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# MEMO

MEMO CONCERNS

**ROV sonar and visual pictures from the field trial “Deep Spill”, June 2000.**

**Final data report.**

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661182.10	22. Feb., 2001	Henrik Rye

## SUMMARY:

The “*Deep Spill*” experiment was carried out in the Norwegian Sea (at 65° N, 4° 50’ E) during 26 – 29 June 2000. The purpose of the field trial was to survey releases of oil and gas at the sea floor in order to improve on the contingency against deep water spills. In addition, numerical models for deep water oil and gas spills were compared to the results from the measurements.

As a part of the experiment, recordings of the underwater plume generated from the releases of the oil and the gas on the sea floor were carried out by means of a Remote Operating Vessel (ROV). These recordings included measurements with a sidescan sonar as well as visual pictures. In addition, counts of oil droplet and gas bubble size distributions were carried out based on the visual pictures taken by the ROV.

This data report contains a description of the results that was obtained by means of the ROV recordings. The ROV was hired from the company “*Oceaneering*” (located in Stavanger, Norway) and was of a type denoted “*Scorpion 10*”.

The report starts with a general description of the equipment used, and an overview of the data taken (Chapters 1 - 5). An inspection of the release arrangement on the sea floor was also carried out (Chapter 6 – 7). Then a general description of the results obtained from the measurements is given (Chapters 8 – 11). Finally, an analysis of the oil droplet and gas bubble size distributions is carried out (Chapters 12 – 14).

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## 1 Equipment used

The company “*Oceaneering*” was subcontracted to carry out the ROV recordings. The ROV operated from the ship “*Far Grip*”, which was the base for the deployment of the release arrangement as well as the generation of the oil and gas released at the sea floor.

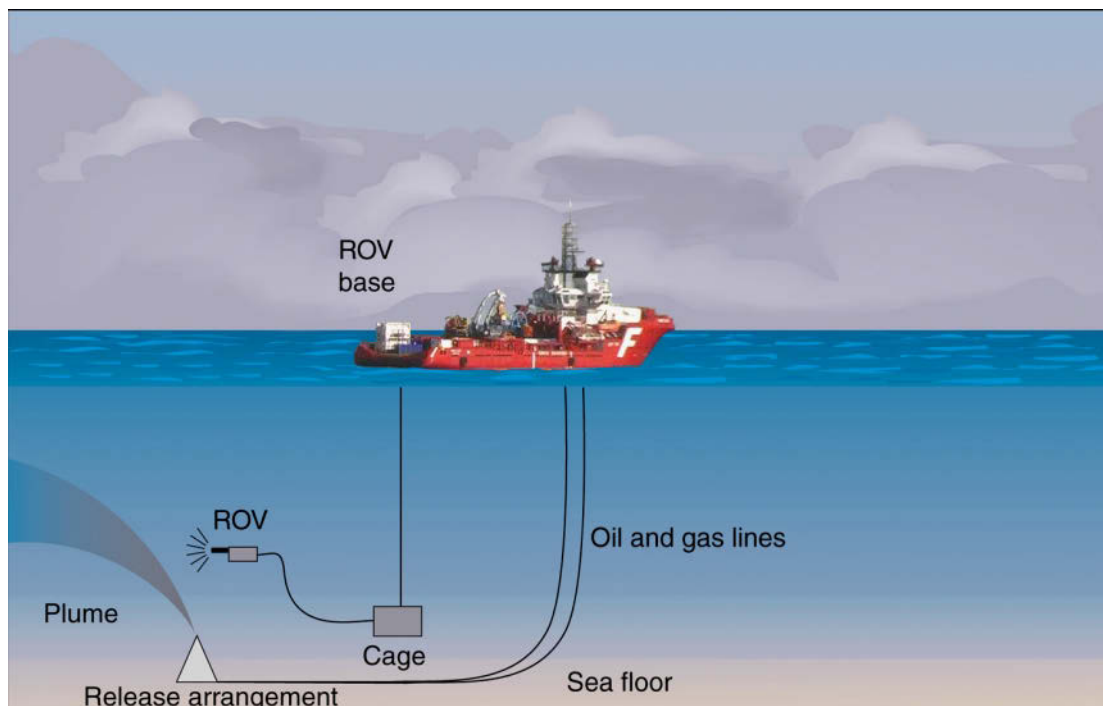
The ROV consisted of two parts. The first part consisted of a non-movable cage that was launched into the water and lowered down to (or close to) the sea floor. From the cage, the ROV movable part (by thrusters) was free to move within a 150 m distance from the cage.

Figure 1.1 shows a picture of the cage and the ROV during launching from “*Far Grip*”.



*Figure 1.1. ROV launched from Far Grip in preparation for deployment operation. Research vessel Håkon Mosby seen in the background.*

Figure 1.2 shows the set-up for the ROV recordings of the underwater plume. The cage was launched down to about 50 m above the sea floor. Then the ROV operated with the cage as the base. The ROV recorded the underwater plume from the sea floor and up maximum about 100 m above the sea floor.



*Figure 1.2. Lay-out of the ROV arrangement operating on the sea floor. The oil and gas were pumped through different lines (made of “coiled steel tubing”) from “Far Grip” and down to the release arrangement on the sea floor.*

The detailed specifications of the ROV used are given in the Appendix A.

The more general specifications are as follows:

#### ROV Type:

Scorpion 10, depth rating 1500 msw fitted with TMS (Tether Management System)

Vehicle hydraulic power unit (HPU): electro-hydraulic power unit provides 75 HP

Thrusters:	6 ea Innerspace thrusters
Speed:	1,5 Knots horizontal , 1 knot lateral , 1 Knot vertical
Tether length:	150m

#### Sonar Specifications:

Type:	Mesotech MS 900 Color Imaging, deep head sonar
Frequency:	675 kHz
Beam width:	1.7°horizontal, 60°vertical
Mechanical resolution:	0.225° (step angle)

SIT Camera SIMRAD 1324

Horizontal Resolution:	700 TV Lines (typical)
Light Sensitivity (limiting):	$2 \times 10^{-4}$ Lux (faceplate)
Light Sensitivity (full video):	$1 \times 10^{-3}$ Lux (faceplate)

OE1366/67 Colour Zoom Camera

Horizontal Resolution:	450 TV Lines for OE1366 460 TV Lines for OE1367
Light Sensitivity:	0.1 Lux (faceplate)
Standard Lens:	Zoom Lens 12:1 Magnification, 5.4mm to 65mm f/1.8 - 2.7

SIMRAD RPT324 Transponder

Overall length :	350 mm
Operational depth :	2000 m max
Transducer beam :	45 degrees

Video recorders

JVC BR - S 600 E                      SVHS players.

Ruler montage

Distance from color camera lens to ruler: 41 cm

Ruler was mounted on front center of ROV skids beneath camera pan/tilt unit

Further details are listed in the Appendix A.

## 2 Measurements carried out

Four different releases were carried out during the “*Deep Spill*” experiment, namely:

- #1. The nitrogen release
- #2. The diesel release
- #3. The oil release
- #4. The natural gas (methane) release

All releases were carried out at 845 m depth through a pipe directed in the vertical with a diameter of 0.12 m. .

Oil and gas rates were varying during the releases, in particular during the start-up period. However, during the actual releases (after the completion of the start-up procedures), the release rates were reasonably stable. For the four releases run, the rates were:

- #1. Nitrogen gas rate 0.60 Nm<sup>3</sup>/s and water 1 m<sup>3</sup>/min.
- #2. Natural gas rate 0.55 Nm<sup>3</sup>/s and diesel 1 m<sup>3</sup>/min.
- #3. Natural gas rate 0.70 Nm<sup>3</sup>/s and oil 1 m<sup>3</sup>/min.
- #4. Natural gas rate 0.70 Nm<sup>3</sup>/s and water 1 m<sup>3</sup>/min.

Three of the four releases were surveyed by the ROV. The release #3 (oil release) was not surveyed by the ROV due to the wave conditions on the site at that time. The oil release took place after a weather period with strong winds, generating swells that caused the ship “*Far Grip*” to move significantly. The launching unit of the ROV was located too far aft on the ship to allow for a secure launch of the ROV down to the sea surface. The launching of the ROV was therefore postponed until the release of the natural gas only (release #4).

It should be stressed that it was not the wave height that limited the operability of the ROV, but the dominant wave period present. It turned out that the wave period caused a significant motion of the ship, due to an unfortunate match between the dominant wave period and the pitch motion of the ship.

The signals that were recorded on the video were the sonar signal as well as the camera visual picture. The visual picture recording switched between the color camera and the black/white camera, dependent on the purpose of the recording. The drop size recordings was carried out with the color camera (by recording the droplets against a ruler as the background), while the black/white camera was used for picturing the underwater plume as such.

The sonar signal and the visual pictures were both recorded on analog video tapes simultaneously during all the three trials, which then amounts to at least 2 x 3 hours of video tapes produced. These tapes were then secured for further inspection and processing after the field trial.

In the following, the results from the ROV recordings of the three releases (#1,2 and 4) are briefly summarized.

### **3 Release #1, The nitrogen release, 26. June 2000**

The nitrogen release was carried out in the time period 1806 – 1921, local time.

Video recordings were carried out in the time period 1757 – 1905, local time.

Originally, it was the intention that the sonar signal as well as the position of the ROV should be recorded as well, along with the pictures. It turned out, however, that the cryogenic pump used to process the nitrogen (LIN) and the methane (LNG) generated noise that influenced seriously on the sonar signal. The sonar signal received was therefore not reliable for positioning of the ROV (relative to the plume).

A transponder with a 2000 m reach was mounted on the ROV for positioning. It also turned out that the transponder signal from the ROV was received on the “*Far Grip*” with poor quality and regularity (possibly due to fouling on the receiver unit on the “*Far Grip*”). However, the signal was recorded with presumably better quality onboard “*Håkon Mosby*”, one of the research vessels. This signal was therefore recorded at “*Håkon Mosby*” for tracking of the ROV paths during the measurements.

Without the transponder signal as well as the sonar signal at hand during the recordings, the plume was easily lost. The orientation and motion of the ROV was therefore based on visual pictures from the cameras, in addition to the depth recording and the geographical orientation of the cameras. A large part of the time spent during the first release was therefore used to develop a recording strategy with these (unexpected) limitations built into the procedures.

Table 3.1 contains a brief review of the data that was recorded.

*Table 3.1. Log for ROV recordings during the nitrogen release, 26. June 2000. All time indications refer to clock on the video (hour and minutes). Cryogenic pump was used to pump nitrogen (and also natural gas) through the gas line. Rhodamine was added to the oil/water line in order to determine dilution properties.*

<b>Local time</b>	<b>Release on ship</b>	<b>ROV position</b>	<b>Comments</b>
1757	Sea water only	At release unit	Clear sonar pictures. Dirty seawater in release? No Rhodamine in release.
1806	Sea water only. Cryogenic pump starts.	At release unit	Noise in sonar recordings. Increase in release rate.
1816	Gas arrives at release site	At release unit	Arrival time of gas 18:15:55. Nice pictures of initial gas plume
1818	Trouble with water release? Water release goes down.	Recording plume, ascending to 837 m	Occasionally some pictures of gas bubbles, but unclear. Some sonar signs of plume, but poor quality.
1825	Gas release, varying gas rates	Lost plume	Seeking back to platform
1840	Still nitrogen only	Back at platform	
1843	Sea water switched on	Observing plume	Poor quality pictures
1848	Water and gas running	Observing plume	Some nice pictures of plume.
1852	Cryogenic pump stops	At release site	Gas plume disappears, some nice visual pictures, good sonar pictures of <i>water</i> plume?
1856	Sea water only	At release site	Some gas is apparently still released? Still some good sonar pictures of plume.
1905	Sea water only	Back to cage	End of video
1906	Gas switched on again		No recording
1907	Start of sea water, including Rhodamine		No recording

#### **4 Release #2. Diesel release, 27. June 2000**

The diesel release was carried out jointly with natural gas (basically methane). Since the methane was expected to form hydrate, the strategy was therefore to look for the point of initial hydrate formation somewhere above the release point. The water temperature at the release point was measured to be close to  $-0.82^{\circ}\text{C}$ .

At the same time, the diesel content in the water was expected to coat the lenses and thus decrease the visibility of the photo equipment. Entering the plume too close to the release point was therefore avoided, where the concentration of the diesel would be large. The recording strategy was therefore to move the ROV upwards along the plume on the outside, until some depth level was reached. Then the ROV was to be moved horizontally into the plume area for recording of oil droplets, gas bubbles, and possibly also hydrate formation.

