Atmospheric Arsenic Dispersion from Yellowknife Giant Mine

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Abstract:

Air dispersion modelling for continuous arsenic releases from the Giant Gold Mine near Yellowknife, NWT were performed seasonally for the years 1991 through 1995. Stack parameters of height, exit temperature, exit velocity and arsenic emission rate were varied for comparison between the current situation, a case where operational efficiency is improved and a case where technological changes are made to the facility. Emission rate had the greatest influence on the ground-level concentration exceedances observed at Yellowknife. At the current stack parameters, it may be possible to change the concentration exceedances at Yellowknife by about 0.01 $\mu g/m^3$ to 0.02 $\mu g/m^3$ simply with operational improvements.

Introduction:

Atmospheric Environment Branch was approached by Environmental Protection Branch with a request to perform air dispersion modelling for continuous arsenic releases from the Giant Gold Mine near Yellowknife, NWT. In particular, modelling was to be done for potential emission reduction changes to the facility as outlined by W. R. Hatch Engineering Limited in their report "Arsenic Emission Control from Pyrometallurgical Operations" completed in February, 1996. This report details changes to the stack itself and to the plant operating procedures designed to reduce arsenic concentrations in the emissions. In this report, representative stack operating conditions from the Hatch report recommendations were modelled.

Based on the report "Air Dispersion Modelling of Roaster Stack Emissions" of May, 1995 by M. M. Dillon Limited, the United States Environmental Protection Agency (US-EPA) model ISCST2 (Industrial Source Complex Short Term) was selected for the exercise. Dillon had demonstrated that a complex terrain model was not necessary, that the Gaussian plume technique was the most refined method, and that most conditions at Yellowknife were non-fumigating. For a detailed description of the ISCST2 model, the reader is referred to the US-EPA documentation available on-line.

Model Description:

Meteorological input data was obtained from Climate Services in Edmonton. The stations selected were Yellowknife for surface reports and Fort Smith for upper air reports. The model runs were done over the time span of 1991 to 1995 and the results shown in this report are the compiled results for this period. To investigate any seasonal differences, data were segregated into winter (November to April) and summer (May to October) periods. These periods roughly correspond to the open and closed-water seasons of Great Slave Lake which would affect the overall meteorology of the area.

Current stack parameters at Giant Mine are given in Table 1. In addition, values changed in the model runs are shown. All combinations of parameters have been run and representative diagrams covering the range of ambient air concentrations will be given in body of this report. However, all specific model runs which showed values greater than 0.02 $\mu g/m^3$ are provided in Appendix I. The combination of three arsenic concentrations (mg/m^3) and two gas exit velocities (m/s) gives six possible emission rates (g/s) which were all input into the model. Table 2 shows the six permutations.

Table 1: Stack parameters at Giant Mine, Yellowknife.

Source Parameter	**'1995' Value**	**Model Changes**
Stack height (m)	47.5	60.6 / 83.3
Stack cross-section (m^2)	5.91	none
Exit gas temperature (°K)	385	350 / 375
Stack Flow (m^3/hr)	45,000	40,000 / 60,000
Exit gas velocity (m/s)	2.7	1.88 / 2.82
Arsenic emission (mg/m^3)	27.5	1 / 20 / 30

Table 2: Permutations of stack emission rates (g/s) for model input.

	Exit Velocities (m/s)	
[As] (g/m^3)	1.88	2.82
0.001	0.011	0.017
0.02	0.222	0.333
0.03	0.333	0.500

The three arsenic emission rates in Table 1 are meant to correspond to the current situation (30 mg/m^3), a scenario with improved operational efficiency within the present system (20 mg/m^3), and a scenario with technological changes to the emission controls (1 mg/m^3). The potential ground-level improvements with the two alternative cases will be compared with the present situation.

In summary, the model was run over the following cases: 5 years x 2 seasons x 3 stack heights x 2 exit temperatures x 6 emission rates. This gives a total of 360 individual runs on the computer. Averaging 5 years worth of results over 2 seasons reduced the number of unique results to 72. A receptor grid was defined for the model outputs. The emission stack was situated at the centre of the square grid with sides of 12 kilometers in length. This space was divided into 300m x 300m squares comprising 41 nodes east to west and 41 nodes north to south. In total, this is equivalent to 1681 defined receptor points. All occurrences of a 24-hour averaged value of concentrations exceeding 0.02 µg/m^3 were saved at each receptor point. Not all combinations of stack parameters would produce any output concentrations exceeding the value of 0.02 µg/m^3. Only about 60 combinations produced outputs.

Model Results:

The complete set of dispersion diagrams generated by the model that contained deposition values greater than or equal to 0.02 μg/m^3 are given in Appendix I. Each plot is labeled with the appropriate input parameters. For orientation, the emission stack lies in the centre of the diagram and the top of the diagram is to the north. Yellowknife lies to the south of the stack at the coordinates x = -1000 m and y = -5350 m on the diagrams. The range of concentrations received at the receptor points was from less than 0.02 μg/m^3 to greater than 0.3 μg/m^3. The contour intervals are at 0.01 μg/m^3 with thicker lines drawn at 0.1, 0.2, and 0.3 μg/m^3. Detailed discussion around specific cases will be shown in this section.

Current Conditions:

Figure 1 illustrates the variations in dispersion patterns for both winter and summer with conditions close to the present situation including the lowest stack height (47.5 m) but highest emission rate (0.500 g/s), temperature (375 K) and exit velocity (2.82 m/s). Higher values are observed overall in the summer though they tend to lie to the north of the site. There is a slight shift in the dominant wind direction with season as the summer winds show a greater spread in the north to south direction while the winter winds show spread east to west. In particular, the area showing exceedance of the 0.08 μg/m^3 line spreads further south towards Yellowknife in the summer season. Although it is recognized that the areas north of the site are likely not well modelled by ISCST2 because of the impact of the water body, the wind fields indicate that Yellowknife may observe its largest concentrations in the summer months.

The NAPS data measured at Yellowknife (1984-93) are shown in Figure 2. It is apparently not the case that the higher concentrations are found only in the summer for arsenic. Half of the top values measured in the period of record are found in each season. However, the maximum value of 1.817 μg/m^3 was found on 28 March 1988. The averages of the data (if the particularly high value found 28 March 1988 is removed) are 0.0244 μg/m^3 for the summer and 0.0238 μg/m^3 for the winter with an annual average of 0.0243 μg/m^3 indicating that there is very little seasonal variability which the model also suggests. For comparison, the model clearly indicates that values between 0.07 μg/m^3 to 0.08 μg/m^3 will be observed in at any time of the year in Yellowknife itself.

A quick look at the other parameters measured shows that nitrates are consistently higher in the winter which is compatible with the situation of greater automobile exhaust emissions within an inversion situation. The total suspended particulate (TSP) values are consistently higher in the spring months of April and May. The reader is referred to the annual National Air Pollutants Survey reports for details.

Change in Stack Temperature:

Using the same parameters as above, Figure 3 shows that the small changes in exit temperature modelled here (350 K to 375 K) are not sufficient to produce any significant change in the dispersion even at the highest emission rates. This is especially true further from the site for, while small differences are evident near the stack, these differences are lessened with distance.

Change in Stack Exit Velocity:

In Figure 4, exit velocity and season are varied with at fixed stack height (47.5m), emission rate (0.333 g/s) and temperature (375 K). The change in exit velocity (1.88 m/s to 2.82 m/s) shows more change in the dispersion patterns than observed with a change in temperature and, again, as distance from the source increases, the change with emission velocity decreases. Generally, the higher emission velocity results in greater dispersion of the emissions such that the ground-level concentrations near the stack are lowered. Under these conditions, values between 0.06 $\mu g/m^3$ and 0.08 $\mu g/m^3$ are likely to be observed at any time of the year at Yellowknife city hall.

Change in Arsenic Emission Rate:

The greatest change in dispersion pattern is observed with changing arsenic emission rate. Figures 5a and 5b show the variation with changing emission rates (0.017 g/s, 0.333 g/s and 0.500 g/s) at fixed stack height (47.5 m), temperature (375 K), and exit velocity (2.82 m/s) in the winter and summer months, respectively. While the case corresponding to the technological approach (lowest emission rate) to emission reduction shows no cases with ground-level concentrations greater than 0.03 $\mu g/m^3$, the current case and the case with improved operational efficiency do show concentrations up to 0.16 $\mu g/m^3$ and 0.13 $\mu g/m^3$ near to the emission source, respectively. Without changing the technology, at distances towards Yellowknife to the south, the ground-level concentrations continue to exceed 0.07 $\mu g/m^3$ to 0.08 $\mu g/m^3$ in all cases and seasons.

Change in Stack Height:

To illustrate the final parameter varied, Figures 6a and 6b show the cases with changing stack height but all other parameters fixed at the maximum values modelled for the winter and summer months, respectively. This is closest to the current operating conditions. Here there is a clear decrease in the ground level dispersion with increased stack height from 47.5 m through 83.3 m. While the air concentrations near to the stack are greatly decreased, however, the dispersion to other regions through long-range transport are increased spreading the pollutant further afield. However, it should be noted that ground-level concentrations at Yellowknife will continue to occasionally exceed between 0.07 $\mu g/m^3$ and 0.08 $\mu g/m^3$ at any time of the year.

For comparison, Figures 7a and 7b show the cases with changing stack height but with the arsenic emission rate set for the condition with improved operating efficiency. These show surprisingly little difference with the current conditions. There is a slight shift in the 0.06 $\mu g/m^3$ exceedance line such that Yellowknife at x = -1000 m and y = -5350 m will likely not observe any levels higher than 0.07 $\mu g/m^3$ with the improved operations. Even considering the errors inherent in the model itself, the small relative change indicates that simply changing the operations in the facility will not greatly improve the regional ground-level concentrations of arsenic observed at Yellowknife.

Conclusions:

The maximum observed concentration occurred with the lowest stack height (47.5 m), the lowest exit gas temperature (350 K), the highest emission rate (0.500 g/s) and the highest exit gas velocity (2.82 m/s). The lowest observed concentrations occurred in several cases especially at the higher stack heights and lower emission rates.

The emission rate is the largest determining factor on the incident dispersed arsenic for a given stack height. Larger emission rates certainly result in higher output concentrations observed along the receptor grid. Stack height seems to have the second largest influence upon dispersed arsenic. The small differences in exit temperature and velocities modelled here have little influence on the observed dispersion.

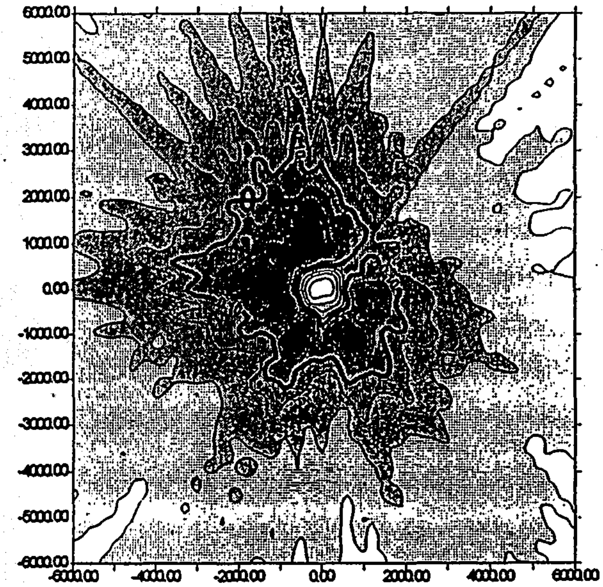
Climatic patterns differ between the two defined seasons. The highest modelled dispersion concentrations are found in the northwest quadrant of the receptor grid during the summer months. In addition, the greatest general spread of concentration is also in the summer months. Although there is some doubt about the model's ability to model to the north of the mine area because of the influence of the water body, model predictions to the south towards Yellowknife should be more reasonable. It is generally to be expected that the higher values measured in Yellowknife should occur in the summer months though it is difficult to find evidence for this in the monitored data.

At the current stack parameters it will be possible to change the concentration exceedances measured at Yellowknife by about 0.01 $\mu g/m^3$ to 0.02 $\mu g/m^3$. Therefore, despite the errors inherent in this modelling exercise, it is apparent that changes in operating efficiency alone will not greatly improve the ground-level exceedances observed at Yellowknife, itself. This does not, however, imply that the long-term averages will not be improved but that is not able to be calculated from these results.

Acknowledgments:

The authors wish to thank the Arctic Environmental Service Centre in Edmonton for access to the computing facilities and for the time to complete the modelling work.

Figure 1: Dispersion variations with season at fixed stack height (47.5 m), emission rate (0.500 g/s), exit temperature (375 K) and exit velocity (2.82 m/s) representing the current operating conditions.



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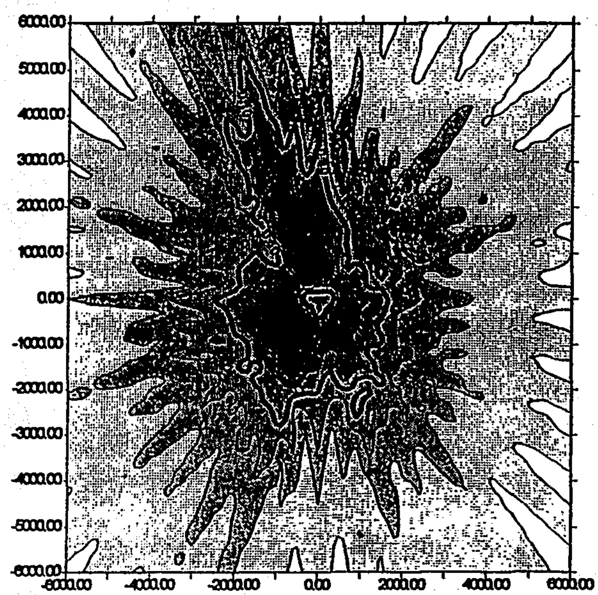
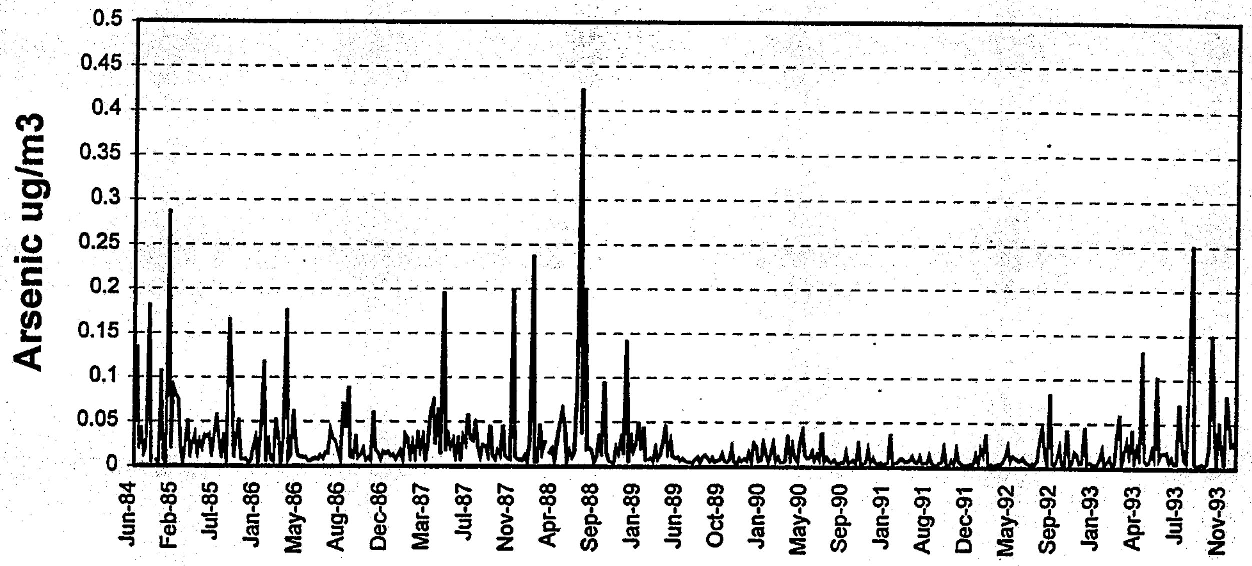


season:s hgt:47.5 temp:375 rate:0.500 vel:2.82

Figure 2: Yellowknife monitored data for summer and winter (1984-1993).



