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Extinguishment of oil spray fires with water

-Experimental procedures and test data

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ABSTRACT

A study of fire risks in ships engine rooms shows that the main risk for fire is connected with leakage of petroleum products. Such a leakage could cause a spray fire, which if it is allowed to develop means severe damage in a short period of time.

Extinguishing a spray fire could mean a considerable risk for the fire fighter. It is therefore quite motivated to have a good protection against such fires, primarily from health aspects, but also for economical reasons.

Todays extinguishing systems of total flooding type in ship engines are too slow to respond to a spray fire, in order to reduce the damage appropriately. They must be completed by a local extinguishing system, fast enough to knock down the fire in its very beginning.

This report comprises an investigation of the fire risks, describes the set-up of some experiments and presents the results from a large number of experiments. The report also gives suggestions for the design of a suitable extinguishing system. The system consist of fast detectors and a water sprinkler rig, for protection of engines running on heavy fuel oils. For engines fueled with marine diesel it is necessary to ad foam as extinguishing media.

Key words: Ship engine, machinery, fires, total flooding, local application foam, CO_2, water, oil fires, detectors.

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PREFACE

One of the most common reasons for fires in the ship's engine-room is leakage of fuel or lubricating oil lines and due to ignition that takes place at hot points in the motor's exhaust system. Such an outbreak of fire can quickly give rise to a dangerous situation in the engine-room.

This report presently describes the problem and puts forth proposals for the design of a local application system for the main and auxiliary machinery in the ship. Moreover, it also gives a digest of the results from a series of fullscale tests, carried out intentionally to verify the proposal of design and dimension of water and foam sprinkler system.

The work has been carried out within the framework for the project "More effective and reliable methods for fighting engine room fires on ships, with minimal risks for personnel" and contains a final report of phase 1 and 2 of the project.

Altogether, the project is financed by the Swedish Fire Research Board (BRANDFORSK), The Swedish Work Environmental Fund (Arbetsmiljöfonden, AMF) and Stiftelsen Sveriges Sjömanshus. The work has been examined by a reference group appointed by the Swedish Maritime Fire Protection Committee (Sjöfartens Brandskyddskommitté, SBK).

Special thanks to Leif Johansson from Leifing Development who has been responsible for the project and assisted in the execution and evaluation of the report. Alfa Laval kindly contributed with oil heaters at our disposal for the experiments.

1 SUMMARY

The report contains a list of fire hazards in engine-rooms, shows the results of investigations on board a number of ships and from fullscale experiments performed with different spray fires, together with a proposal for designing and dimensions of a local applications system for ship's engine room. The proposal is based on a system employing fast response IR-detectors and water or foam sprinklers.

A technical fire study of a ship's engine room reveals that spray fires in connection with oil leakage creates a predominant risk for fires. Most fires are caused due to fuel leakage or lubricating oil system. Such type of spray fires can easily cause serious damage.

To extinguish a spray fire manually involves considerable risks. Hence, it is justifiable to have good safety measures against such fires, first and foremost, taking into consideration personal protection and also economical reasons.

Experience from fire accidents show that the existing fire extinguishing system in use today for total protection works extremely slow to limit the damage at an acceptable level. One or more local applications system is therefore needed as a complement to protect first and foremost the area around the main and auxiliary machines.

Normally, a Halon based system is used for that purpose. As Halon agents will be prohibited soon, an alternative has to be developed. The experiments carried out show that a system with water which is discharged through high speed nozzles can be used to extinguish a spray fire in heavy oil products. Spray fires in light products can be extinguished by foam application or at least controlled till the fuel flow can be shut off. Special foam nozzles however are not required as

conventional high speed nozzles work extremely well. Foam mixture also gives a good protection against pool fires.

In order to define the different engine rooms and possible fire scenarios, the engine types are divided into four different categories. The results of the experiments performed correspond well to the fire situation in an engine room with medium spin engines. It is extremely difficult to come to any conclusion regarding the effectiveness of foam or water sprinkler systems in the event of a fire on top of a long stroke ship's engine. The simulated oil spray fires however, correspond very well to what can be expected even in case of leakage on a big engine.

2 BACKGROUND

2.1 Prohibition against new installation of Halon 1211 and 1301 can be expected in the early 90s

At present there is a strong conviction that halogens actively contribute to environmental pollution. Disuse of halogens as a fire extinguishing medium is therefore probable. At the time this report was written in August 1990, there was no change of decision regarding this matter.

On the contrary, the International Maritime Organisation (IMO) adopted a resolution at its meeting the same summer, to prohibit the new installation of halogen system on ships in international traffic from July 1992. The meeting also agreed that its main goal was to discontinue the present systems by the turn of the century.

At the meeting held in London, "Montreal Protocol Review Meeting", discussions and procedures were firmly laid for acceptance of carbon-fluorine-combinations that can replace the halogens in question. Certain substances can be commercially available within a few years. The time aspect, however, is such that the development of a new fire safety system as complement or as replacement to the halogen (overall filling system) must be on a priority basis. Even if one hopes to retain the existing halogen system at least in passenger ferries, the completion of a local applications system signifies a reduced risk that halogens would above all be needed. Local applications system would be effective against the most common fire situations.

2.2 A firetechnical study of an engine room shows that spray fires caused by oil leakage constitute a dominant fire risk

In the report published earlier "Fire prevention measures in an engine-room" from SALTEC [2] it is among other things reported about the number of studied cases of engine-room fires with relation to ignition sources and risk components. On studying the material, we find that a great deal of fires have been caused by fuel or lubricating oil leakage on hot surfaces of the exhaust system. The quantity of fires of this type can be as high as 75 % of the total reported number.

The problem of spray fires has earlier been studied among other places at SP [3,7]. The studies clearly show that spray fires due to oil leakage can quickly cause serious damage. The risk for personal injuries and damage to property due to fuel leakage are caused by spray flames, secondary fires as well as the presence of smoke and toxic gases. Flame length, effect development, generated heat and production of smoke and toxic gases are therefore important factors to take into consideration when evaluating the risks.

Engine manufacturers have taken far reaching preventive measures in their new engine-types, with the aim of limiting the risk for fire. The high pressure pipes to the fuel injectors are integrated in the engine construction or have coaxial performance with leakage alarm function. Measures have also been taken to insulate or encapsulate the hot surfaces in the exhaust system.

It is, however, practically impossible to completely eliminate the risks for ignition despite the preventive measures taken. A leakage might still occur in the high pressure system due to material exhaustion, which gives rise to the spread of (atomized) combustible oil. Extensive engine breakdown can even result in fuel duct failure. An example of this is the fire on MS Mariella during the autumn of 1990.

Modern medium spin engines which burn heavy oil vibrate strongly and the problem of material exhaustion that resulted in leakage and serious fires have been noted on a number of ships. Surfaces with temperatures sufficiently high enough to cause ignition are always present, not least as a consequence of faulty insulation or due to the fact that maintenance was carried out during a short call at port.

The development towards operation with heavy oils has meant that the system for fuel management on board the ship has become more and more extensive. Due to the declining quality of the combustible oil, it must be heated up to a temperature of about 130 °C to be able to use in the fuel system. To prevent the oil from emitting gas at such temperatures, modern ships are today equipped with pressurized fuel system. Such a system certainly does not work at a pressure higher than approximately 4-6 bar, but instead the entire fuel system i.e. even the return piping after the main engine becomes pressurized with high temperature oil which means that the total length of the pressurized fuel pipe in the engine room is considerable [14]. The quality of the combustible oil delivered also varies, which results in an additional load on the machinery. To name an example, the bunker oil purchased for the experimental project had a water content varying from 0.1 - 7.5 %. The viscosity has also varied strongly, from 196 to 513 mm^2/s, for oil with specification IF 180.

2.3 Todays fire extinguishing systems work too slow in order to limit the damage. Local application systems are required as a complement

For several years, the modern tonnage is extensively equipped with halogens as the main fire extinguishing medium in the engine-room. This applies in the first place to passenger ferries and also container ships. Many ships have CO_2 as fire extinguishing medium against fires in the hold and the same is then used also in the engine-room, often in combination with the halogen system as local applications system. Today according to SOLAS [17] either Halogen, CO_2, high expansion foam or water sprinklers under pressure are accepted as extinguishers in the engine-room.

New stipulations mean that in future CO_2 as the main fire extinguishing medium can result in lowered security level in comparison to the present day. This decision is obviously unacceptable to the modern capital intensive units which transports passengers and valuables. According to the existing safety rules for the discharge of such a system, the engine-room should first be evacuated before the fire extinguishing system is activated. This is very important in the case of CO_2 as the concentration in the engine-room is lethal. It is less serious in the case of halogens since the concentration dose in question ought not result in serious personal injury.

Hence, it can take 15-20 minutes from the time a fire starts until the CO_2 system is activated. In most cases, within that time, an extensive fire damage can jeopardize the safety of the ship. It is therefore necessary to develop a better overall safety system that can be released without risk to the crew or to complete the existing CO_2

system with automatic or foam sprinkler, as safety for the most critical areas in the engine-room.

Local applications system must be designed for automatic release since the engine room space is often unmanned during the greater part of the day and due to the fact that the automatic system has better chance to quickly extinguish the fire. They should be designed in such a way that the evacuation of the engine room is not required when any of the local applications system is released.

The motive in installing rapid local applications system is partly to reduce the risk for engine room personnel, who to a greater extent can avoid the dangerous manual fire extinguishing manoeuvres and partly to considerably reduce the risks that such frequently occurring engine-room fires entail, in order to avoid the serious consequences that can lead to economic and safety disasters. An automatic local applications system fights fire within a few seconds and consequently has the potential to extinguish the fire with minimal fire damage.

