isocontours superimposed on patient anatomy, which is required to demonstrate doses to specific organs. A method has been developed to display patient anatomy in pseudocolor, using the continuous temperature-color scale, sometimes called the heated-object spectrum. Isodose contours, also in color, are superimposed on the anatomic display. The method provides improved visualization of the anatomic distribution of radiation dose, especially when compared to previous methods of dose isocontours superimposed on anatomy which was also displayed as isocontours. The results suggest that future refinements of the method, such as improved techniques of data filtering and the application of the science of color perception, may lead to further improvements in the display.

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CHAPTER I

INTRODUCTION

For the past few years, research has been undertaken at Vanderbilt University, Radiation Oncology Center, for the development of a method for computing radiation doses to patients from dental diagnostic x-ray exposures. Programs for computer simulation, using the method of statistical trials (commonly called the Monte Carlo Method), have been developed. The anatomic input data were provided in serial computed tomographic (CT) scans of a female cadaver. Some of the output data have been displayed as two-dimensional isocontour plots to illustrate patient radiation doses from the various dental diagnostic x-ray exposures. However, it was difficult to differentiate between lines representing anatomy and isocontour lines representing radiation dose (Figure 4.4). Thus, to minimize this difficulty and to enhance the visual analysis process, a method was developed for generating pseudo-color images of the Monte Carlo data. This method, uses the continuous temperature-color scale (or heated-object) technique (CTCS) for assigning colors (color coding) to the anatomic representation of the Monte Carlo input data. Discrete colors are assigned to the Monte Carlo dose output data, which are superimposed on the CTCS anatomic image.

1.1 Purpose of study

The purpose of this study is as follows:

1. Utilize the CTCS technique for generating color images representing the anatomic Monte Carlo input data (Chapter III).

2. Utilize discrete colors, unrelated to the CTCS spectrum for generating color isocontour lines of the Monte Carlo output dose data (Chapter III).

3. Generate color images representing anatomy with isocontour lines of interest superimposed (Chapter IV).

4. Perform a visual comparison of color images versus the isocontour plot generated by Pujol and Gibbs (1,2)[1] (Chapter IV).

1.2 Chapter coverage

Chapter II presents a survey of the literature pertaining to the color assignment techniques used by various investigators.

Chapter III presents a discussion of the method (procedures, etc.) utilized for generating and displaying images of the Monte Carlo data in color. This chapter presents the apparatus used for the study, a flowchart of the overall computer program, and the software used for generating pseudocolor images of the Monte Carlo data.

Chapter IV presents the results of the project, anatomic images in pseudocolor, with superimposed isodose contours.

Chapter V presents a discussion of the results and the problems encountered within this research project.

Chapter VI presents a summary and a conclusion of the results

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[1]Numbers in parentheses refer to similarly numbered references in the List of References.

of this project. Several areas for further investigation are suggested.

CHAPTER II

SURVEY OF THE LITERATURE

The following chapter presents a survey of the literature pertaining to the various techniques used by investigators for assigning colors to data. In choosing a particular color coding scheme, consideration should be given to the proper selection of colors that will provide maximum discernibility of information derived from the image. In addition, for studies containing many (greater than 64) levels of intensity, the color scheme should be able to accommodate the individual color coding of each data level. Thus, to present this literature survey, the following chapter is presented in two parts: (2.1) Discrete color coding, and (2.2) Continuous color coding.

2.1 Discrete color coding

In the research by Coleman and Katz (3), data for classifying foreign bodies and tumors in the eye were divided into three ranges and each range was assigned the colors red, green, and blue. In the research by Curry and White (4), returning ultrasound echoes from the cartoid artery were divided into three frequency ranges according to the magnitude of the observed Doppler shift. Each frequency range was expressed in colors of red, yellow, and blue. For both studies, a three-color assignment scheme was used for displaying the output data. Since both studies were interested in only three levels of output, a three-color assignment was sufficient. However, for investigations generating many output data levels, a three-color assignment would not be sufficient for providing detail contained in the collected data. In the study by Bronson and Pickering (5), ten discrete colors (black, grey, brown, blue, green, cyan, magenta, orange, yellow, and white) were used for generating color images of ultrasound B-scans. The data values used for generating these images used 256 x 256 pixels (picture elements) with ten different intensity levels in steps of 1, 2, 3, or 4 colors per level. In the work by Baum (6), the colors violet, magenta, dark red, light red, brown, yellow, dark green, medium green, light green, light blue, dark blue, and white were used for providing color levels for tissue differentiation. Although the number of color levels was increased to provide more discernible information, these studies were limited to ten and twelve color levels, respectively. In addition, using the discrete color coding method will generate contouring (artificial boundaries) between the colors. In the study by Milan and Taylor (7), the colors black, red, orange, yellow, and white were used. Again, utilization of these colors generated similar results (discrete color levels) as the above investigations. Although discrete color coding was applicable for all the above studies, these studies consisted of small output data sets. However, if there are more than 64 intensity levels in the digital image, the above color coding scheme would not be applicable for providing increased discernible color levels without using shades of the primary colors. Milan and Taylor also noted that, "There should be a relationship between color mapping and intensity of grey-scale, or other data, that can be represented by discernible color levels."

They also noted that, "The choice of colors used for this study is defined as the Temperature-Color Scale" (8). It was these studies (7,8), that initiated the following studies on the Continuous Temperature-Color Scale coding technique.

2.2 Continuous color coding

Chan, et al. (9), extended the work of Milan and Taylor, by investigating the temperature-color scale (TCS) as a continuous temperature-color scale (CTCS) spectrum. Their studies concluded that,

1. Using a continuous pseudocolor scale (CTCS) eliminates the artificial contouring which occurs with a few discrete color levels.
2. The CTCS lies in the region of the visible spectrum where the human eye has its greatest sensitivity to luminance change.

Todd-Pokropek and Pizer (10) concluded that more than sixty-four color levels are required to generate a CTCS spectrum that would prevent artificial contouring of output data (images). Other studies (11,12,13), containing large data sets utilized the CTCS technique with excellent results. It was these studies that provided the initial foundation for establishing a linear relationship between the Monte Carlo input data and assigned color, using the CTCS spectrum. The input data set contains over fourteen hundred different CT levels (numbers) of interest. Four hundred and ninety-two different color levels are used to generate the CTCS spectrum. These levels far exceed the number of color levels suggested by Todd-Pokropek and Pizer, for eliminating artificial contouring.

CHAPTER III

METHOD

The following chapter presents a discussion of the equipment used for developing the computer program (Appendix) and for generating color graphic images of the Monte Carlo input/output data. To facilitate the overall presentation of the developed program, the following chapter is presented in two parts: (3.1) Equipment used for the study, and (3.2) Software used for generating pseudocolor images.

3.1 Equipment used for the study

This section presents a description of the equipment used for generating and displaying the Monte Carlo input/output data in pseudocolor. Figure 3.1 presents a block diagram illustrating the interfacing of these devices.

The computer used in this study was a Digital Equipment Corporation (DEC), VAX 11/780. The VAX 11/780 was used to perform data I/O, Arithmetic Logic Unit (ALU) calculations, and memory and disk assignment operations. The terminal device for input/output to the VAX 11/780 was a DEC VT100-AA.

The graphics processor used in this study was a Vectrix Corporation, VX384-A color graphics processor. The Vectrix was used for processing and storing data from the VAX 11/780 computer. The Vectrix provides a spatial resolution of 672 x 480 pixels (picture elements), 8 bits of intensity resolution for each red, green, and blue electron gun. It is capable of simultaneously displaying 512 colors from a

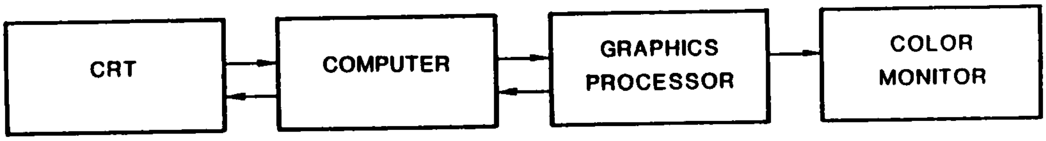

Figure 3.1. Equipment used in displaying the Monte Carlo input/output data

total palette of 16.8×10^6 colors. The processed data are output to the Aydin monitor for generating color images.

The color monitor used in this study was an Aydin Controls Corporation Model 8830, analog patriot series monitor. The Aydin color monitor was used for displaying the output data from the Vectrix. The monitor is an in-line gun, high resolution (700 x 700 pixels) red, green, blue, shadow mask display device designed for compatibility with alphanumeric and graphic raster-scan display systems.

3.2 Software used for generating pseudocolor images

The following section presents a flowchart (Figure 3.2; Appendix) of the procedures used for generating and displaying color images. To facilitate discussions of the flowchart, the following section is presented in seven parts: (3.2.1) Input data, (3.2.2) Load Vectrix color table, (3.2.3) Display CTCS spectrum, (3.2.4) Linear interpolation of the Monte Carlo input data, (3.2.5) Display a miniature CTCS spectrum, (3.2.6) Color display of anatomic data (Monte Carlo input data), and (3.2.7) Isocontour plot routines (color plots of Monte Carlo output data).

3.2.1 Input data

The Monte Carlo input/output data were obtained from Vanderbilt University, Radiation Oncology Center. The input data represented eighteen anatomical cross-sections of a female cadaver head recorded in intervals of one centimeter. The output data represented radiation

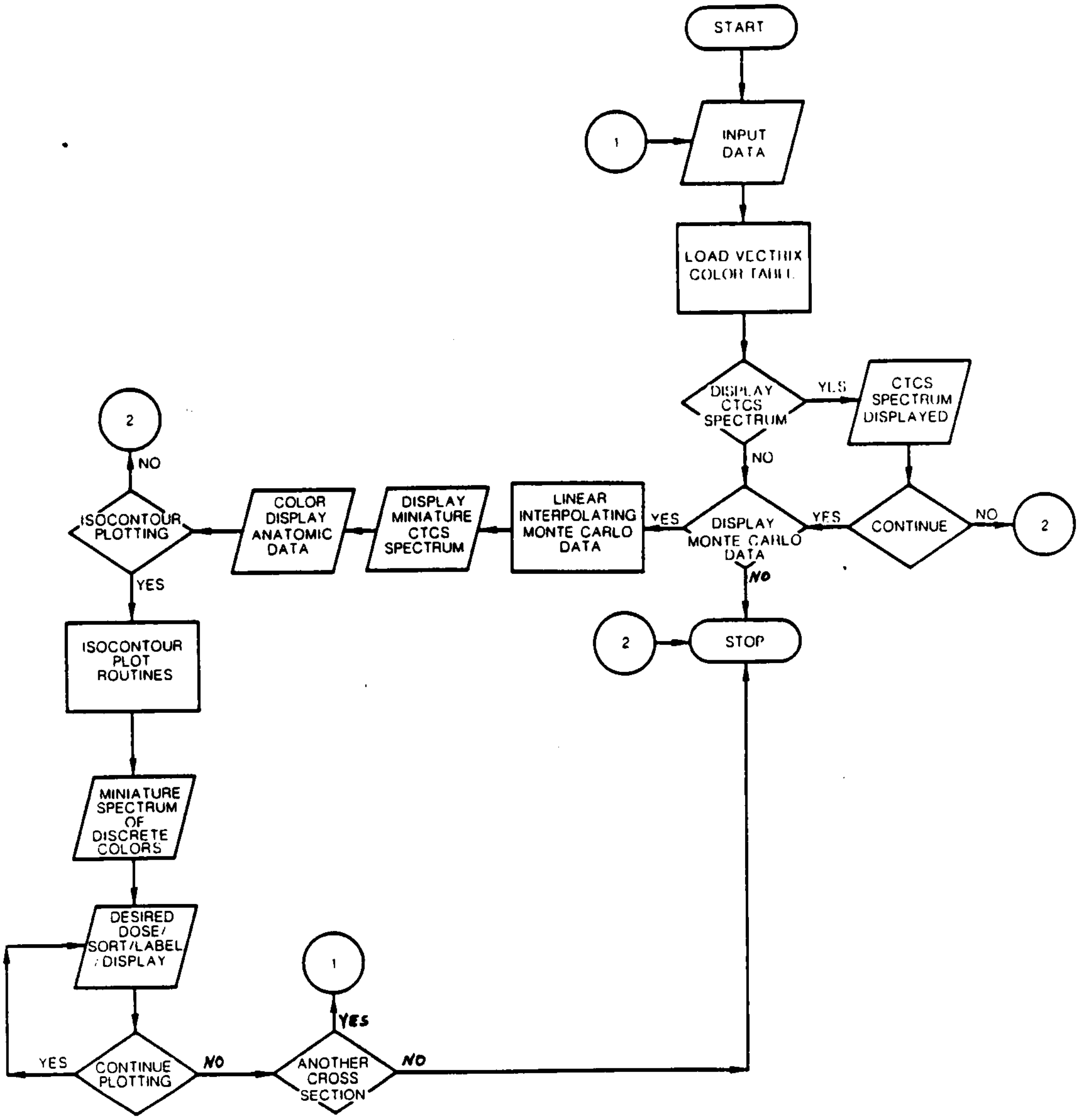

Figure 3.2. A flowchart of the computer program

dosage within the head of the cadaver as generated by the Monte Carlo algorithm. Both data sets were then input by magnetic tape to the VAX 11/780 computer (Section 3.1) at The University of Tennessee Space Institute (UTSI). The data served as the input data (subroutine READ-TAPE-SLICE and subroutine READ-TAPE-DOSE) to the computer program. The computer program is then initiated when a particular Slice Number of interest is input to the computer.

3.2.2 Load Vectrix color table

Subroutine COLOR-TABLE, was used for loading the Vectrix RAM with tabulated numerical values for CTCS spectrum simulation. These numerical values are referenced (as a lookup table) by the Vectrix processor for controlling the red, green, and blue electron guns of the Aydin monitor for pseudocolor simulation. Due to the limited color slots available within the Vectrix processor (512 addresses), numerical values were selected by trial and error to provide effective simulation of the CTCS spectrum. Table 3.1 illustrates RAM addresses (slots) 0-18 assigned to color intensities reserved for plotting isocontour curves of the dose data values, and addresses 19-511 for the CTCS color representation of the anatomic Monte Carlo input data set. The nineteen colors used for isocontour plotting were chosen to provide a discernible contrast between the CTCS colors and the particular isocontour plots of interest.