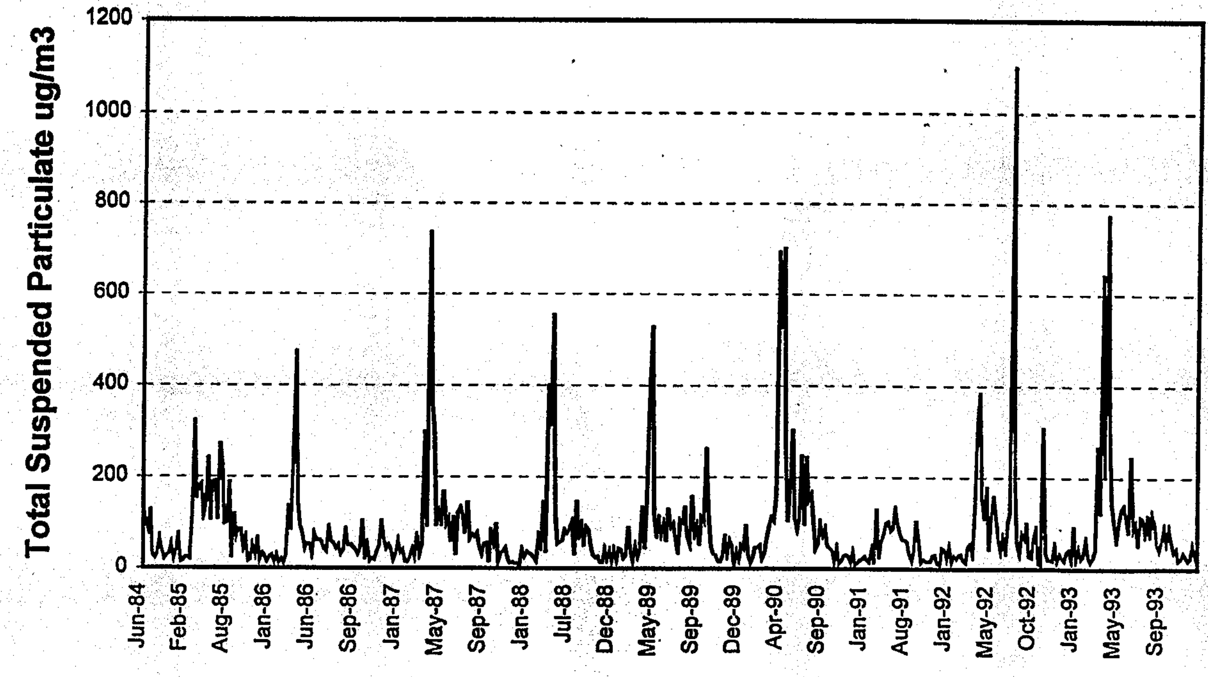
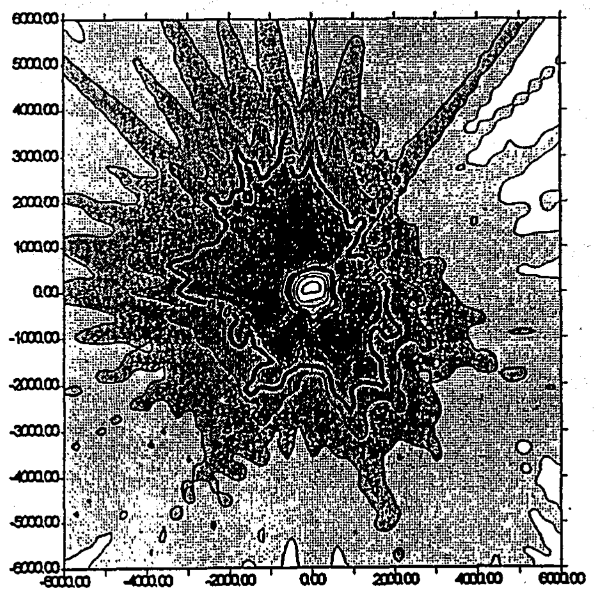


Figure 3: Dispersion variations with exit temperature in winter at fixed stack height (47.5 m), emission rate (0.500 g/s) and exit velocity (2.82 m/s)..



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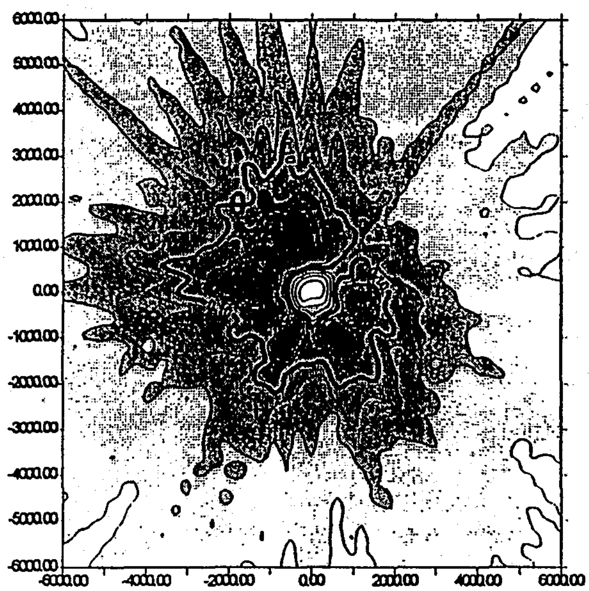
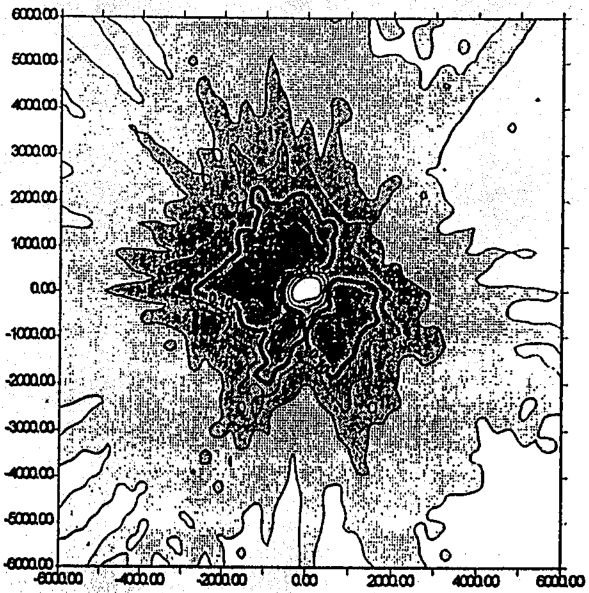


season:w hgt:47.5 temp:375 rate:0.500 vel:2.82

Figure 4: Dispersion variations with exit velocity and season at fixed stack height (47.5 m), temperature (375 K) and emission rate (0.333 m/s).



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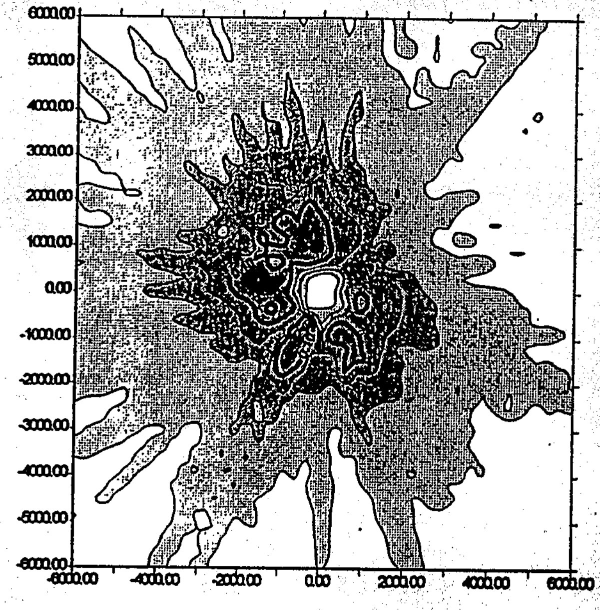

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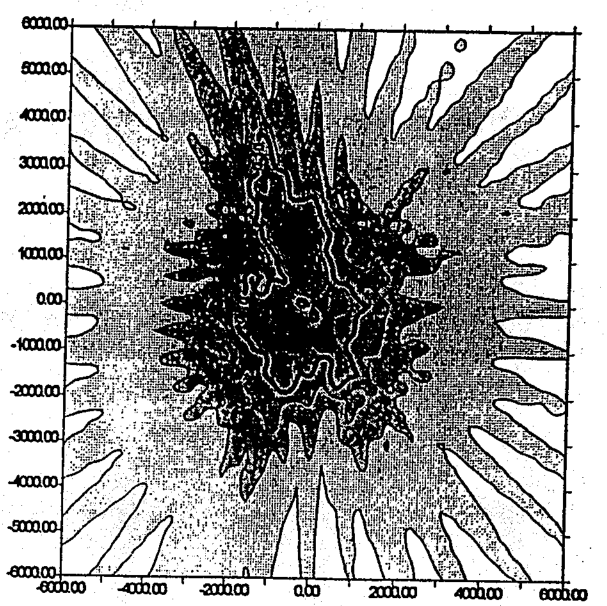

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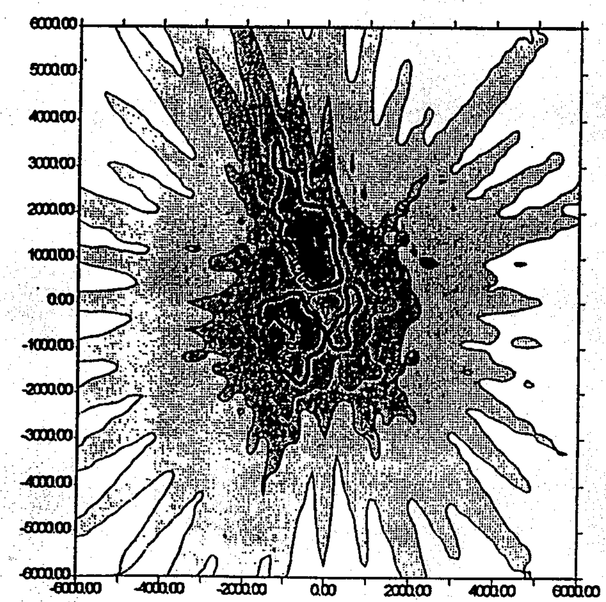
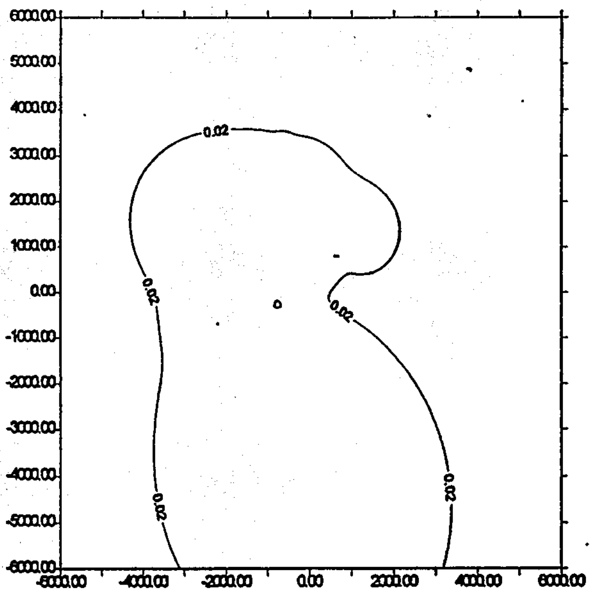


season:s hgt:47.5 temp:375 rate:0.333 vel:2.82

Figure 5a: Dispersion variations with emission rate in winter at fixed temperature (375 K), stack height (47.5 m) and exit velocity (2.82 m/s).



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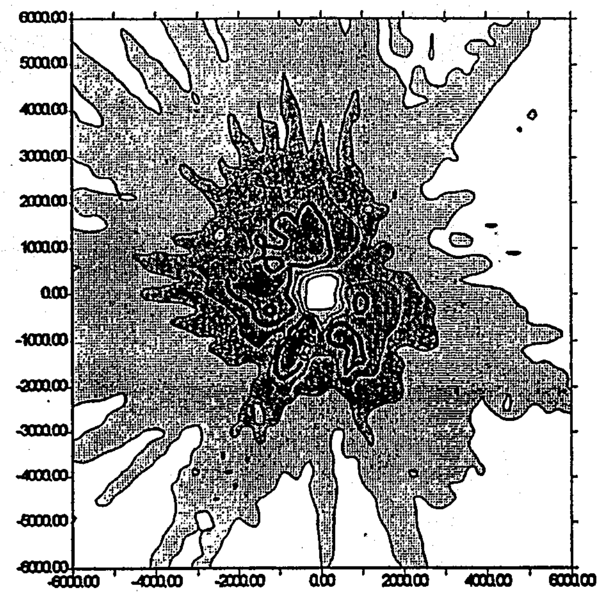

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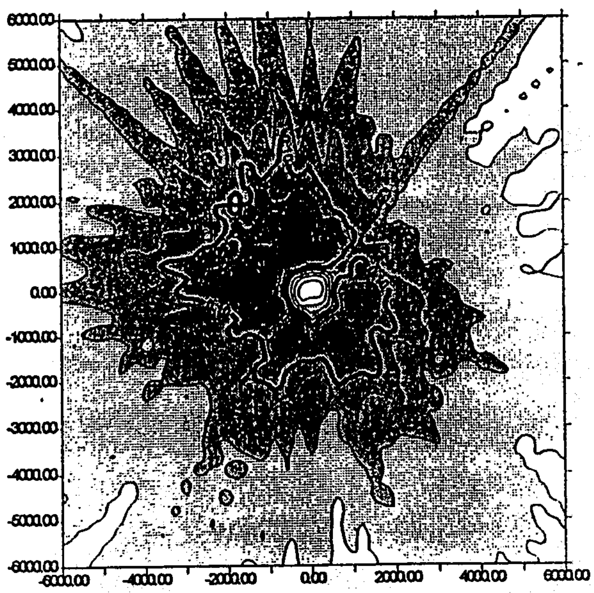
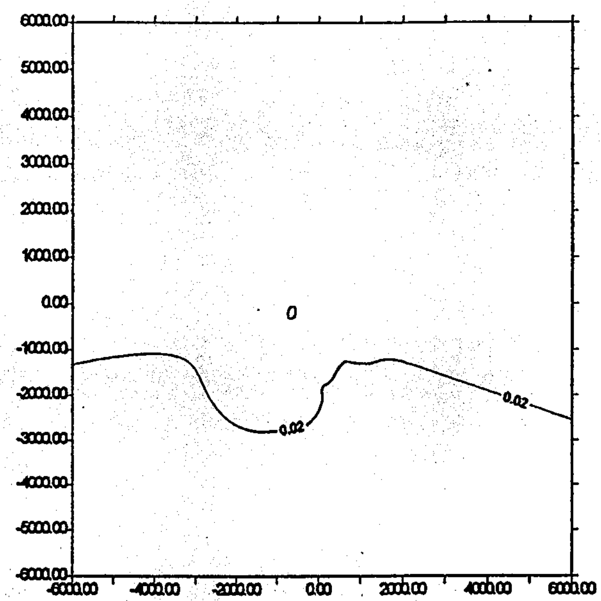


season:w hgt:47.5 temp:375 rate:0.500 vel:2.82

Figure 5b: Dispersion variations with emission rate in summer at fixed temperature (375 K), stack height (47.5 m) and exit velocity (2.82 m/s).