The installation of an alarm and detection system for the ship engine room is well regulated according to IMO and several local maritime regulating bodies. These rules apply in general to fire detection and are not directed at co-operation with a fully automatic local applications system. In connection with the pre-study covering local applications system, we reviewed the literature on the different research projects account of fire detection in the ship. The reports we found were mainly concerned with the main fire alarm system and less concerned with the local applications system. On the contrary, the Norwegian Veritas (DnV) in its publication "Additional fire protection (F-AMC) Local extinguishing system" [8] stated rules for installation of selective safety with halogen 1301 as extinguishing medium. These rules demand that the detection system should consist of both smoke and flame detector for the functioning of the detection system. This system should be constructed in such a way so as to halt the engine room's exhaust fans before it is activated. This is probably a pre-requisite if a gas forming extinguishing system is used. Unfortunately, according to our own opinion, it will take too long time for it to give effect to be acceptable in a local applications system.

2.4 Some basic design concepts for the detection system could be put forward

The following basic demands are required to decide the detection principles that can be possible for use in the automatic release of a local applications system.

- The detector must be quick so that fire extinguishing can come into action as soon as the fire breaks out.
- The detector must be built to withstand environmental effects in the engine-room.
- The detector should selectively register the predicted fire behaviour (flame, smoke, temperature, gas etc.) in order to avoid erroneous alarm.
- The detector must function independently of the changes in air currents and temperatures caused by variations on the load in the combustion engines and ventilation fans.
- The detector system must be capable of transmitting the alarm signal to the main alarm system and to the different functioning parts of the machine which eventually would be activated at the time of the alarm.

The flame detector has the greatest potential in this use. It has fast response and implies built-in intelligence for protection against interference. One objection against UV detectors is that they are inclined to give false alarms if maintenance work such as welding or grinding work is performed nearby. Since the IR-detectors work within another wavelength area, they can be made insensitive to such disturbances.

There are since the early 80s several types of detectors that are selectively sensitive used to minimise the risk for disturbance [9,10]. Tests performed, confirm to a certain extent a high degree of disturbance tolerance. The usual principle is to use an extended sensitivity within the spectral band, where warm CO_2 has the maximum emission. It is not clear if one can disregard the interference risk in the case of MIG-welding with CO_2 as protective gas. Our experience, however, is that there exists at least one type of detector that can handle such disturbances.

3 THE SURVEYS CARRIED OUT UNDERLINE THE NEED FOR A LOCAL APPLICATIONS SYSTEM IN ORDER TO PREVENT OR LIMIT A FIRE OUTBREAK BEFORE IT IS TOO EXTENSIVE

The situation on board a number of ships with medium spin engines have been studied. The studies comprise:

- A review of the engine-room and installations.
- Conversations with the chief engineer and engine room personnel.
- Temperature recordings on the engine block etc.
- Measurements of air flow speed in the engine-room.
- Video and photo documentation of the engine room and measuring procedures.

The common denominator for the ships we studied is that they have been involved in a fire outbreak at least once. On the whole, all the employees we talked to, had experienced a serious fire accident. Obviously, the usual reason was fuel leakage.

Another notable detail is that for the most part, such incidents have been limited in scope through timely advice and quick action by the personnel. This has been possible due to the manual monitoring in existence. In most cases the extinguishing process could be carried out at an early stage of the fire outbreak, with minimum effort. Alternatively, ignition has been prevented due to the cooling of the leaked fuel. It is possible that more unfavourable conditions exist on a ship which operates with unguarded engine-rooms.

One aspect pointed out by the personnel is the risk that oil fog does not ignite directly but manages to fill a great part of the engine-room before ignition takes place. In such a case there is a risk that an explosion or deflagration takes place. A water or foam based local applications system should be able to minimise this risk through cooling and flushing of the oil fog, in order to prevent ignition completely or at least make it difficult to ignite. On condition, of course, that such leakage is detected on time.

3.1 Temperature recordings reveal that there are areas with temperatures sufficient enough to ignite leaking oil

We have had the opportunity to conduct a relatively extensive temperature recording during the trip on board M/S Olympia. She is equipped with four medium spin engines of Pielstieck type and is quite modern in its design. Hence, she ought to have represented the type of ship in question.

Temperature recordings were conducted during a normal trip from Helsinki to Stockholm preceded by an orientation review on the trip. In the preparatory recordings we could identify a number of points which were potential ignition sources. These points were registered with temperature meters and temperatures were recorded in quick succession during the trip. The following points were identified as extremely interesting:

- Connection between cylinder block and exhaust pipe.
- Bolt fittings on the exhaust manifold.
- Connection between exhaust manifold and turbo aggregate.
- The sensor flange for temperature measurements of the intake to the turbo aggregate.

The recordings show that temperatures up to 460 °C can be recorded at most places. Only one type of temperature recordings are shown here in the form of temperature lapse in figure 1.

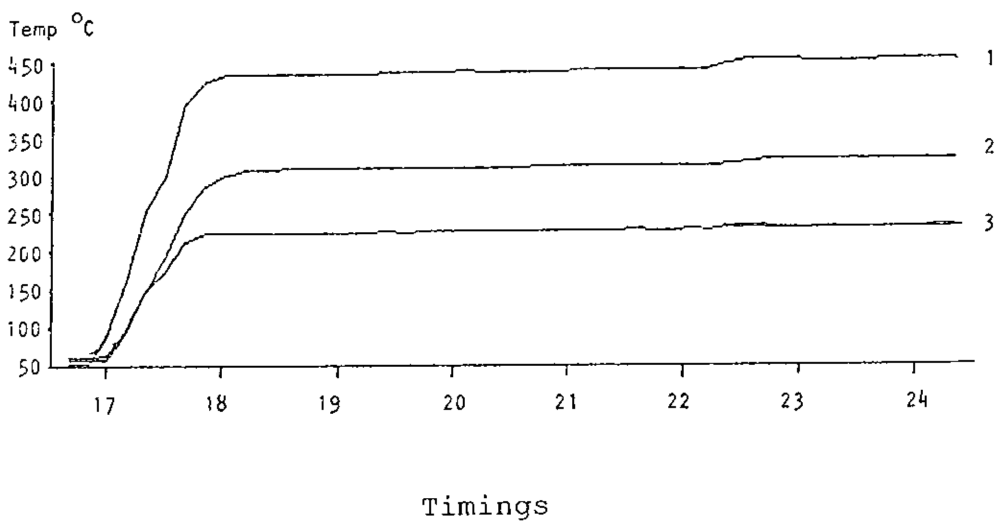

Figure 1. *Temperature vs. time for some of the measurement points. Graph 1 is for the sensor flange on the turbo aggregate, number 2 for the bolt fittings on the exhaust manifold and number 3 for the connection between cylinder block and exhaust pipe.*

The highest temperatures were recorded on the sensor flange and the bolt-fittings. The temperatures between the cylinder and exhaust pipe were surprisingly not so high which can be explained by the good contact between the cold cylinder head and exhaust pipe.

What is common for all temperature points, is that they have a high thermal capacity which is shown in the slow rise in temperature. This signifies that they are difficult to cool down which is extremely important for their capacity to ignite a combustible agent.

The temperature recordings on the Olympia were followed up with a review on board M/S Svea. We used portable measuring instruments (pyrometer and surface temperature meter), to verify the observations on board the Olympia. The above mentioned temperature recordings of up to 460 °C were also observed on board Svea.

It is difficult to anticipate at what temperatures spurting oils can be ignited. Testing done earlier at SP [3] show that mineral oil spray that comes into contact with a hot surface can already be ignited at a surface temperature of 300 °C. A stabilised spray fire can be maintained if the surface temperature exceeds 350 °C. At exactly what temperatures that occurs, depends on the spray situation, air mixture, temperature of the oil etc.

There is no relevant ignition data for heavy oil types since it is not possible to define them clearly. Heavy oils (bunker oil) are a mixture of heavy and light fractions in different proportions. The data for different hydrocarbons listed in the literature [16] shows an extremely long span in the ignition temperatures, from slightly over 200 °C to 600 °C.

3.2 The oilflow in question can signify a fire outbreak with high consequences

There are primarily 3 different oil supply systems around the main engines; the fuel systems high pressure and low pressure parts as well as the lubricating oil system. Each in turn is a potential fire risk. In addition follows the hydraulic system for long stroke engines.

The predominant risk arises from the fuel systems low pressure part. Pipe failures are frequent and the systems capacity is enormous. The supply from the booster pump system to an engine is in the size-range of 1 kg/s at the pressure of approximately 6 bar. A complete failure of the engines main line would theoretically cause a fire effect of 30 MW. Even with perhaps a more realistic average leakage, the outcome would be considerably high.

The fuel systems high pressure part has a capacity of approximately 0.1 kg/s at a pressure of 400 - 600 bar. In general, it is well enclosed and many engine types are even integrated in the engine block. It ought to therefore entail a minimum risk. If however, a leakage did occur, there would be a very thin oil fog in the engine room which presumably is extremely easy to ignite. There is therefore reason to take into consideration even such type of risk.

A large number of different types of oils are used as fuel; from high viscosity heavy oils to diesel. The heavy bunker oil is heated to approximately 130 °C at the engine front and is therefore easily ignitable. One advantage is that they are so viscous at lower temperatures that there is hardly any risk for fire. Due to the high melting point, they ought to be easily extinguished through cooling. Diesel oil in spray form naturally burns very well. It ought to be taken therefore as "worst case" to assume a failure on a fuel line carrying diesel oil.

The lubricating oil system has a capacity that lies between the two mentioned above, in the size range of 0.2 kg/s at moderate pressure. On the whole, however, lubricating oil burns just as good as bunker oil (heavy) and the installations are much more difficult to predict than the fuel system. It would therefore be unwise to ignore that risk.

The hydraulic system for a long stroke engine always involves a risk. As mentioned earlier, hydraulic oil fires have however been studied earlier at SP [3]. Special treatment has therefore not been given to hydraulic oil in this project.

4 DESCRIPTION OF THE EXPERIMENTS AND SUMMARY OF TEST RESULT

A great deal of the project consists of the laboratory test of 3 different types:

- Chemical/physical determination of the most relevant features of the oils used.
- Determination of the oils effective thermal values, combustion characteristics and ignition features in spray form.
- Fullscale extinguishing test on a model engine.