It turned out that the diesel and gas bubbles were moving too fast relative to the ROV when the plume area was entered. This motion made it difficult to have good pictures of the bubbles or the droplets. This problem was partly solved by letting the ROV ascend jointly with the bubbles/droplets inside the plume area.

The coating of the diesel on the lenses was evident from the recordings made, but it turned out that the lenses were “self-cleaned” by the ambient water when the ROV moved outside the plume area again. The strategy was therefore changed towards the end of the recording period by moving the ROV into the plume closer to the release point. At the same time, the ascent of the ROV inside the plume area was extended, because no hydrates were discovered at shorter distances from the release point. Maximum ascent was at 789 m depth, which is about 56 m above the release point.

Table 4.1 contains the log from the #2 ROV recordings. There was a long period with starting problems with the pumps in the time period 0750 – 0838. The ROV was just staying at the release arrangement, awaiting the real spill to start (methane, combined with diesel), and checking equipment. During this time period, some nice plume pictures were also taken, some of which are close-ups on details in the plume behavior.

It is possible to distinguish between diesel droplets and gas bubbles by looking at their motion characteristics. The gas bubbles contain less momentum (= mass or density times the rise velocity) than the diesel droplets. Therefore, the gas bubbles tend visually to “wobble” to a larger extent than the diesel droplets. The diesel appears thus visually to be “calmer” than the gas bubbles. It is more difficult to separate the two by light, because both seem to reflect the light emitted by the ROV more or less in the same manner.

Some of the recordings of bubble/droplet sizes were found to be of a sufficient quality for further examination. Results from diesel droplet counts are given later in the report.

The sonar scans were of limited value due to noise from the cryogenic pumps.

Table 4.1. Log for ROV recordings during the diesel release, 27. June 2000. All time indications refer to clock on the video (hour and minutes).

Local time	Release on ship	ROV position	Comments
0750	Water pumping. N2 started pumping at 07:50:50	At release unit or platform	Dirty water released, no gas. Some sonar picture of water plume.
0759	Water and N2	“	Gas appearing at 07:59:30.
0800	Start pumping diesel, but abrupted two times	“	Pumping problems. Water and gas released with varying intensities. Some nice pictures of the releases.
0832	Diesel and N2 pumping	“	Diesel seems to appear at release arrangement at 08:32:31 (color change).
0834	Switch to methane	“	
0840	Full methane rate from 0838.	“	Still N2 released at the sea floor. Nice close-up pictures of the plume.
0842	Methane and diesel running	Rise to 10 m above sea floor. First plume entrance (“dive”).	Some droplets recording, pictures not quite in focus.
0844	“	New dive at 834 m.	
0847	“	New dive at 823 m	
0849	“	At platform	
0851	“	Dive at 808 m	Pictures unclear. Position lost
0856	“	At platform	
0857	“	Rise to 820 m outside plume	
0859	“	Dive at 820 m	Few bubbles. Lost plume
0901	“	At platform	Violent plume. Some nice pictures
0902	“	Rise to 811 m outside plume	Evidence of diesel droplets present 09:02:36.
0904	“	At 811 m	Lost plume
0908	“	At platform. Dive at platform	Droplets recorded. Diesel ?
0909	“	New dive at platform, out of plume again and ascend outside plume to 815 m	
0912	“	Dive at 815 m, ascending to 800 m	Some droplets (?) recorded. Lost plume
0915	“	At platform	
0916	“	Ascent to 840 m. Dive	Good droplet pictures
0918	“	Out of plume at 827 m	
0920	“	At platform. Ascending to 840 m. Dive	Good droplet pictures
0922	“	Out of plume at 822 m	Some diesel droplet pictures

<b>Local time</b>	<b>Release on ship</b>	<b>ROV position</b>	<b>Comments</b>
0924	Switch to N2 at 0923.	At platform. Dive at platform, ascending inside plume	Good pictures
0930	N2 and switch to sea water at 0928	Ascending to 789m inside plume	Some good diesel droplet pictures
0931	Sea water, N2 switched off 0930	Out of plume	ROV down to sea floor. Lost plume.
0935	-	Moving at the sea floor	Visiting a representative of the local inhabitants on the site.

## **5 Release #4. Methane release, 29. June 2000.**

The last release consisted of LNG (methane) only. The purpose of this release was primarily to look for hydrate formation and the dissolution of the plume into the water.

At this stage, a technique was developed for recording the plume with the ROV. It was the intention to use this technique for this trial as well. The most optimum procedure for recording the plume was as follows:

1. Start at release unit.
2. Ascend outside plume area
3. Move horizontally into the plume at some depth level
4. Switch camera from black/white to color to record bubble sizes
5. Ascend inside plume area while recording bubbles.
6. Move out of plume area, when bubbles are no longer recorded

This procedure was followed to a large extent during the last experiment, with minor changes or variations.

One disadvantage with this procedure was that when moving out of plume area at some depth level (in particular far above bottom), the orientation of the ROV was easily lost. It was then necessary to move down to the sea floor and reorient the ROV in order to find the path back to the release unit.

The basic issue was to look for the hydrate formation. When it turned out that no hydrate formation was apparent close to the release unit, priority was given to ascend inside plume area as far above sea floor as possible to look for the hydrate. The ROV succeeded to move up to 100 m above the sea floor inside plume area, but still hydrate formation was not visually apparent in the recordings taken.

Some of the recordings of bubble sizes are of sufficient quality to be used as a basis to determine or estimate gas bubble size distributions. The results from these counts are given later in the report.

Table 5.1 contains the log from the #4 ROV recordings.

Table 5.1. Log for ROV recordings during the methane release, 29. June 2000. All time indications refer to clock on the video (hour and minutes). CST = Coiled Steel Tubing arrangement.

Local time	Release on ship	ROV position	Comments
1011	No release	At release unit or platform	Check of instruments. Video switched off for some period.
1047	Start nitrogen pumping	“	No release.
1049	Sea water pumping	“	Dirty water release. Start release at 10:49:47. No apparent gas present.
1051	“	“	Moving into dirty water plume. Only small particles.
1053	“	“	Occasionally dirty water. Increased release rate. Still no gas at platform
1104	Nitrogen and water running	“	Nitrogen plume observed 11:04:16. Some nice pictures of bubbles.
1107	Methane switched on	“	Recording releases. Occasionally no gas in release.
1110	Methane and water running	“	Occasionally monitoring inside plume. Pictures of mixed quality. Still nitrogen at release, probably.
1115	“	Plume recording	Rising to 830 m inside plume. Unclear pictures. May be nitrogen and not methane gas?
1117	“	At platform	
1118	“	New plume recording	Rising to 790 m inside plume. Some nice bubble pictures
1121	“	At 790 m depth	Moving downwards
1131	“	At platform	Gas leakage at platform recorded. Nice platform pictures 11:30:49
1132	“	New plume recording	Rising inside plume
1134	“	At platform	
1135	“	New plume recording	Rising to 794 m. Inside plume from 837 m depth. Some nice bubble pictures
1138	“	Outside plume recording	Rising to 750 m
1139	“	At platform	
1141	“	Rising from platform	Rising outside plume to 823 m, then inside plume to 750 m. Good bubble pictures. In particular 11:41:21.
1145	“	Descending inside plume	Out of plume at 750 m. Inside plume again and descending. Some nice bubble pictures.
1146	“	At the sea floor	
1158	“	At the platform	Rising outside plume
1200	“	Recording inside plume	Rise inside plume to 825 m. No

<b>Local time</b>	<b>Release on ship</b>	<b>ROV position</b>	<b>Comments</b>
			particular new information
1205	“	Inspection of CST	Some nice pictures of CST motions due to swell at the sea surface.
1214	“	Back at platform	
1215	“	Last dive inside plume	Rise to 744 m. No hydrate seen.
1221	“	Move out of plume	Out of plume at 744 m depth.
1222	“	Down to sea floor	
1240	“	At platform	Inspection of methane leakage and new inspection of CST. Good pictures of methane leakage.
1248	“	End of video	
1307	Switch back to nitrogen.		

The sonar scans were of limited value due to noise from the cryogenic pumps.

## 6 Inspection of CST and the platform on the sea floor.

Considerable efforts were made in order to make a proper installation of the platform on the sea floor. The ROV made during the field trial some inspections of the release arrangement as well as of the Coiled Steel Tubing (CST) on the sea floor. The platform was finally deployed at about 30 – 35 m north of moon pool location. The ship “*Far Grip*” was kept in DP rather exactly on the 65° N and 4° 50’E during the time of deployment. The CST was lying on the sea floor between the release arrangement and the point where the CST rises from the sea floor. See the outline shown in Figure 1.2.

In the following, a collection of pictures from the ROV recordings is presented to illustrate the results from the deployment. Comments are included in the figure texts.

The picture identity added to the figure texts refers to the dating in the Tables 3.1, 4.1 and 5.1. The numbers refer to “hour-minute-second”, and should correspond uniquely to the similar dating in the Tables (which are given in hour-minutes).

This type of picture identity refers to all ROV pictures shown in the present report.

Note that all the pictures show much better resolution on print, compared to what might be seen on a PC screen.



*Figure 6.1. Picture identity 12-07-24. Picture of the CST approaching the sea floor beneath the moon pool 845 meters above.*



Figure 6.2. Picture identity 12-08-06. Demonstration of the motion of the CST at the spot where the CST meets the sea floor. Due to swell motion of the ship, the CST will be moving accordingly. This motion is then transformed to the motion of the CST where it hits the bottom. Some indication of formation of mud brought into suspension may be seen on the picture.



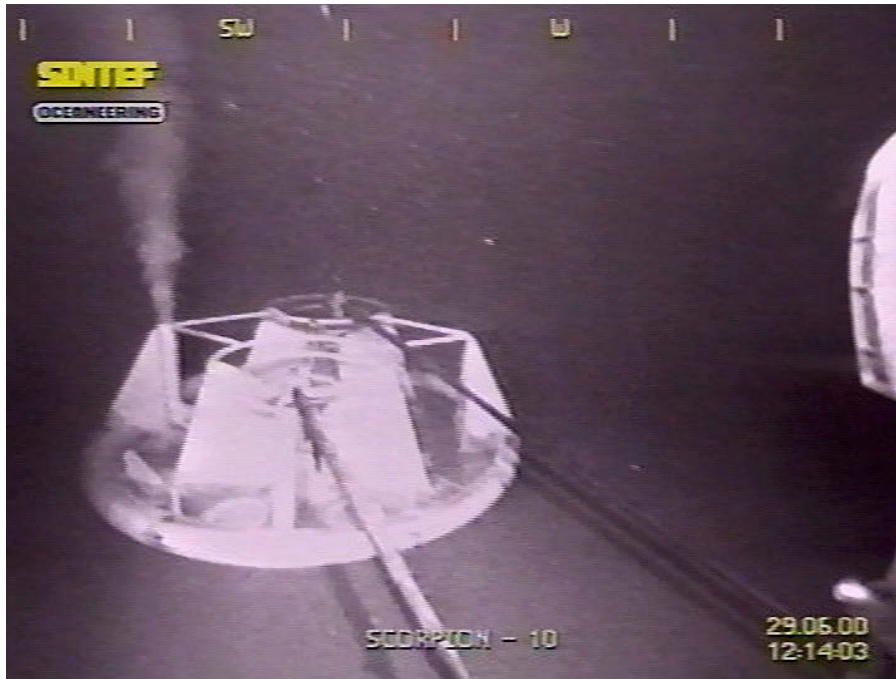
Figure 6.3. Picture identity 12-11-04. Traces of the CST tracks on the sea floor. The CST is buried in the mud. The tracks may have changed their location during the deployment.



Figure 6.4. Picture identity 12-11-27. Same as Figure 6.3, but the CST is covered by the mud to a much lesser extent.



Figure 6.5. Picture identity 12-13-50. The CST is approaching the platform and starts lifting off the mud layer.