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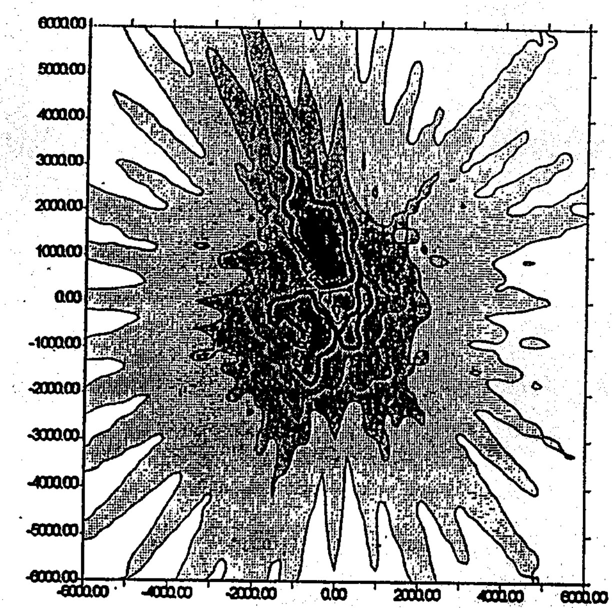

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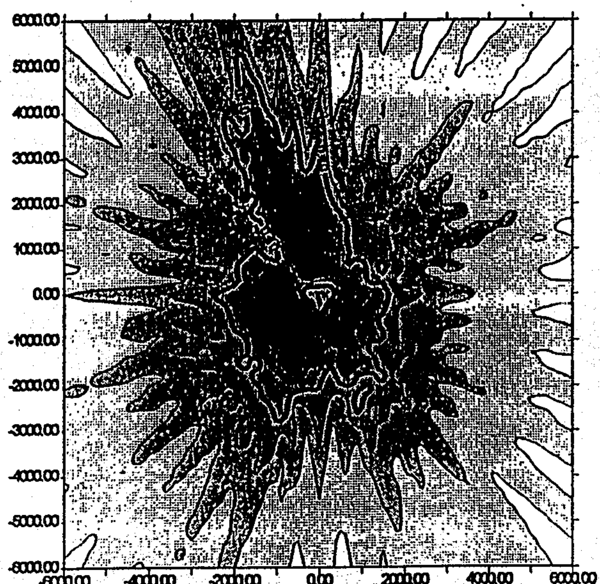
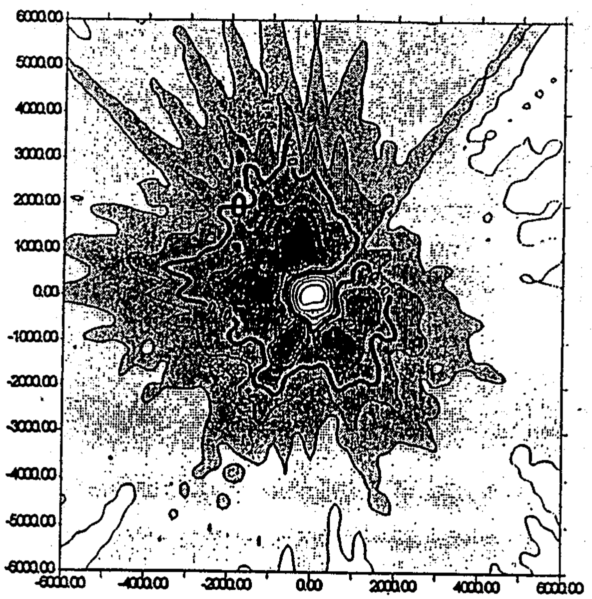


season:s hgt:47.5 temp:375 rate:0.500 vel:2.82

Figure 6a: Dispersion variations with stack height in winter at fixed temperature (375 K), emission rate (0.500 g/s) and exit velocity (2.82 m/s).



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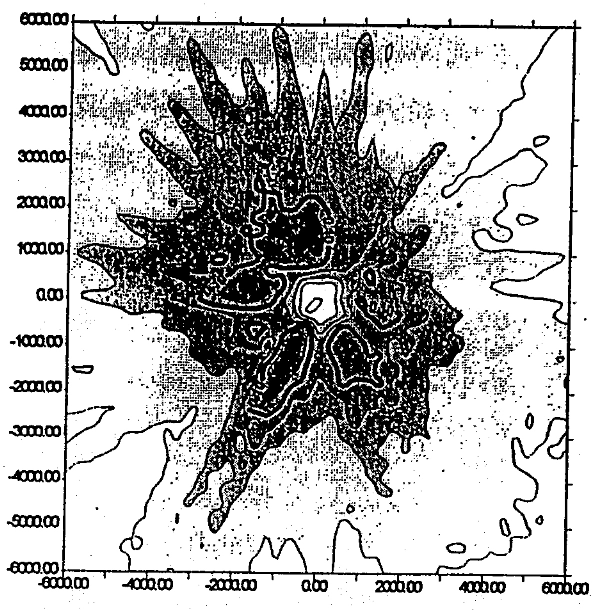

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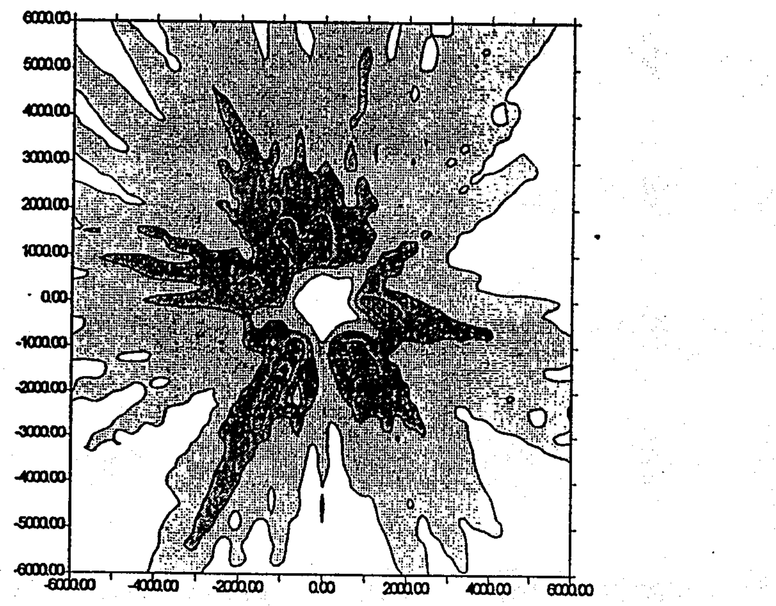
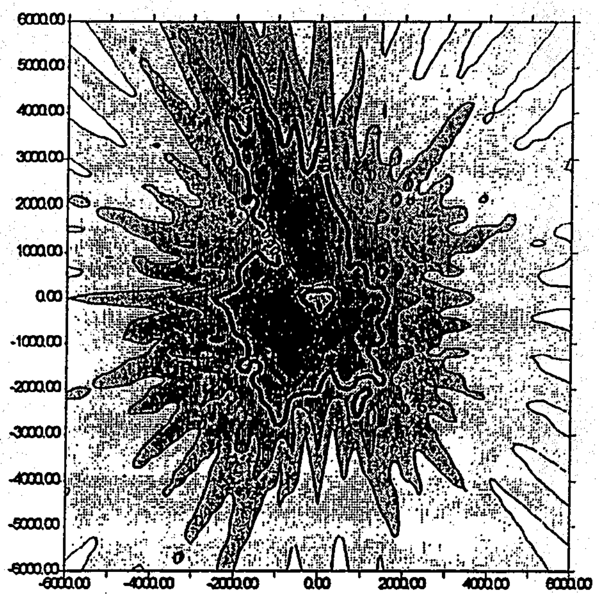


season:w hgt:83.3 temp:375 rate:0.500 vel:2.82

Figure 6b: Dispersion variations with stack height in summer at fixed temperature (375 K), emission rate (0.500 g/s) and exit velocity (2.82 m/s).



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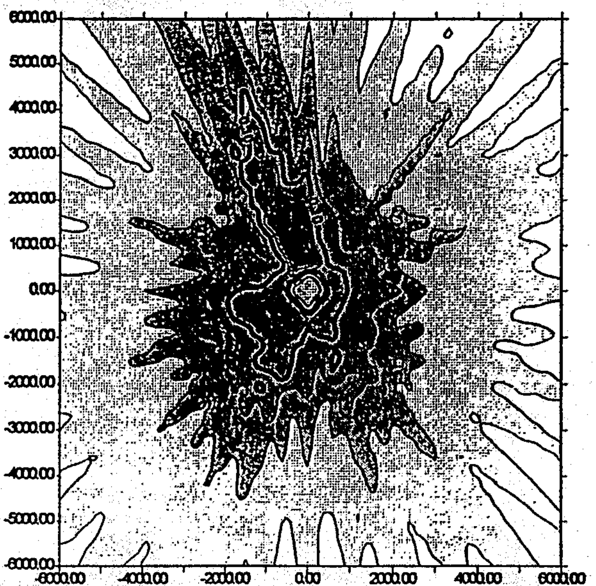

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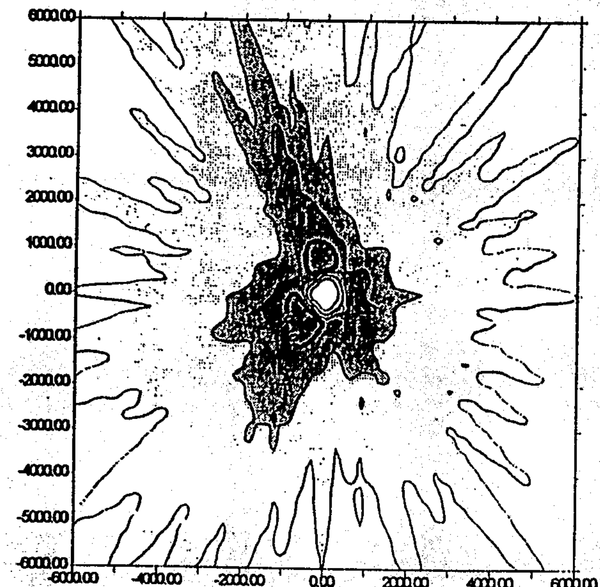
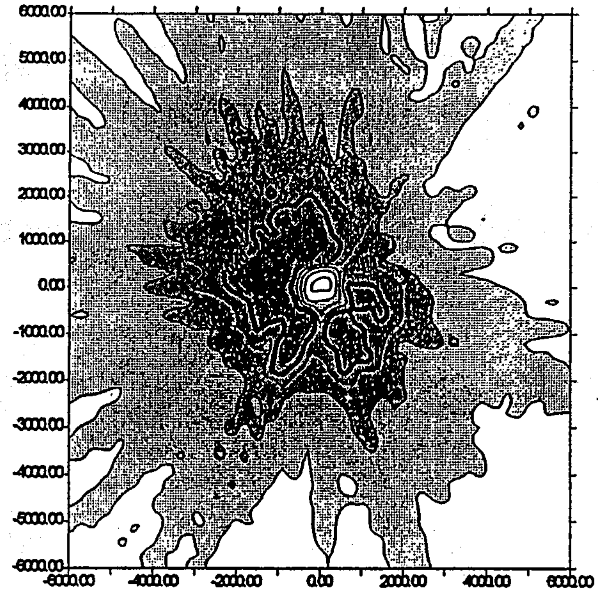


season:s hgt:83.3 temp:375 rate:0.500 vel:2.82

Figure 7a: Dispersion variations with stack height in winter at fixed temperature (375 K), emission rate (0.333 g/s) and exit velocity (2.82 m/s).



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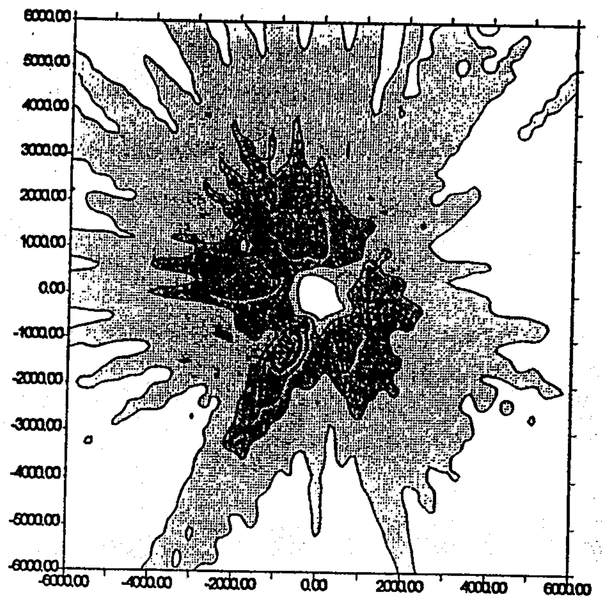

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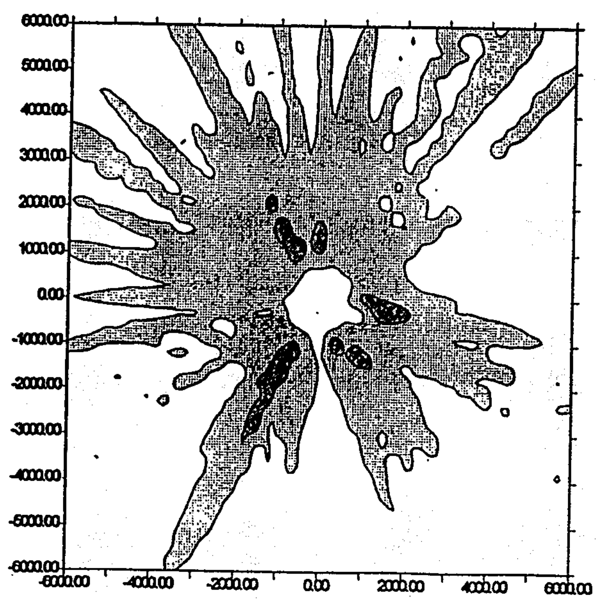
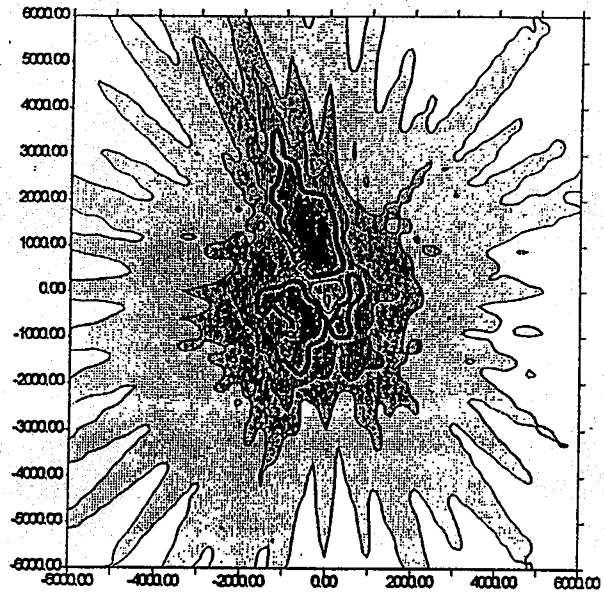


season:w hgt:83.3 temp:375 rate:0.333 vel:2.82

Figure 7b: Dispersion variations with stack height in summer at fixed temperature (375 K), emission rate (0.333 g/s) and exit velocity (2.82 m/s).