The main points of the test are described as follows:

- How does a spray fire develop in the types of oil in question?
- When can it be detected?
- Can the fire be extinguished with a water or foam spray?

Following is a summary of the result together with references to the data appendices.

4.1 We have tested four different types of oil with varying features and combinations.

In order to include as much as possible of the actual volume of risks, we have tested four types of oil with different combinations. The oils were purchased from a bunker dealer in Gothenburg and tested in existing conditions. The types tested are:

- Marine bunker; ordered quality IF 180 (two different samples, see below)
- Marine diesel; winter quality
- Lubricating oil for marine use (so called cylinder oil)
- Fuel oil 1 (only as reference in a few tests)

The important chemical and physical features of the included oils were determined with routine analytical methods. The result is summarised in table 1.

Table 1. *Some important chemical and physical properties for the oil samples used in the tests. Note that different values are given for bunker oil, because the tests very made at two different occasions, with oil from two different stocks.*

Oil	Density (g/cm^3) at various temperatures (° C)					Viscosity (mm^2/s) at various temperatures (° C)					Net calorific value (MJ/kg)	Water content (%)	Flash-point (° C)
	20	50	70	80	120	20	50	70	80	120			
Fuel oil no 1	0,86	-	-	-	-	8,9	-	-	-	-	42,13	0,05	73
Marine diesel	0,86	-	-	-	-	7,0	-	-	-	-	42,35	0,05	71
Bunker oil sample 1	-	0,95	-	0,93	0,89	-	513	-	99	16	40,70	0,1	111
Bunker oil sample 2	-	0,93	-	0,92	0,89	-	196	-	48	≈20	37,10	7,5	-
Lubrica-ting oil	-	-	0,90	-	-	-	-	47	-	-	39,57	0,2	234

As can be seen, the density and viscosity lies in the same size range at different working temperatures for all oils except lubricating oil. The thermal values are also comparable (37 - 42 MJ/kg). Most notable however, is the great difference in viscosity at 50 °C between the two bunker oil samples. Since the oil was heated to 120 °C during the actual testing, it has however little significance for the actual combustion course. The second bunker oil sample contained 7.5 % water which meant difficulties in determining density and viscosity at 120 °C. These are there-fore theoretical values determined from the several tests carried out at lower tempe-ratures. It is difficult to say what the high water content signifies with respect to the other tests performed. Since the oil was continually circulated through pumps and heaters, the water appears as emulsion. It cannot be excluded that to a certain extent that must have influenced the combustion.

4.2 The ignition and fire features of the oils in spray form were tested according to a firmly established method for compara-tive reasons

The basic idea in carrying out these tests was to verify that diesel oil at room tempe-rature has fire qualities that can be compared to those of bunker oil at 130 °C. Be-cause of that, it was possible to carry out fewer extinguishing tests with bunker oil at high pressure, since diesel oil gave the dimensionable risk. In so doing, we could direct a major part of the test to study the consequences of oil leakage in a low pres-sure system which is usually more common.

The pre-test meant that we tested the different kinds of oil sprays under a hood where the combustible products are collected. On the whole, temperature recordings were done according to a standard method [7] which gives among others:

- The degree of combustion
- Effective thermal value during combustion in spray form
- Smoke potential

The test arrangement as shown in figure 2 signifies that a low pressure aggregate (5 - 10 bar) is used for spraying oil towards an ignition source. In order to guarantee the convergence in measurements, two tests were performed with two different sources of ignition and at two different oil flows.

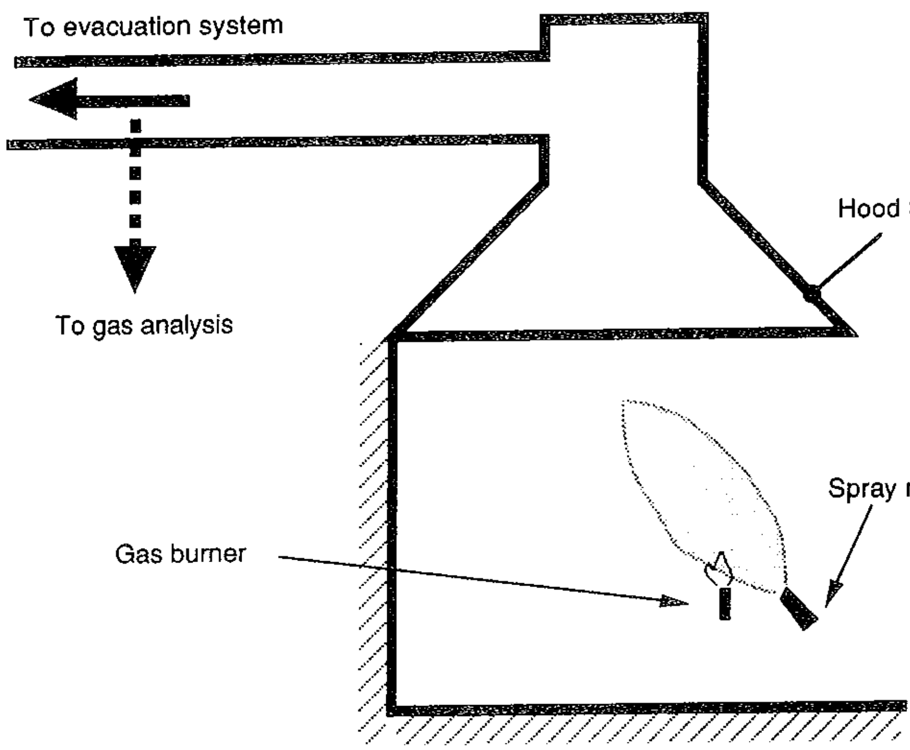

Figure 2. *A hood, 3 m x 3 m, is connected to an evacuating system via a pipe meter in order to collect all combustible gases. The development of the fire effect is registered from the amount of oxygen used. The spray is ignited with a gas burner.*

The oil was preheated in a barrel and reheated with special oil heaters. The pressure was measured at the tip of the nozzle. A standard nozzle which gives 20 - 60 g/s at a pressure of approximately 10 bar was used.

These measurements gave a good background for comparison partly between this test and similar tests done in other connections. The result concerning the effective thermal value during combustion in spray form is summarised in table 2, together with data for production of smoke, carbonmonoxid and carbondioxide.

Table 2. *Effective heat content and other parameters during combustion in spray form. The small ignition source was a 15 mm dia. gas burner with a power of 10 - 15 kW and the large a 100 mm dia. gas burner with a power of 170 - 180 kW.*

Oil	Species production rates (maximum)			Effective heat content (MJ/kg) at oil flow ≈ 10 g/s		Effective heat content (MJ/kg) at oil flow ≈ 20 g/s	
	Smoke (Ob m^3 /s)	CO_2 (g/s)	CO (g/s)	Small ignition source	Large ignition source	Small ignition source	Large ignition source
Fuel oil no 1	5	60	1	31,4	36,5	39,0	39,3
Marine diesel	8	60	3	29,1	37,8	39,6	39,7
Bunker oil, sample 1	14	50	3	28,5	33,0	33,6	34,0
Lubricating oil	4	40	<0,5	19,5	31,8	19,4	18,5

The tests revealed that combustion characteristics were similar for the different oils. As anticipated, diesel oil showed the highest effective thermal value. The differing results for lubricating oil is due to the fact that it is difficult to ignite compared to other oils and therefore has a higher heat release at a lower flow.

4.3 Extinguishing tests were done in a model arrangement

The working hypothesis behind the extinguishing tests was that:

- An oil spray fire has started in an engine
- The fire is quickly detected
- A local applications system is automatically activated or through a quick manual manoeuvre
- Water or foam mixture is used as fire extinguishing medium

The test was carried out on a simple model according to figure 3 below.

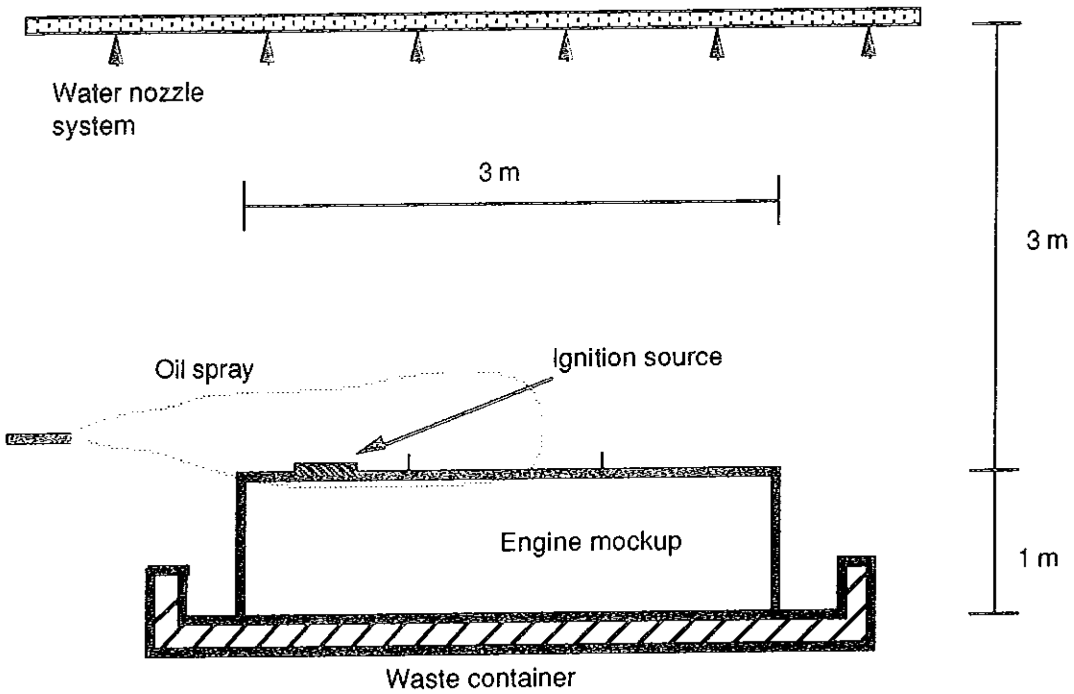

Figure 3. *The test was carried out on a simple model of an engine top. The oil was spurted out on a metal box with a heated surface. The extinguishing apparatus was placed 3 m above the metal box.*

Due to the fact that the engine model was only 1 m high and was placed directly in the collecting vessel, the model simulated a higher and warmer motor side. In this way, it is easier to understand the risk for a pool fire on top of the tank.