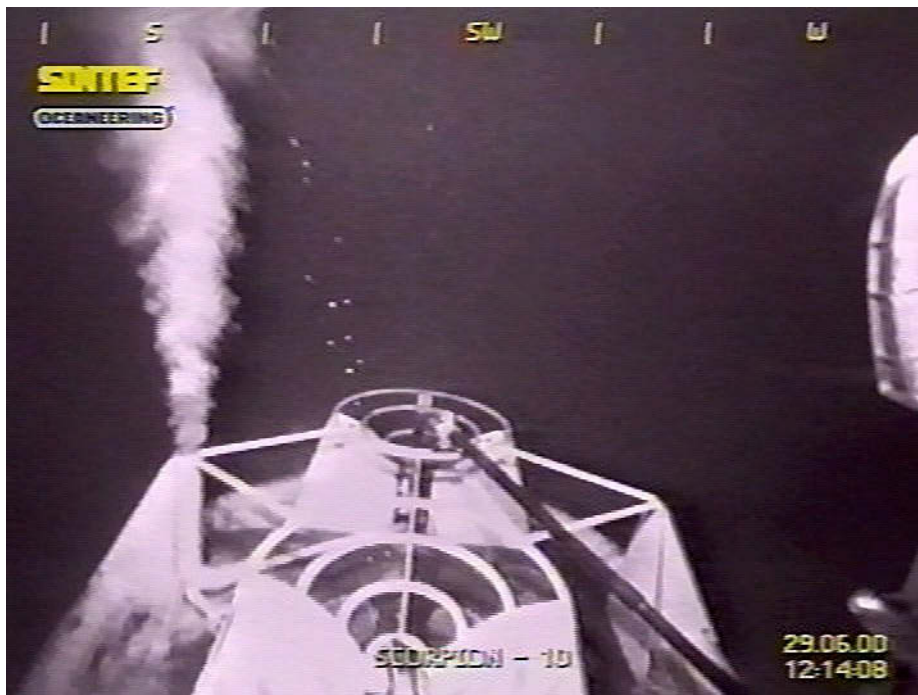


*Figure 6.6. Picture identity 12-14-03. The CST is entering the platform. The platform is placed nicely on the seabed, which consists of fine silt/soft clay.*

## 7 Inspection of gas leakage

During the methane release the last day, a gas leakage from the gas line was detected. The following set of pictures shows the pictures from the leakage point and also some indications of hydrate formation at the leakage point.

No effects from this leakage were detected during the experiment. It is anticipated from the pictures that it was quite small, with no practical implications. However, it should be noted as an experience to be taken into consideration if additional experiments are planned with this setup.



*Figure 7.1. Picture identity 12-14-08. Observation of gas bubbles escaping from the release arrangement to the right of the release plume.*

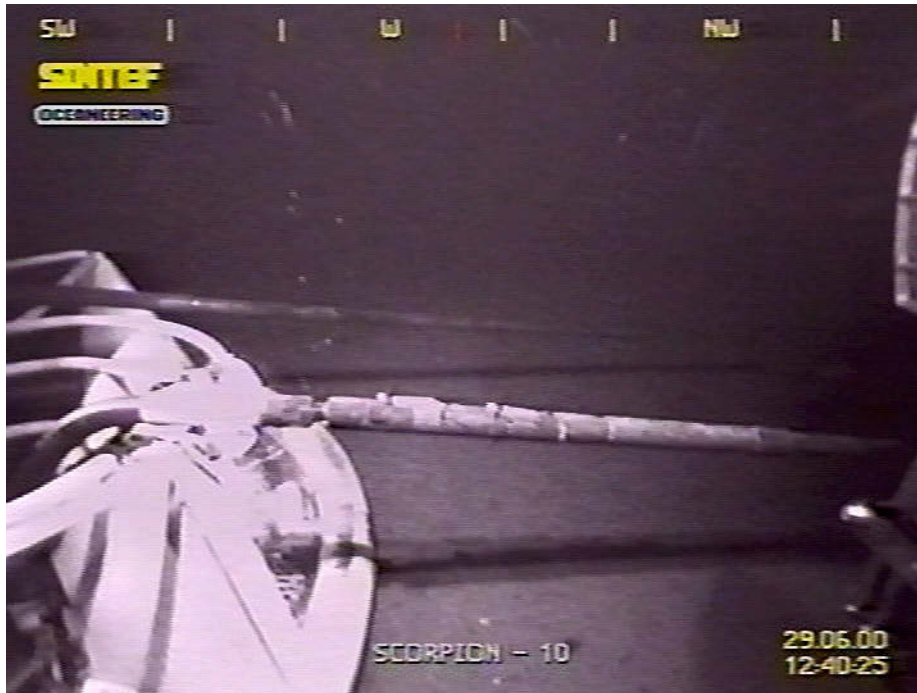


Figure 7.2. Picture identity 12-40-25. A closer look at the position of the leakage point. Some bubbles may be seen above the leakage point.



Figure 7.3. Picture identity 12-42-35. A switch is made to color camera for a closer look at the leakage point.



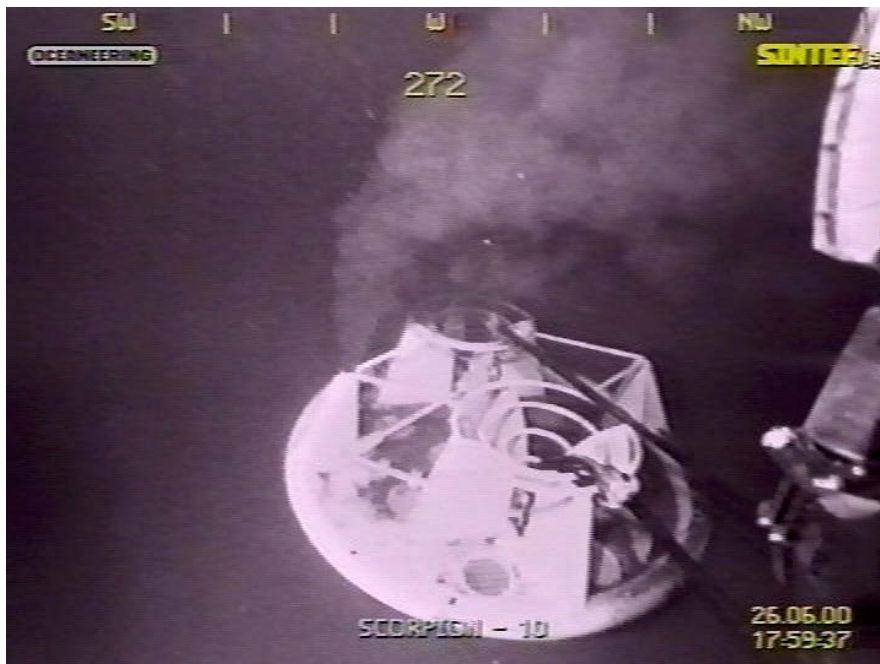
*Figure 7.4. Picture identity 12-41-45. Close up look at the leakage point. The leakage is at the downward side of the connections made to the right. Note also the (probable) formation of hydrate at the downward side (bright spot with a droplet shape). This was probably the only hydrate that was observed during this experiment.*

## 8 Releases of water

The releases were performed in such a way that water was pumped through the oil line first. Then the nitrogen was switched on through the gas line next. Then the oil/diesel was switched on to replace the water through the oil line, and finally the methane was switched on to replace the nitrogen through the gas line. It was done in this order to prevent hydrate formation in the CST system and release arrangement.

In all experiments, the water was therefore switched on first. All the three ROV recordings therefore contain pictures (and similar sonar recordings) of only water releases prior to the gas releases.

All releases of water contain small particles, which makes the water look dirty or muddy. One dive was also performed into this type of plume to look for particle sizes. It appeared that the particles are small, and below detection limit (for a read-off by the ruler). There was no apparent fall-out or flocculation of particles out of the plume observed. They simply appear to follow the plume in a passive manner. This indicates also that particle sizes are relatively small, probably below order 0.1 mm in diameter.



*Figure 8.1. Picture identity 17-59-37. Release of “dirty” water only prior to the nitrogen release the first day. The water was taken from the ballast water tanks onboard “Far Grip”.*



Figure 8.2. Picture identity 07-57-14. Release of dirty water prior to the diesel release the second day.



Figure 8.3. Picture identity 10-50-15. Release of dirty water the last day, prior to the methane release. The releases in the oil line before the present one contained the diesel and the oil releases. It may therefore be that the color of the water is caused by the presence of small oil and diesel particles left on the walls inside the CST. The particles are then washed out by the water flow.

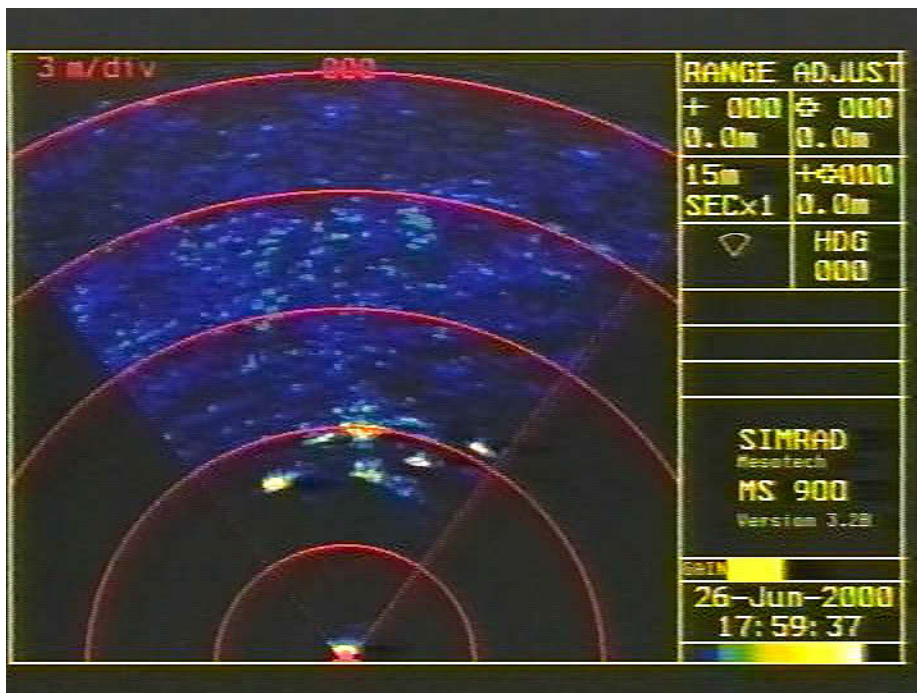


Figure 8.4. *Picture identity 10-49-47. Release of dirty water the last day, prior to the methane release. The releases before this one contained the diesel and the oil release. The situation is thus similar to the one shown in Figure 8.3, except that this figure shows a more close-up picture of the release at the onset of the water release.*

## 9 Sonar measurements

Sonar recordings were made continuously in parallel to the video picture recordings. Unfortunately, the cryogenic pump (used for pumping the gas) distorted the sonar signal, as illustrated below. However, the potential for the use of sonar for recordings of plumes was clearly demonstrated during the experiment, because some signals were recorded both before and after the pumping of the gas.

Some indications are also given for the ability of the sonar to record plumes with small-sized particles of oil or other matter in the plume.



*Figure 9.1. Picture identity 17-59-37. Recording of the sonar signal prior to the nitrogen release the first day. Note that the similar ROV picture is shown in figure 8.1 (same number for the picture identity, 17-59-37). The water plume is apparently not shown on the sonar at all. The color dots on the sonar signal are probably due to reflections from the release arrangement.*

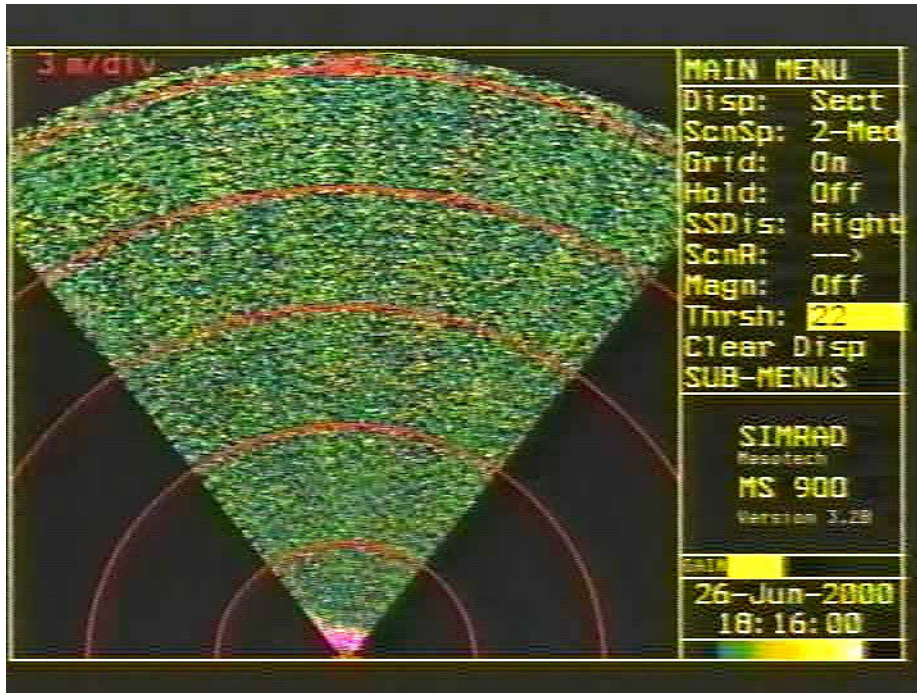


Figure 9.2. Picture identity 18-16-00. Example of noise on the sonar signal generated from the cryogenic pump.