Table 3.1. The Vectrix pseudocolor lookup table

SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED
0	0	0	0	60	0	0	187	120	0	0	247	180	0	179	255
1	255	0	0	61	0	0	188	121	0	0	248	181	0	180	255
2	0	255	0	62	0	0	189	122	0	0	249	182	0	181	255
3	155	0	155	63	0	0	190	123	0	0	250	183	0	182	255
4	100	0	0	64	0	0	191	124	0	0	251	184	0	183	255
5	0	230	0	65	0	0	192	125	0	0	252	185	0	184	255
6	160	105	200	66	0	0	193	126	0	0	253	186	0	185	255
7	205	0	0	67	0	0	194	127	0	0	254	187	0	186	255
8	0	205	0	68	0	0	195	128	0	0	255	188	0	187	255
9	135	130	200	69	0	0	196	129	0	128	255	189	0	188	255
10	230	0	0	70	0	0	197	130	0	129	255	190	0	189	255
11	110	155	200	71	0	0	198	131	0	130	255	191	0	190	255
12	0	100	0	72	0	0	199	132	0	131	255	192	0	191	255
13	205	0	205	73	0	0	200	133	0	132	255	193	0	192	255
14	155	0	0	74	0	0	201	134	0	133	255	194	0	193	255
15	185	80	200	75	0	0	202	135	0	134	255	195	0	194	255
16	0	155	0	76	0	0	203	136	0	135	255	196	0	195	255
17	85	180	200	77	0	0	204	137	0	136	255	197	0	196	255
18	180	0	180	78	0	0	205	138	0	137	255	198	0	197	255
19	0	0	41	79	0	0	206	139	0	138	255	199	0	198	255
20	0	0	47	80	0	0	207	140	0	139	255	200	0	199	255
21	0	0	53	81	0	0	208	141	0	140	255	201	0	200	255
22	0	0	59	82	0	0	209	142	0	141	255	202	0	201	255
23	0	0	65	83	0	0	210	143	0	142	255	203	0	202	255
24	0	0	71	84	0	0	211	144	0	143	255	204	0	203	255
25	0	0	77	85	0	0	212	145	0	144	255	205	0	204	255
26	0	0	83	86	0	0	213	146	0	145	255	206	0	205	255
27	0	0	89	87	0	0	214	147	0	146	255	207	0	206	255
28	0	0	95	88	0	0	215	148	0	147	255	208	0	207	255
29	0	0	101	89	0	0	216	149	0	148	255	209	0	208	255
30	0	0	107	90	0	0	217	150	0	149	255	210	0	209	255
31	0	0	113	91	0	0	218	151	0	150	255	211	0	210	255
32	0	0	119	92	0	0	219	152	0	151	255	212	0	211	255
33	0	0	125	93	0	0	220	153	0	152	255	213	0	212	255
34	0	0	131	94	0	0	221	154	0	153	255	214	0	213	255
35	0	0	137	95	0	0	222	155	0	154	255	215	0	214	255
36	0	0	143	96	0	0	223	156	0	155	255	216	0	215	255
37	0	0	149	97	0	0	224	157	0	156	255	217	0	216	255
38	0	0	155	98	0	0	225	158	0	157	255	218	0	217	255
39	0	0	161	99	0	0	226	159	0	158	255	219	0	218	255
40	0	0	167	100	0	0	227	160	0	159	255	220	0	219	255
41	0	0	168	101	0	0	228	161	0	160	255	221	0	220	255
42	0	0	169	102	0	0	229	162	0	161	255	222	0	221	255
43	0	0	170	103	0	0	230	163	0	162	255	223	0	222	255
44	0	0	171	104	0	0	231	164	0	163	255	224	0	223	255
45	0	0	172	105	0	0	232	165	0	164	255	225	0	224	255
46	0	0	173	106	0	0	233	166	0	165	255	226	0	225	255
47	0	0	174	107	0	0	234	167	0	166	255	227	0	226	255
48	0	0	175	108	0	0	235	168	0	167	255	228	0	227	255
49	0	0	176	109	0	0	236	169	0	168	255	229	0	228	255
50	0	0	177	110	0	0	237	170	0	169	255	230	0	229	255
51	0	0	178	111	0	0	238	171	0	170	255	231	0	230	255
52	0	0	179	112	0	0	239	172	0	171	255	232	0	231	255
53	0	0	180	113	0	0	240	173	0	172	255	233	0	232	255
54	0	0	181	114	0	0	241	174	0	173	255	234	0	233	255
55	0	0	182	115	0	0	242	175	0	174	255	235	0	234	255
56	0	0	183	116	0	0	243	176	0	175	255	236	0	235	255
57	0	0	184	117	0	0	244	177	0	176	255	237	0	236	255
58	0	0	185	118	0	0	245	178	0	177	255	238	0	237	255
59	0	0	186	119	0	0	246	179	0	178	255	239	0	238	255

Table 3.1. (Continued)

SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED
240	0	239	255	300	44	255	255	360	104	255	255	420	164	255	255
241	0	240	255	301	45	255	255	361	105	255	255	421	165	255	255
242	0	241	255	302	46	255	255	362	106	255	255	422	166	255	255
243	0	242	255	303	47	255	255	363	107	255	255	423	167	255	255
244	0	243	255	304	48	255	255	364	108	255	255	424	168	255	255
245	0	244	255	305	49	255	255	365	109	255	255	425	169	255	255
246	0	245	255	306	50	255	255	366	110	255	255	426	170	255	255
247	0	246	255	307	51	255	255	367	111	255	255	427	171	255	255
248	0	247	255	308	52	255	255	368	112	255	255	428	172	255	255
249	0	248	255	309	53	255	255	369	113	255	255	429	173	255	255
250	0	249	255	310	54	255	255	370	114	255	255	430	174	255	255
251	0	250	255	311	55	255	255	371	115	255	255	431	175	255	255
252	0	251	255	312	56	255	255	372	116	255	255	432	176	255	255
253	0	252	255	313	57	255	255	373	117	255	255	433	177	255	255
254	0	253	255	314	58	255	255	374	118	255	255	434	178	255	255
255	0	254	255	315	59	255	255	375	119	255	255	435	179	255	255
256	0	255	255	316	60	255	255	376	120	255	255	436	180	255	255
257	1	255	255	317	61	255	255	377	121	255	255	437	181	255	255
258	2	255	255	318	62	255	255	378	122	255	255	438	182	255	255
259	3	255	255	319	63	255	255	379	123	255	255	439	183	255	255
260	4	255	255	320	64	255	255	380	124	255	255	440	184	255	255
261	5	255	255	321	65	255	255	381	125	255	255	441	185	255	255
262	6	255	255	322	66	255	255	382	126	255	255	442	186	255	255
263	7	255	255	323	67	255	255	383	127	255	255	443	187	255	255
264	8	255	255	324	68	255	255	384	128	255	255	444	188	255	255
265	9	255	255	325	69	255	255	385	129	255	255	445	189	255	255
266	10	255	255	326	70	255	255	386	130	255	255	446	190	255	255
267	11	255	255	327	71	255	255	387	131	255	255	447	191	255	255
268	12	255	255	328	72	255	255	388	132	255	255	448	192	255	255
269	13	255	255	329	73	255	255	389	133	255	255	449	193	255	255
270	14	255	255	330	74	255	255	390	134	255	255	450	194	255	255
271	15	255	255	331	75	255	255	391	135	255	255	451	195	255	255
272	16	255	255	332	76	255	255	392	136	255	255	452	196	255	255
273	17	255	255	333	77	255	255	393	137	255	255	453	197	255	255
274	18	255	255	334	78	255	255	394	138	255	255	454	198	255	255
275	19	255	255	335	79	255	255	395	139	255	255	455	199	255	255
276	20	255	255	336	80	255	255	396	140	255	255	456	200	255	255
277	21	255	255	337	81	255	255	397	141	255	255	457	201	255	255
278	22	255	255	338	82	255	255	398	142	255	255	458	202	255	255
279	23	255	255	339	83	255	255	399	143	255	255	459	203	255	255
280	24	255	255	340	84	255	255	400	144	255	255	460	204	255	255
281	25	255	255	341	85	255	255	401	145	255	255	461	205	255	255
282	26	255	255	342	86	255	255	402	146	255	255	462	206	255	255
283	27	255	255	343	87	255	255	403	147	255	255	463	207	255	255
284	28	255	255	344	88	255	255	404	148	255	255	464	208	255	255
285	29	255	255	345	89	255	255	405	149	255	255	465	209	255	255
286	30	255	255	346	90	255	255	406	150	255	255	466	210	255	255
287	31	255	255	347	91	255	255	407	151	255	255	467	211	255	255
288	32	255	255	348	92	255	255	408	152	255	255	468	212	255	255
289	33	255	255	349	93	255	255	409	153	255	255	469	213	255	255
290	34	255	255	350	94	255	255	410	154	255	255	470	214	255	255
291	35	255	255	351	95	255	255	411	155	255	255	471	215	255	255
292	36	255	255	352	96	255	255	412	156	255	255	472	216	255	255
293	37	255	255	353	97	255	255	413	157	255	255	473	217	255	255
294	38	255	255	354	98	255	255	414	158	255	255	474	218	255	255
295	39	255	255	355	99	255	255	415	159	255	255	475	219	255	255
296	40	255	255	356	100	255	255	416	160	255	255	476	220	255	255
297	41	255	255	357	101	255	255	417	161	255	255	477	221	255	255
298	42	255	255	358	102	255	255	418	162	255	255	478	222	255	255
299	43	255	255	359	103	255	255	419	163	255	255	479	223	255	255

Table 3.1. (Continued)

SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED	SLOTS	BLUE	GREEN	RED
480	224	255	255	488	232	255	255	496	240	255	255	504	248	255	255
481	225	255	255	489	233	255	255	497	241	255	255	505	249	255	255
482	226	255	255	490	234	255	255	498	242	255	255	506	250	255	255
483	227	255	255	491	235	255	255	499	243	255	255	507	251	255	255
484	228	255	255	492	236	255	255	500	244	255	255	508	252	255	255
485	229	255	255	493	237	255	255	501	245	255	255	509	253	255	255
486	230	255	255	494	238	255	255	502	246	255	255	510	254	255	255
487	231	255	255	495	239	255	255	503	247	255	255	511	255	255	255

3.2.3 Display CTCS spectrum

Subroutine PRINT-COLOR-SPECTRUM, utilizes the lookup table discussed in Section 3.2.2, and generates a CTCS spectrum upon an Aydin color monitor (Figure 3.3). The first nineteen slots illustrate nineteen discrete colors to be used for color coding the isocontour plots and the other four hundred and ninety-two slots (simulating the CTCS spectrum) to be used for the linear interpolation procedures (Section 3.2.4).

3.2.4 Linear interpolation of the Monte Carlo input data

Referring to subroutine MAKE-IMAGE and Figure 3.4, a linear correlation of the Monte Carlo input data (Section 3.2.1) versus color (CTCS spectrum values) was developed for assigning discernible color values to the Monte Carlo CT numbers. Utilizing the point-slope equation (14),

$$y = mx + b, \tag{1}$$

the above procedure is developed by letting,

$$\text{Slope} = m = \frac{Y2-Y1}{X2-X1} = \frac{511.-19.}{X2-X1} = \frac{492.}{X2-X1}\,, \tag{2}$$

where, referring to Table 3.1, Y2 is the maximum slot value, 511, containing the numerical value for the color white, Y1 is the minimum slot value, 19, containing the numerical value for the color red, X2 is a maximum anatomic data value, and X1 is a minimum anatomic data value. Both values X1, X2 are acquired upon reading the CT data within subroutine READ-TAPE-SLICE (Section 3.2.1). Solving Equation (1),

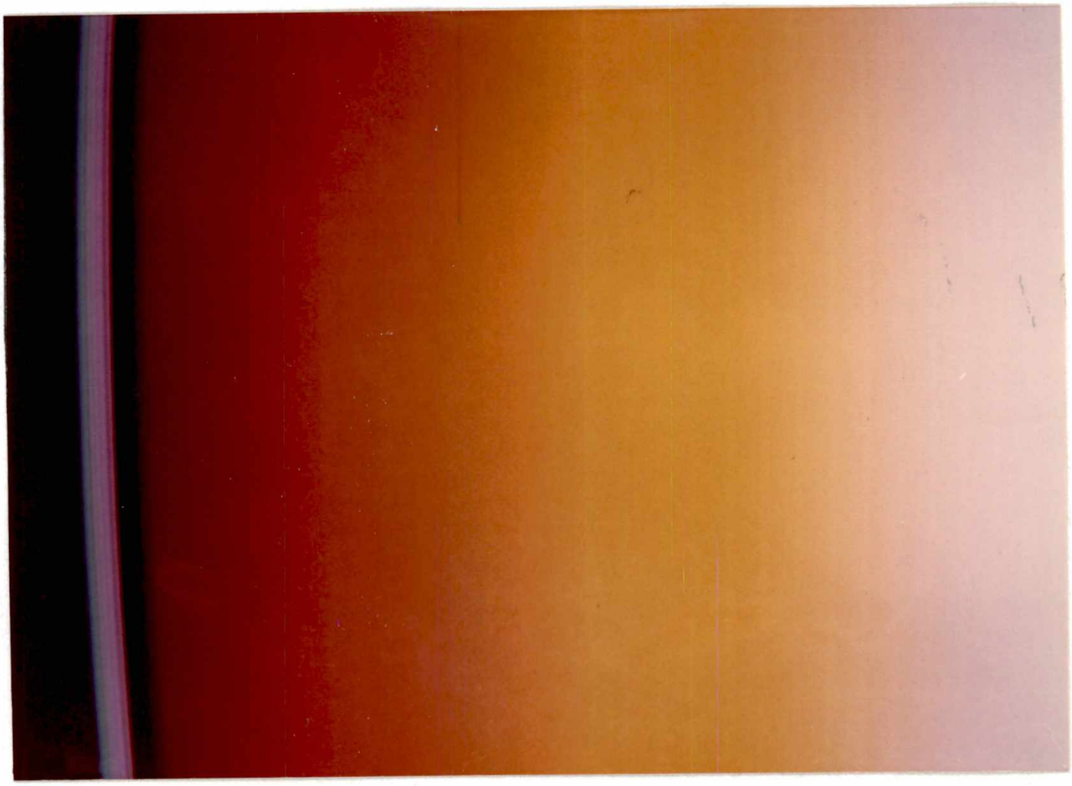

Figure 3.3. An image illustrating the nineteen discrete colors used for isocontour plotting and the CTCS spectrum used for CT number assignment