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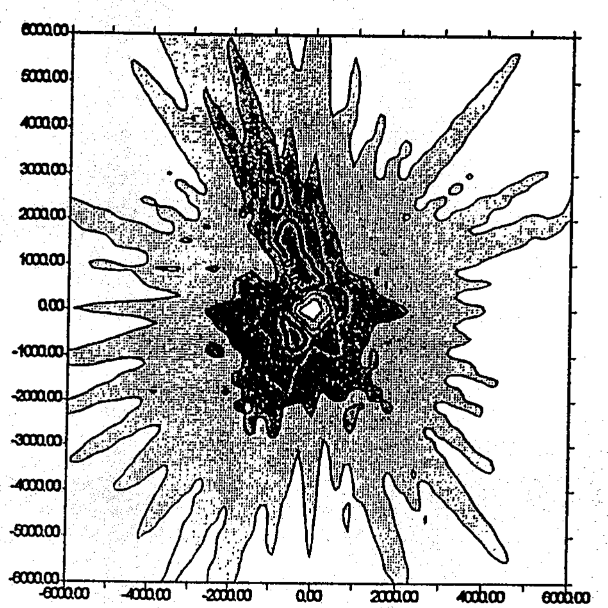

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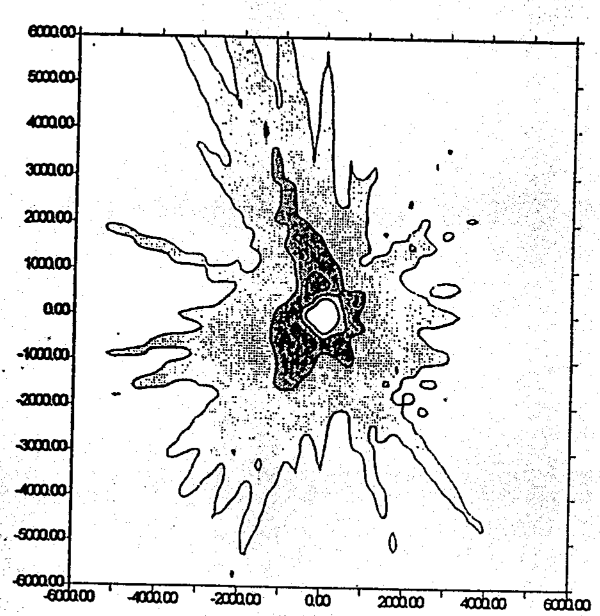
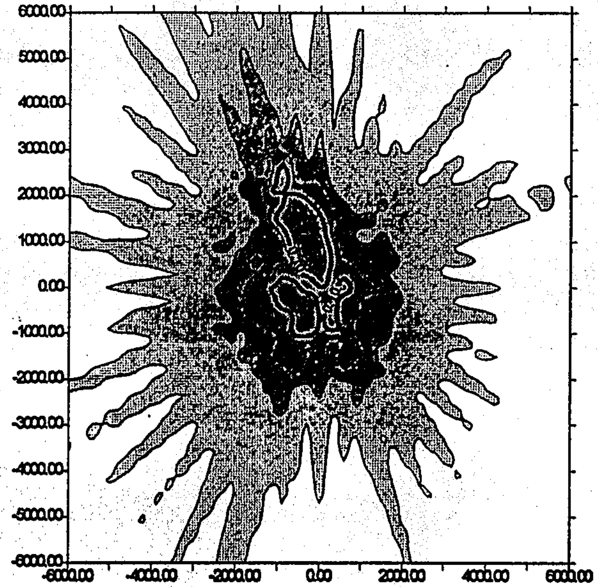


season:s hgt:83.3 temp:375 rate:0.333 vel:2.82

Appendix I

All modelled dispersion diagrams for the cases where concentration values of greater than or equal to 0.02 $\mu g/m^3$ were identified by the model ISCST2. Note that the mine stack is located in the centre of each plot and inside a grid area with 12 kilometer sides. Each plot shows the results of 1681 receptor points at the given parameters. The possible combinations are listed here:

Seasons	Summer	Winter			
Stack height (m)	47.5	60.6	83.3		
Exit temperature (K)	350	375			
Exit velocity (m/s)	1.88	2.82			
Emission rate (g/s)	0.011	0.017	0.222	0.333	0.500



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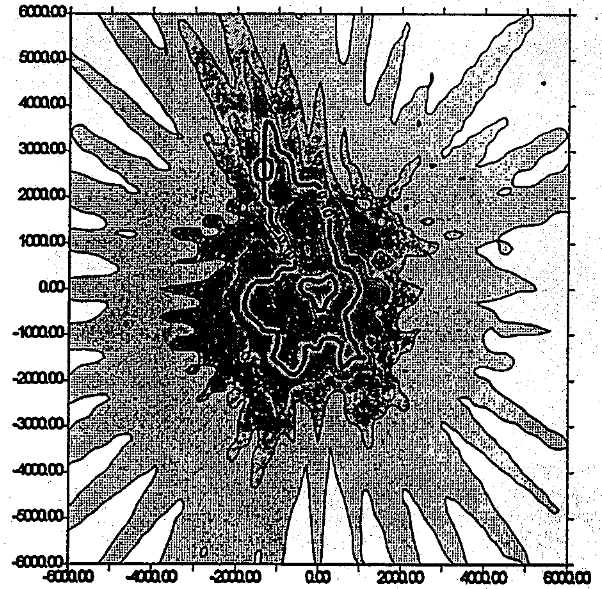

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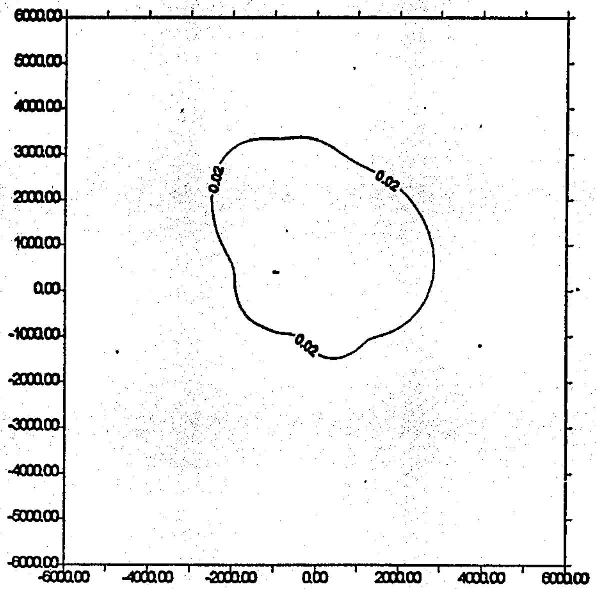

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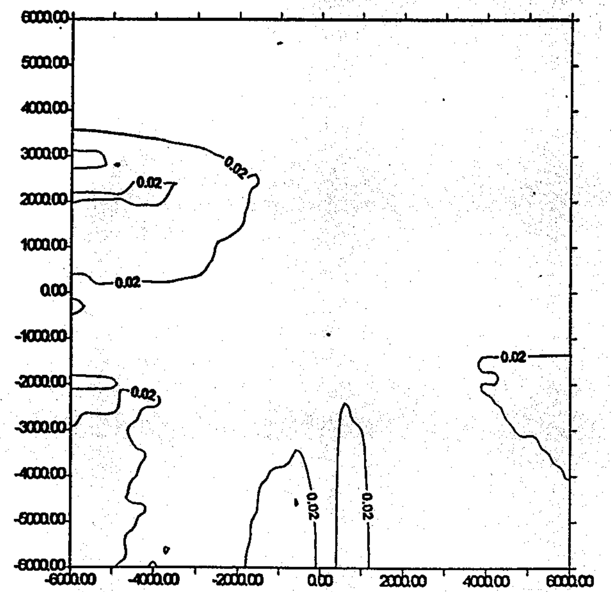

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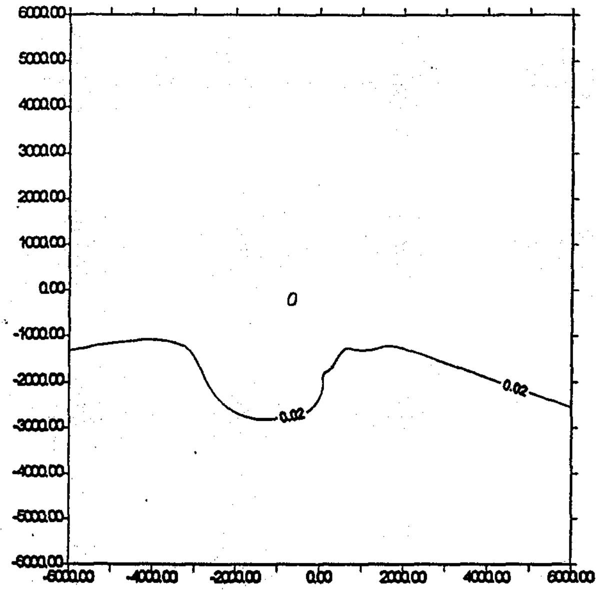

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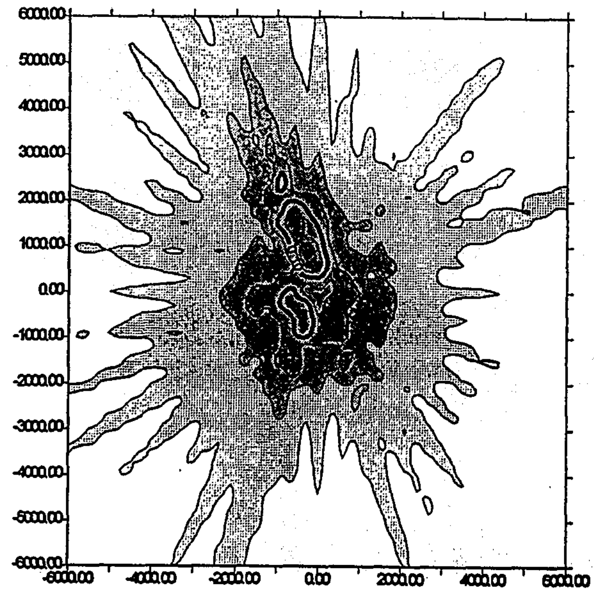

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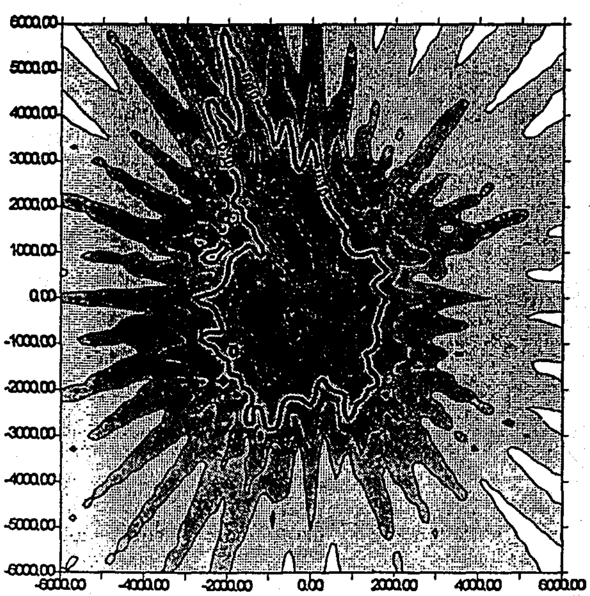

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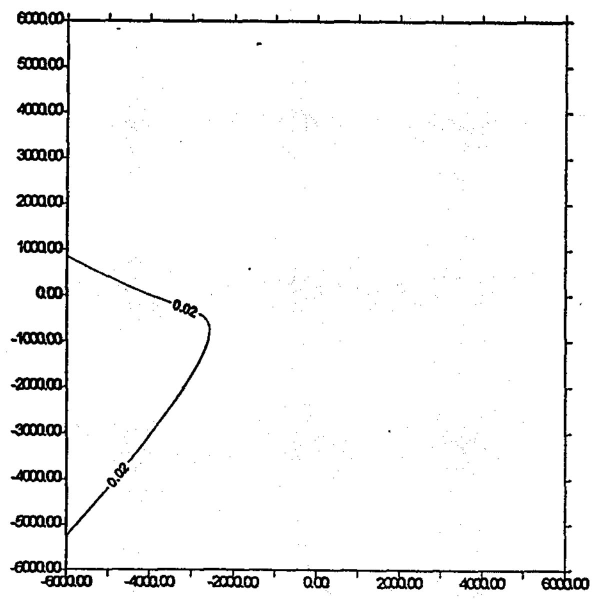

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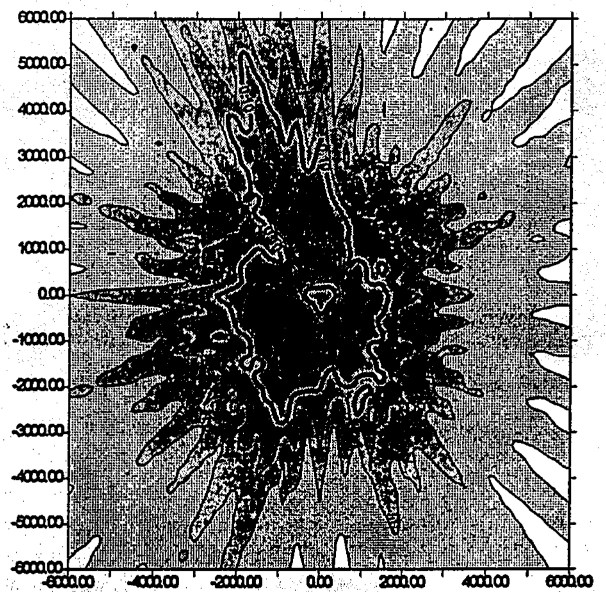