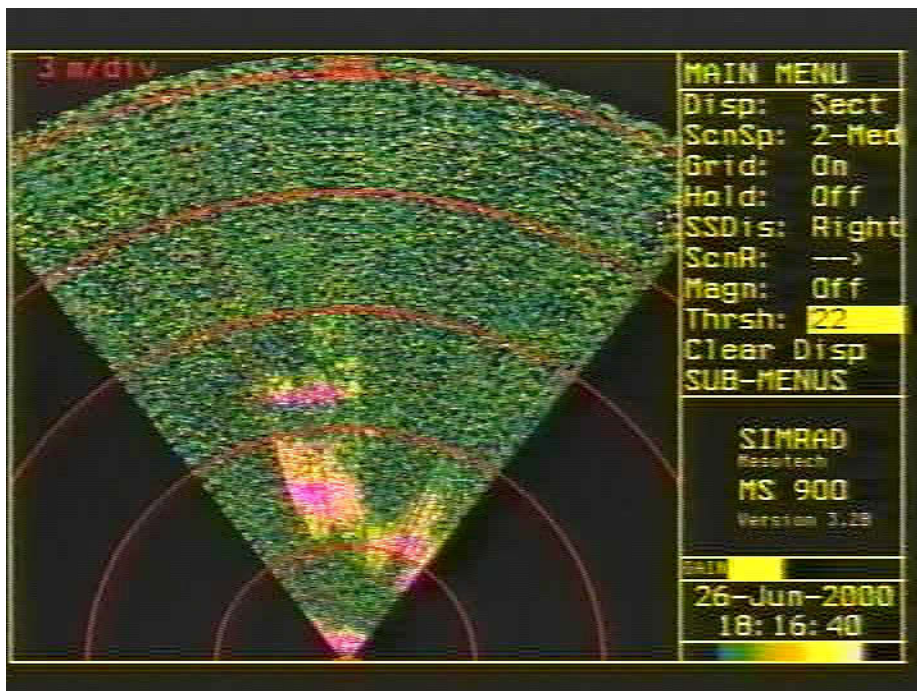


Figure 9.3. Picture identity 18-16-40. Occasionally, signals indicating the presence of the underwater plume appeared on the sonar signal. The picture shows one example of recording of the underwater plume (nitrogen gas) with the sonar signal, including the noise from the cryogenic pump.

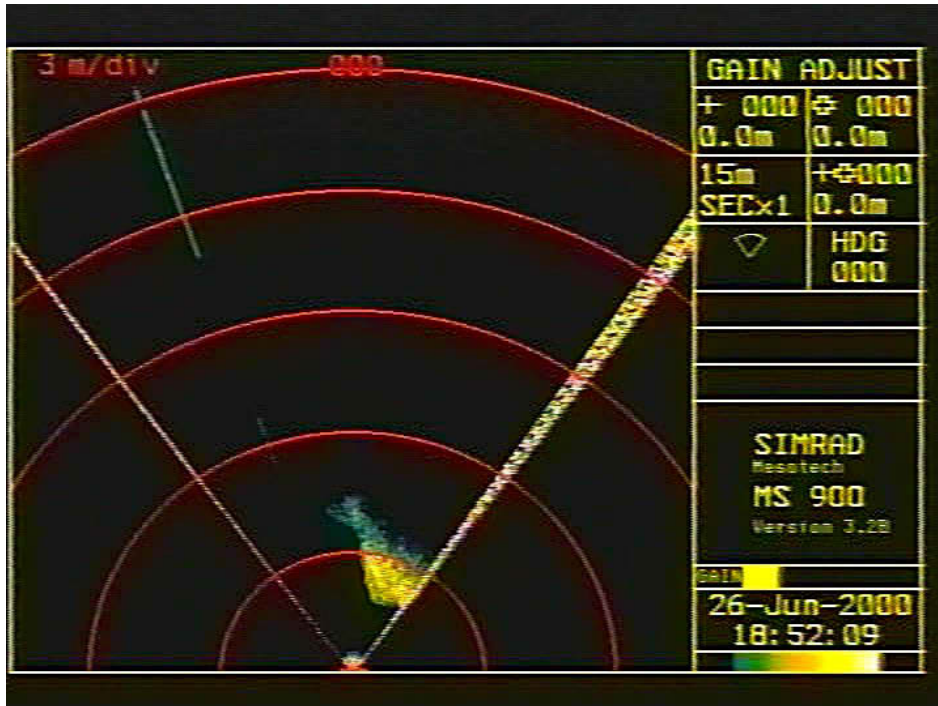


Figure 9.4. Picture identity 18-52-09. The cryogenic pump has just stopped pumping the nitrogen gas (release at the first day). While the noise from the cryogenic pump is fading away from the sonar signal, the signature from the nitrogen plume appears suddenly clearly on the sonar signal. This gas plume was generated just before the cryogenic pump was switched off. The plume will cease to occur shortly after this instance, because the gas release stops immediately when the cryogenic pump is switched off. The plume example here is therefore just an instant of opportunity, showing the gas plume clearly on the sonar screen.

## 10 Examples of observed gas plume behavior

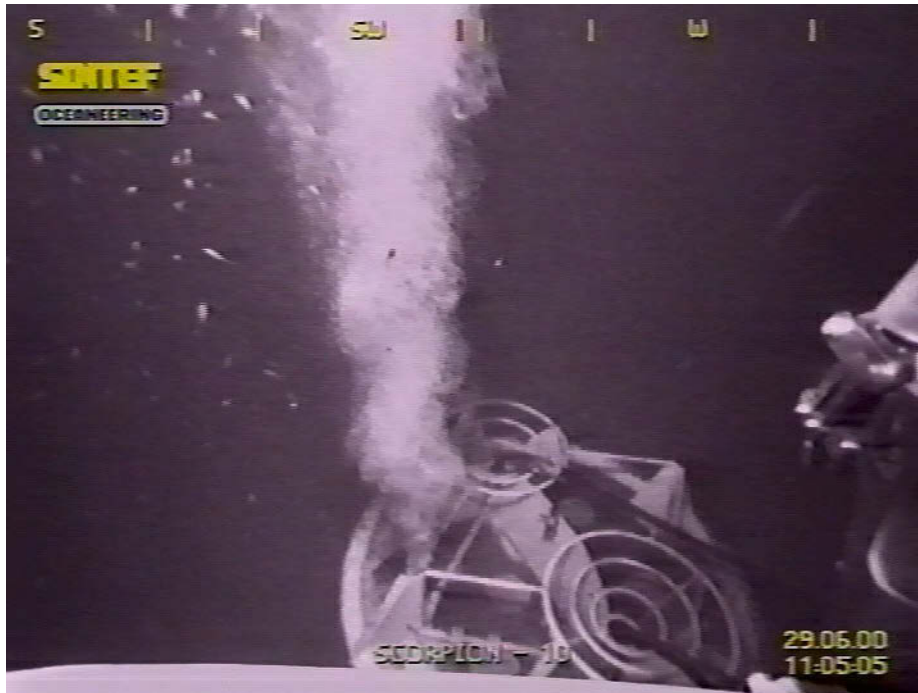
The following pictures show some typical examples of underwater gas plumes from the nitrogen and the methane releases.



*Figure 10.1. Picture identity 18-16-00. Initiation of the nitrogen plume.*



*Figure 10.2. Picture identity 18-48-22. Well developed nitrogen plume. Some ambient currents are present directed to the right. Although not apparent in this picture, the video shows in this particular case a tendency for a separation of the plume, where the gas bubbles are moving upwards (to the left), and the water tends to move more slowly in the horizontal direction to the right (in the downstream direction).*



*Figure 10.3 Picture identity 11-05-05. Vertically ascending methane plume. Weak ambient currents.*



*Figure 10.4. Picture identity 12-01-42. Vertically ascending and weakly meandering methane plume. Weak ambient currents.*

## 11 Examples of observed diesel plume behavior

Pictures are shown similarly for the diesel release. It behaves apparently like the gas plume. This is expected, because the buoyancy of the plume will be governed by the gas and to a lesser extent by the oil. The plume is shown for somewhat larger distances from the release arrangement in this case as well. The plume will tend to break up in a more “puff-like” behavior at larger distances, similar to what you expect from patterns generated by growing meanders in the plume. This also made it more difficult to ascend outside the plume area, as illustrated in Figures 11.4 and 11.5.



*Figure 11.1. Picture identity 08-32-12. Release of water and nitrogen just prior to the diesel release.*

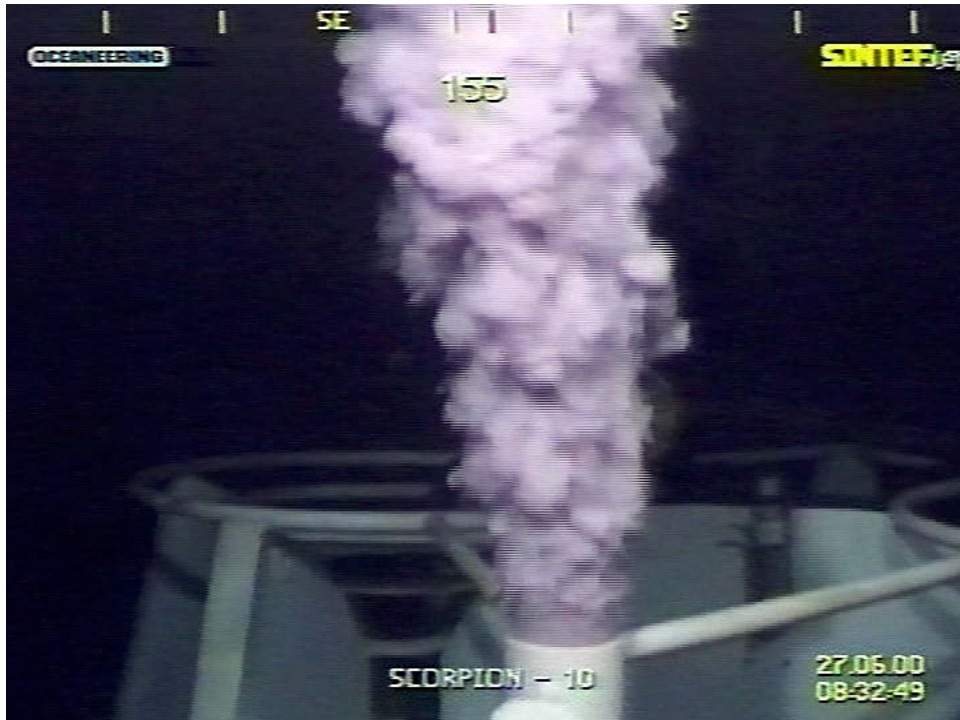


Figure 11.2. Picture identity 08-32-49. Release of diesel and nitrogen just after the arrival of diesel at the release opening. Note the color change in the release.



Figure 11.3. Picture identity 08-42-34. Development of the plume above the diesel and methane release.



*Figure 11.4. Picture identity 08-50-50. Further development of the diesel and methane plume. Undulating or meandering plume.*



*Figure 11.5. Picture identity 09-16-09. Further breakup of the plume at larger distances.*

## 12 Droplets and bubbles in the underwater plumes

One of the purposes of the field trial was to detect sizes and distributions of the droplets and the bubbles generated. The ROV cameras proved to be suitable for this purpose. The following collection of pictures illustrates the problems and the prospects of using this kind of technique for the description or determination of the bubbles/droplets behavior.