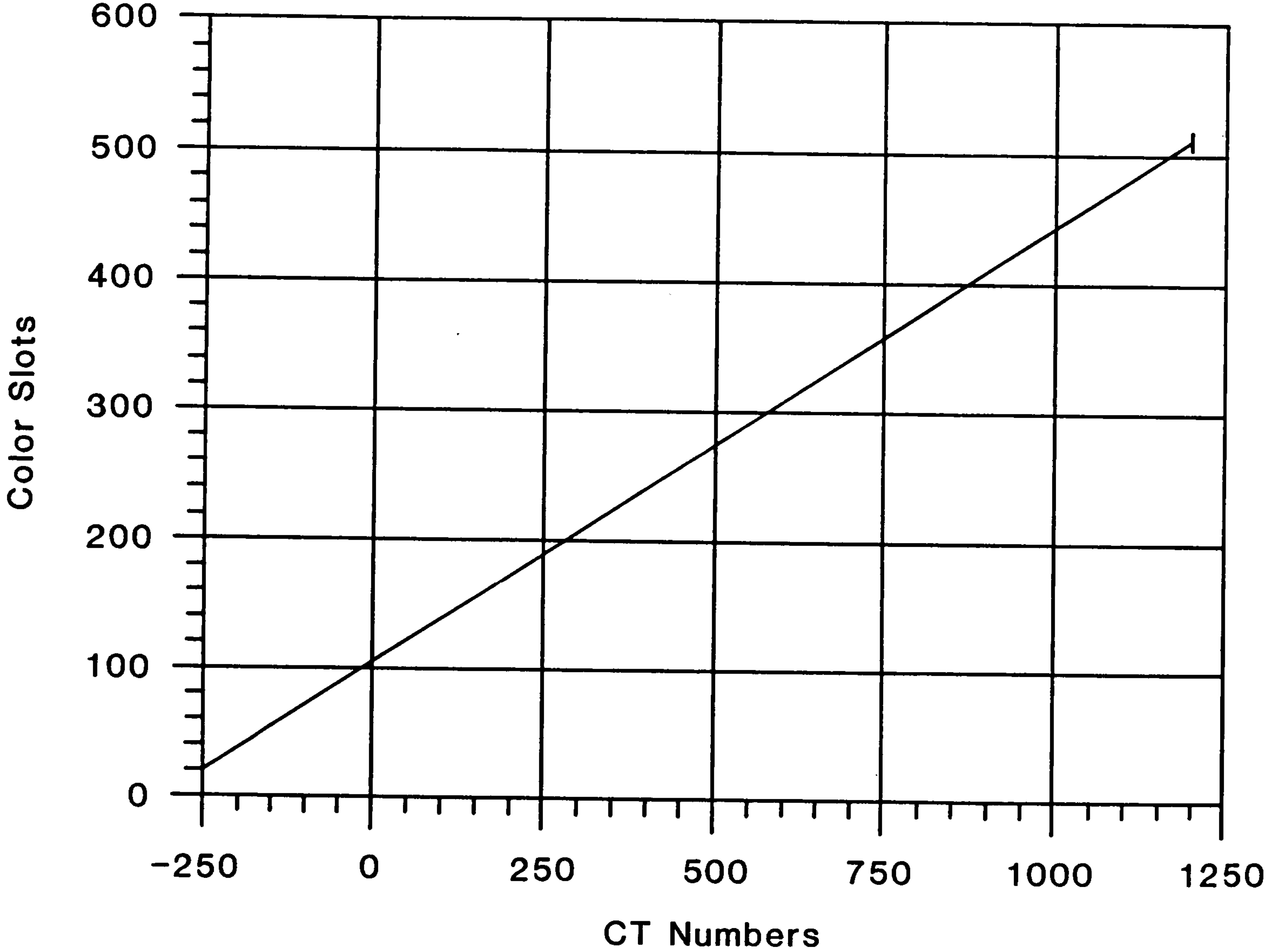

Figure 3.4. CT numbers vs color slots

for the y-intercept,

$$b = y - mx, \tag{3}$$

where y = Y2, and x = X2.

Thus, substituting Equation (2) into Equation (3),

$$b = 511. - \frac{(492.)(X2)}{(X2-X1)} . \tag{4}$$

Substituting Equations (2) and (4) into Equation (1),

$$y = \frac{(492.)(X2)}{(X2-X1)} + \left(511. - \frac{(492.)(X2)}{(X2-X1)}\right) = Cy, \tag{5}$$

where, Cy is a function of X1 that selects the particular color values within the CTCS spectrum.

3.2.5 Display a miniature CTCS spectrum

Subroutine IMAGE-SPECTRUM, generates and displays a miniature CTCS spectrum (Figure 4.1) for correlating assigned CTCS colors to CT data values. This miniature spectrum, as with the previously displayed CTCS spectrum (Section 3.2.3), is generated by displaying the numerical values located in slots 19-511 of the Vectrix (Section 3.2.2).

3.2.6 Color display of anatomic data (Monte Carlo input data)

After the above procedures are completed, the data are then displayed (in X and Y coordinates) by subroutine DISPLAY-IMAGE (Appendix) on the Aydin color monitor.

3.2.7 Isocontour plot routines (Color plots of Monte Carlo output data)

If isocontour plots are desired, the isocontour plot routines are called and generation of discrete color coded isocontour lines are initiated (subroutine MAKE-ISODOSE). Subroutine CONTUR, used within the isocontour plot routines was written by Phil Sherrod, Vanderbilt University Computer Center, and later modified by Dr. S. Julian Gibbs (15), Radiation Oncology Center, Vanderbilt University Hospital. Subroutine CONTUR,was used at Vanderbilt to drive a vector plotter. To produce output suitable for the Vectrix, it was converted to raster output, with appropriate scaling to the Vectrix pixel dimensions.

3.2.7a Display a miniature discrete color spectrum

A second miniature spectrum (Figure 4.2) is generated and displayed for correlating color coded isocontour lines to Monte Carlo output dose data values of interest (subroutine ISOCONTOUR-SPECTRUM). The particular colors are stored in slots 0-18 of the color table (Section 3.2.2). These colors provide a visual distinction between colors used for isocontour plotting and those used for anatomic representation.

3.2.7b Desired dose data values

It is at this part of the program, subroutine READ-GRID, that the isocontour plots for the particular radiation dose data values of interest are input to the computer program. Once the number of values (from 1 to 19) are entered, the program proceeds with its plotting routines (Sections 3.2.7c, 3.2.7d, and 3.2.7e). Upon completion, program control is returned to this subroutine for additional desired input values.

3.2.7c Sort desired values in ascending order

Once subroutine READ-GRID, has completed its execution, subroutine SORTER, is called for sorting (in ascending order) and color coding (Section 3.2.7a) desired values of choice.

3.2.7d Write desired values beside miniature spectrum

Subroutine LABEL, then proceeds to label the desired numerical values of interest next to the corresponding colors of the second miniature spectrum (Section 3.2.7a).

3.2.7e Display input isocontour values

Subroutine CONTUR, then proceeds to generate and display the desired isocontour lines of interest, superimposed upon the displayed anatomic cross-section of interest. If additional isocontour plots or another cross-section is desired, the above procedures are repeated.

CHAPTER IV

RESULTS

The previous chapter presented the procedures used for generating images of the Monte Carlo data. The following chapter presents these images and compares them to those generated by Pujol and Gibbs (1,2).

Figure 4.1 provides a color image of an anatomic cross-section generated by the program for a slice through the mid-facial region. The figure illustrates bone as white (CT numbers approaching 1200), air as black (CT numbers less than -250), and soft tissue as shades of the CTCS spectrum (CT numbers between -250 and 1200). A comparison of Figure 4.1 with Figure 4.4 shows the excellent discernible detail generated by the CTCS spectrum, as compared to the figure of Pujol and Gibbs. The image consists of 320 x 320 pixels, each pixel representing 0.64 mm^2.

Figure 4.2 duplicates Figure 4.1, but with isocontour lines of interest superimposed. Each isocontour line represents a particular dose data value (Monte Carlo output data) of choice. Figure 4.3 provides a close-up of Figure 4.2. Figure 4.2 also illustrates the two miniature spectra scales showing color gradations which may be used for color comparison of input/output data to numerical values. The selected dose data values for this image were 100, 200, 500, 1000, 2000, 5000, 8000, 10000, and 12000 micrograys. These values matched those selected by Pujol and Gibbs in Figure 4.4. A comparison of Figure 4.2 and Figure 4.4 illustrates the marked improvement in