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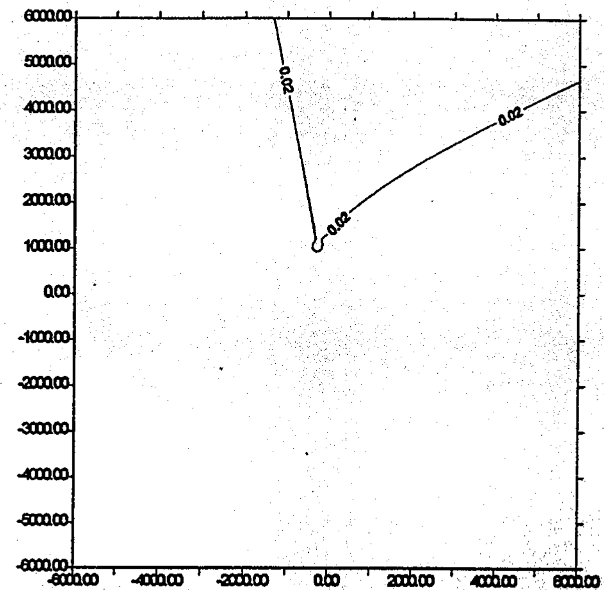

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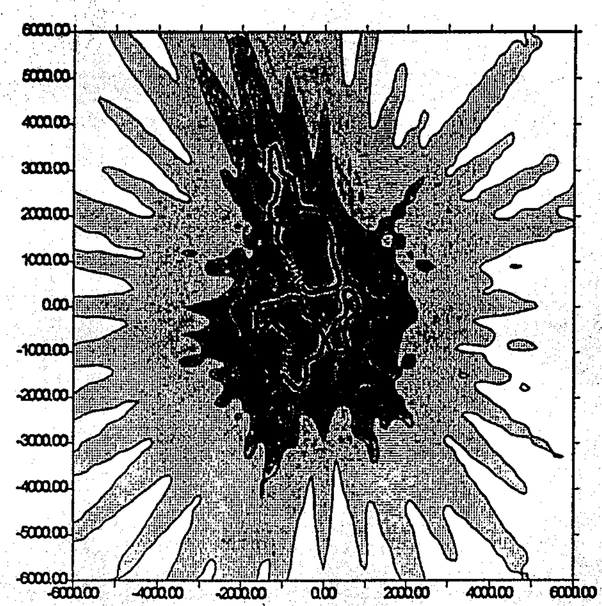

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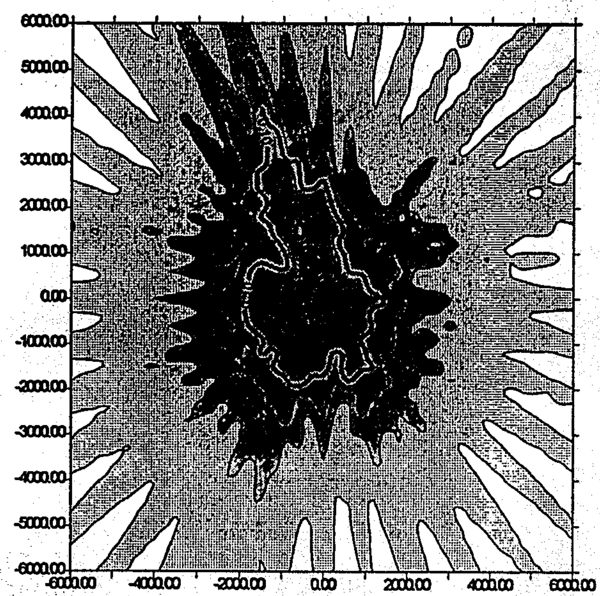

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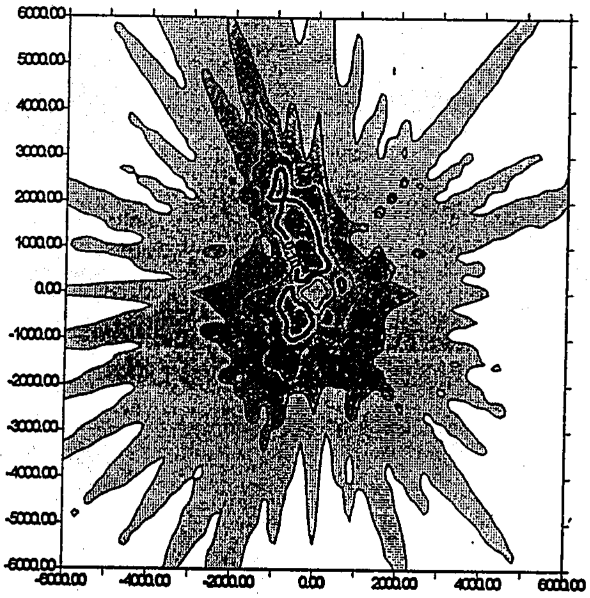

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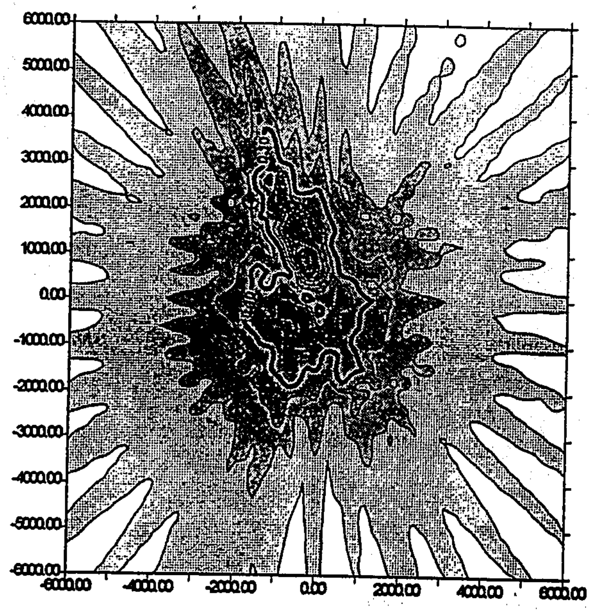

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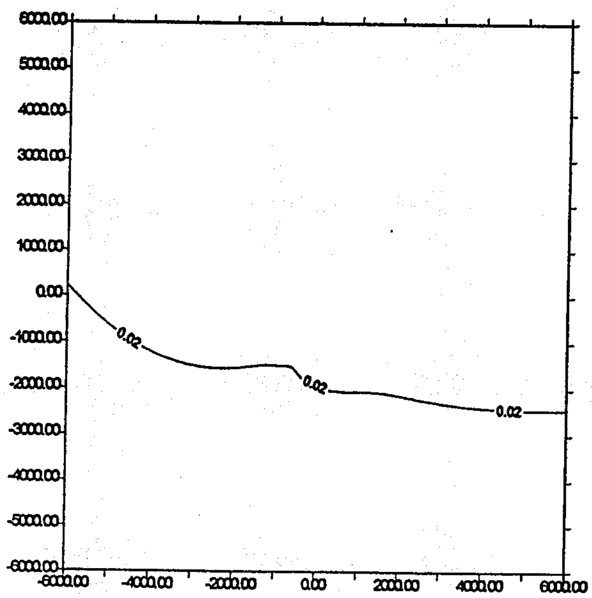

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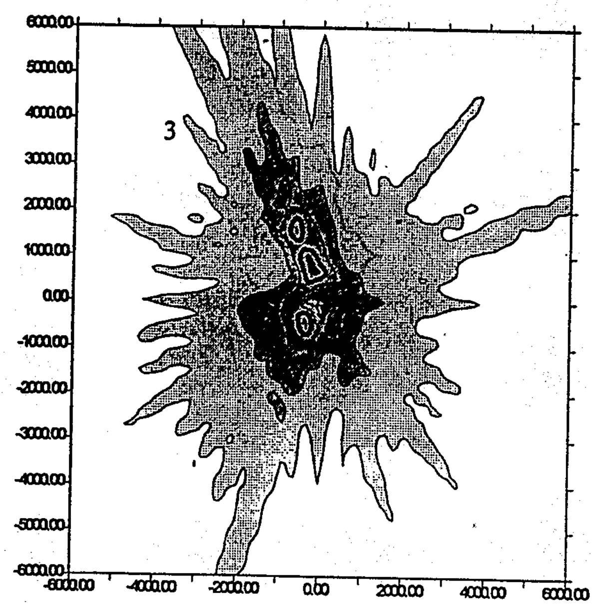

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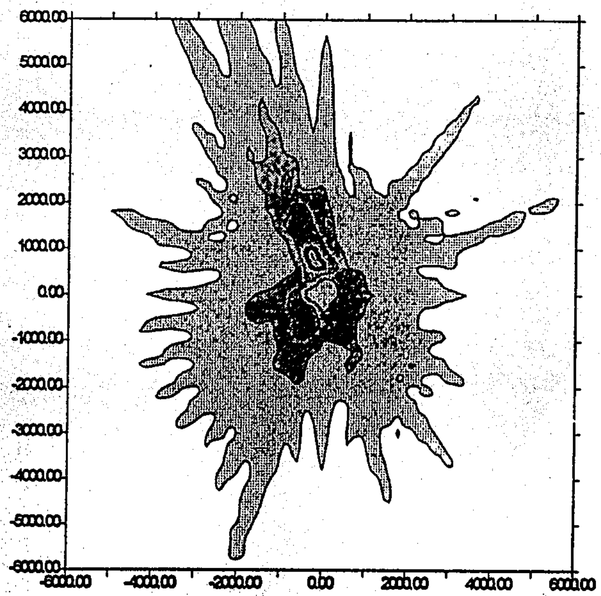

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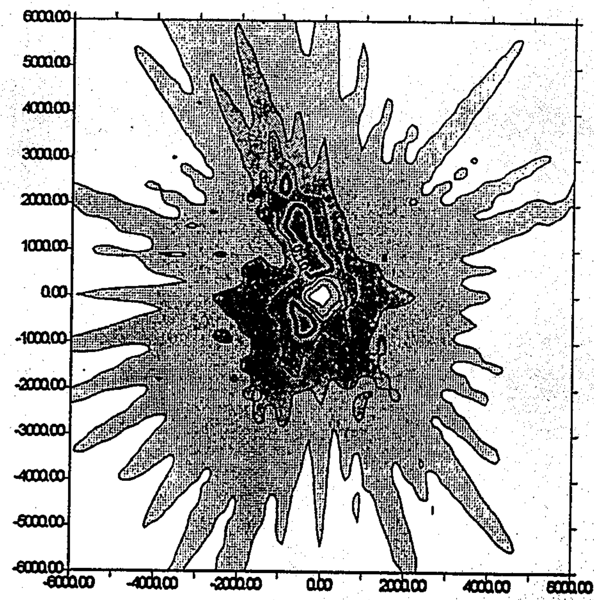

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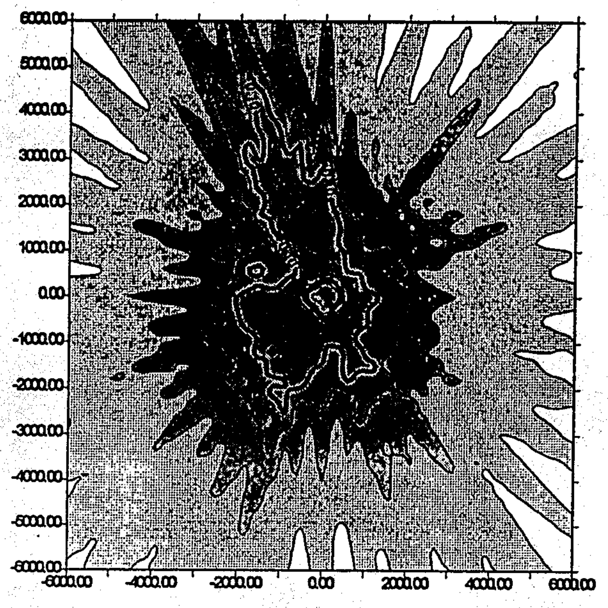

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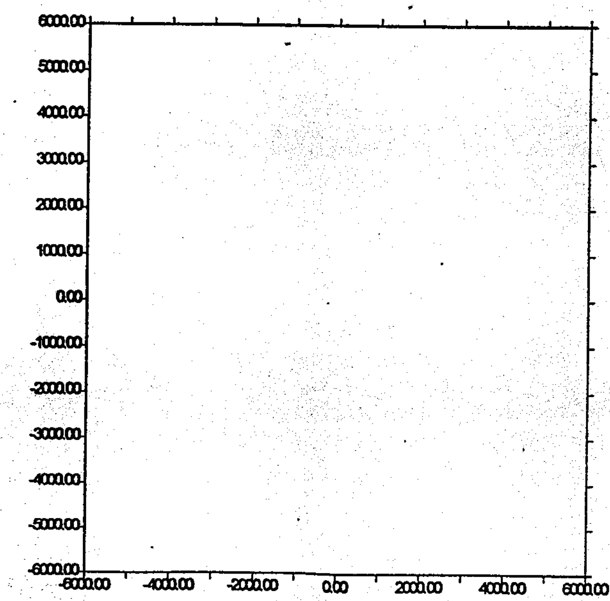

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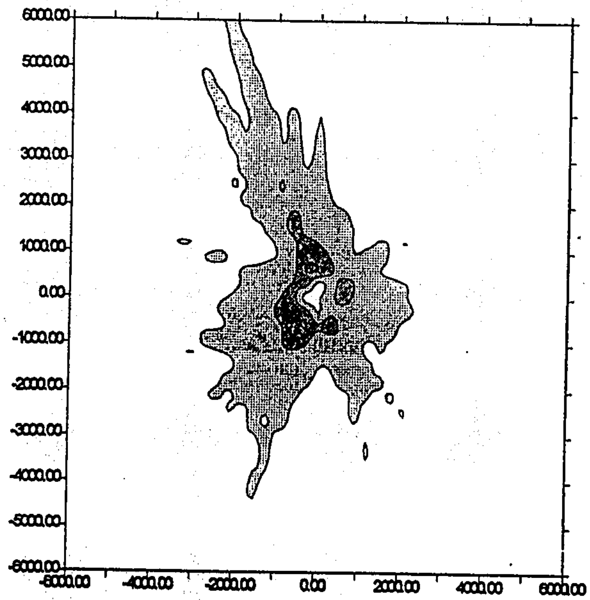

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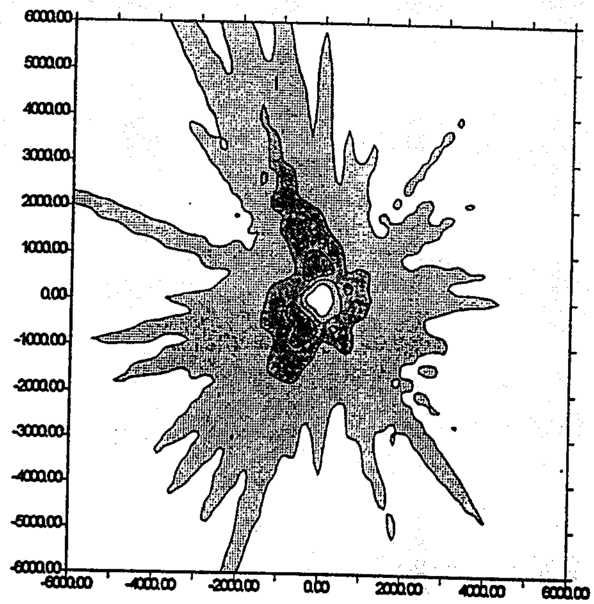