*Figure 12.1. Picture identity 11-40-13. Methane release. Appearance of a gas cloud when entering into a bubble plume.*



*Figure 12.2. Picture identity 08-51-49. Methane and diesel release. Appearance of a gas and diesel cloud when entering into the plume. The separation between diesel droplets and gas bubbles is unclear.*



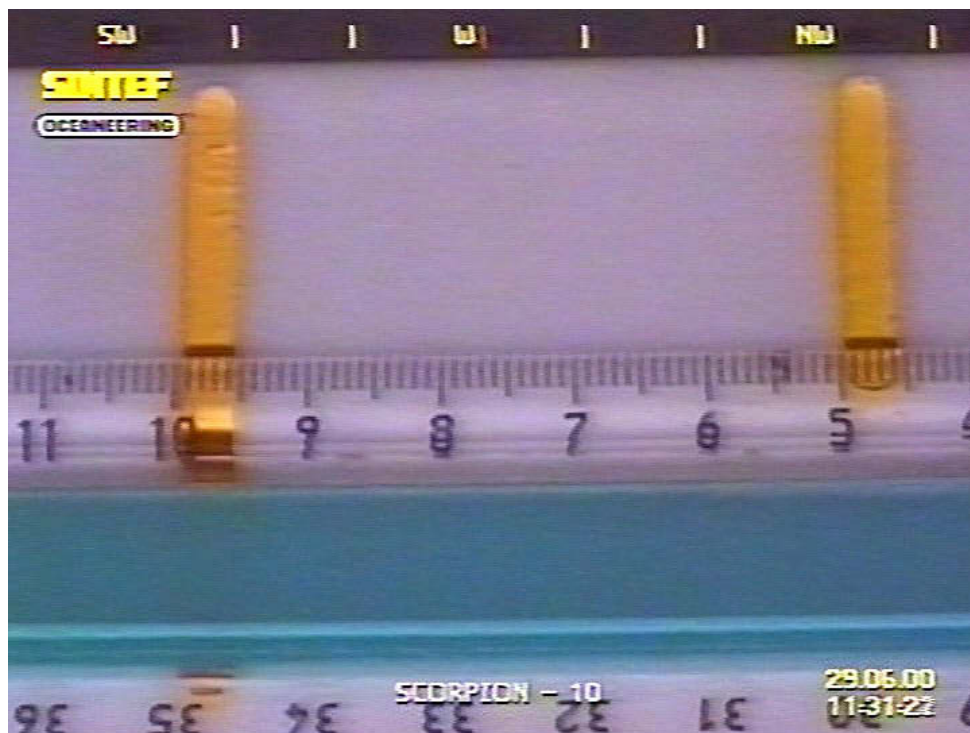
*Figure 12.3. Picture identity 09-02-41. Diesel and methane release. In this particular case, it is possible to distinguish between the gas bubbles and the diesel droplets. The diesel droplets are more "glassy" and moves more slowly than the gas bubbles. Some diesel droplets can be seen in the foreground, while the gas bubbles are concentrated at larger distances from the ROV. Another indicator for separating the diesel droplets from gas bubbles is the motion characteristics. The gas bubbles tend to "wiggle" a lot, moving back and forth while ascending. The diesel droplets stay more calmly while they are ascending. The reason for this different motion characteristic is the varying momentum (mass times velocity) between gas bubbles (low momentum) and diesel droplets (large momentum).*



*Figure 12.4. Picture identity 09-09-15. Diesel and methane release. The ruler that has been mounted is shown by the black/white camera. Also, the picture shows diesel droplets attached to the lens, which occasionally happens when the ROV moves inside the plume too close to the release point.*

### 13 Examples of observed droplet and bubble sizes

The ROV was equipped with a ruler that was mounted in front of one of the cameras (the color camera). This camera was basically used for close-up pictures. The distance from color camera lens to ruler was 41 cm. The ruler was mounted on front center of ROV skids beneath the camera pan/tilt unit. See the picture of the ruler in Figure 13.1 (color camera) and Figure 12.4 (black/white camera).



*Figure 13.1. Picture identity 11-31-21. A picture of the ruler mounted on the ROV. Picture taken by the color camera.*

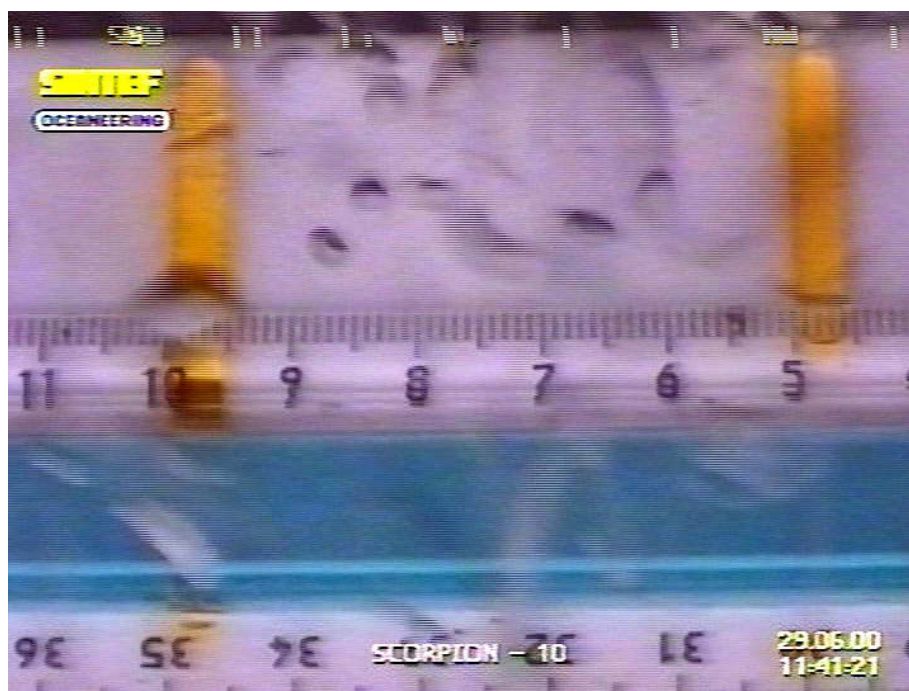
When the close-up picture camera was switched on, the oil droplets or the gas bubbles were observed to pass the volume of water between the ruler and the camera. This would happen while the ROV was located within the plume volume. Most of the droplets/bubbles were too unclear and also passing too fast for a proper size determination. However, under some circumstances, it turned out that the droplets/bubbles were reasonably sharp enough to be considered further. This would happen when all the three following circumstances took place at the same time:

1. The gas bubbles or oil (diesel) droplets were moving sufficiently close to the ruler so that the droplet/bubble was in focus.
2. The droplet/bubble was moving sufficiently slow (relative to the ROV) so that the individual pictures of the droplets/bubbles became sharp enough for size determination.
3. The ROV operator was able to focus the color camera on the ruler combined with sufficient light.

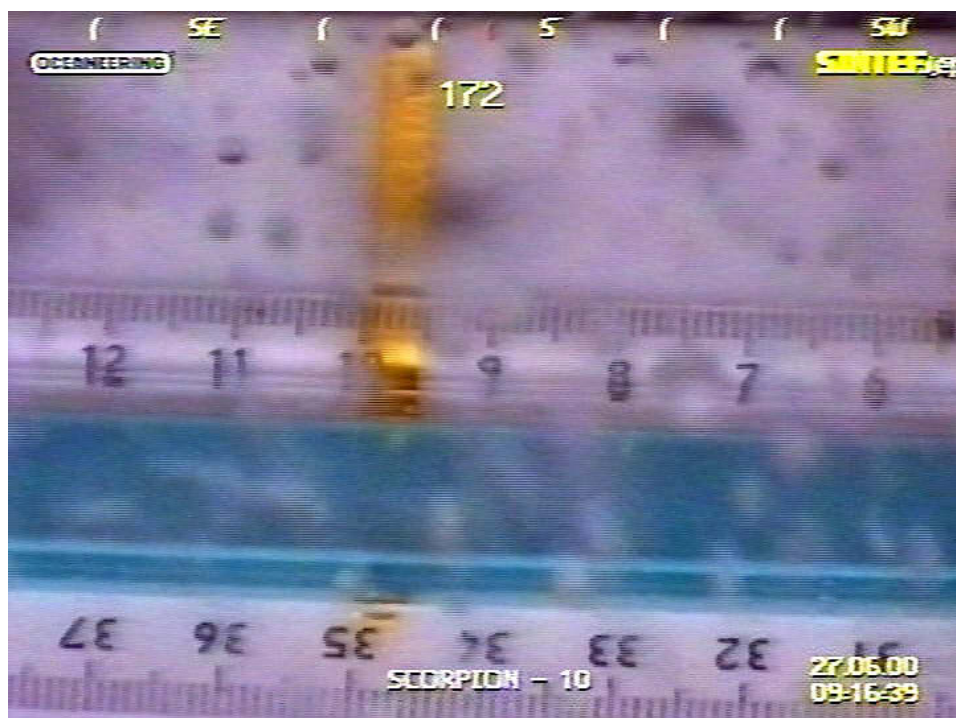
All these three conditions occurred frequently during all the three releases, although the bulk of the “plume visits” were less successful in this respect. However, it turned out to be sufficient that only some sequences of pictures were of reasonable quality for droplet/bubble size determination.

The VHS picture generation for this purpose is rather large. As an example, just one minute of ROV recording of droplets/bubbles produce approximately  $25 \times 60 = 1500$  pictures for further examination of the presence of droplets/bubbles. Therefore, a selection of pictures was made in order to count diesel droplet as well as gas bubble sizes. The results from the count are described in the next chapter.

The following pictures show examples that have a potential for being read off for droplet size or bubble size determination. The two pictures show one example from the gas bubble size distribution (Figure 13.2), and one example from the diesel droplet size distribution (Figure 13.3). *(It should be noted that the pictures as they appear on the PC screen are of much lower resolution than as they appear when they are printed out on a proper printer.)*



*Figure 13.2. Picture identity 11-41-21. Methane release. Picture taken for gas bubble size determination. The picture shows 2 – 3 bubbles that may be clear enough for size determination, by comparing the diameter against the size of a millimeter shown on the ruler.*



*Figure 13.3. Picture identity 09-16-39. Diesel droplets, mainly. Some diesel droplets appear to be relatively sharp at the upper part of the picture.*

## 14 Size distributions of gas bubbles and diesel droplets

### 14.1. General about the gas bubble and diesel droplet counts

During the surveys of the plumes with the ROV, the color camera took close-up pictures while the ROV was ascending inside the plume.

Counts were carried out for the methane release case (release #4) and for the diesel release case (release #2). In the following, results from 8 cases selected for droplet and/or bubble size distributions are described, 4 cases for the gas bubble size distribution and 4 cases for the diesel droplet size distribution.

It should be stressed that it was necessary to read off the individual bubbles and droplets manually. The video sampled pictures rather frequently, and it became therefore evident that the same bubble/droplet appears on many pictures in a sequence. The observer had then to keep track of the different bubbles/droplets that appeared on the screen, in order to avoid counting the same droplet/bubble more than one time.

### 14.2. Gas bubble size distribution

4 cases were selected for reading off the gas bubble size distributions. The criterion for selecting the cases was to look at the distribution at various distances from the source. Gas bubbles with a reasonable quality to be read off from the pictures were found between about 9 and 85 m above the source.

*Table 14.1. Counts of methane gas bubble sizes at release #4 carried out 29. June 2000. Each second represents 25 pictures read off for bubble sizes. A total of 667 bubbles were read off from a total of 3400 pictures.*

Case No.	Time interval, local time	Depth interval	No. of bubbles counted
1	11-17-45 --- 11-18-15	836 – 826 m	124
2	11-18-16 --- 11-18-27	826 – 822 m	184
3	11-19-15 --- 11-20-05	806 – 787 m	201
4	11-43-50 --- 11-44-35	780 – 760 m	158

The results from the count are shown in Figures 14.1 and 14.2. Figure 14.1 shows the distribution of the methane bubbles diameters for cases 1 and 2. The count is separated into two parts, the distribution determined within the depth range 836 – 826 m depth (closest to the source) and the depth range 826 – 822 m depth (at a longer distance from the source). Both distributions appear to concentrate within the range 1 – 5 mm diameter sizes of the bubbles, with some gas bubbles appearing with sizes closer to 8 mm diameter.

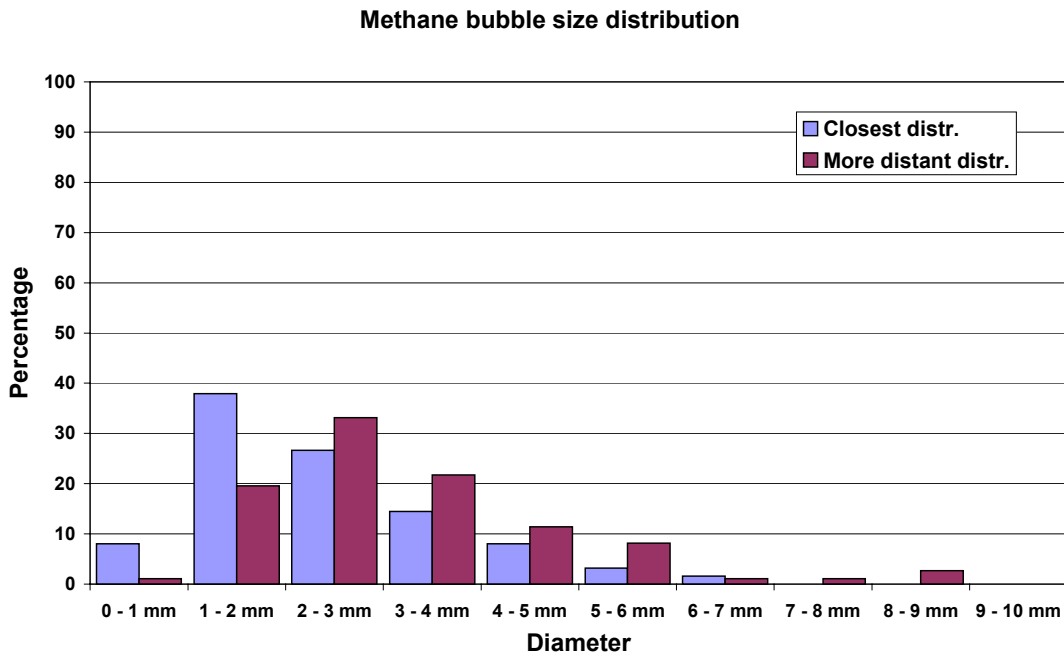


Figure 14.1. Distribution of the gas (methane) bubble diameters, below 822 m depth. Cases 1 (closest distribution) and 2 (more distant distribution).