As extinguishing system a set of spray nozzles were used. They were mounted on a pipe arrangement 3 m above the "engine top". Water spray varied, partly through placing the nozzles at different distances from each other and partly through using nozzles with different force and spreading angle. The nozzles used were manufactured by Spraying Systems CO, USA and were of the Full Jet type. Specifications and data is shown in table 3.

Table 3. *Specifications and data for the water nozzles which were used in the extinguishing test. Nozzles were manufactured by Spraying Systems CO, USA and were of the Full Jet type.*

Model designation	Spray angle at 6 bars nozzle pressure (°)	Flow rate at 6 bars nozzle pressure (l/min)
HH4	63	48
1HH10	71	120
1HH30100	30	55

The nozzles were evenly distributed as to cover an area of approximately 12 m^2.

Heating and feeding of bunker oil was carried through a system of pumps using both low and high pressure together with the oil heater and cooler. The oil was spurted out through a number of well defined nozzles at various flows and pressure, in order to simulate the different types of leakages. Ignition was done with an electrically heated iron-plate or with a pilot flame, in cases where spontaneous ignition did not take place within a reasonable time. The system is schematically described in fig.4.

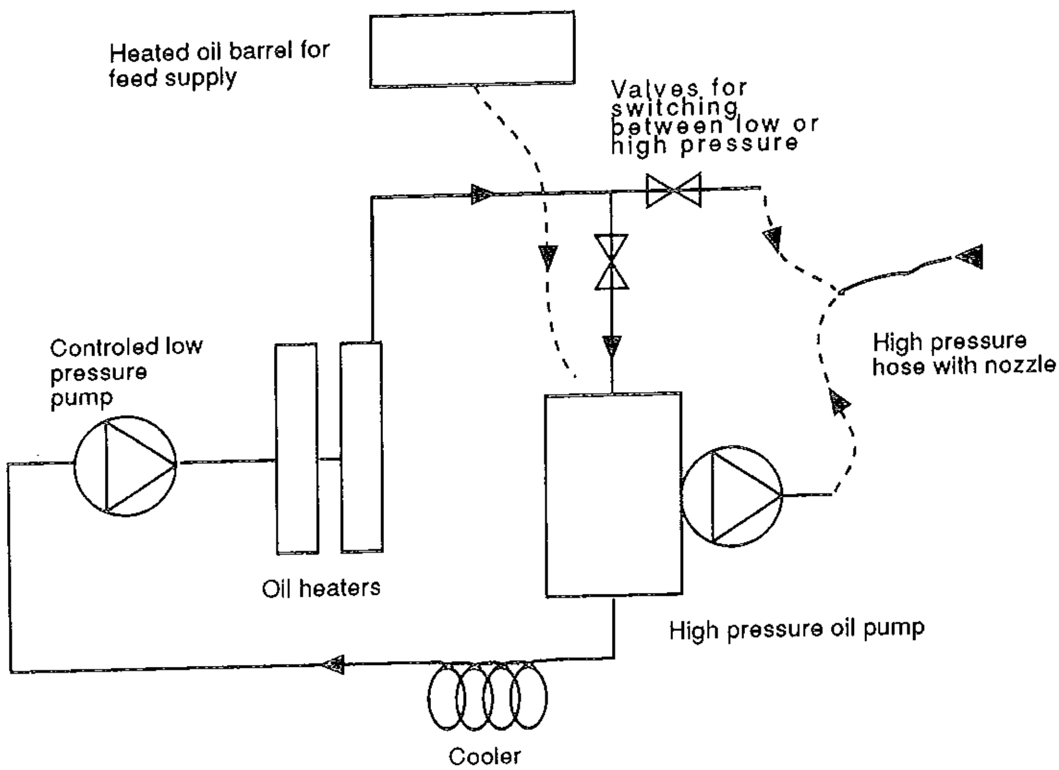

Figure 4. The oil was conditioned in a closed system by heater and cooler for pumping purposes.

4.4 The result from the fire extinguishing test shows that the water spray enables the extinguishing and controlling of the fire

Apart from a number of preparatory pre-tests, 46 documented extinguishing tests were carried out. The evaluation of the results from the diagrams, tables and similar objective data are difficult due to the great amount of uncorrelated data. Our summary is therefore based on the findings of these data and also from the impressions that have arisen during the test trial.

A number of clear conclusions can be drawn, some of them not so surprising.

- We could extinguish low pressure sprays up to approximately 0.5 kg/s whilst high pressure diesel was not possible to extinguish.
- Even if we could not extinguish the fire, the fire was dampened and pool fire was prevented.
- A spray fire in diesel oil is more difficult to extinguish than a bunker oil spray fire.
- A flaming high pressure spray is worse than a low pressure spray
- Foam mixture gives better penetration than just water as well as positive secondary effects against an eventual pool fire
- Good water covering of protective objects plus a border zone of approximately 1 m is necessary
- One can find an optimum between water covering and spray speed
- The traditional water application rate concept is difficult to apply since the demand for penetration and spray impact necessitates a certain overlap. As an example it can be mentioned that the mean water application rate during the tests varied between 15 and 60 $1/m^2/min$.

A summary of all fire extinguishing tests carried out is given in table 4.

Table 4. *Summary of data and results from extinguishing tests. Note that several of the tests with bunker oil were carried out with oil from sample 2, i.e. with a lower viscosity at 50 °C and with an extremely high water content (7.5 %). For an explanation of the concept* ***fire reduction*** *see paragraph 4.5 below. In the column for oil type, the abbreviations stands for BO 1=bunker oil sample 1, BO 2=bunker oil sample 2, FO=fuel oil no 1, MD=marine diesel and LO=lubricating oil, respectively. The abbreviation SPR 5 in the spray angle column designates tests with a conventional low expansion foam nozzle.*

Fuel system				Extinguishing system			Results		
Type of oil	Flow rate (kg/s)	Pres-sure (bar)	Temp (° C)	Flow rate (l/min)	Spray angle (°)	Foam added (%)	Extin-guished	Fire reduction (%)	Diagram in enclosure
BO 2	0,04	100	120	150	30	0	YES	-	1
BO 2	0,04	100	120	150	30	0	YES	-	2
BO 2	0,19	150	120	300	63	0	NO	80	3
BO 2	0,19	155	120	590	71	0	NO	90	4
BO 1	0,2	6	120	300	30	0	YES	-	5
BO 2	0,43	4	120	300	30	0	NO	70	6
BO 2	0,43	4	120	300	30	2,5	NO	80	7
BO 2	0,43	4	120	300	63	0	YES	-	8
BO 1	0,48	4	120	300	30	0	YES	-	9
BO 2	0,5	6	120	300	63	0	NO	85	10
BO 2	0,5	6	120	300	63	3	YES	-	11
BO 2	0,5	6	120	300	63	3	YES	-	-
BO 2	0,55	7	120	150	30	0	NO	35	12
BO 2	0,55	7	120	150	30	1,5	NO	50	13
BO 2	0,55	7	120	300	70	0	NO	60	14
BO 2	0,55	7	120	300	70	0,6	NO	80	15
BO 2	0,55	7	120	300	30	0	NO	50	16
BO 2	0,65	8,5	120	240	63	0	NO	85	17
BO 2	0,65	8,5	120	300	63	0	NO	70	18
BO 2	0,7	3	120	580	71	0	NO	40	19
BO 2	0,7	3	120	580	71	3	YES	-	20
BO 2	0,7	3	120	580	71	3	NO	60	21
LO	0,17	6	70	300	30	0	YES	-	22
FO	0,2	6	20	300	30	0	YES	-	-
MD	0,018	110	20	600	30	1	NO	85	23
MD	0,018	100	20	600	30	1	NO	80	24
MD	0,02	130	25	580	71	6	NO	70	25
MD	0,03	150	25	450	(SPR 5)	3	NO	45	26
MD	0,035	80	20	600	30	1	NO	85	27
MD	0,04	88	25	580	71	6	NO	80	28
MD	0,08	100	20	600	30	1	NO	85	29
MD	0,2	90	20	600	30	1	NO	95	30
MD	0,08	6	20	600	30	0	YES	-	31
MD	0,1	9,6	25	580	71	6	NO	90	32
MD	0,1	9,6	25	450	(SPR 5)	3	YES	-	33
MD	0,1	9,6	25	450	(SPR 5)	3	YES	-	34
MD	0,2	6	20	300	30	0	NO	85	35
MD	0,2	6	20	300	30	0	NO	75	36
MD	0,2	6	20	700	71	0	NO	90	37
MD	0,2	6	20	600	30	0	NO	90	38
MD	0,2	6	20	600	30	0	NO	-	-
MD	0,2	6	20	600	30	1	YES	-	39
MD	0,2	6	20	600	30	1	YES	-	40
MD	0,2	8	25	580	71	6	NO	85	41
MD	0,2	8	25	450	(SPR 5)	3	NO	60	42
MD	0,4	6	20	600	30	1	YES	-	43

4.5 The radiation level was measured in order to see how the water spray controled the fire

As a complement to the observations of extinguishing effect, the radiation was measured from the fire at two different places in the testing locale. If the radiation during the entire course is normalised with respect to the maximum radiation, its level gives a measure of the suppression of the fire.This is clearly illustrated in the diagram example, see figure 5. In this connection, it must be pointed out that these recordings were only to obtain a measurement of the extinguishing effect, and not the developed effect from the fire. No attempt was made to get the radiation level in absolute terms.