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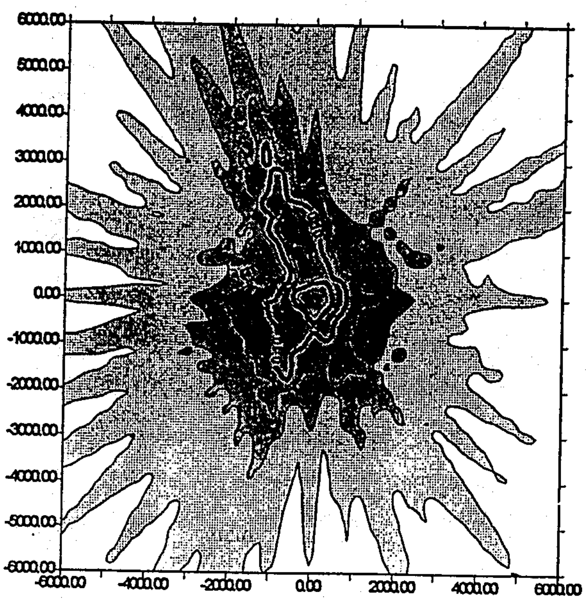

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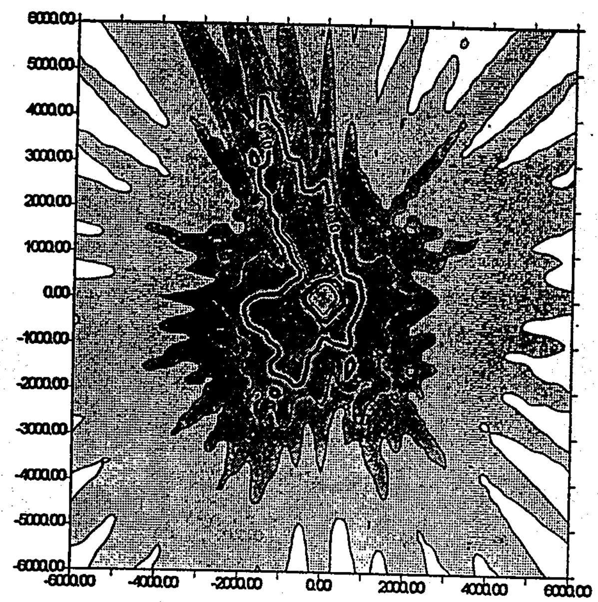

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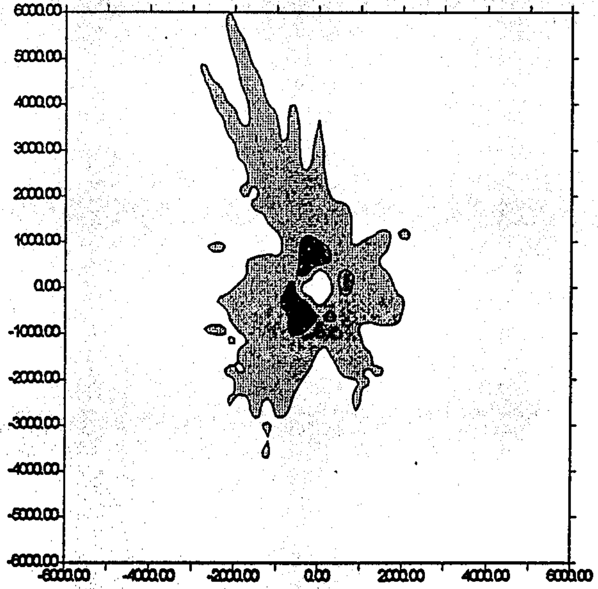

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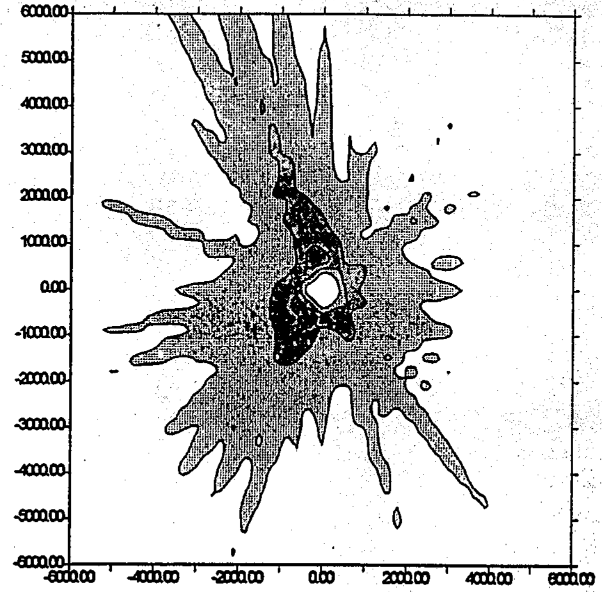

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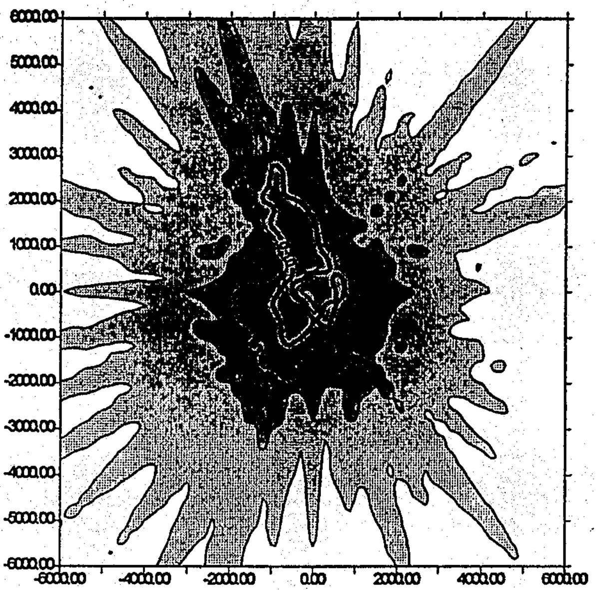

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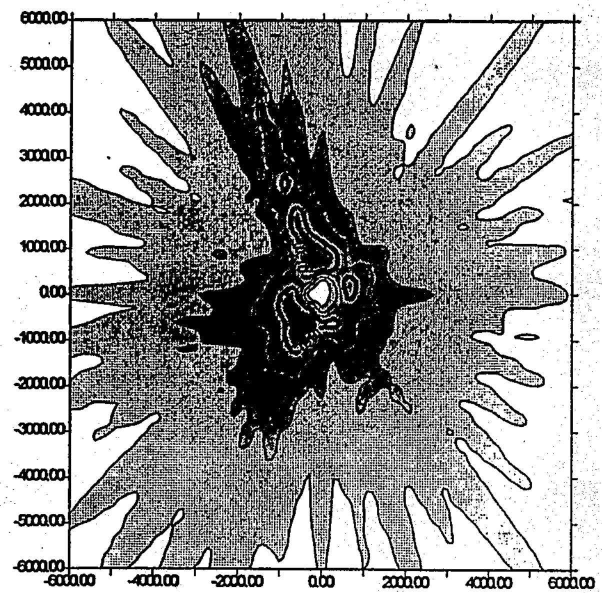

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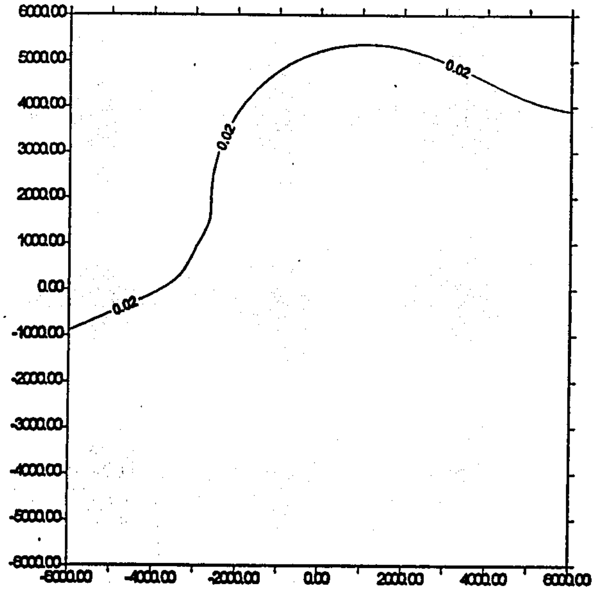

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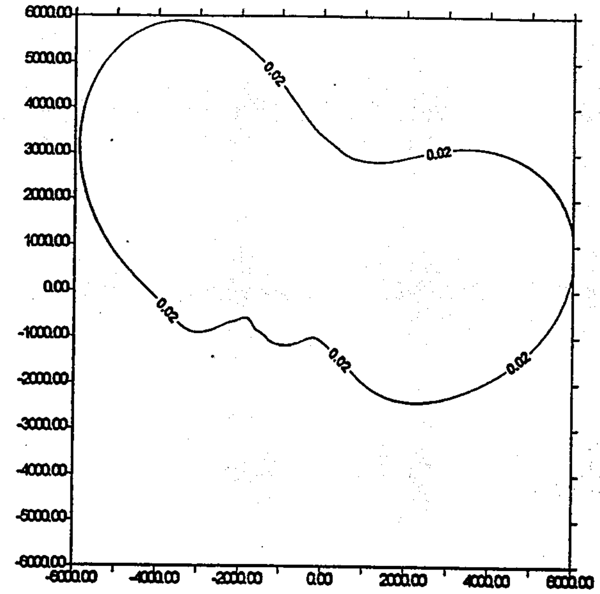

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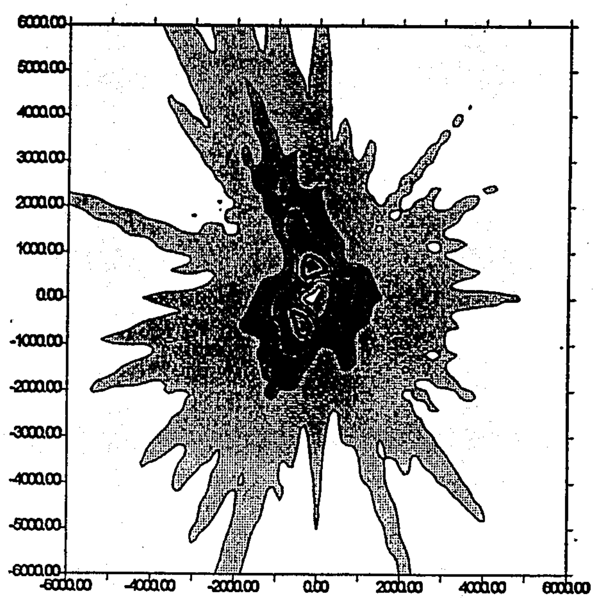

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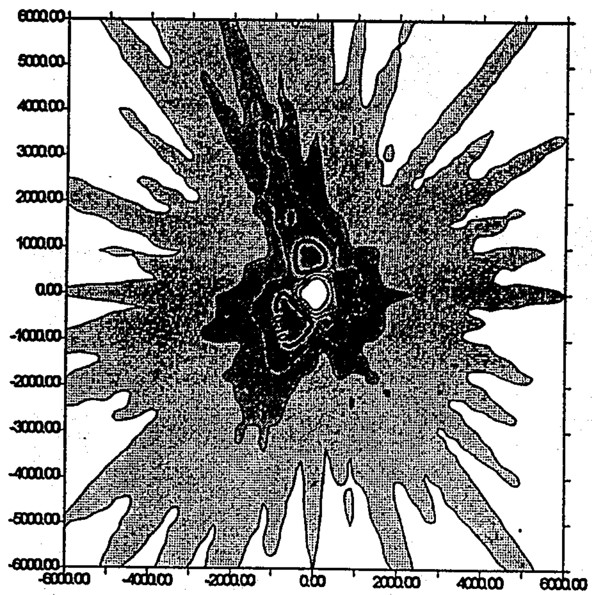

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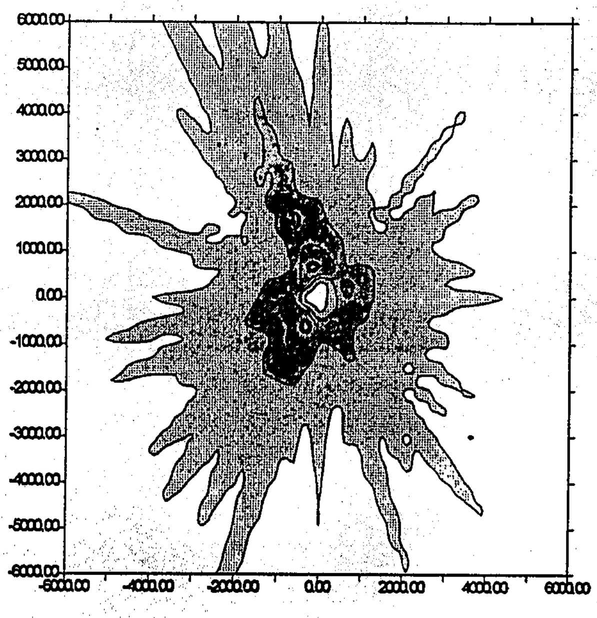

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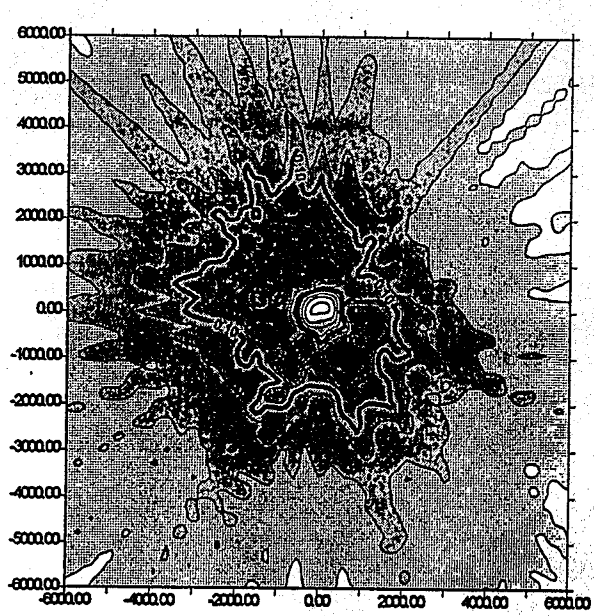