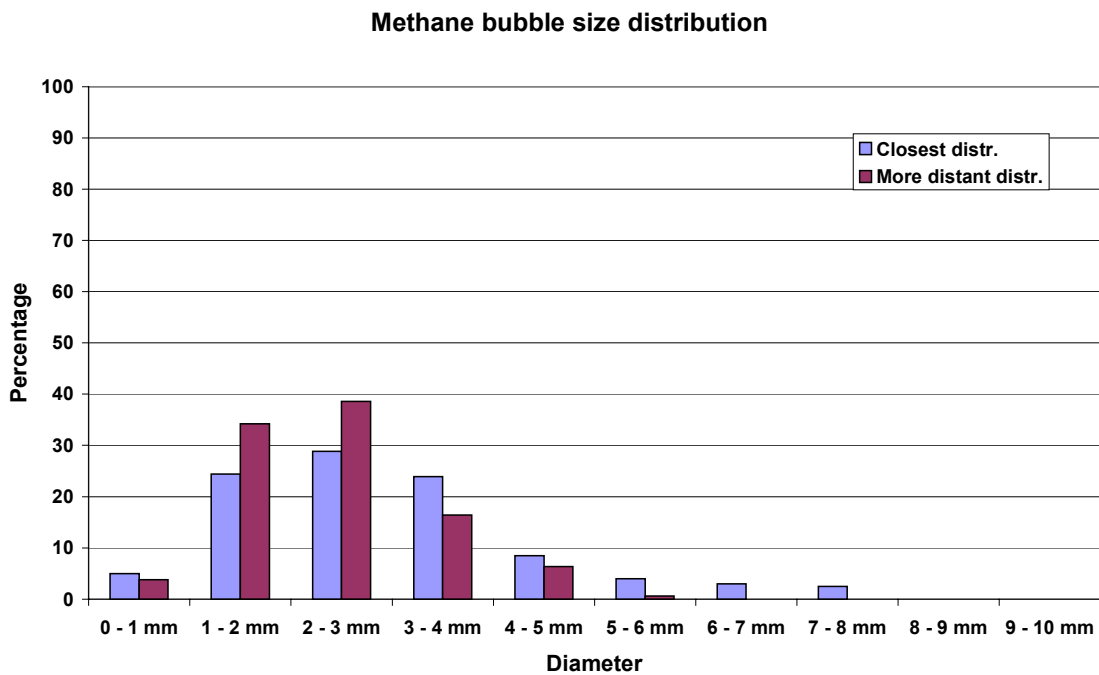
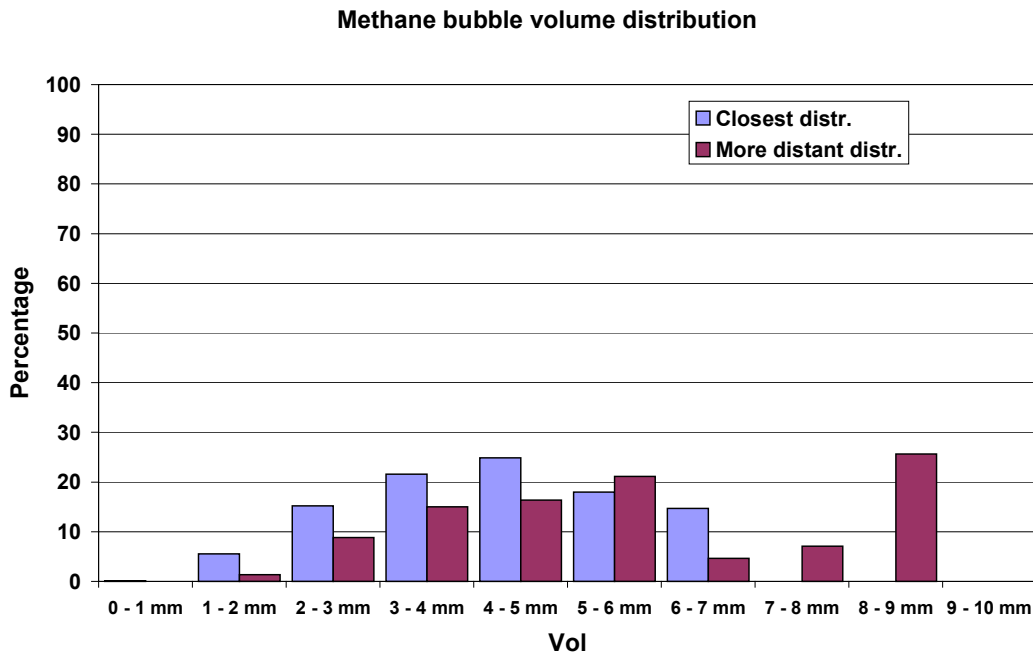
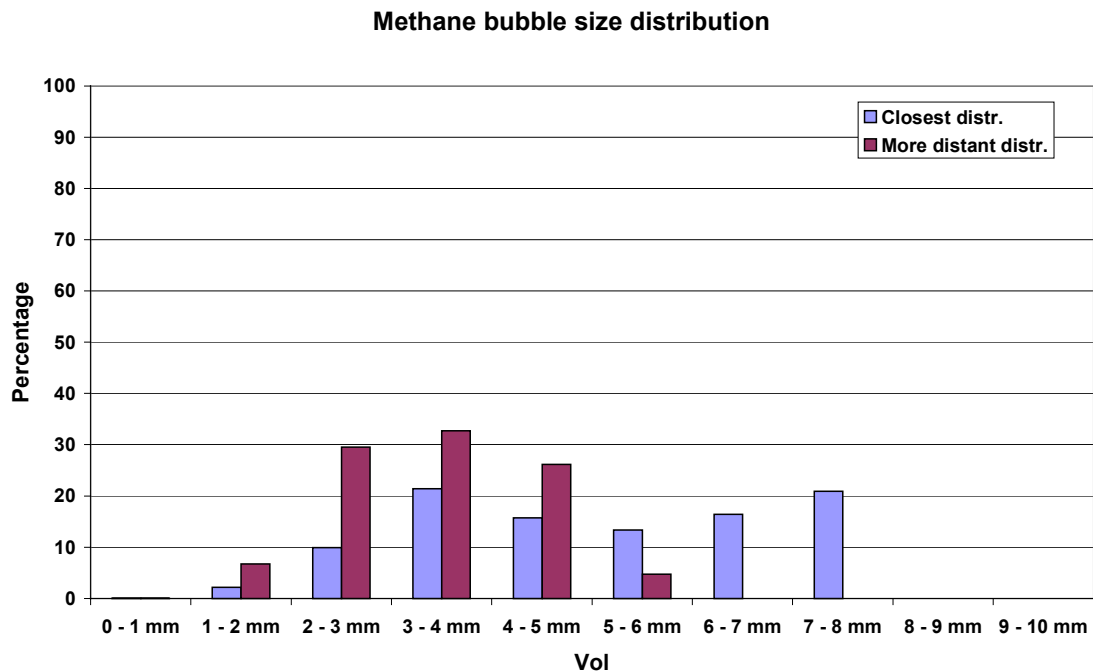


Figure 14.2. Distribution of the gas (methane) bubble diameters, between 806 and 760 m depth. Cases 3 (closest distribution) and 4 (more distant distribution).

A similar distribution is shown for the volume of the gas bubbles, see Figures 14.3 and 14.4. This distribution is based on the same material as for the diameter distribution, except that the diameter is taken to the third power (in order to arrive at volume estimates). In this diagram, the volume distribution is distorted towards larger gas bubbles, compared to the distribution shown in Figures 14.1 and 14.2. The reason for this distortion is that bubbles increase the mass (volume) faster than the corresponding increase in diameter.



*Figure 14.3. Distribution of the gas (methane) bubble volumes, below 822 m depth. Cases 1 (closest distribution) and 2 (more distant distribution).*



*Figure 14.4. Distribution of the gas (methane) bubble volumes, between 806 and 760 m depth. Cases 3 (closest distribution) and 4 (more distant distribution).*

Note that any increase in volume corresponding to the gas expansion effect is negligible for the cases considered. The change in gas volume for one single bubble moving between 760 and 836 m depth will be about 10 %, and the corresponding change in radius will be about 3 %. This change is negligible compared to the uncertainty in the drop size read-off carried out manually (ranging the bubbles into 10 different mm intervals).

One of the purposes to read off distributions for gas bubbles at various distances from the source was to look for some “separation” effect in terms that larger gas bubbles may follow another path through the water column than smaller gas bubbles. Due to this separation, the gas bubble distribution may change with the distance from the source (narrowing the distribution at increasing distance from the source). This effect is however not evident from the data that was read off. The reason for this is attributed to the fact that the rise velocity for gas bubbles is more or less the same for gas bubble diameters larger than about 2 mm. The bubbles will tend to break up at about 8 mm diameter. The rise velocity is close to 0.3 m/s for “clean” bubbles in this gas bubble diameter interval. Therefore, no separation effects is expected for the drop size interval determined from the data.

### 14.3 Diesel droplet size distribution

4 cases were selected for reading off the diesel droplet size distributions. The criterion for selecting the cases was the same as for the gas bubble size distribution, that is, to look at the distribution at various distances from the source. Diesel droplets with a reasonable quality to be read off from the pictures were found between about 5 and 56 m above the source.

Table 14.2. Counts of diesel droplets at release #2 carried out 27. June 2000. Each second represents 25 pictures read off for droplet sizes. A total of 677 droplets were read off from a total of 5325 pictures.

Case No.	Time interval, local time	Depth interval	No. of bubbles counted
5	09-16-29 --- 09-16-32	840 – 839 m	215
6	09-16-48 --- 09-16-52	835 – 834 m	129
7	09-21-50 --- 09-22-40	830 – 822 m	139
8	09-28-14 --- 09-30-49	810 – 789 m	194

The results from the counts of the diesel droplets are shown in Figures 14.5 – 8. Figures 14.5 and 14.6 show the distribution of the droplet diameters.

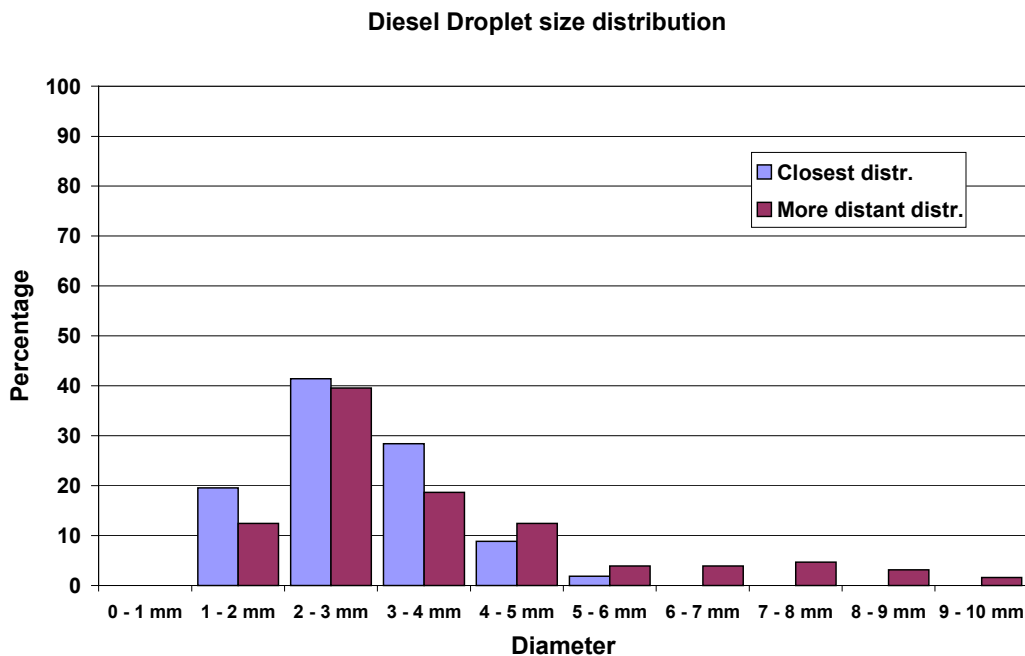


Figure 14.5. Distribution of the diesel droplet diameters, below 834 m depth. Cases 5 (closest distribution) and 6 (more distant distribution).