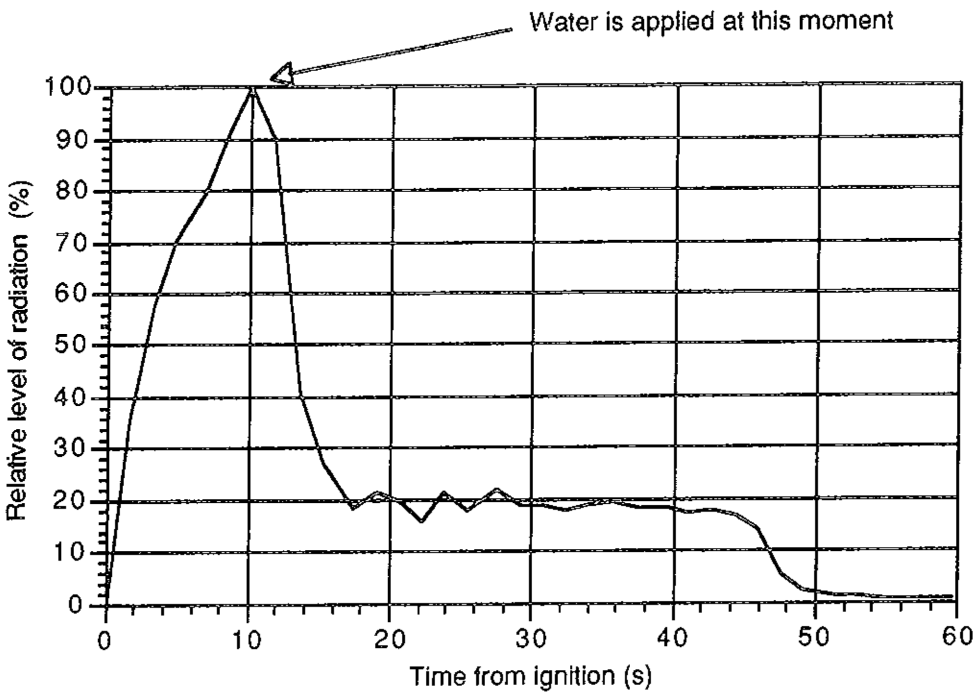

Figure 5. *Diagram showing the radiation level during a typical fire outbreak (0.55 kg/s low pressure bunker oil) Radiation level decreases slowly to 20 % of its maximum after the addition of water with a timing of 10 seconds.(i.e. the fire reduction is 80 %). The oil was shut off after 45 seconds.*

An estimate of the fire reduction in percentage is given in table 4. In case where information is lacking, it is because the fire was extinguished or that radiation measurements were not possible to record. It can be shown that even if the fire was not extinguished, it can be suppressed and controlled in most cases in order to considerably reduce the risk for fire spreading and secondary damages. The radiation versus time for the whole test lapse is given in enclosures, with reference to each test in table 4.

4.6 A detector system was tested with excellent results

A detector system of the Cerberus make S 2406 (2-phase flame-IR), was tested in a few of the extinguishing tests. The detector reacted exceptionally quick to the flame and showed good disturbance tolerance, e.g. it was exposed to interference from a MIG weld with CO_2 as protection gas and did not give any faulty recordings.

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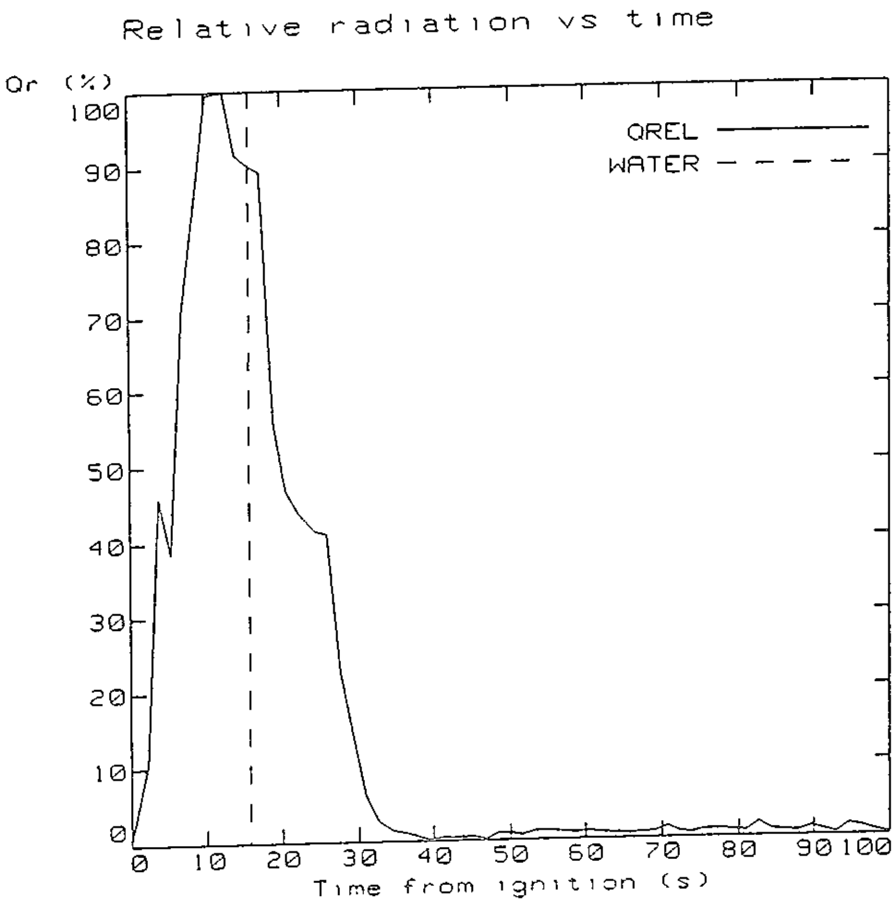

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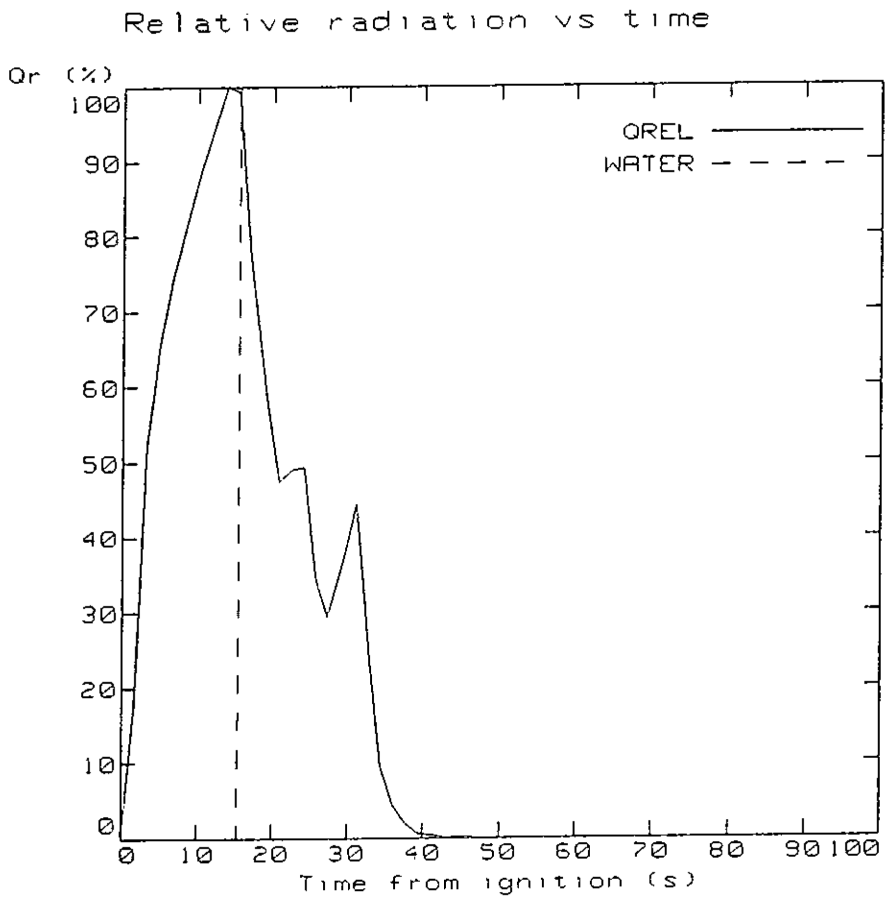

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Enclosure 3

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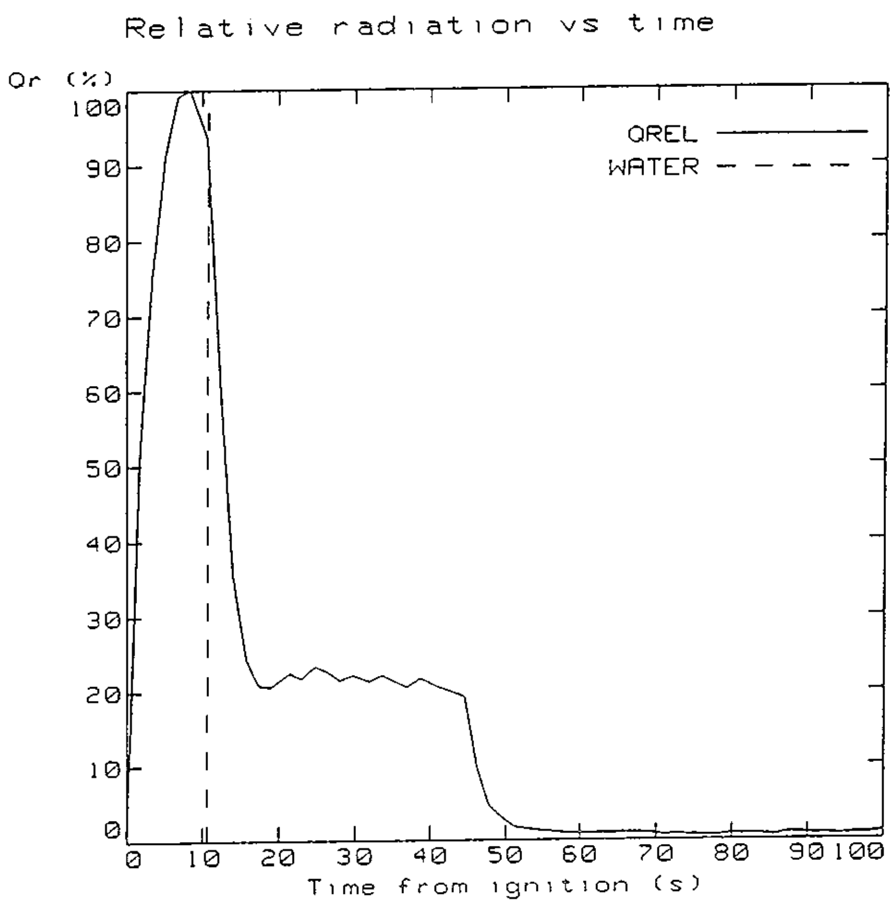