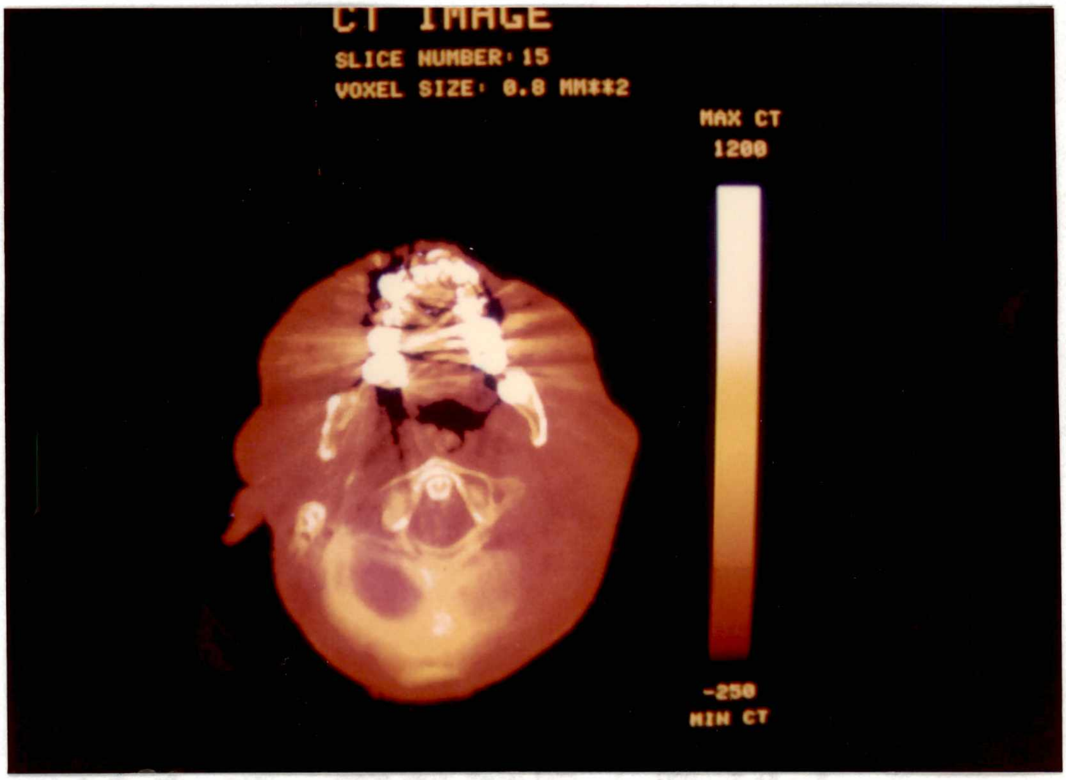

Figure 4.1. A color image of a slice through the mid-facial region

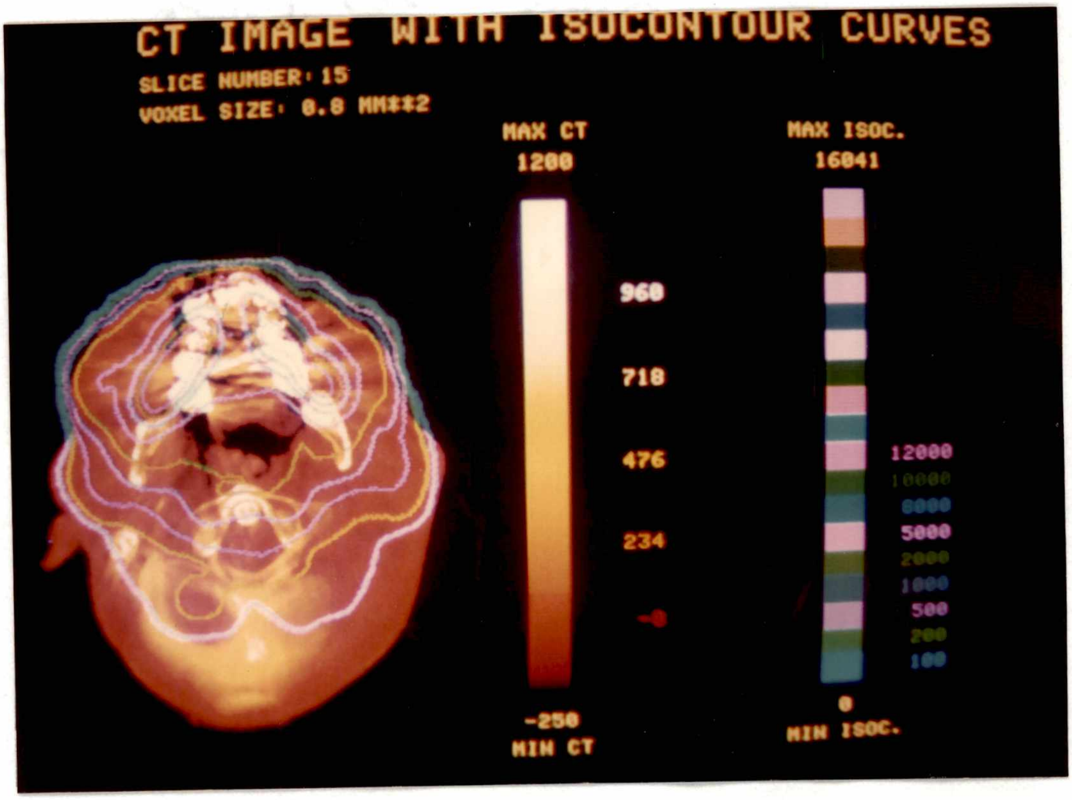

Figure 4.2. Isocontour lines of radiation dose superimposed upon Figure 4.1

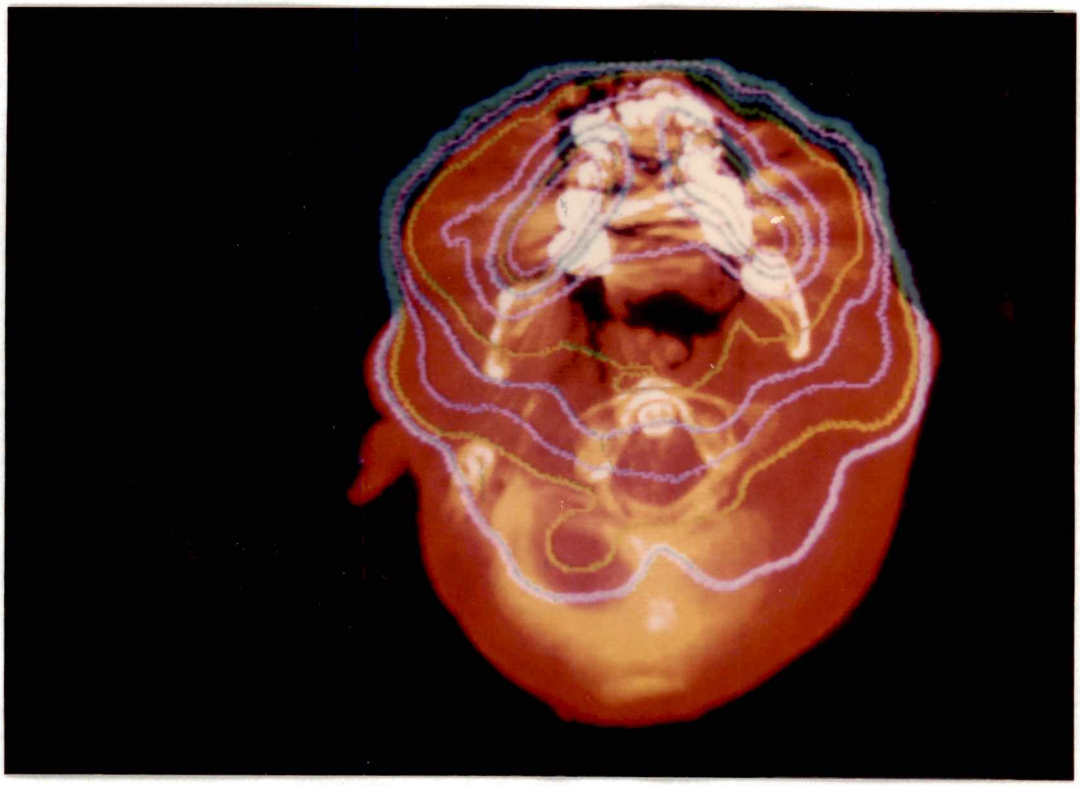

Figure 4.3. A close-up of Figure 4.2

SLICE NUMBER 15

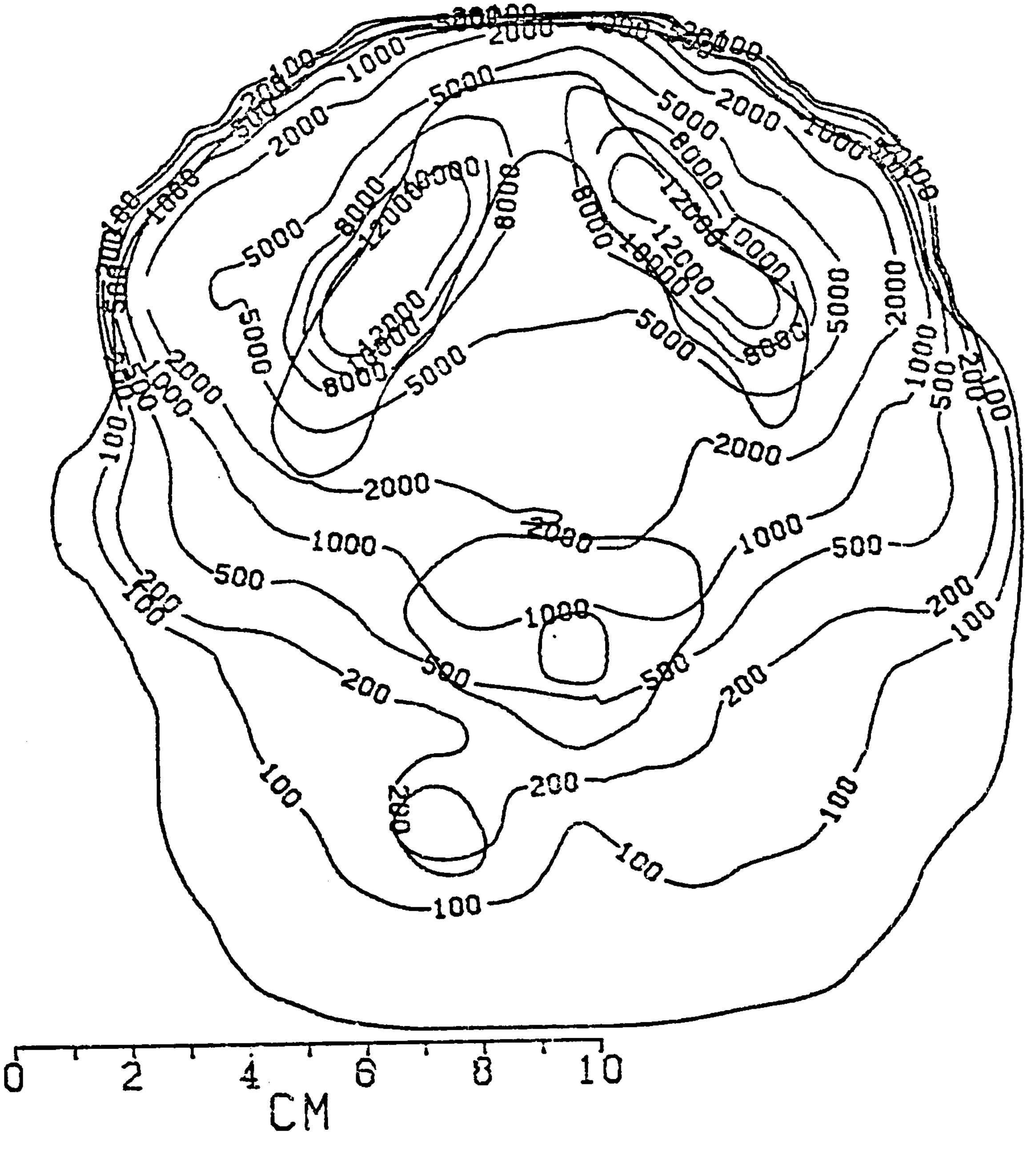

Figure 4.4. Isocontour lines representing anatomy and radiation dose

interpretability given by the CTCS spectrum - isocontour dose level display combination. With multiple isocontour lines representing dose superimposed upon isocontour lines representing anatomy, the difficulties of determining which is which are evident. While Figure 4.4 lacks distinction between lines representing anatomy and isocontours representing radiation dose, Figure 4.2 readily provides clarity and visual distinction between anatomy and dose isocontour plots. In addition, Figure 4.2 provides additional information as to the internal tissues within the anatomic cross-section of interest. This added information should benefit investigators in determining anatomic dose distribution.

CHAPTER V

DISCUSSION

A comparison of the images developed by superimposing isocontour lines of dose radiation on CTCS anatomical detail shows an advantage over the type of presentation by Pujol and Gibbs. In particular, the new method presents information in a more easily interpretable form. A visual comparison of these images illustrates the enhancement which color adds to the analytical process. In addition, the figures also provided additional information on the internal tissues within the anatomic cross-section of interest. A problem encountered in generating these images was the selection of a proper color scheme for color coding the many different numerical values of the input data. The study revealed that the use of the continuous temperature-color scale technique provided more discernible color levels for the Monte Carlo input data.

Another problem was to select nineteen discrete colors which were unrelated to CTCS colors so that the superimposed isocontour lines would be discernible. This selection of colors was determined by trial and error. Another problem was the utilization of the isocontour plot routines developed by Phil Sherrod and utilized by Pujol and Gibbs. For this project, these plot routines, developed for the Zeta plotter at Vanderbilt University Computer Center, had to be extensively modified for application to the Vectrix graphics processor.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

For this research, a computer program (Appendix) was developed for generating color images of the Monte Carlo input/output data. The CTCS spectrum provided excellent color images representing the anatomic Monte Carlo input data. The nineteen colors utilized for representing radiation dose data (Monte Carlo output data) provided excellent contrast between themselves and with the color coded anatomic background. The program generated excellent color images representing anatomy with isocontour lines of interest superimposed. A visual comparison of these images to those images previously generated by Pujol and Gibbs, demonstrated the greater clarity and detail provided by the new color images. This added clarity and detail should provide more information for establishing better illustrations and teaching aids.

Since only one slice (Slice Number 15) of the head section of the female cadaver was used for this study, an area for further research is to repeat this study for the remaining seventeen slices. All color images generated within this research project were displayed in pseudocolor (false color) by the Aydin monitor (which is a graphics system). Another area for further investigation is to repeat the study using an imaging system with greater resolution and better color control. Such a system should provide more life-like detail within the displayed color images. Another area of investigation is the use of more powerful systems with increased RAM to allow handling of more colors within memory. These systems would allow for a closer one-to-one linear representation of CT numbers (-250 to 1200) versus CTCS spectrum color levels. Also, such systems could increase the spatial resolution from 700 x 700 pixels provided by the Aydin, to 1024 x 1024 pixels or greater. Such increased resolution should greatly enhance detail and other information desired by the investigator.

In addition to these potential hardware improvements, refinements to the software may be considered. The dose distribution (Monte Carlo output) data are quite noisy, and are filtered for display. Current filtering techniques are quite general - useful for essentially any data. Specific methods applicable to dose distribution data may be developed to minimize the possibility of artifacts in the display. Further, application of principles of color perception to the color lookup tables may be considered, with the potential of improved perceptibility of image details.