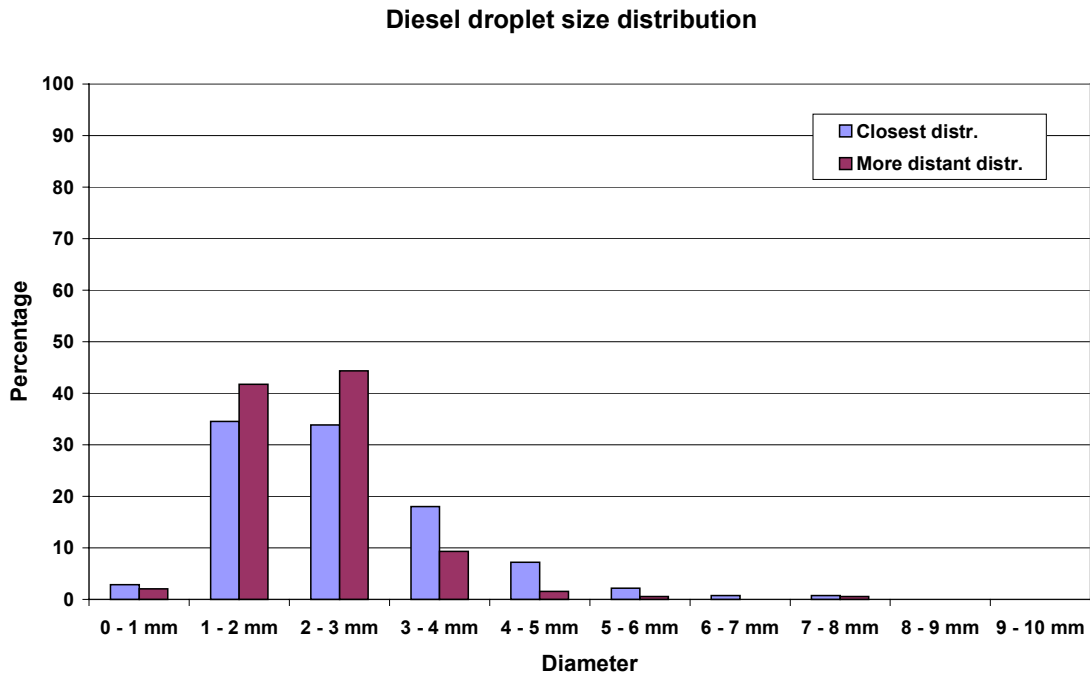


Figure 14.6. Distribution of the diesel droplet diameters located between 830 and 789 m depth. Cases 5 (closest distribution) and 6 (more distant distribution).

A similar distribution is shown for the volume of the diesel droplets, see Figures 14.7 and 14.8.

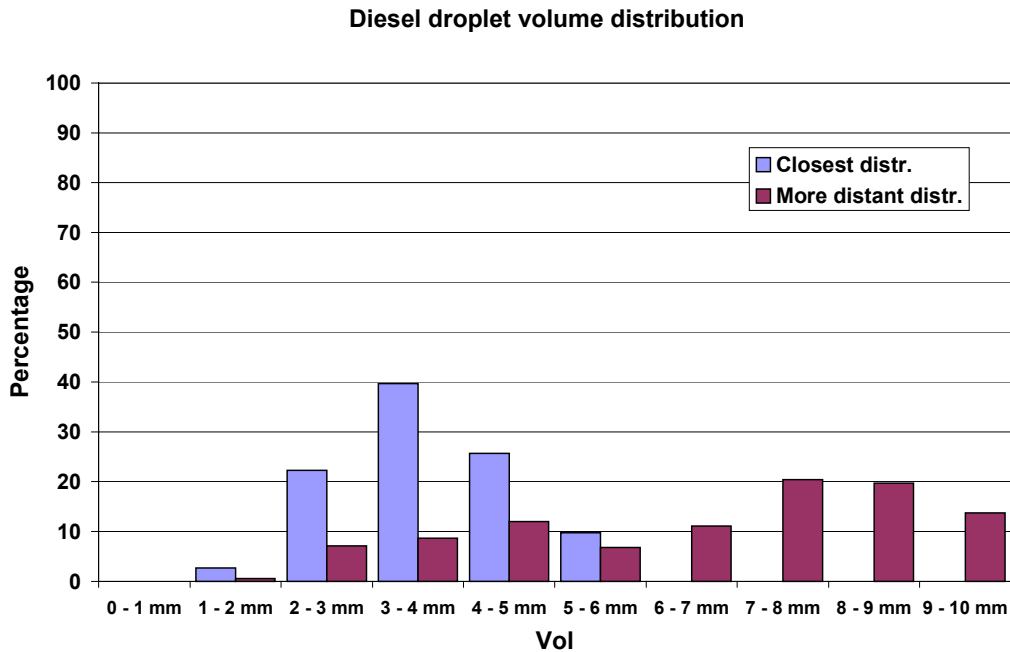
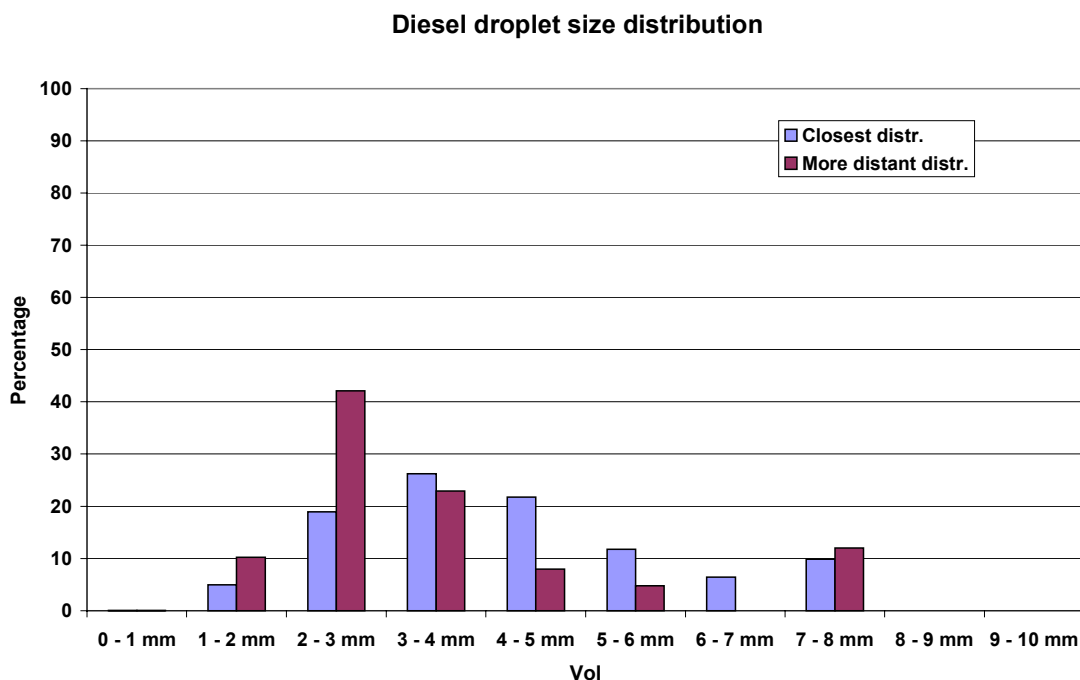


Figure 14.7. Distribution of the diesel droplet volumes below 834 m depth. Cases 5 (closest distribution) and 6 (more distant distribution).



*Figure 14.8. Distribution of the diesel droplet volumes, between 830 and 789 m depth. Cases 7 (closest distribution) and 8 (more distant distribution).*

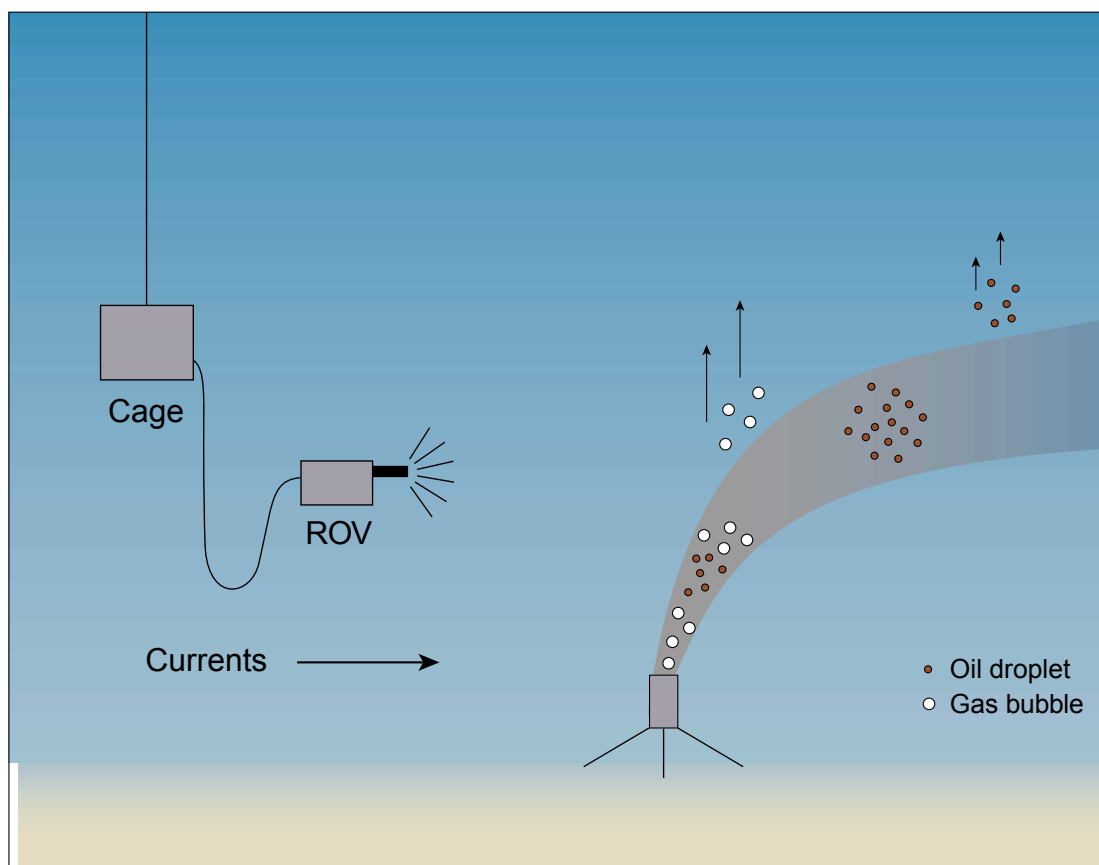
The results from the counts of the diesel droplets may be more difficult to interpret than the gas bubble (methane) release. One of the reasons for this is that the release consists of both gas bubbles (methane) and diesel droplets. In volume, the release consists of about 73 vol% of diesel and 27 vol% of gas at 845 m depth. However, both diesel and methane does not mix with water, and the bubbles/droplets observed may therefore be either methane gas bubbles, diesel droplets, or a mixture of both. It is therefore necessary to distinguish between the gas bubbles and the diesel droplets. This may not be so easy, because they may appear in the plume at the same time.

The first two cases (No. 5 and 6) were both recorded within 11 m from the release opening (at between 834 and 840 m depth). At this stage, the plume consists of a relatively violent mixture of the gas bubbles and the diesel droplets. Also, the vertical ascent of the plume is relatively fast. Simulations with the *DeepBlow* model indicated an average vertical velocity of the underwater plume equal to 0.5 m/s at 834 m depth (this depth corresponds to the end of Case No. 6).

Due to the visual impression from the droplets observed (by the motion characteristics), the bulk of objects observed is apparently diesel droplets and/or gas bubbles coated with diesel. However, there was no apparent color difference, so the motion characteristics were the only criterion to separate between the two. The distribution shown in the Figure 14.5 and 14.6 is basically made up by diesel droplets.