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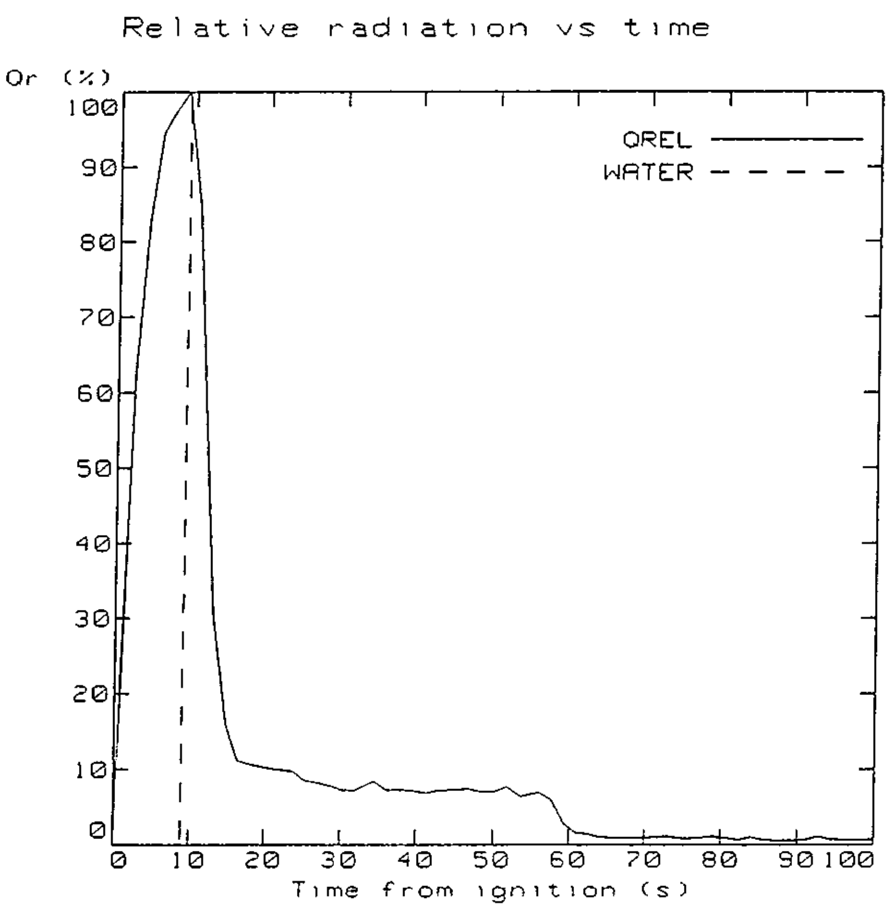

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Enclosure 5

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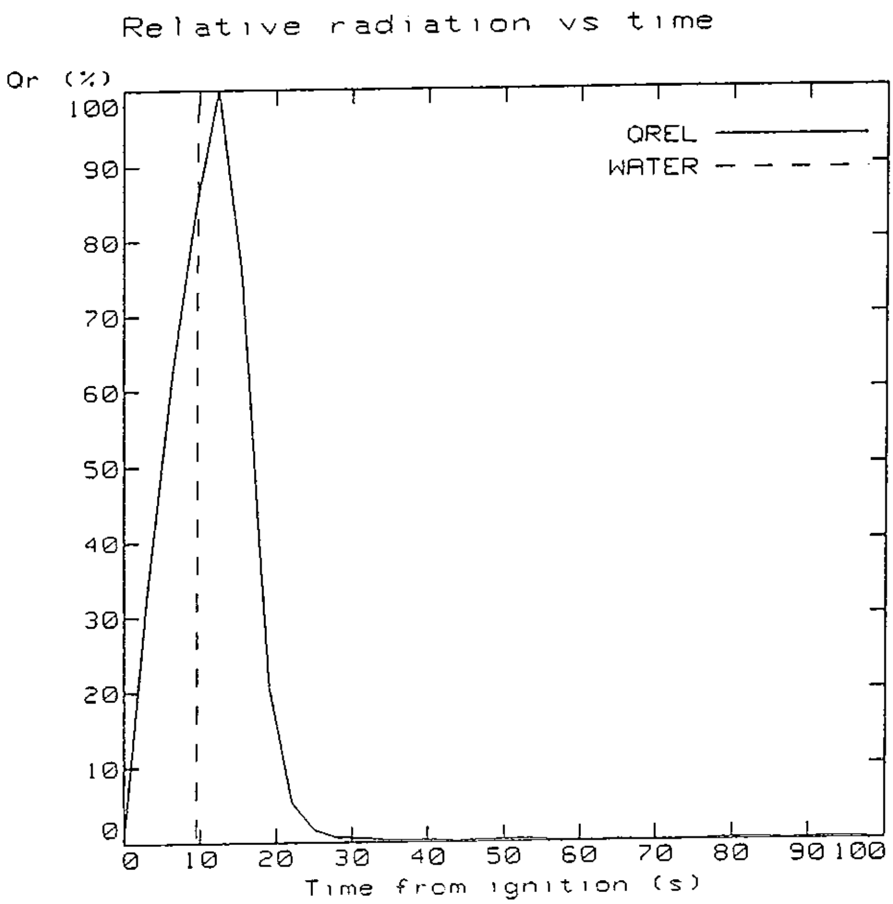

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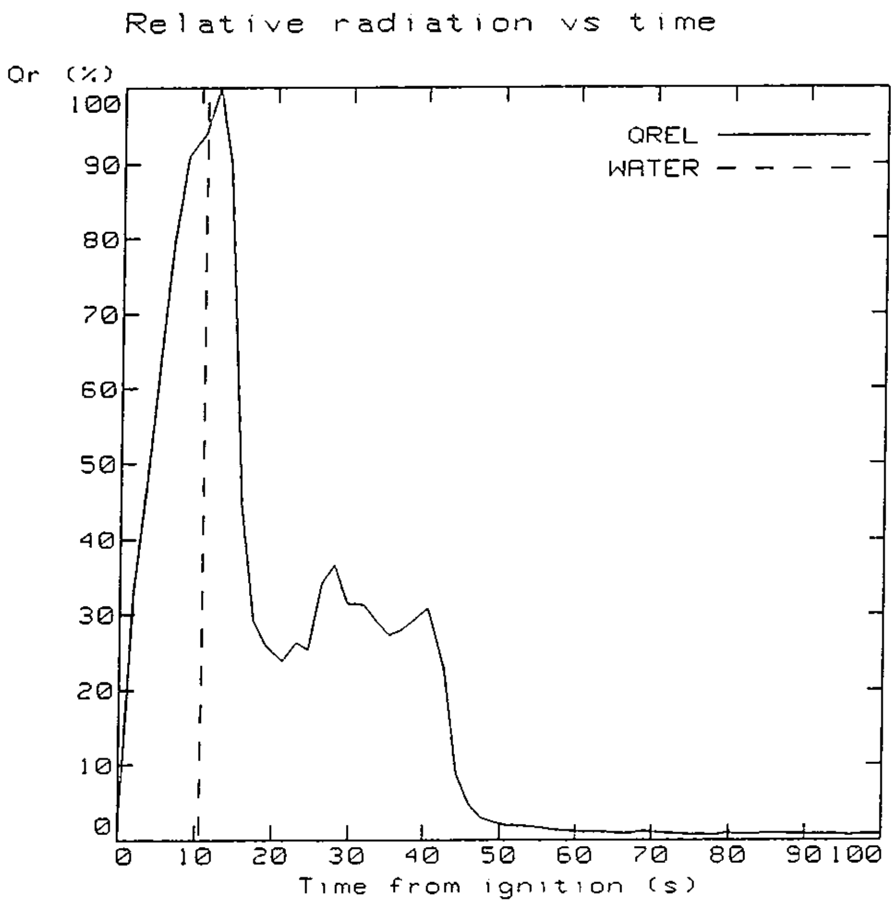