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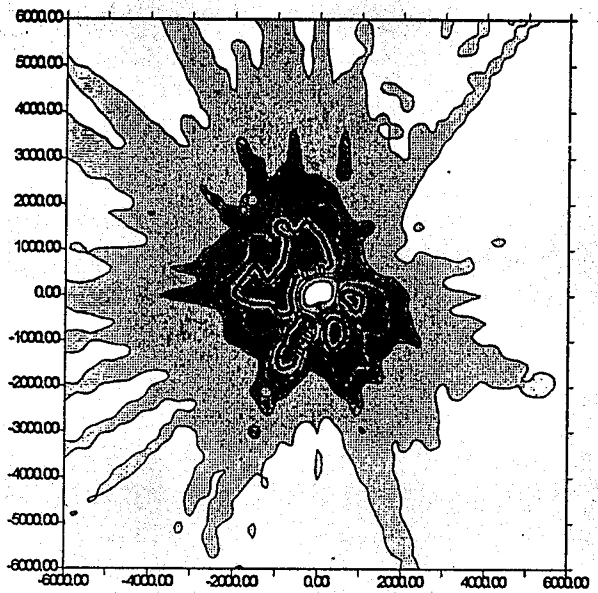

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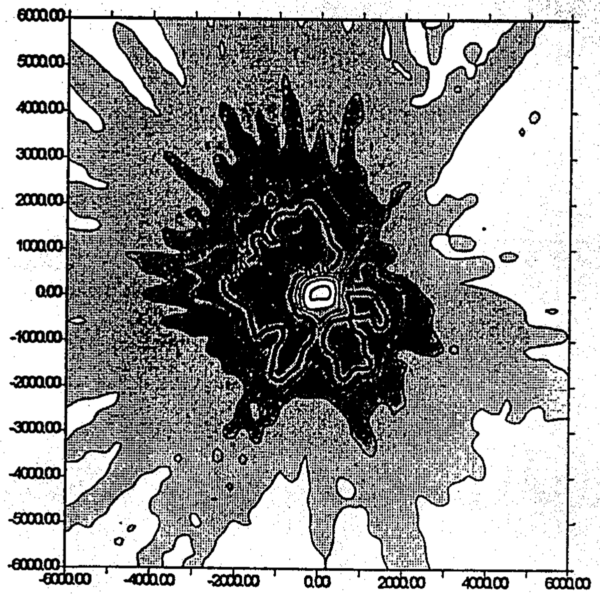

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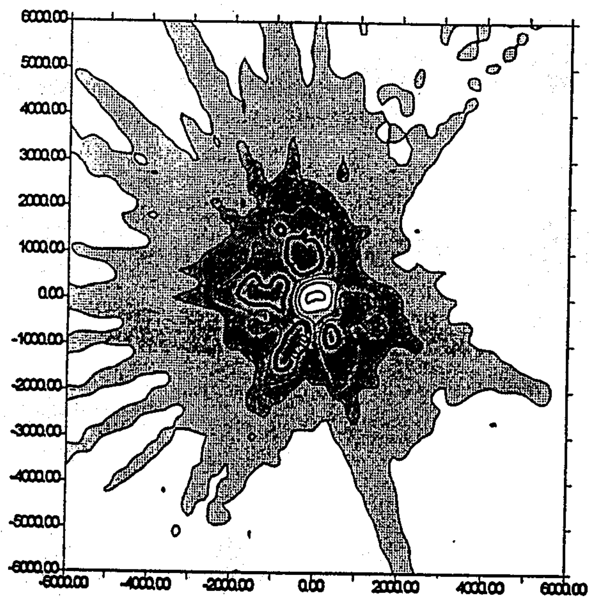

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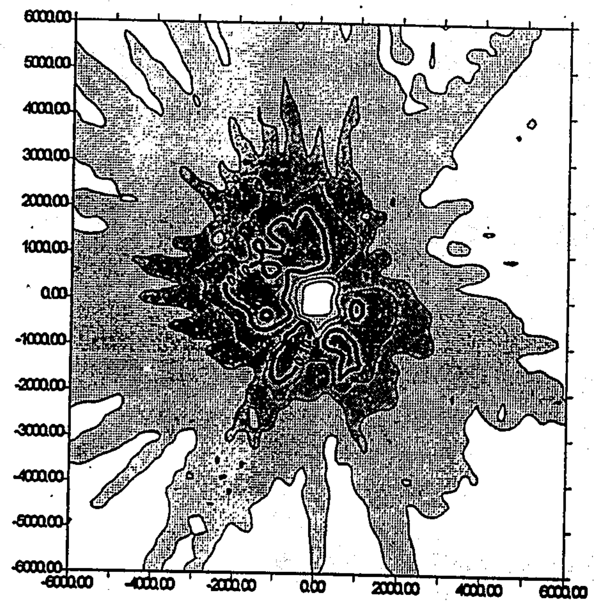

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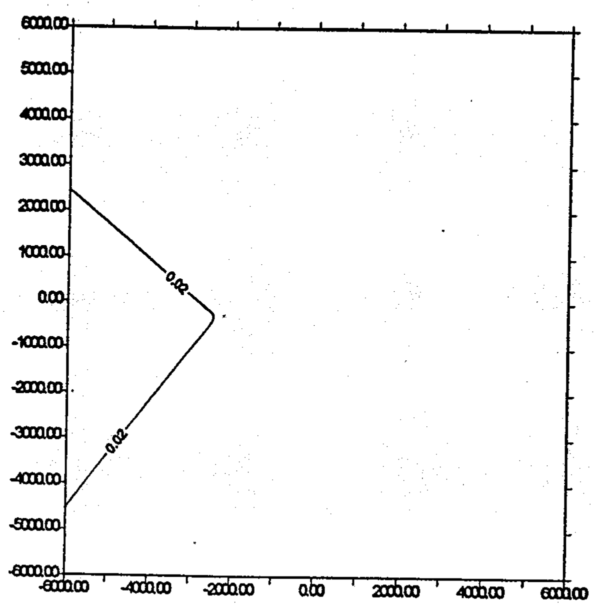

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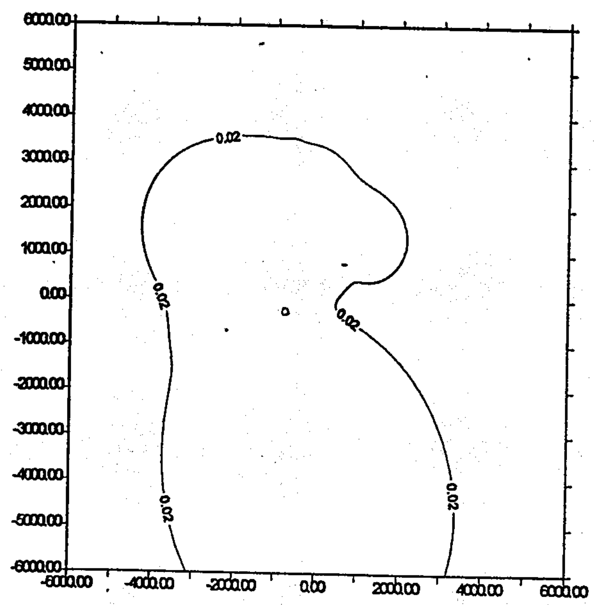

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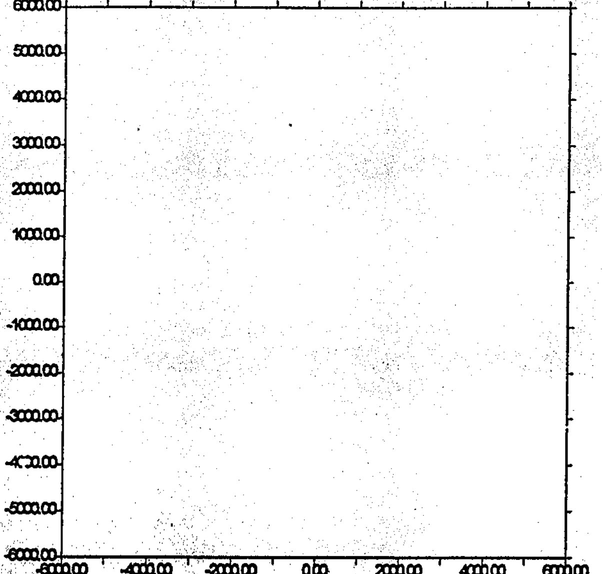

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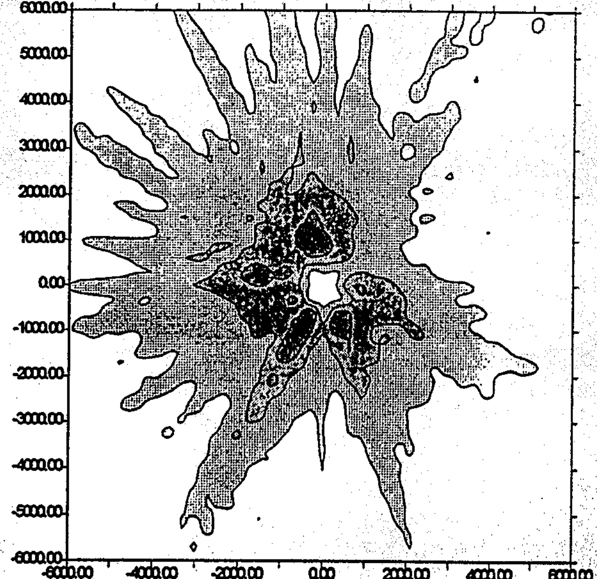

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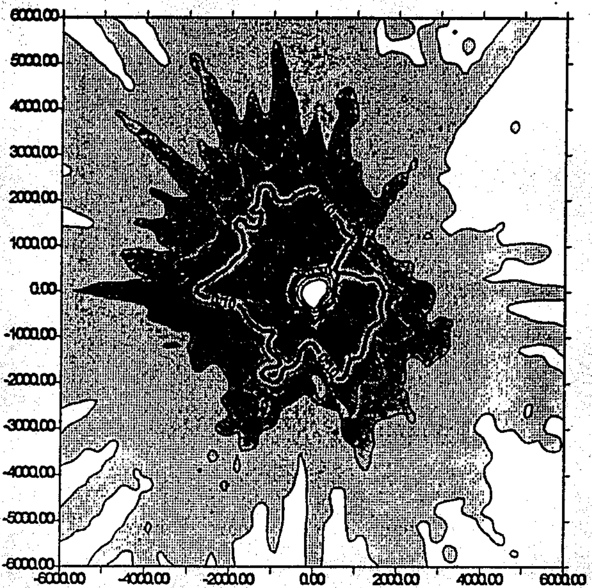

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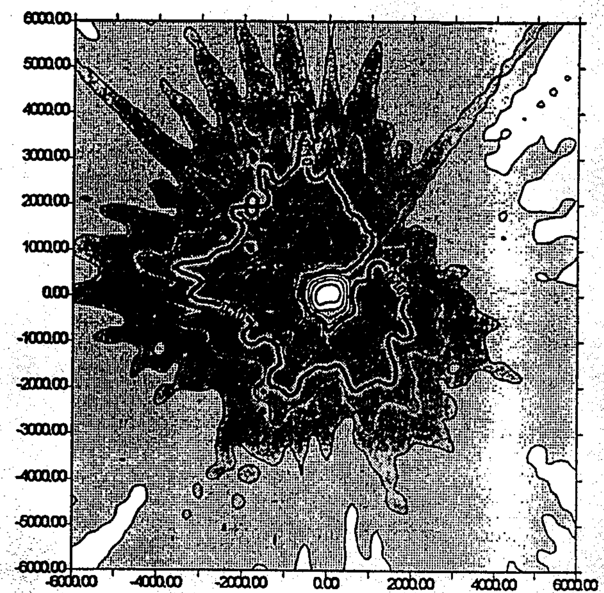

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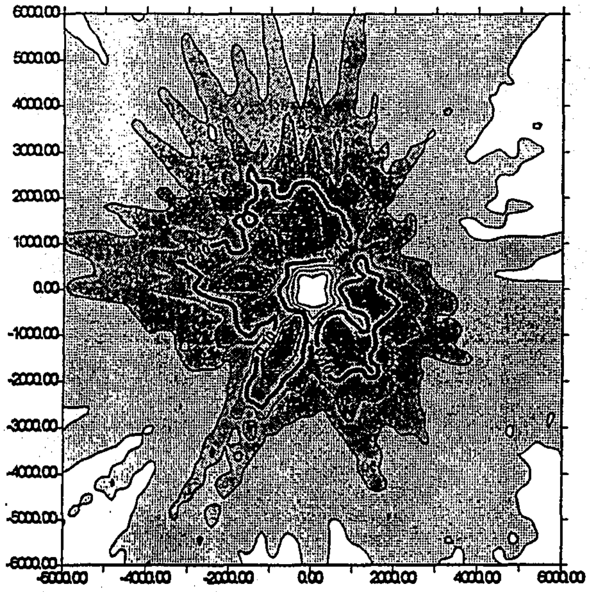

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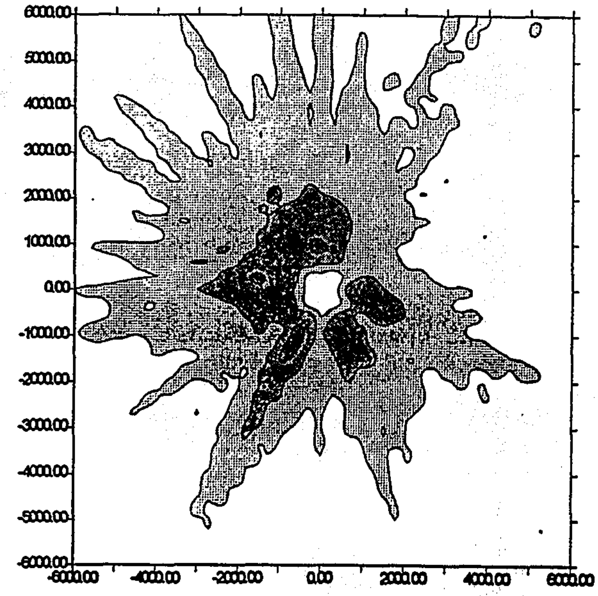

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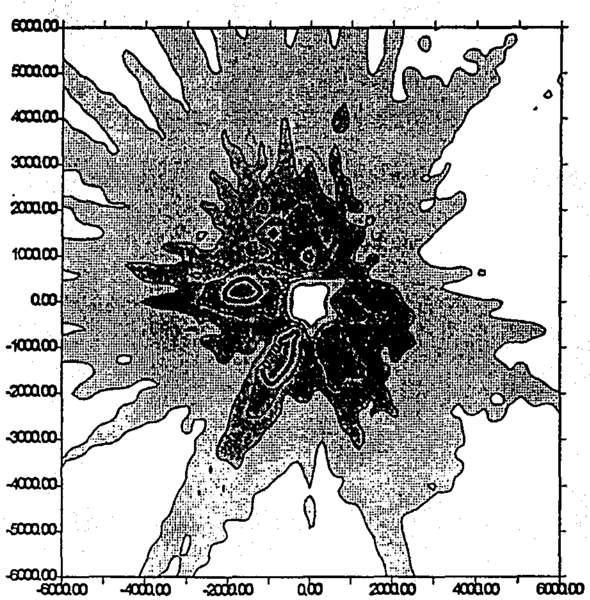