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APPENDIX

COMPUTER GENERATION OF TWO-DIMENSIONAL PSEUDOCOLOR IMAGES OF MONTE CARLO INPUT/OUTPUT DATA

This appendix presents a listing of the computer program developed in this project. The program is written in FORTRAN IV and FORTRAN 77 programming languages, with execution on the VAX 11/780 at The University of Tennessee Space Institute's Computer Center.

```
C
C     ************************** MAIN **************************
C
      COMMON/IICOLOR/ICOLOR(0:512)/IMAGES/IIMAGE(320,320)
     1/DOSES/DOSE(321,321)/ISPEED/IXS(102400),IYS(102400)
     2/CONVERT/IMAGE(375,375)/CHARACTZ/CHARACT(320,320)
      COMMON IRED(0:512),IGREEN(0:512),IBLUE(0:512)
      INTEGER XX2,XX1,XC2,XC1
C
      WRITE(7,*)'EOEO'
C     ARRAY "IMAGE" SERVES AS CONVERSION ARRAY FOR IIMAGE AND DOSE
C     IVARY IS USED AS A DOUBLE IMAGE DISPLAY OPTION
      IVARY=0
C
      CALL COLOR_TABLE
C
C
      TYPE*,'     '
      TYPE*,'     '
      TYPE*,'THIS PROGRAM PRESENTS THE DEVELOPMENT OF ALGORITHMS'
      TYPE*,'TO DISPLAY TWO-DIMENSIONAL PSEUDOCOLOR IMAGES OF'
      TYPE*,'MONTE CARLO INPUT/OUTPUT DATA ARRAYS.  THIS ALGORITHM'
      TYPE*,'DESIGNED AT THE UNIVERSITY OF TENNESSEE SPACE INSTITUTE'
      TYPE*,'(1984) IS IN CONJUNCTION WITH ONGOING RESEARCH AT THE'
      TYPE*,'VANDERBILT UNIVERSITY MEDICAL CENTER DEPARTMENT OF'
      TYPE*,'RADIOLOGY AND RADIOLOGICAL SCIENCES, (NASHVILLE, TN)'
      TYPE*,'     '
      TYPE*,'     '
C
C     **** READS MODIFIED CT DATA TAPE ARRAYS ******
   18 TYPE*,'WHAT HEAD SLICE ARE YOU INTERESTED IN (1-18)?'
      ACCEPT*,MM
      IF (MM.LT.1.OR.MM.GT.18) GO TO 18
      N=MM+10
      K=N+20
      KK=K+20
      CALL READ_TAPE_SLICE(XX2,XX1,N,MM)
      CALL READ_TAPE_DOSE(XD2,XD1,IXD2,IXD1,K,MM)
C     CALL READ_TAPE_CHARACT(XC2,XC1,KK,MM)
C
      TYPE*,'     '
   99 TYPE*,'     '
      TYPE*,'     '
      ERASE=LIB$ERASE_PAGE(1,1)
      TYPE*,'PLEASE INDICATE OPTION OF INTEREST'
      TYPE*,'
      TYPE*,'1-->DO YOU WANT ANOTHER HEAT SLICE?'
      TYPE*,'2-->DISPLAY COLOR SPECTRUM'
      TYPE*,'3-->PRINT COLOR SPECTRUM TABLE BIT PATTERN'
      TYPE*,'4-->GENERATE OVERALL DISTRIBUTION TABLE OF'
```

```
      TYPE*,'     CT NUMBERS (IN INTERVALS OF 50 FROM'
      TYPE*,'     -2048 TO 4096) FOR PARTICULAR SLICE'
C
C     SINCE -2048 TO 4096 ARE MINIMUM AND MAXIMUM
C     LIMITATIONS FOR CT NUMBERS GENERATED BY THE
C     GE-CT/T800 SCANNER MACHINE, OVERALL CT DISTRIBUTIONS
C     WILL BE BETWEEN THESE VALUES.
C
      TYPE*,'5-->DISPLAY CT IMAGE (AND ISODOSE CURVES)'
      TYPE*,'6-->DISPLAY CHARACTERIZED (TISSUE) CT IMAGE'
      TYPE*,'7-->DISPLAY DOSE DATA'
      TYPE*,'9-->TERMINATE PROGRAM EXECUTION'
      TYPE*,'
      ACCEPT*,ISELECT
      IF(ISELECT.EQ.1) GO TO 1
      IF(ISELECT.EQ.2) GO TO 2
      IF(ISELECT.EQ.3) GO TO 3
      IF(ISELECT.EQ.4) GO TO 4
      IF(ISELECT.EQ.5) GO TO 5
      IF(ISELECT.EQ.6) GO TO 6
      IF(ISELECT.EQ.7) GO TO 7
      IF(ISELECT.EQ.9) GO TO 9
      GO TO 9
    1 TYPE*,'WHAT HEAD SLICE ARE YOU INTERESTED IN (1-18)?'
      ACCEPT*,MM
      IF(MM.LT.1.OR.MM.GT.18) GO TO 1
      N=MM+10
      K=N+20
      KK=K+20
      CALL READ_TAPE_SLICE(XX2,XX1,N,MM)
      CALL READ_TAPE_DOSE(XD2,XD1,IXD2,IXD1,K,MM)
C     CALL READ_TAPE_CHARACT(XC2,XC1,KK,MM)
      TYPE*,'DO YOU WANT TO CONTINUE OR STOP (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) TO TO 99
      GO TO 9
    2 WRITE(7,*)'EOEO'
      CALL COLOR_SPECTRUM
      TYPE*,'DO YOU WANT TO CONTINUE OR STOP (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) GO TO 99
      GO TO 9
    3 CALL PRINT_COLOR_SPECTRUM
      TYPE*,'DO YOU WANT TO CONTINUE OR STOP (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) GO TO 99
      GO TO 9
    4 CALL CT_INTERVAL_COUNT(XX2,XX1,MM)
      TYPE*,'DO YOU WANT TO CONTINUE OR STOP (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) GO TO 99
```

```
      GO TO 9
    5 CALL MAKE_IMAGE(XD2,XD1,XC2,SC1,IXD2,IXD1,MM,IVARY)
      TYPE*,'DO YOU WANT TO CONTINUE OR STOP (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) GO TO 99
      GO TO 9
    6 CALL MAKE_CHARACT(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      TYPE*,'DO YOU WANT TO CONTINUE OR STOP (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) GO TO 99
      GO TO 9
    7 CALL MAKE_DOSE(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      TYPE*,'DO YOU WANT TO CONTINUE OR STOP (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) GO TO 99
    9 STOP
      END
C
C
C
C     ***** READS THE CT DATA ARRAY (320 x 320) *******
C
      SUBROUTINE READ_TAPE_SLICE(XX2,XX1,N,MM)
      COMMON/IMAGES/IIMAGE(320,320)
      DIMENSION ILINE(20)
      INTEGER XX1,XX2
C
C     XX2 IS ARRAY CT_MAX
C     XX1 IS ARRAY CT_MIN
C
      XX2=0
      XX1=0
C
C     TYPE 0.8 MM**2 CT VOXELS ARE AUTOMATICALLY UP-SCALED
C     (SCALE=1.25) TO 1 MM**2 VOXELS
C
      DO IY=1,320
        DO IIX=0,300,20
             READ(N,10)ILINE
             DO J=1,20
                IX=IIX+J
                IIMAGE(IX,IY) = ILINE(J)
                IF(XX2.LT.IIMAGE(IX,IY)) THEN
                XX2=IIMAGE(IX,IY)
                ELSE IF (XX1.GT.IIMAGE(IX,IY)) THEN
                XX1=IIMAGE(IX,IY)
                ENDIF
             ENDDO
        ENDDO
      ENDDO
```

```
      REWIND N
      WRITE(*,1)MM,XX1,XX2
    1 FORMAT(//,1X,'FOR SLICE",I3,' CT_MIN=',I5,
     1'  CT_MAX=',I5,/)
   10 FORMAT(20I5)
      RETURN
      END
C
C
C
C     ***** READS THE CHARACTERIZED TISSUE ARRAY (320 x 320) *****
C     ***** THIS SUBROUTINE READS THE CHARACTERIZED CT DATA  *****
C     *****    ARRAY (0=OUTSIDE AIR, 1=INSIDE AIR SACKS,     *****
C     *****    2=LUNG, 3=FAT, 4=MUSCLE, 5=BONE)              *****
C
      SUBROUTINE READ_TAPE_CHARACT(XC2,XC1,KK,MM)
      COMMON/CHARACTZ/CHARACT(320,320)
      DIMENSION DLINE(8)
C
C     XC2 IS ARRAY TISSUE TYPE MAX
C     XC1 IS ARRAY TISSUE TYPE MIN
C
      XC2=0.
      XC1=0.
C
C     THE 0.546875 MM**2 TISSUE TYPE VOXELS ARE AUTOMATICALLY
C     UP-SCALED (BY 1.828571) TO 1 MM**2 VOXELS.
C
      DO IY=1,320
        IX=0
        DO IIX=1.40
             READ(KK,10)DLINE
             DO J=1.8
                IX=IX+1
                CHARACT(IX,IY) = DLINE(J)-1.0
                IF(XC2.LT.CHARACT(IX,IY)) XC2=CHARACT(IX,IY)
             ENDDO
        ENDDO
      ENDDO
      REWIND KK
      WRITE(*,1)MM,XC1,XC2
    1 FORMAT(//,1X,'FOR SLICE",I3,' MIN_TISSUE_TYPE=',F5.3,
    1'   MAX_TISSUE_TYPE=',F5.3,/)
   10 FORMAT(8E12.5)
C
      RETURN
      END
C
C
C
C     ***** READS THE DOSE DATA ARRAY (320 x 320) *******
```

```
C
      SUBROUTINE READ_TAPE_DOSE(XD2,XD1,IXD2,IXD1,K,MM)
      COMMON/DOSES/DOSE(321,321)
      DIMENSION DLINE(8)
C
C     XD2 IS ARRAY MAX_DOSE
C     XD1 IS ARRAY MIN_DOSE
C
C     SINCE DOSE VALUES RANGE FROM 0 TO 10**5
C     A LOGARITHMIC CONVERSION (Y=LOG X) IS PERFORMED
C     TO DOWN SCALE VALUES (FROM 0 TO 10**1).
C
      XD2=0.
      XD1=0.
      IXD1=0
C
C     THE 0.546857 MM**2 DOSE VOXELS ARE AUTOMATICALLY UP-SCALED
C     (BY 1.828571) TO 1 MM**2 VOXELS.
C
      DO IY=1,320
        IX=0
        DO IIX=1,40
             READ(K,10)DLINE
             DO J=1.8
                IX=IX+1
                DOSE(IX,IY) = DLINE(J)
                IF(DOSE(IX,IY).LE.1) THEN
                  DOSE(IX,IY)=0.
                ELSE
                  DOSE(IX,IY)=LOG(DOSE(IX,IY)-1.)
                ENDIF
                IF(XD2.LT.DOSE(IX,IY)) XD2=DOSE(IX,IY)
             ENDDO
        ENDDO
      ENDDO
      IXD2=EXP(XD2)
      REWIND K
      WRITE(*,1)MM,IXD1,IXD2
    1 FORMAT(//,1X,'FOR SLICE',I3,' MIN_DOSE=',I3,
     1'  MAX_DOSE=',17,/)
   10 FORMAT(8E12.5)
C
      RETURN
      END
C
C
C
C     ****       LOAD COLOR TABLE WITH COLORS FOR          ****
C     ****   ISOCONTOUR PLOTTING (BLUE,GREEN,MAGENTA,BROWN) ****
C     ****                     AND                          ****
C     ****   WARM BODY TECHNIQUE (RED,ORANGE,YELLOW,WHITE)  ****
```

```
C
      SUBROUTINE COLOR_TABLE
C
      COMMON IRED(0:512),IGREEN(0:512),IBLUE(0:512)
      COMMON/IICOLOR/ICOLOR(0:512)
      OPEN(UNIT=5,NAME='COLORS.DAT',TYPE='OLD')
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
C
      WRITE(7,*)'EOEO'
C
      WRITE(7,10)
   10 FORMAT(1X,'Q 0,512')
C
C
C     "I" REPRESENTS THE SLOT NUMBERS FOR THE COLOR TABLE
C     "J" REPRESENTS THE BIT PATTERN FOR THE PARTICULAR COLORS
C
C     LOAD FIRST 20 SLOTS FOR ISOCONTOUR PLOTTING
C     (BLUE,BROWN,GREEN,MAGENTA)
C
      DO J=0,18
      I=J
      READ(5,*)IRED(I),IGREEN(I),IBLUE(I)
      WRITE(7,*)IRED(I),IGREEN(I),IBLUE(I)
      ENDDO
C
C     ************** RED **************
      DO J=41,161,6
      I=I+1
      IRED(I)=J
      IGREEN(I)=0
      IBLUE(I)=0
      WRITE(7,*)IRED(I),IGREEN(I),IBLUE(I)
      ENDDO
      DO J=167,255
      I=I+1
      IRED(I)=J
      IGREEN(I)=0
      IBLUE(I)=0
      WRITE(7,*)IRED(I),IGREEN(I),IBLUE(I)
      ENDDO
C
C     ************** ORANGE **************
      DO J=128,255
      I=I+1
      IRED(I)=255
      IGREEN(I)=J
      IBLUE(I)=0
      WRITE(7,*)IRED(I),IGREEN(I),IBLUE(I)
      ENDDO
```

```
C
C     ************** YELLOW **************
      DO J=1,127
      I=I+1
      IRED(I)=255
      IGREEN(I)=255
      IBLUE(I)=J
      WRITE (7,*)IRED(I),IGREEN(I),IBLUE(I)
      ENDDO
C
C     ************** WHITE **************
      DO J=128,255
      I=I+1
      IBLUE(I)=J
      IGREEN(I)=255
      IRED(I)=255
      WRITE(7,*)IRED(I),IGREEN(I),IBLUE(I)
      ENDDO
C
C     INITIALIZES ICOLOR TO COLOR VALUE
      DO I=0,511
      ICOLOR(I)=I
      ENDDO
C
      CLOSE(UNIT=7)
C
      RETURN
      END
C
C
C
C     **** GENERATE COLOR SPECTRUM ON VECTRIX ****
C
      SUBROUTINE COLOR_SPECTRUM
      COMMON/IICOLOR/ICOLOR(0:512)
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