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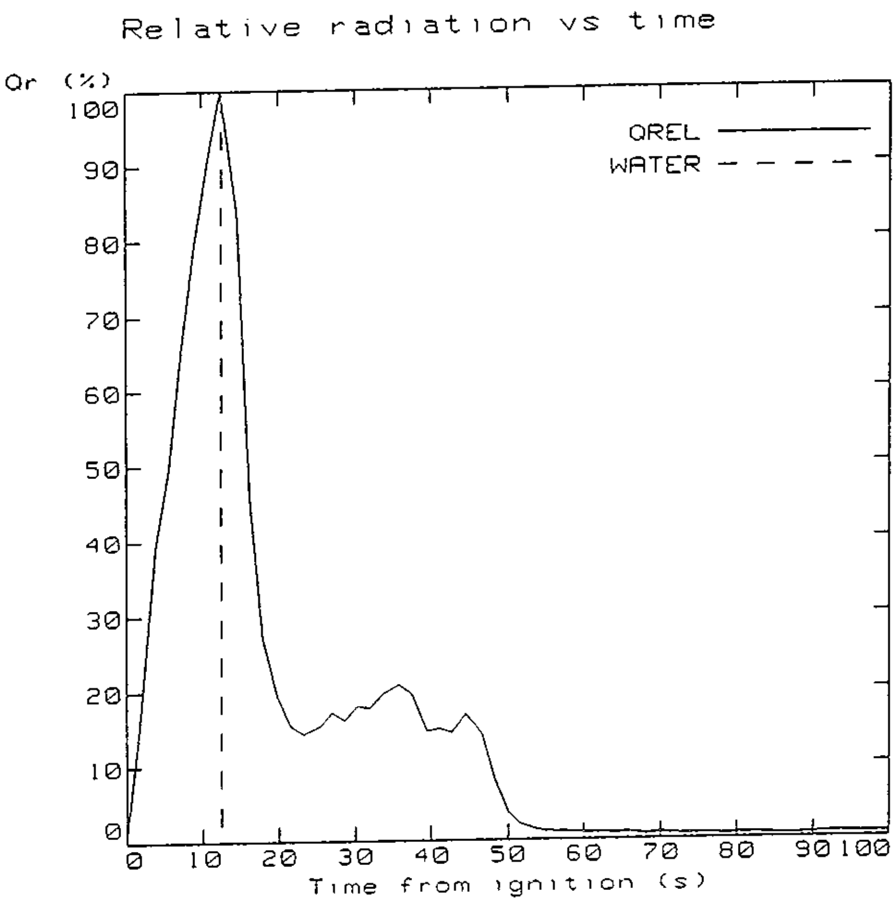

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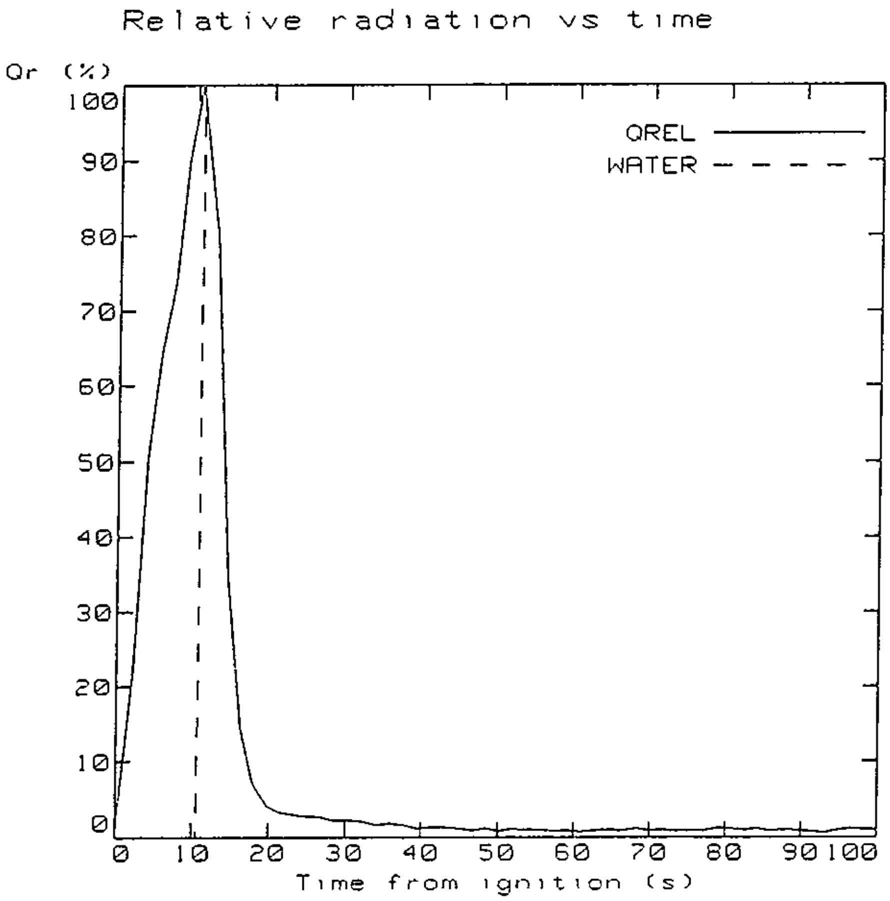

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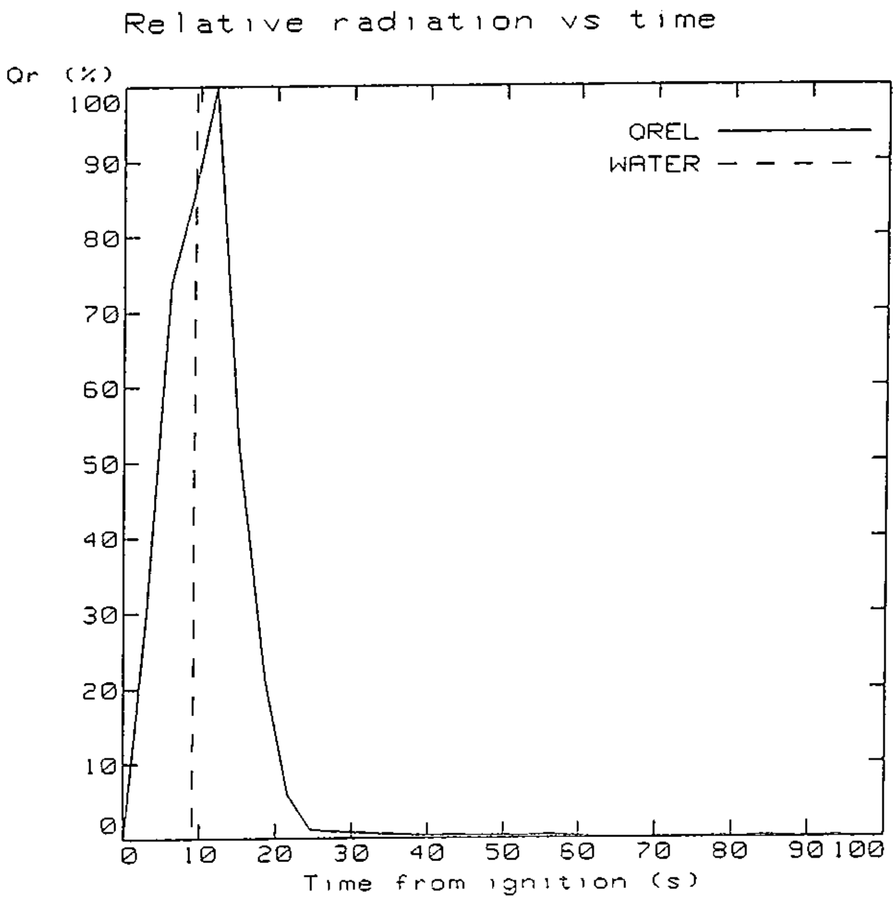

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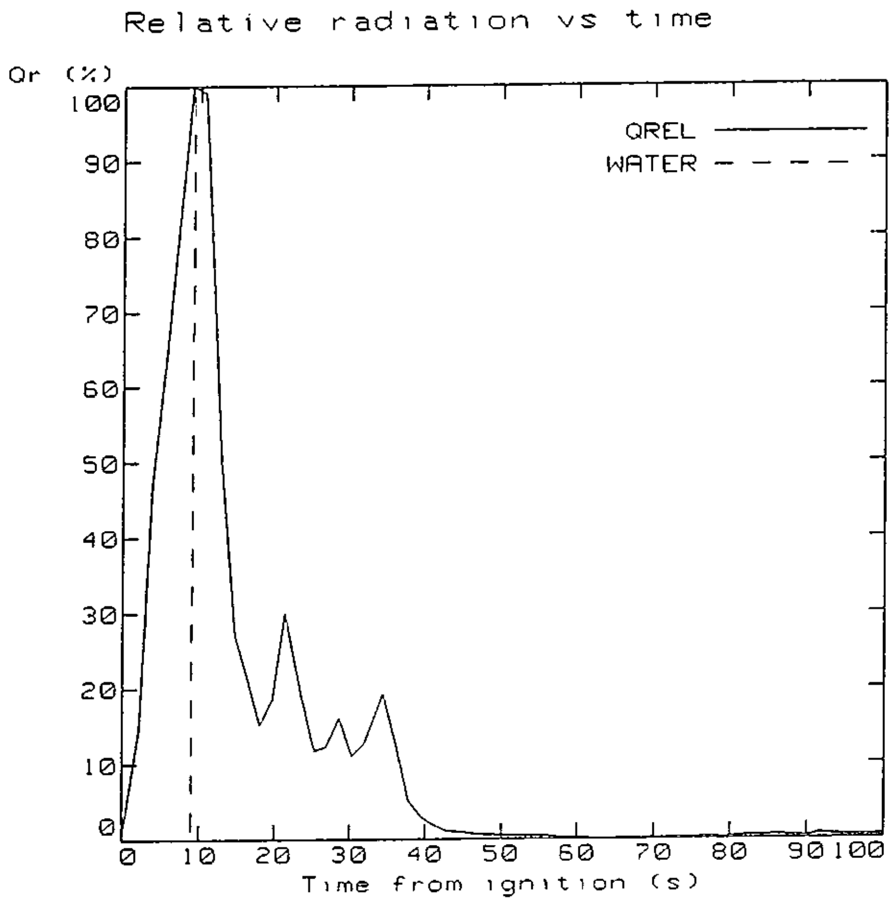