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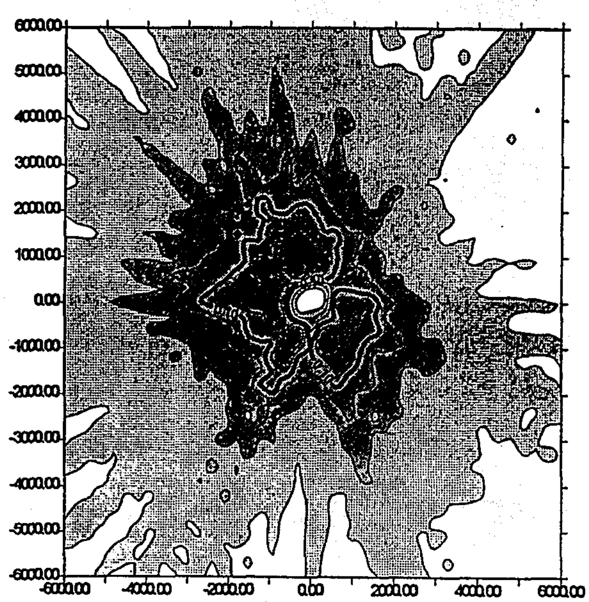

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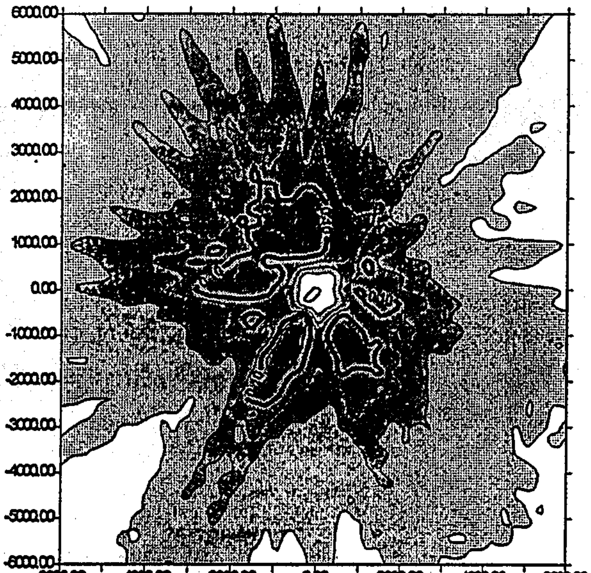

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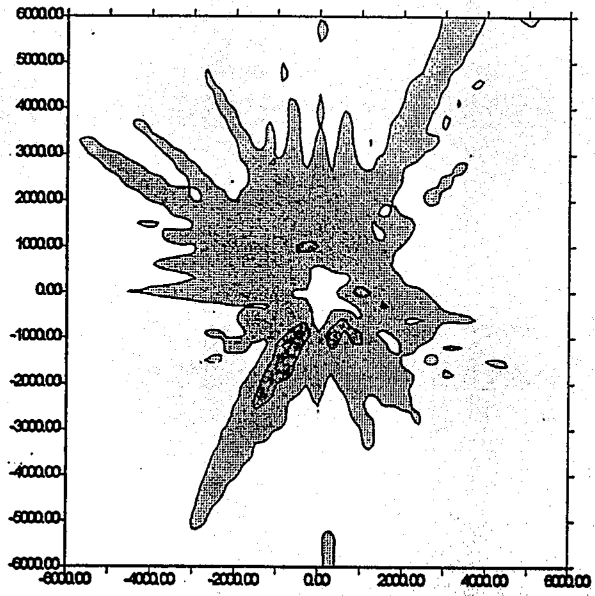

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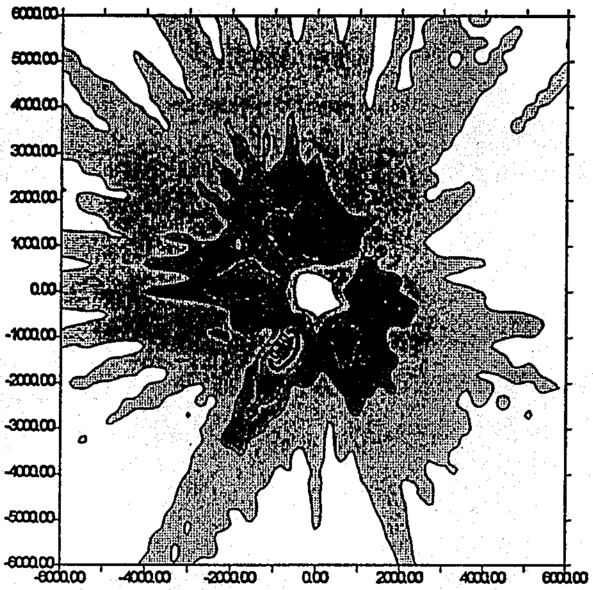

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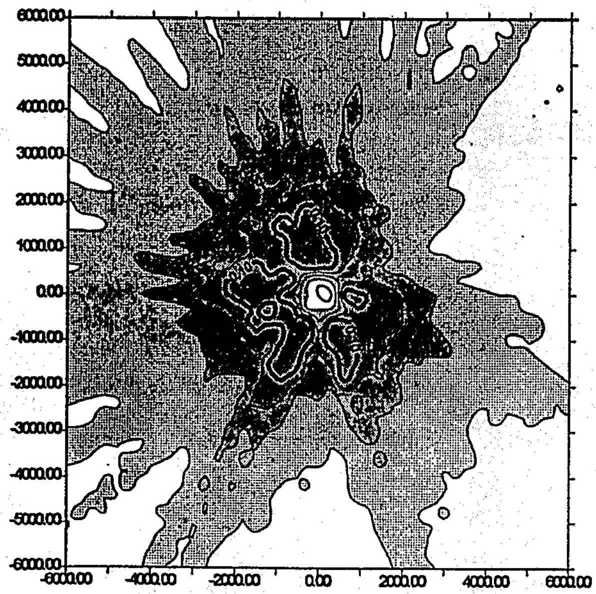

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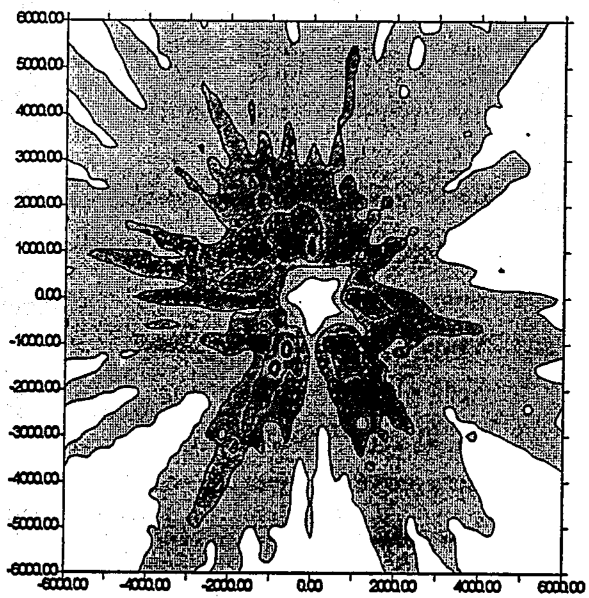

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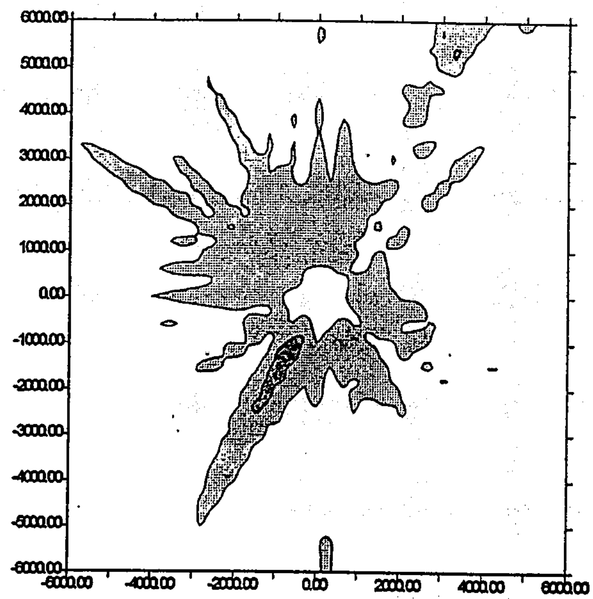

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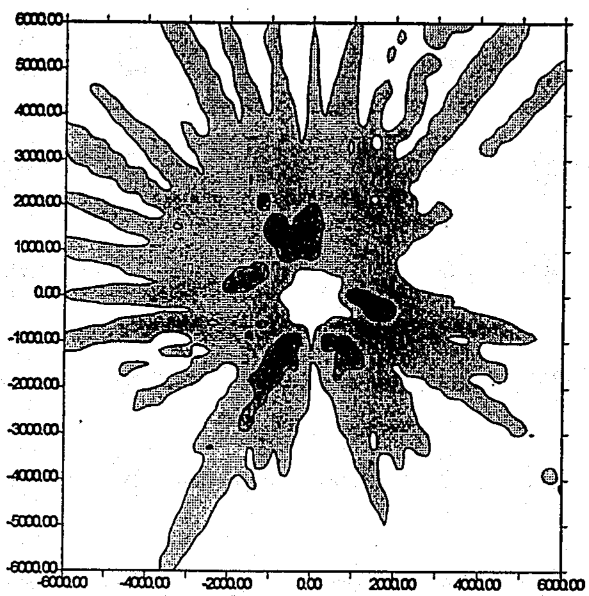

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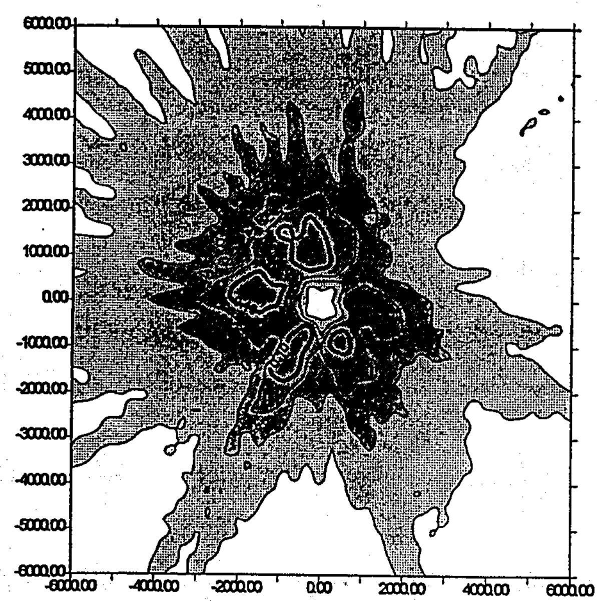

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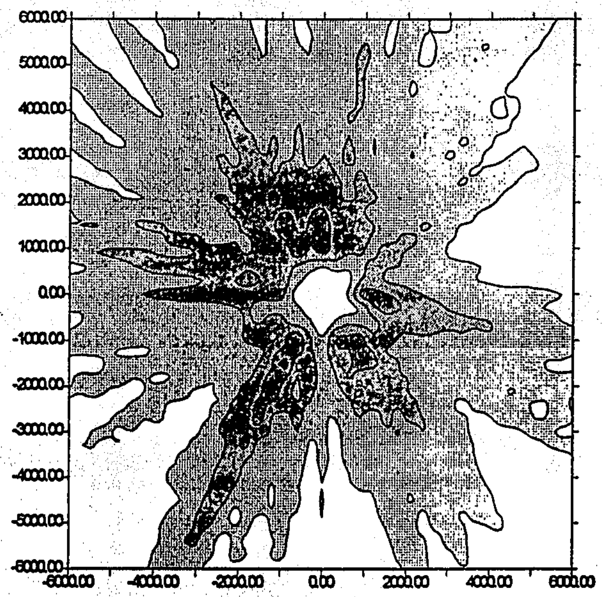

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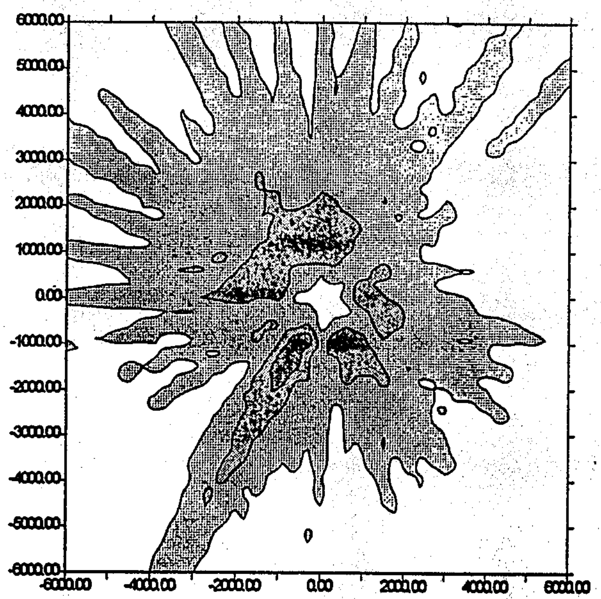

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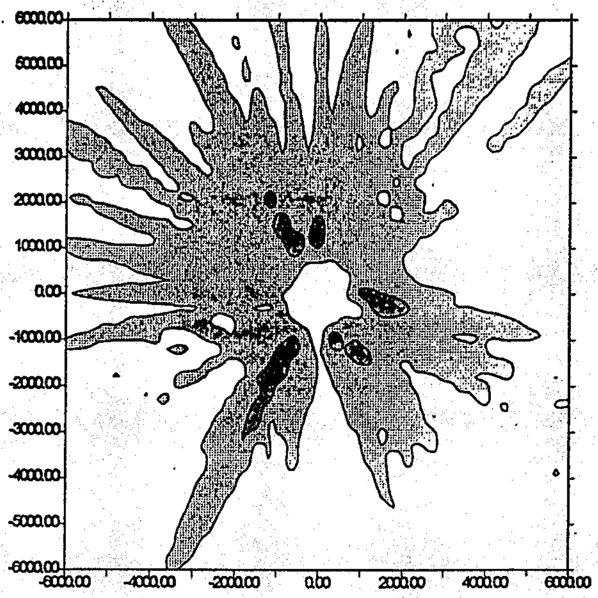

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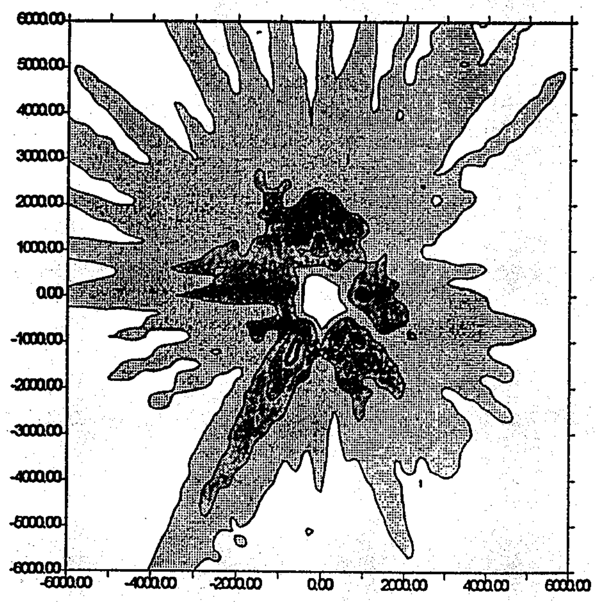

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