      DO I=0,511
      WRITE(7,20)ICOLOR(I),I,I
   20 FORMAT(IX,'C',I4,' M',I4,',I  L',
     1I4,',480')
      ENDDO
      CLOSE(UNIT=7)
      RETURN
      END
C
C
C
C     ****      PRINT COLOR TABLE OF COLORS FOR          ****
C     ****   ISOCONTOUR PLOTTING(BLUE,GREEN,MAGENTA,BROWN)   ****
C     ****                     AND                         ****
```

```
C     ****  WARM BODY TECHNIQUE (RED,ORANGE,YELLOW,WHITE).  ****
C
      SUBROUTINE PRINT_COLOR_SPECTRUM
C
      COMMON IRED(0:512),IGREEN(0:512),IBLUE(0:512)
      COMMON/IICOLOR/ICOLOR(0:512)
C
      OPEN(UNIT=6,NAME='VCOLOR.DAT',TYPE='NEW')
C
      WRITE(6,7)
    7 FORMAT('1',T51,'VECTRIX PSEUDOCOLOR LOOKUP TABLE',///,T13,
     14('SLOTS',2X,'BLUE',2X,'GREEN',2X,'RED',6X),/)

C     ** ICOLOR LOADS COLOR TABLE SLOTS (FOR HARDCOPY) **
C
      DO I=0,127
      WRITE(6,711)ICOLOR(I),IBLUE(I),IGREEN(I),IRED(I),
     1ICOLOR(I+128),IBLUE(I+128),IGREEN(I+128),IRED(I+128),
     2ICOLOR(I+256),IBLUE(I+256),IGREEN(I+256),IRED(I+256),
     4ICOLOR(I+384),IBLUE(I+384),IGREEN(I+384),IRED(I+384)
  711 FORMAT(12X,4(I4,2X,I4,2X,I4,2X,I4,7X))
      IF(I.EQ.59.OR.I.EQ.119)WRITE(6,7)
      ENDDO
C
      CLOSE(UNIT=6)
C
      RETURN
      END
C
C
C
C     **** THIS SUBROUTINE PERFORMS CT INTERVAL COUNT ****
C     ****              FOR THE 320x320 ARRAY          ****
C
      SUBROUTINE CT_INTERVAL_COUNT(XX2,XX1,MM)
      COMMON/IMAGES/IIMAGE(320,320)
      DIMENSION IILEFT(150),IIRIGHT(150),IICOUNT(150)
      INTEGER XX1,XX2
      OPEN(UNIT=6,NAME='MMI1.OUT',TYPE='NEW')
C
C
      I=0
      WRITE(6,9)MM
    9 FORMAT(//,T49,'*** NUMBER OF CT NUMBERS PER INTERVAL ***',///
     1,T3,'SLICE',I3,' IN INTERVALS OF 50',/)
      WRITE(6,1I)XX1,XX2
   11 FORMAT(T3,'MINIMUM VALUE=',I7,/,T3,'MAXIMUM VALUE=',I7,//)
      WRITE(6,111)
  111 FORMAT(32X,'INTERVALS',3X,'CT NUMBERS',5X,'INTERVALS',2X,
     1'CT NUMBERS',4X,'INTERVALS',3X,'CT NUMBERS',//)
C
```

```
      DO INTERVAL=-2100,4100,50
      I=I+1
      ILEFT=INTERVAL
      IRIGHT=ILEFT+49
      ICOUNT=0
       DO IY=1,320
         DO IX=1,320
            IF(IIMAGE(IX,IY).GE.ILEFT.AND.
     1         IIMAGE(IX,IY).LE.IRIGHT) THEN
              ICOUNT=ICOUNT+1
            ENDIF
         ENDDO
      ENDDO
      IICOUNT(I)=ICOUNT
      IILEFT(I)=ILEFT
      IIRIGHT(I)=IRIGHT
      ENDDO
      DO I=1,42
      WRIGHT(6,7)IILEFT(I),IIRIGHT(I),IICOUNT(I),ILEFT(I+42)
     1,IIRIGHT(I+42),IICOUNT(I+42),IILEFT(I+84),IIRIGHT(I+84),
     2IICOUNT(I+84)
    7 FORMAT(30X,4(I5,2X,I5,3X,I5,6X))
      ENDDO
C
    1 FORMAT(20I5)
      CLOSE(UNIT=6)
      RETURN
      END
C
C
C
C     **** THIS SUBROUTINE ASSIGNS CT NUMBERS TO COLOR ****
C
      SUBROUTINE MAKE_IMAGE(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      COMMON/IICOLOR/ICOLOR(0:512)/IMAGES/IIMAGE(320,320)
     1/ISPEED/IXS(102400),IYS(102400)/CONVERT/IMAGE(375,375)
C
C
      IF(IVARY.EQ.320) THEN
         X1=-250.
         X2=1200.
         GO TO 320
      ELSE
         GO TO 22
      ENDIF
   21 TYPE*,'IMPROPER ENTRY FOR X1 (AND/OR) X2'
   22 TYPE*,'ENTER CT_WINDOW_MIN & CT_WINDOW_MAX (FOR'
      TYPE*,'PERTINENT INFORMATION USE CT VALUES BETWEEN'
      TYPE*,'-250 TO 1200)'
      ACCEPT*,X1,X2
```

```
      IF(X1.LT.-2048..OR.X2.GT.4096.) TO TO 21
      IF(XL.GE.X2) GO TO 22
  320 SLOPE=492./(X2-X1)
      YINCPT=511.-(492.*(X2/(X2-X1)))
      II=0
C
      DO IIY=319,0,-1
        IY=320-IIY
           DO IX=1,320
             IMAGE(IX,IY)=IIMAGE(IX,(IIY+1))
           IF(IMAGE(IX,IY).LT.X1) THEN
             GO TO 55
            ELSE IF(IMAGE(IX,IY).GT.X2) THEN
             II=II+1
             IXS(II)=IX
             IYS(II)=IY
             IMAGE(IXS(II),IYS(II))=ICOLOR(511)
             GO TO 55
           ENDIF
C
            II=II+1
            IXS(II)=IX
            IYS(II)=IY
C
C     STRAIGHT LINE (Y=M*X+B) ASSIGNMENT OF CT NUMBER TO COLOR
C
            NCL=INT((IMAGE(IX,IY)*SLOPE)+YINCPT)
            IMAGE(IXS(II),IYS(II))=ICOLOR(NCL)
   55      ENDDO
      ENDDO
C
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
      IF(IVARY.EQ.0) WRITE(7,*)'EOEO'
      CLOSE(UNIT=7)
      CALL IMAGE_SPECTRUM(X2,X1,IVARY,MM)
      CALL DISPLAY_IMAGE(II,IVARY)
C
      IF*IVARY,NE,0) GO TO 66
      TYPE*,'DO YOU WANT ISODOSE CURVES? (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.0) GO TO 66
      CALL MAKE_ISODOSE(XD2,XD1,X2,X1)
      RETURN
   66 IF(IVARY.EQ.320) GO TO 316
      TYPE*,'DO YOU WANT CORRESPONDING TISSUE DATA DISPLAYED'
      TYPE*,'WITH THIS IMAGE? (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) THEN
       IVARY=320
       CALL MAKE_CHARACT(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
       GO TO 316
```

```
      ELSE
       TYPE*,'DO YOU WANT CORRESPONDING DOSE DATA DISPLAYED'
       TYPE*,'WITH THIS IMAGE? (YES-1,NO-0)'
       ACCEPT*,IGO
       IF(IGO.NE.1) GO TO #L¢
       IVARY=320
       CALL MAKE_DOSE(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      ENDIF
316   IVARY=0
      TYPE*,'DO YOU WANT A NEW CT IMAGE WINDOW (YES-1,NO-0)'
      ACCEPT*,IWINDOW
      IF(IWINDOW.EQ.1) GO TO 22
      RETURN
      END
C
C
C
C     ****  THIS SUBROUTINE DISPLAYS THE CT COLOR SPECTRUM  ****
C     ****                    WITH IMAGE                    ****
C
      SUBROUTINE IMAGE_SPECTRUM(X2,X1,IVARY,MM)
      COMMON/IICOLOR/ICOLOR(0:512)
      INTEGER*2 MM
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
      MX1=X1
      MX2=X2
      WRITE(7,*)'M',(95+IVARY),375,'C',340,
     1' JM 2 $ CT IMAGE'
      WRITE(7,*)'M',(103+IVARY),350,'C',340,
     1' JM 1 $ SLICE NUMBER:'
      WRITE(7,*)'M',(168+IVARY),350,'C',340,
     1' JM 1 $',MM
      WRITE(7,*)'M',(103+IVARY),335,'C',340,
     1' JM 1 $ VOXEL SIZE" 0.8 MM**2'
      WRITE(7,*)'M',(285+IVARY),10,'C',340,
     1' JM 1 $ MIN CT'
      WRITE(7,*)'M',(242+IVARY),25,'C',340,'$',MX1
      K=17
      DO IIY=36,282
      K=K+2
      WRITE(7,*)'M',(300+IVARY),IIY
      WRITE(7,*)'C',ICOLOR(K),' RF',20,1
      ENDDO
      WRITE(7,*)'M',(242+IVARY),305,'C',340,'$', MX2
      WRITE(7,*)'M',(285+IVARY),320,'C',340,
     1' JM 1 $ MAX CT'
      CLOSE(UNIT=7)
      RETURN
      END
```

```
C
C
C
C    **** THIS SUBROUTINE ASSIGNS TISSUE TYPE TO COLOR ****
C
      SUBROUTINE MAKE_CHARACT(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      COMMON/IICOLOR/ICOLOR(0:512)/CHARACTZ/CHARACT(320,320)
     1/ISPEED/IXS(102400),IYS(102400)/CONVERT/IMAGE(375,375)
C
      IF(IVARY.NE.320) WRITE(7,*)'E0E0'
C
C     TO MAINTAIN ACTUAL VOXEL PROPORTIONS, SCALE IS A FACTOR
C     WHICH DOWN-SCALES THE TISSUE VOXELS RELATIVE TO THE CT VOXELS.
C
      SCALE=0.68359375
C
      II=0
      DO IY=1,320
        DO IX=1,320
         IF(CHARACT(IX,IY).LE.1.) GO TO 10
         II=II+1
         IXS(II)=NINT((IX*SCALE))
         IYS(II)=NINT((IY*SCALE))
C
C     STRAIGHT LINE (Y=M*X+B) ASSIGNMENT OF TISSUE TO COLOR
C
      SLOPE=492./(XC2-XC1)
      YINCPT=511.-(492.*(XC2/(XC2-XC1)))
      NCL=INT((CHARACT(IX,IY)*SLOPE)+YINCPT)
      IMAGE(IXS(II),IYS(II))=ICOLOR(NCL)
  10    ENDDO
      ENDDO
      CALL CHARACT_SPECTRUM(XC2,XC1,IVARY,MM)
      CALL DISPLAY_IMAGE(II,IVARY)
      IF(IVARY.EQ.320) GO TO 316
      TYPE*,'DO YOU WANT CORRESPONDING CT DATA DISPLAYED'
      TYPE*,"WITH THIS IMAGE? (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) THEN
       IVARY=320
       CALL MAKE_IMAGE(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
       GO TO 316
      ELSE
       TYPE*,'DO YOU WANT CORRESPONDING DOSE DATA DISPLAYED'
       TYPE*,'WITH THIS IMAGE? (YES-1,NO-0)'
       ACCEPT*,IGO
       IF(IGO.NE.1) GO TO #L¢
       IVARY=320
       CALL MAKE_DOSE(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      ENDIF
 316  IVARY=0
```

```
      RETURN
      END
C
C
C
C     **** THIS SUBROUTINE DISPLAYS THE TISSUE COLOR SPECTRUM ****
C     ****                      WITH IMAGE                     ****
C
      SUBROUTINE CHARACT_SPECTRUM(XC2,XC1,IVARY,MM)
      COMMON/IICOLOR/ICOLOR(0:512)
      INTEGER*2 MM
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
      MX1=XC1
      MX2=XC2
      WRITE(7,*)'M',(20+IVARY),375,'C',340,
     1' JM 2 $ TISSUE TYPE IMAGE'
      WRITE(7.*)'M',(28+IVARY),350,'C',340,
     1' JM 1 $ SLICE NUMBER:'
      WRITE(7,*)'M',(101+IVARY),350,'C',340,
     1' JM 1 $',MM
      WRITE(7,*)'M',(28+IVARY),335,'C',340,
     1' JM 1 $ VOXEL SIZE: 0.546875 MM**2'
      WRITE(7,*)'M',(275+IVARY),10,'C',340,
     1' JM 1 $ MIN TYPE'
      WRITE(7,*),(232+IVARY),25,'C',340,'$',MX1
      K=17
      DO IIY=36,282
      K=K+2
      WRITE(7,*)'M',(300+IVARY),IIY
      WRITE(7,*)'C',ICOLOR(K),' RF',20,1
      ENDDO
      WRITE(7,*)'M',(232+IVARY),305,'C',340,'$', MX2
      WRITE(7,*)'M',(275+IVARY),320,'C',340,
     1' JM 1 $ MAX TYPE'
      CLOSE(UNIT=7)
      RETURN
      END
C
C
C
C     **** THIS SUBROUTINE ASSIGNS DOSE TO COLOR ****
C
      SUBROUTINE MAKE_DOSE(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      COMMON/IICOLOR/ICOLOR(0:412)/DOSES/DOSE(321,321)
     1/ISPEED/IXS(102400),IYS(102400)/CONVERT/IMAGE(375,375)
C
      IF(IVARY.NE.320) WRITE(7,*)'EOEO'
C
C     TO MAINTAIN ACTUAL VOXEL PROPORTIONS, SCALE IS A FACTOR
C     WHICH DOWN-SCALES THE DOSE VOXELS RELATIVE TO THE CT VOXELS.
```

```
C
      SCALE=0.68359375
C
      II=0
      DO IY=1,320
        DO IX=1,320
         IF(DOSE(IX,IY).EQ.0.) GO TO 10
         II=II+1
         IXS(II)=NINT((IX*SCALE)+40.0)
         IYS(II)=NINT((IY*SCALE)+40.0)
C
C     STRAIGHT LINE (Y=M*X+B) ASSIGNMENT OF DOSE TO COLOR
C     WHERE DATA VALUES HAVE BEEN SCALED (Y=LOG X).
C
         DSLOPE=492./(XD2-XD1)
         DYINCPT=511.-(492.*(XD2/(XD2-XD1)))
         NNCL=INT(DSLOPE*DOSE(IX,IY)+DYINCPT)
         IMAGE(IXS(II),IYS(II))=ICOLOR(NNCL)
   10   ENDDO
      ENDDO