However, at larger distances from the release source, the gas bubbles and diesel droplets may separate due to the difference in rise velocities of the individual bubbles/droplets. This has been illustrated in the Figure 14.9. Figure 14.9 illustrates the bent-over of the underwater plume caused by the ambient currents. However, the gas bubbles and the diesel droplets have both their own

motion relative to the plume due to the buoyancy of the individual droplets/bubbles. This individual motion of the bubbles/droplets will cause the bubbles/droplets to leave the plume, as illustrated in Figure 14.9. The gas bubbles will leave the plume first, because their rising velocity (0.3 m/s) is larger than the rise velocity of the diesel droplets.



*Figure 14.9. Illustration of the leaving of gas bubbles and diesel droplets from a bent plume during the diesel release, release #2.*

The amount of gas bubbles leaving the underwater plume has been calculated by the *DeepBlow* model for various ambient ocean currents. Figure 14.10 shows the results from the calculations. For an ambient velocity of 0.15 m/s, about 50 % of the gas has left the plume at about 823 m depth, which is only about 22 m above the release depth. The similar number for a 0.10 m/s current will be at about 808 m depth. Typical order-of-magnitude of the currents close to the sea floor during the diesel release is of this order of magnitude (0.10 – 0.15 m/s close to the sea floor). Therefore, it can be anticipated that a large part of the gas bubbles may have left the plume during the two last cases considered (Case No. 7 and 8, see Table 14.2.)

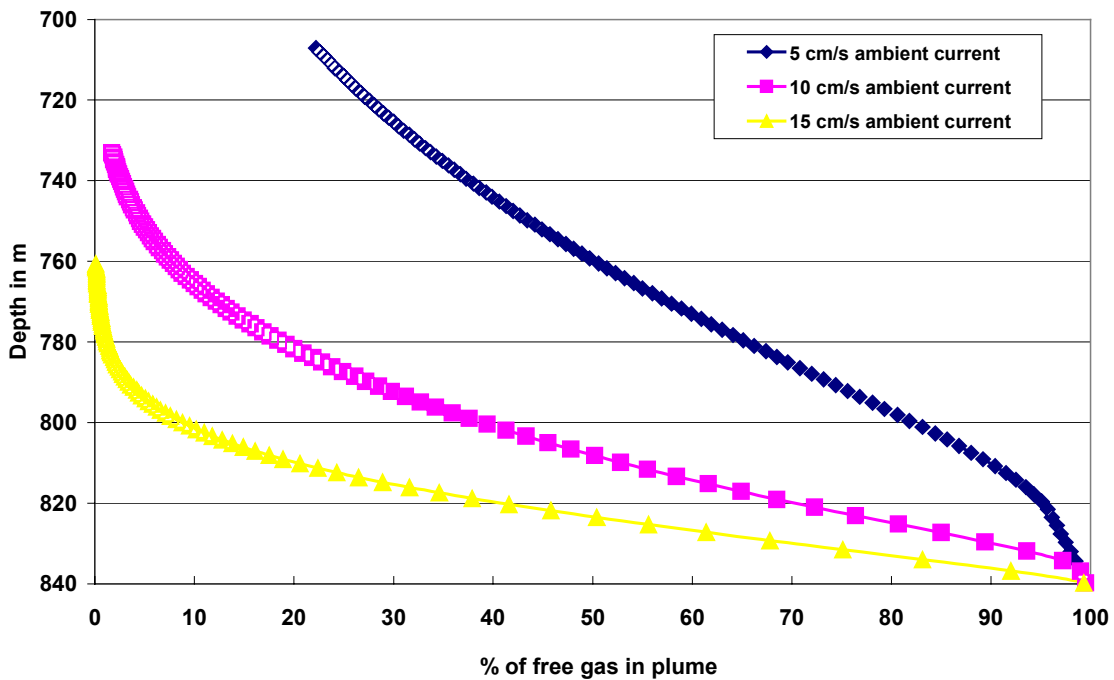


Figure 14.10. Calculation of amount of free gas left in underwater plume during the diesel release (Release #2) for various ambient current velocities. The gas that has left the plume will rise through the water column as free gas bubbles, rising with a velocity of about 0.3 m/s.

From Figures 14.5 – 14.8, it may seem that the distribution for the cases 7 and 8 are somewhat narrower than the distribution of the diesel droplets shown for the cases 5 and 6. However, this may not be the case. Firstly, the number of large droplets counted are relatively small all together (for droplets larger than 6 mm, the number of droplets counted for cases 5 and 6 is 17, while for cases 7 and 8, only 3 diesel droplets were counted). Secondly, the distribution may be biased because different sizes of the diesel droplets may move with different rise velocities if they have left the plume area. This may be the case for the droplets at the larger distance from the source. When the ROV is moving inside the droplet area, some sizes may be easier to be determined if the droplets move with the same velocity as the ROV. The size range of diesel droplets are typically of order 1 – 8 mm, which corresponds to a rise velocity in the range 5 – 12 cm/s. Therefore, the distribution observed may be biased due to a mismatch between the rise velocity of the ROV and the rise velocity of some of the oil droplet size classes. Therefore it is difficult to conclude on the possible change in droplet or bubble size distribution as a function of the distance from the source.

## 15 Short visit to some local inhabitants

As a final to this report, some pictures of the local inhabitants have been included. The pictures were mainly taken while the ROV was on one of the many strolls on the sea floor, having lost the track of the plume, and was searching back for the location of the release arrangement.

The biologists are hereby encouraged to identify the different species.



Figure 15.1. Picture identity 12-12-56.



Figure 15.2. Picture identity 09-35-29. Details are shown in Figure 15.3.

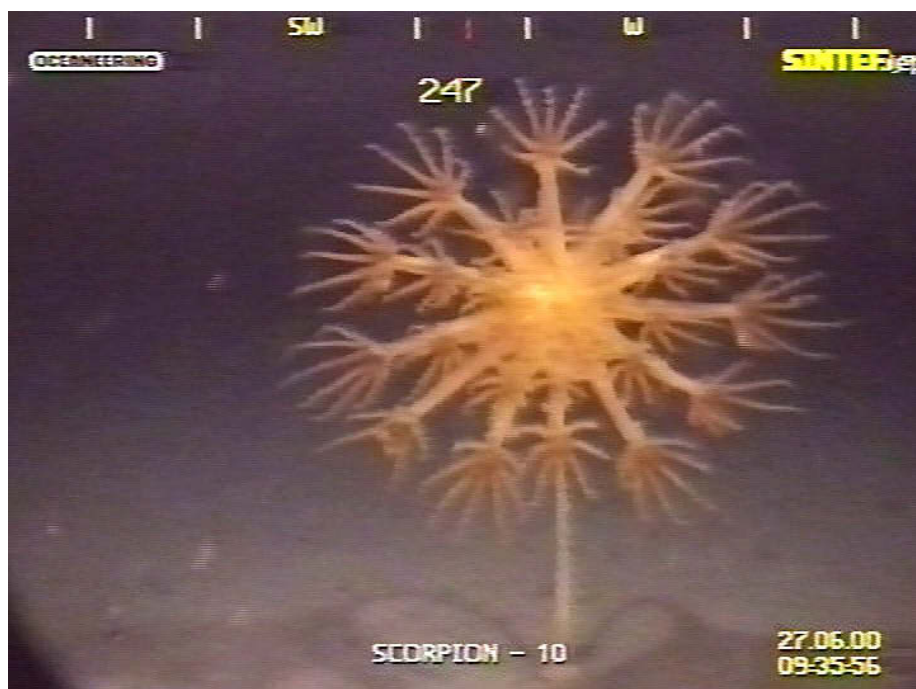


Figure 15.3. Picture identity 09-35-57. This is the same specie as shown in Figure 15.2.

## APPENDIX A

*Specifications of the equipment used by OCEANEERING during the Deep Spill experiment June 2000.*

**TO** : Henrik Rye, Sintef **DATE** : 23.08.00  
**FROM** : Jan Einar Schulze, Oceaneering AS **REF.** :  
**INT. CC** : Eivind Brimsø **FILE** :  
**SUBJECT** : Deep Spill – ROV Specifications

---

Specifications on ROV and relevant equipment used in “Deep Spill” experiment June 2000 are as follows:

**Scorpion 10, depth rating 1500 msw fitted with TMS (Tether Management System)**

**Vehicle hydraulic power unit (HPU):** electro-hydraulic power unit provides 75 HP  
**Thrusters:** 6 ea Innerspace thrusters  
**Speed:** 1,5 Knots horizontal , 1 knot lateral , 1 Knot vertical  
**Tether length:** 150m

**Distance from Color camera lens to ruler:** 41 cm  
**Ruler was mounted on front center of ROV skids beneath camera pan/tilt unit**

**Sonar Specs**

**Type** Mesotech MS 900 Colour Imaging, deep head sonar  
**Frequency** 675 kHz  
**Beamwidth** 1.7°horizontal, 60°vertical  
**Mechanical resolution** 0.225° (step angle)  
**Scanning arcs** 360° continuous, or 30°, 60°, 120° sector  
**Sector center** 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, 330°  
**Scanning speed** 1 shot/step, 1 shot/2 step, 1 shot/4 step  
**Side scan** Transducer may be locked at 0°, 90°, 180°, 270°  
**Power supply** 22 - 26 VDC  
**Depth** 3000 m  
**Ranges** 0 - 5, 10, 20, 50, 100 m  
**Data input** RS-232 - C user labels. Date, time, heading, depth, data  
**Timing resolution** + 20 μs

**SIT CAMERA SIMRAD 1324**

**ELECTRICAL**

**Horizontal Resolution** 700 TV Lines (typical)  
**Light Sensitivity (limiting)** 2 x 10<sup>-4</sup> Lux (faceplate)  
**Light Sensitivity (full video)** 1 x 10<sup>-3</sup> Lux (faceplate)  
**Sensor Type** 1" Silicon Intensifier Target (SIT)  
**Signal to Noise Ratio** >40dB weighted (AGC off)  
**Scanning** 625 Line / 50 Hz CCIR  
525 Line / 60 Hz RS-170 (optional)  
**Power Input** Constant Voltage 16V - 24V dc, 675mA (max.)  
**Grey Scale** 10 Shades (RETMA)

**Cable Compensation** 1,200 metres of RG59 Coaxial  
**Video Output** 1.0V Pk - Pk composite video into 75 Ohms  
**Electro-Magnetic Compatibility** EN50081-1 Emission / EN50082-1 Immunity

**ENVIRONMENTAL**

**Water Depth** 3,000 metres, deeper options available

**OPTICAL**

**Standard Lens** 6.5mm f/1.8  
**Water Compensation** Plano-Concave Acrylic Port  
**Iris Control** Automatic Light Control (ALC)  
**Focus Control** Fixed, (150mm to infinity)  
**Angle of View** 86° Diagonal (nominal) in water

**OE1366/67 Colour Zoom Camera****ELECTRICAL**

**Horizontal Resolution** 450 TV Lines for OE1366  
460 TV Lines for OE1367  
**Light Sensitivity** 0.1 Lux (faceplate)  
**Signal to Noise Ratio** >48dB (weighted)  
**Sensor Type** 13" Hyper-HAD CCD  
**Scanning** 625 Line / 50 Hz PAL for OE1366  
525 Line / 60 Hz NTSC for OE1367  
**Power Input** Constant Voltage 16V - 24V dc, 550mA max  
**Video Output** 1.0V Pk - Pk composite video into 75 Ohms  
**Focus / Zoom Control** Standard Single-Wire Tri-state  
**Electro-Magnetic Compatibility** EN50081-1 Emission / EN50082-1 Immunity

**ENVIRONMENTAL**

**Water Depth** 3,000 metres, deeper options available  
**Temperature** Operating -5°C to +40°C  
Storage -20°C to +60°C  
**Vibration** 10g, 20 - 150Hz, 3-axes (non-operating)  
**Shock** 30g peak, 25mS half-sine pulse

**OPTICAL**

**Standard Lens** Zoom Lens 12:1 Magnification, 5.4mm to 65mm f/1.8 - 2.7  
**Water Compensation** Multi-Element Optical Compensator  
**Iris Control** Automatic  
**Focus Control** Remotely Controlled, 0mm to Infinity  
**Angle of View** Angle of View 55° (min. Zoom) to 5.3° (max. Zoom) diagonal, in water

**MECHANICAL**

**Size** Diameter 80mm (3.15") main body

<b>Weight</b>	Diameter 93mm (3.66") rubber guard Length 175mm (6.89") exc. connector Air 1.8 Kg (4.0 lb.) Water 1.0 Kg (2.2 lb.)
<b>Standard Housing</b>	6Al/4V ASTM B 348 Titanium Alloy

SIMRAD RPT324 TRANSPONDER

<b>Overall length :</b>	350 mm
<b>Operational depth :</b>	2000 m max
<b>Transducer beam :</b>	45 degrees

**VIDEO RECORDERS**

JVC BR - S 600 E , SVHS players.