      CALL DOSE_SPECTRUM(IXD2,IXD1,IVARY,MM)
      CALL DISPLAY_IMAGE(II,IVARY)
      IF(IVARY.EQ.320) GO TO 316
      TYPE*,'DO YOU WANT CORRESPONDING CT DATA DISPLAYED'
      TYPE*,'WITH THIS IMAGE? (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.EQ.1) THEN
       IVARY=320
       CALL MAKE_IMAGE(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
       GO TO 316
      ELSE
       TYPE*,'DO YOU CORRESPONDING TISSUE DATA DISPLAYED"
       TYPE*,'WITH THIS IMAGE? (YES-1,NO-0)'
       ACCEPT*,IGO
       IF(IGO.NE.1) GO TO 316
       IVARY=320
       CALL MAKE_CHARACT(XD2,XD1,XC2,XC1,IXD2,IXD1,MM,IVARY)
      ENDIF
  316 IVARY=0
      RETURN
      END
C
C
C
C     **** THIS SUBROUTINE DISPLAYS THE DISE COLOR SPECTRUM ****
C                             WITH IMAGE                    ****
C
      SUBROUTINE DOSE_SPECTRUM(IXD2,IXD1,IVARY,MM)
      COMMON/IICOLOR/ICOLOR(0:512)
      INTEGER*2 MM
```

```
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
C
      WRITE(7,*)'M',(65+IVARY),375,'C',340,
     1' JM 2 $ DOSE IMAGE'
      WRITE(7,*)'M',(70+IVARY),350,'C',340,
     1' JM 1 $ SLICE NUMBER:'
      WRITE(7,*)'M',(135+IVARY),350,'C',340,
     1' JM 1 $',MM
      WRITE(7,*)'M',(70+IVARY),335,'C',340,
     1' JM 1 $ VOXEL SIZE: 0.546875 MM**2'
      WRITE(7,*)'M',(275+IVARY),10,'C',340,
     1' JM 1 $ MIN DOSE'
      WRITE(7,8)'M',(232+IVARY),25,'C',340,'$',IXD1
      K=17
      DO IIY=36,282
      K=K+2
      WRITE(7,*)'M',(300+IVARY),IIY
      WRITE(7,*)'C',ICOLOR(K),' RF',20,1
      ENDDO
      WRITE(7,*)'M',(251+IVARY),305,'C',340,'$', IXD2
      WRITE(7,*)'M',(275+IVARY),320,'C',340,
     1' JM 1 $ MAX DOSE'
      CLOSE(UNIT=7)
      RETURN
      END
C
C
C     **** THIS SUBROUTINE OUTPUTS CT NUMBERS OR DOSE VALUES ****
C     ****       (AS A FUNCTION OF COLOR) TO THE VECTRIX       ****
C
      SUBROUTINE DISPLAY_IMAGE(II,IVARY)
      COMMON/IICOLOR/ICOLOR(0:512)/ISPEED/IXS(102400),IYS(102400)
     1/CONVERT/IMAGE(375,375)
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW',RECL=264,
     1FORM='FORMATTED')
C
      WRITE(7,100)(IMAGE(IXS(I),IYS(I)),(IXS(I)+IVARY),IYS(I),
     1I=1,II)
  100 FORMAT(1X,20('C',I4,'D',I3,',',I3))
      TYPE*,'FINISH=',II
      CLOSE(UNIT=7)
      RETURN
      END
C
C
C
C     ****  THIS SUBROUTINE CALCULATE AND OVERLAY ISODOSE ****
C     ****                 CURVES UPON IMAGE               ****
C
      SUBROUTINE MAKE_ISODOSE(XD2,XD1,X2,X1)
```

```
C
      COMMON FACT,PMSIZE,IOLDX,IOLDY,JSW
      COMMON/GGRID/GRID(321,321)
      COMMON/DOSES/DOSE(321,321)
C
      IOLDX=0
      IOLDY=0
      JSW=5
      N=0
      FACT=4.
      PMSIZE=4.
      XD2=EXP(XD2)
C
      CALL ISOCONTOUR_SPECTRUM(XD2,XD1,X2,X1)
C
C     READ INPUT DATA FILE
      CALL READ_GRID(XD2,XD1)
C
      RETURN
      END
C
C
C
C
C
      SUBROUTINE ISOCONTOUR_SPECTRUM(XD2,XD1,XX2,XX1)
      COMMON/IICOLOR/ICOLOR(0:512)
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
C
C     LABEL WARM BODY SPECTRUM
      IINC=NINT((XX2-XX1)/6.)
      INC=IINC+XX1
      DO IIY=36,282,41
      IF(IIY.EQ.77.OR.IIY.EQ.118.OR.IIY.EQ.159.OR.
     IIIY.EQ.200.OR.IIY.EQ.241) THEN
      WRITE(7,*)'M',285,IIY,'C',ICOLOR((IIY-19)*2),'$',INC
      INC=INC+IINC
      ELSE
      ENDIF
      ENDDO
C
C     GENERATE ISOCONTOUR SPECTRUM
      WRITE(7,*)'M',225,375,'C',340,
     1' JM 2 $ WITH ISOCONTOUR CURVES'
      IXD1=XD1
      IXD2=XD2
      WRITE(7,*)'M',426,10,'C',340,
     1' JM 1 $ MIN ISOC.'
      WRITE(7,*)'M',383,25,'C',340,'$',IXD1
C
```

```
C     DRAWS ISOCONTOUR SPECTRUM
      K=0
      DO IIY=36,288,14
      K=K+1
      WRITE(7,*)'M',450,IIY
      WRITE(7,*)'C',ICOLOR(K),' RF',20,14
      ENDDO
C
      WRITE(7,*)'M',397,305,'C',340,'$', IXD2
      WRITE(7,*)'M',426,320,'C',340,
     1' JM 1 $ MAX ISOC.'
      CLOSE(UNIT=7)
      RETURN
      END
C
C
C
C     ***** READS THE GRID DATA ARRAY (320 x 320) *****
C
      SUBROUTINE READ_GRID(XD2,XD1)
      COMMON/IICOLOR/ICOLOR(0:512)
      COMMON/GGRID/GRID(321,321)
      COMMON/DOSES/DOSE(321,321)
      DIMENSION BAR(20)
      LOGICAL*1 SAME,DASH,UP
C
       DO IY=1,320
        DO IX=1,320
         GRID(IX,IY)=EXP(DOSE(IX,IY))
        ENDDO
       ENDDO
C
      IXD1=XD1
      IXD2=XD2
C
      NX=321
      NY=321
      ZBIAS=1.0
      ZMIN=0.
      ZMAX=XD2
      VDIST=200.
      VHIGHT=10.
      DASH=.TRUE.
C
C     CONSTANTS USED FOR CONTINUAL COLOR INCREMENTATION
      IIY=36
      IB=0
      IIB=0
   99 TYPE*,'HOW MANY ISOCONTOUR LINES DO YOU WANT DISPLAYED?'
      ACCEPT*,NB
```

```
      DO IBX=1,NB
      TYPE*,'WHAT ISOCONTOUR VALUES DO YOU WANT DISPLAYED?'
      ACCEPT*,VALUE
      WRITE(*,20)IXD2,IXD1
   20 FORMAT(/,1X,'(MAX_VALUE=',I7,' MIN_VALUE=',I3,')',/)
      BAR(IBX)=VALUE
      ENDDO
      CALL SORTER(NB,BAR)
      CALL LABEL(NB,IIY,IB,BAR)
      CALL CONTUR(NX,NY,BAR,NB,VHIGHT,VDIST,IBX,
     1DASH,ZBIAS,ZMIN,ZMAX,IIB)
      TYPE*,'CONTINUE ISOCONTOUR PLOTTING? (YES-1,NO-0)'
      ACCEPT*,IGO
      IF(IGO.NE.0) GO TO 99
      RETURN
      END
C
C
C
      SUBROUTINE SORTER(NB,BAR)
      DIMENSION BAR(20)
C
      DO 20 IBX=1,NB
      IP1=IBX+1
      DO 21 J=IP1,NB
      IF(BAR(IBX).LE.BAR(J)) GO TO 21
       T=BAR(IBX)
       BAR(IBX)=BAR(J)
       BAR(J)=T
   21 CONTINUE
   20 CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE LABEL(NB,IIY,IB,BAR)
      COMMON/IICOLOR?ICOLOR(0:512)
      DIMENSION BAR(20)
      INTEGER IBAR(20)
      OPEN(UNIT=7,NAME='VECTRIX:',TYPE='NEW')
C     LABEL ISOCONTOUR SPECTRUM
      DO IBX=1,NB
      IIY=IIY+14
      IBAR(IBX)=BAR(IBX)
      WRITE(7,*)'M',435,(IIY-4),'C',ICOLOR(IB+IBX),'$',IBAR(IBX)
      ENDDO
      IB=IB+(IBX-1)
      CLOSE(UNIT=7)
      RETURN
      END
```

```
C
C
C
      SUBROUTINE CONTUR(NX,NY,BAR,NB,VHIGHT,VDIST,IBX,
     1DASH,ZBIAS,ZMIN,ZMAX,IIB)
C
C
C*****************************************************************
C
C     SUBROUTINE FOR DOING CONTOUR PLOTTING.
C
C     SUBROUTINE CONTR.  WRITTEN AT VANDERBILT UNIVERSITY COMPUTER
C     CENTER BY PHIL SHERROD.  OCT. 1971.
C       (ADDRESS:  PHIL SHERROD/BOX 1577 STA B / VANDERBILT UNIV. /
        NASHVILLE, TENN. 37203)
C
C       RENAMED AS SUBROUTINE CONTUR AND
C
C       MODIFIED BY S. JULIAN GIBBS, DEPT. OF RADIOLOGY, VANDERBILT
C
C           UNIVERSITY, JULY, 1980
C
C       MODIFIED BY DR. AL PUJOL, JR AND CALVIN D. PRATHER,
C       THE UNIVERSITY OF TENNESSEE SPACE INSTITUTE, AUGUST,
C       1984.  ADDED AS "SUBROUTINE CONTUR" IN PSEUDO-
C       COLOR IMAGE DISPLAY PROGRAM (IMAGE.FOR).
C
C********************************************************************
C
C     INPUT ARGUMENTS TO CONTUR:
C
C       IX:   INPUT VECTOR CONTAINING X COORDINATES

C             OF INPUT INTERPOLATED DOSE ARRAY

C
C       IY:   INPUT VECTOR CONTAINING Y COORDINATES

C             OF INPUT INTERPOLATED DOSE ARRAY

C       GRID  ARRAY OF INTERPOLATED VALUES OF DOSE
C


C
C       GRID  CONVERTED ARRAY OF GRID FOR SMOOTHING
C
C       NX:   DIMENSION OF ARRAY X AND FIRST DIMENSION OF

C             ARRAY GRID
```

```
C
C       NY:   DIMENSION OF ARRAY Y AND SECOND DIMENSION OF
C             ARRAY GRID
C
C       BAR:  VECTOR OF LENGTH NB CONTAINING DOSE VALUES
C             FOR WHICH CONTOUR LINES ARE TO BE DRAWN
C
C       NB:   DIMENSION OF BAR
C
C       VHIGHT:  SIZE OF CONTOUR LINE ANNOTATIONS
C
C       VDIST:   DISTANCE BETWEEN ANNOTATIONS
C
C       DASH:  LOGICAL VARIABLE; IF TRUE, DRAWS DASHED
C       ISOCONTOURS; IF FALSE, DRAWS SOLID ISOCONTOURS
C
C
C *****************************************************************
C
C       GRID:  CONTUR USES USER-DETERMINED TECHNIQUE FOR
C              SMOOTHING INPUT DOSE ARRAY IN BODY X AND Y
C              DIRECTIONS (SUBROUTINE SMOTHER).  IT THEN INTERPOLATES
C              BY USER-DETERMINED METHOD (SUBROUTINE INTERP) TO FORM
C              ARRAY GRID.  NOTE THAT GRID IS DIMENSIONED IN SUB-
C              PROGRAM 'SAME' AND THE DIMENSIONS THERE MUST AGREE
C              WITH THE DIMENSIONS GIVEN TO IT IN SUBROUTINE CONTUR.
C
C *****************************************************************
C
      LOGICAL*1 SAME,DASH,UP
      COMMON/GGRID/GRID(321,321)
      COMMON/IICOLOR/ICOLOR(0:512)
      DIMENSION BAR(NB)
      COMMON/SAMEC/VB.VL.LX.LY.LXC.LYC.VLC
      PX(IX)=((IX*0.68359375)+40.0)
```

```
      PY(IY)=((IY*0.68359375)+40.0)
C
C     MAXIMUM NUMBER OF DECIMAL PLACES IN CONTOUR LINE ANNOTATIONS.
      MAXDEC=0
C
      NYM=320
C
C     DRAW ISOBARS FOR EACH OF THE REQUESTED VALUES.
C
      DO 20 IBX=1,NB
      VB=BAR(IBX)
      IF(VB.LT.ZMIN.OR.VB.GT.ZMAX)GO TO 20
      ICCOLOR=ICOLOR(IIB+IBX)
C
C     SET UP CONSTANTS FOR ISOBAR LABELS.
C
      NDEC=MAXDEC
      PVB=ABS(VB)
      VB=VB+ZBIAS
      IF(MAXDEC)44,45,46
   46 IVB=PVB*10**MAXDEC+.5
C     FIND OUT HOW MANY DEC. PLACES ARE ACTUALLY NEEDED.
      DO47IN=1,MAXDEC
      IND=MAXDEC-IN+1
      ITP=10**IND
   47 IF((IVB/ITP)*ITP.EQ.IVB)GO TO 48
      IND=0
C     NDEC = NUMBER OF DEC. PLACES ACTUALLY NEEDED
   48 NDEC=MAXDEC-IND
      IF(NDEC)44,45,44
   45 NDEC=-1
   44 IF(PVB.LT.1.01)PVB=1.01
      IAL=ALOG10(PVB)
C     IDEC = NUMBER OF CHARACTERS TO BE PRINTED IN NUMBER.
      IDEC=IAL+2+NDEC
      IF(BAR(IBX).LT.0.)IDEC=IDEC+1
      VLNGTH=VHIGHT*(IDEC+.5)
C     SCAN ACROSS GRID LOOKING FOR A CHANGE ACROSS DESIRED VALUE.
C
      PVB=BAR(IBX)
      NX2=NX-2
      DO 21 INITX=2,NX2,2
      VLC=ABS(GRID(INITX,1))
      LXC=INITX
      LYC=1
      DO22INITY=2,NY
      IF(SAME(INITX,INITY,NX,NY))GO TO 22
      IF(GRID(INITX,INITY))22,24,24
C
```

```
C     CROSSED BOUNDARY.  SEE IF AREA IS WIDE ENOUGH TO FOLLOW.
C
   24 IF(INITY.LE.2.OR.INITY.GE.NYM)GO TO 22
      TVL=VL
      ILX=LX
      ILY=LY
      IF(.NOT.SAME(INITX,INITY+1,NX,NY))GO TO 32
      IF(SAME(INITX+1,INITY,NX,NY))GO TO 23
      VLC=TVL
      IF(.NOT.SAME(INITX-1,INITY,NX,NY))GO TO 32
C
C     AREA IS WIDE ENOUGH SO BEGIN FOLLOWING IT.
C
   23 LYD =+1
      LXD =+1
      IX=INITX
      IY-INITY
      ITIME=0
      NXD=+1
      NYD=0
      DISTL=.75*VDIST
      GRID(INITX,INITY)=SIGN(GRID(INITX,INITY),-1.)
      GRID(ILX,ILY)=SIGN(GRID(ILX,ILY),-1.)
   35 LX=ILX
      LXC=INITX
      LY=ILY
      LYC=INITY
      VL=TVL
      VLC=ABS(GRID(INITX,INITY))
      CALL SMOOTH(PX(INITX),PY(INITY),0,ICCOLOR)
        UP=.TRUE.

      ISC=-2
      PHX=PX(INITX)
      PHY=PY(INITY)
      IFAIL=0
C
C     MOVE TO NEW POINT NEAR TO LINE.
   25 IX=IX+NXD
C
      IY=IY+NYD
C     SEE IF WE HAVE REACHED OUR INITIAL POINT.
C
      IF(IX.EQ.INITX.AND.IY.EQ.INITY)GO TO 36
C
C     NOT AT INITIAL POINT.  SEE IF AT EDGE OF GRID.
C
      IF(IX.LT.1.OR.1X.GT.NX.OR.IY.LT.1.OR.IY.GT.NY)GO TO 26
C
C     NOT AT EDGE OF GRID.  SEE IF WE CROSSED THE LINE.
C
```

```
      IF(SAME(IX,IY,NX,NY))GO TO 27
C
C     CROSSED BOUNDARY SO PLOT THE POINT.
C
      GRID(IX,IY)=SIGN(GRID(IX,IY),-1.)
      GRID(LX,LY)=SIGN(GRID(LX,LY),-1.)
      TPHX=PHX
      TPHY=PHY
      PHX=PX(IX)
      PHY=PY(IY)
        IPEN=ISC

        IF(.NOT.DASH)GO TO 150

        IF(IPEN.EQ.-3)GO TO 150

        IF(UP)GO TO 140

        UP=.TRUE.

        IPEN=-3

        GO TO 150

 140    UP=.FALSE.

        IPEN=-2

 150 CALL SMOOTH(PHX,PHY,IPEN,ICCOLOR)

C

C     TAKE CARE OF LABELS ON ISOBARS.
C
      IF(ISC.NE.-2)GO TO 42
      DISTL=DISTL+SORT((TPHX-PHX)**2+(TPHY-PHY)**2)
      IF(DISTL.LT.VDIST)GO TO 43
      VSX=PHX
      VSY=PHY
      ISC=-3
      GO TO 43
   42 VLDIST=SORT((VSX-PHX)**2+(VSY-PHY)**2)
      IF(VLDIST.LT.VLNGTH)GO TO 43
      CALL PVAL(VSX,VSY,PHX,PHY,VHIGHT,NDEC,IDEC,PVB)
      ISC=-2
      DISTL=0.
   43 IFAIL=0
C
C     HIT OCCURRED SO MOVE IN SAME DIRECTION AS BEFORE HIT MOVE.
C
```

```
      INX=LXD
      INY=LYD
      GO TO 29
C
C     NO HIT OCCURRED SO MOVE IN OPPOSITE DIRECTION AS BEFORE LAST MOVE.
C
   27 INY=-LYD
      INX=-LXD
C
C     TEST FOR RUNNING OFF OF END OF A LINE.  (WON'T USUALLY HAPPEN).
C
      IFAIL=IFAIL+1
      IF(IFAIL.GT.2)GO TO 26
   29 IF(NXD)31,30,31
C
C     NEXT MOVE IS IN THE X DIRECTION.
C
   30 LYD=NYD
      NYD=0
      NXD=INX
      GO TO 25
C
C     NEXT MOVE IS IN THE Y DIRECTION.
C
   31 LXD=NXD
      NXD=0
      NYD=INY
      GO TO 25
C
C     MOVED OFF END OF GRID SO TERMINATE LINE.
C
   26 CALL SMOOTH(PHX,PHY,-24,ICCOLOR)
      IF(ISC.NE.-2)CALL PVAL(VSX,VSY,PHY,PHY,VHIGHT,NDEC,IDEC,PVB)
C
C     NOW WORK IN OPPOSITE DIRECTION FROM INITIAL HIT POINT.
C
   33 IF(ITIME)34,34,32
   34 ITIME=1
      LYD=+1
      LXD=-1
      IX=INITX
      IY=INITY
      NXD=-1
      NYD=0
```

```
      DISTL=0.
      GO TO 35
C
C     RETURNED TO INITIAL POINT SO TERMINATE LINE.
C
   36 VL=TVL
      LX=ILX
      LY=ILY
      PHX=PX(INITX)
      PHY=PY(INITY)
      CALL SMOOTH(PHX,PHY,-24,ICCOLOR)
      IF(ISC.NE.-2)CALL PVAL(VXS,VSY,PHX,PHY,VHIGHT,NDEC,IDEC,PVB)
C
C     FINISHED LINE.  SET UP TO CONTINUE SEARCH.
C
   32 VLC=ABS(GRID(INITX,INITY))
      LXC=INITX
      LYC=INITY
   22 CONTINUE
   21 CONTINUE
C
C     PLOT IS FINISHED.  WIND IT UP.
C
   20 CONTINUE
      IIB=IIB+(IBX-1)
      RETURN
      END
C
C
C
      LOGICAL FUNCTION SAME(IX,IY,NXX,NYY)
      COMMON/GGRID/GRID(321,321)
      COMMON/SAMEC/VB,VL,LX,LY,LXC,LYC,VLC
      A=ABS(GRID(IX,IY))
      SAME=(A.GE.VB.AND.VLC.GE.VB).OR.(A.LT.VB.AND.VLC.LT.VB)
      LX=LXC
      LXC=IX
      LY=LYC
      LYC=IY
      VL=VLC
      VLC=A
      RETURN
      END
C
C
C
C     SUBROUTINE SMOOT COPYRIGHT 1968 CALIF. COMPUTER PRODUCTS
      SMOOT   V068   6/28/68
C        THE SMOOTH ROUTINE SIMULATES THE PLOT ROUTINE WITH A NEW PLOT
C     MODE (DRAWING A SMOOTH CURVE TO THE NEW POINT).  THE SMOOTH MODE
```

```
C       IS INITIALIZED WITH THE UNITS DIGIT OF IC = 0 (FOR AN OPEN
C       CURVE) OR = 1 (FOR A CLOSED CURVE).
C            THE VALUE OF IC FOR SMOOTHING IS THE NEGATIVE OF
C       THE PEN VALUES FOR PLOTTING.  THERE IS, THEREFORE, NO RE-
C       ORIGINING WHILE SMOOTHING.  USING POSITIVE VALUES FOR IC
C       WHILE SMOOTHING WILL BE TREATED AS A CALL TO PLOT.  TO END
C       THE CURVE AND RETURN TO THE PLOT MODE LET IC BE LESS THAN -23.
C         SUBROUTINE SMOOT  (XN,YN,IC,ICCOLOR)

      SUBROUTINE SMOOTH (XN,YN,IC,ICCOLOR)
      JC=IC
      KC=JC-JC/10*10
      LC=NC-IPC
      PXN=XN
      PYN=YN
      IREP=0
      IF(KC)1,4,14
    1 IF(KC+1)2,5,4
    2 IF(IPC)3,3,14
    3 IF(JC+24)10,10,17
    4 ISW=-1
      GO TO 6
    5 ISW=1
    6 JSW=-1
      NC=-KC/10*10
      X3=PXN
      Y3=PYN
      MC=NC+3
    9 IPC+KC
      RETURN
   10 IF(IPC+1)11,13,13
   11 IF(ISW-1)12,15,14
   12 IF(ISW+1)14,16,14
   13 KC=NC+2
      IPC=1
      IIX3=NINT(X3)
      IIY3=NINT(Y3)
      WRITE(7,*)'RE','C',ICCOLOR,'D',IIX3,IIY3
   14 IIPXN=NINT(PXN)
      IIPYN=NINT(PYN)
      WRITE(7,*)'RE','C',ICCOLOR,'D',IIPXN,IIPYN
      RETURN
   15 IREP=2
   16 IREP=IREP+1
      KC=1
   17 IF(IABS(JSW)-1)14,18,14
   18  X1=X2
       Y1=Y2
       X2=X3
       Y2=Y3
       X3=PXN
```

```
      Y3=PYN
     IF(IPC+1)20,19,19
19     VX3=X3-X2
       VY3=Y3-Y2
     D3 = VX3*VX3+VY3*VY3
       SX1=X2
       SX2=X3
       SY1=Y2
       SY2=Y3
       GO TO 40
20   IF(JSW)21,14,23
21   IF(ISW)22,14,24
22    VX2=X3-X2
      VY2=Y3-Y2
     CALL REFLX(VX3,VY3,VX2,VY2)
      D2=VX2*VX2+VY2*VY2
      GO TO 26
23    JSW=1
24    VX2=VX3
      VY2=VY3
      VX3=X3-X2
      VY3=Y3-Y2
25   D2=D3
      UX1=UX2
      UY1=UY2
26    D3=VX3*VX3+VY3*VY3
      UX2=D2*VX3+D3*VX2
      UY2=D2*VY3+D3*VY2
     DUMMY=UX2*UX2+UY2*UY2

     IF(DUMMY.GT.0.)THEN

      DV=1./SQRT(DUMMY)

     ELSE

      DV=1.E10
     ENDIF

      UX2=DV*UX2
      UY2=DV*UY2
      IF(ISW-JSW)27,27,45
27   IF(JSW)23,14,28
28   T=0.
      CALL WHERE (X,Y,D)
      IF (ABS(X1-X)-0.01*D) 29,30,30
29    IF (ABS(Y1-Y0-0.01*D) 31,30,30
30    IIX1=NINT(X1)
      IIY1=NINT(Y1)
      WRITE(7,*),'RE','C',ICCOLOR,'D',IIX1,IIY1
```

```
   31 IF(IPC+3)32,40,32
   32  D=ABS (UX1*VX2+UY1*VY2)
       D1=D
       UUX1=D*UX1
       UUY1=D*UY1
       D=ABS (UX2*VX2+UY2*VY2)
       UUX2=D*UX2
       UUY2=D*UY2
       D=D+D1
       AX=UUX2+UUX1-VX2-VX2
       BX=VX2-UUX1-AX
       AY=UUY2+UUY1-VY2-VY2
       BY=VY2-UUY1-AY
       N=10.*D+1.
       D=1./FLOAT (N)
       DO 33 I=1,N
        T=T+D
        X=((AX*T+BX)*T+UUXL)*T+X1
        Y=((AY*T+BY)*T+UUY1)*T+Y1
   33 IIXX=NINT(X)
      IIYY=NINT(Y)
      WRITE(7,*)'RE','C',ICCOLOR,'D',IIXX,IIYY
   40  IF(IREP)9,9,41
   41   IREP=IREP-1
        IF(ISW)43,14,42
   42    PXN=SX1
         PYN=SY1
         SX1=SX2
         SY1=SY2
         SX2=SX3
         SY2=SY3
         GO TO 18
   43 CALL REFLX (VX3,VY3,VX2,VY2)
C     EARLIER VERSION USED
C     CALL REFLX(VX3,VY3,VX2,VY2
         X=VX3
         Y=VY3
         VX3=VX2
         VY3=VY2
         VX2=X
         VY2=Y
         X1=X2
         Y1=Y2
         GO TO 25
   45 JSW=1
      SX3=X3
      SY3=Y3
      GO TO 40
      END
```

```
C
C
C
C     SUBROUTINE REFLX  COPYRIGHT 1968 CALIF. COMPUTER PRODUCTS
C     REFLX  V068      6/28/68
C          SUBROUTINE REFLX (VX1,VY1,VX2,VY2)
C     EARLIER VERSION OF THIS SUBROUTINE WAS
        SUBROUTINE REFLX (VX1,VY1,VX2,VY2)
        PS=VY1*VY1
        DS=VX1*VX1
        SS=DS+PS
        DS=DS-PS
        PS=2.0*VX1*VY1
      IF(SS.NE.0.)THEN

              TEMP=(PS*VY2+VX2*DS)/SS

              VY2=(PS*VX2-VY2*DS)/SS

      ELSE

              TEMP=1.E10

              VY2=1.E10

      END IF

        VX2=TEMP
        RETURN
        END
C
C
C
      SUBROUTINE WHERE(X,Y,FACT1)
      COMMON FACT,PMSIZE,IOLDX,IOLDY,JSW
      X=IOLDX/(100.*FACT)
      Y=IOLDY/(100.*FACT)
C     TYPE*,'IN WHERE','X=',X,'Y=',Y
      FACT1=FACT/PMSIZE
      RETURN
      END
C
C
C
C     IN SUBROUTINE PVAL:
C         SX, SY, IS COORDINATES OF LABEL
C         VH IS HEIGHT OF LABEL
C         VB IS THE LABEL
C         ANGLE IS ANGLE OF LABEL IN DEGREES
C         NDEC IS NUMBER OF DIGITS OF LABEL
```

```
C
      SUBROUTINE PVAL(VSX,VSY,PHX,PHY,VH,NDEC,IDEC,VB)
      SX=VSX
      SY=VSY
      PX=PHX
      PY=PHY
      RANGLE=ATAN2(PY-SY,PX-SX)
      ANGLE=RANGLE*57.29578
      IF(ANGLE.LT.0.)ANGLE=ANGLE+360.
      IF(ANGLE.LE.90..OR.ANGLE.GE.270.)GO TO 1
      ANGLE=ANGLE+180.
      TMP=SX
      SX=PX
      PX=TMP
      TMP=SY
      SY=PY
      PY=TMP
      RANGLE=ANGLE/57.29578
      S=.5*9SORT((SX-PX)**2+(SY-PY)**2)-IDEC*.95*VH)
      IF(S.LT.-.5*VH)RETURN
      CR=COS(RANGLE)
      SR=SIN(RANGLE)
      SX=SX+S*CR+.5*VH*SR
      SY=SY+S*SR-.5*VH*CR
      ISX=NINT(SX)
      ISY=NINT(SY)
      IVB=NINT(VB)
      IANGLE=NINT(ANGLE)
C
C     'M' MOVE LABEL TO X,Y COORDINATE POINT
C     'JA' ADJUST ANGLE OF LABLE
C     'C' DEFINE COLOR OF LABEL
C     'JM' IS SIZE (5 x 9) OF LABEL
C     '$' DISPLAY CHARACTER STRING
C     WRITE(7,*)'M',ISX-10,ISY,
C    1'C56', ' JM 1 ' , '$', IVB
C     TYPE*,'ISX=',ISX,'ISY=',ISY,'VH=',VH,'IVB=',IVB
C     TYPE*,'IANGLE=',IANGLE,'NDEC=',NDEC
C     CALL NUMBER(SX,SY,VH,VB,ANGLE,NDEC)
      RETURN
      END
```

VITA

Calvin Douglas Prather was born in Ripley, Mississippi, on August 27, 1956. He attended elementary schools in Falkner, Mississippi, and was graduated from Falkner High School in May 1974. The following August he entered Mississippi Valley State University, and in May 1978 he received a Bachelor of Science degree in Mathematics. In the summer of 1978 he accepted a graduate research assistantship (Remote Sensing Division) at The University of Tennessee Space Institute (UTSI), Tullahoma and began studies toward a Master's degree. This degree was awarded in August 1985.

During the period August 1978 to the present he has been employed at UTSI in the Energy Conversion Division.

The author is a member of the Alpha Chi Honors Society.