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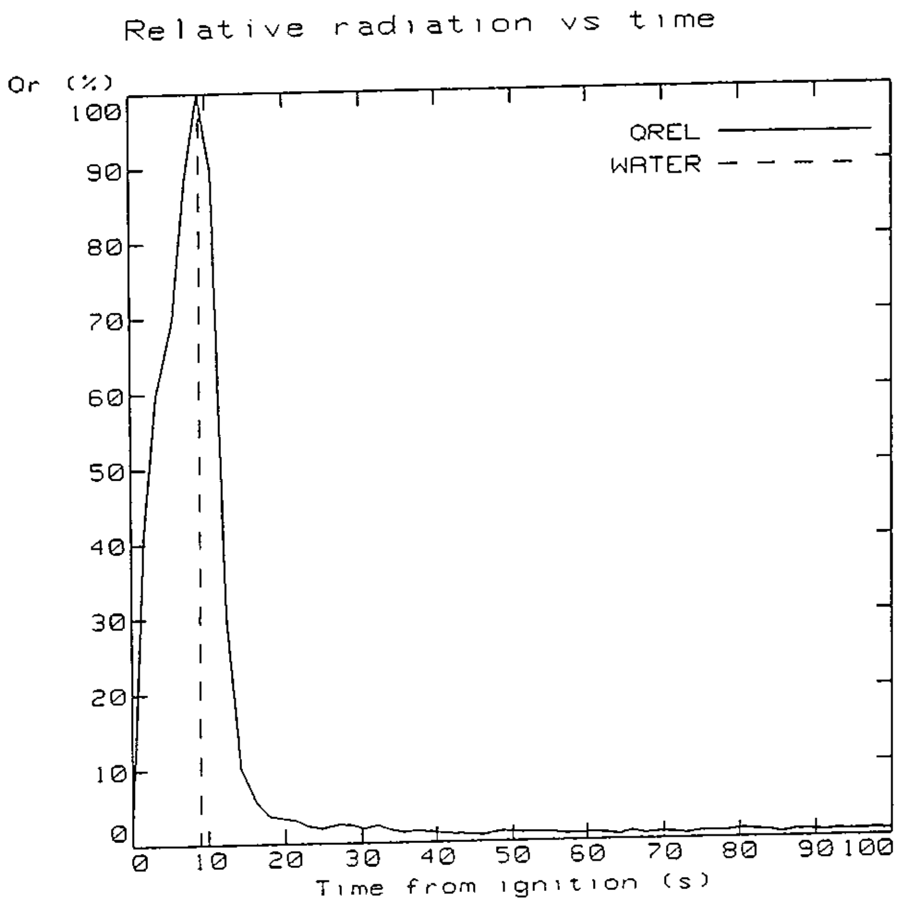

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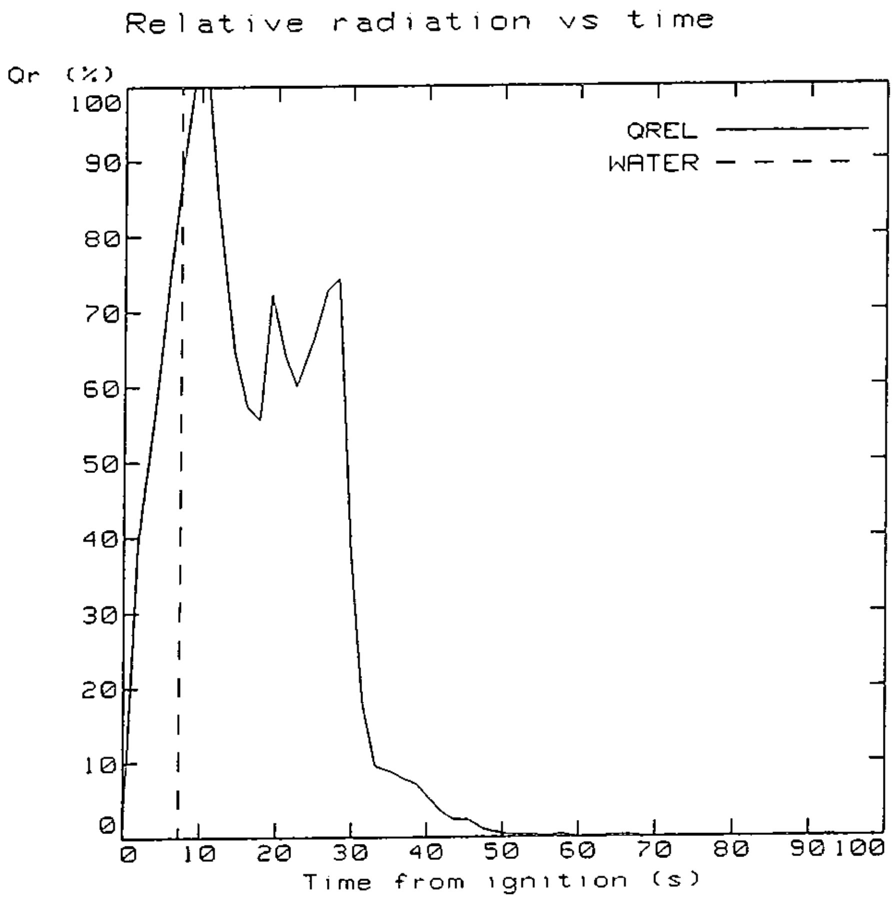

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Enclosure 13

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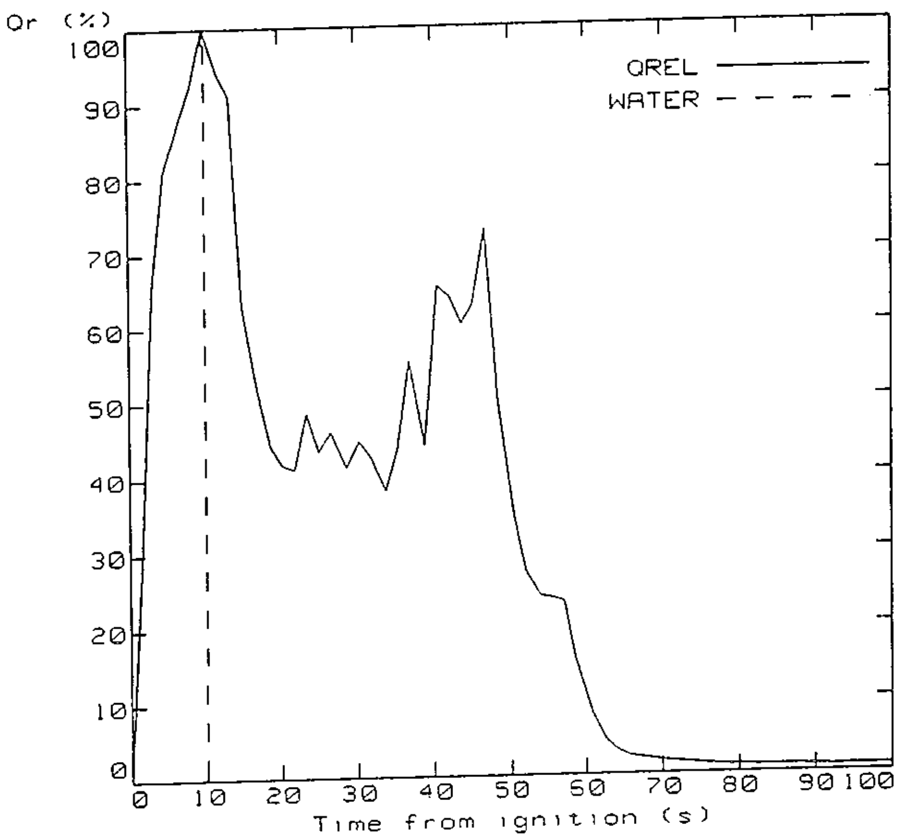
Relative radiation vs time



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Enclosure 14

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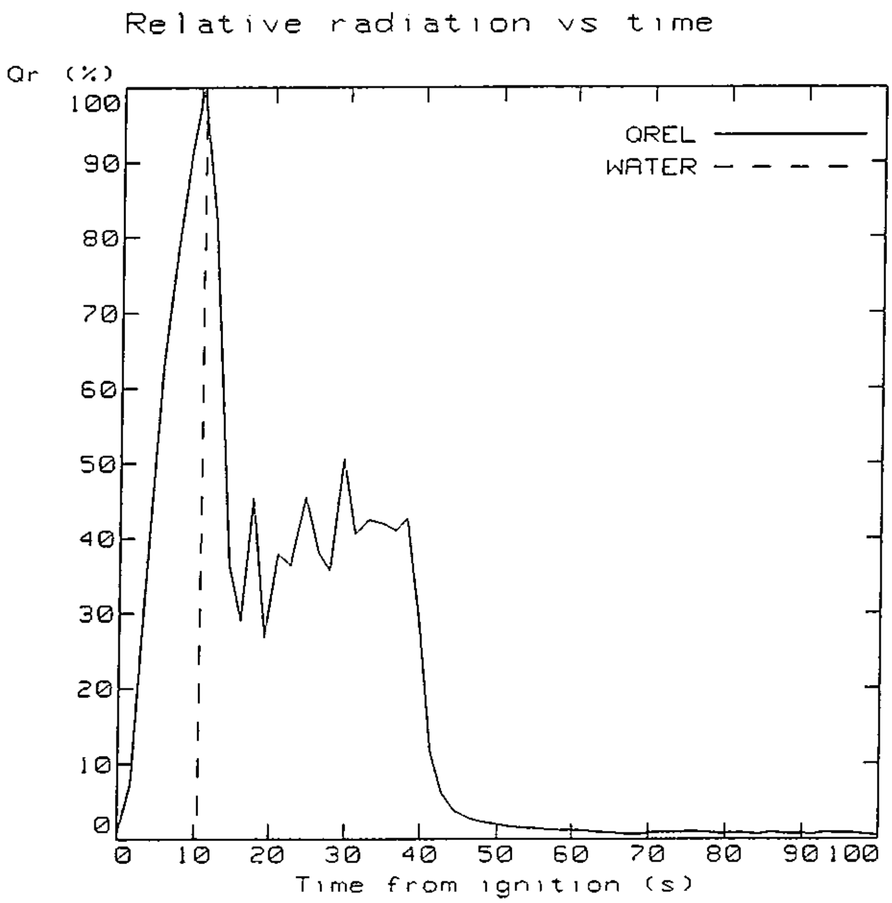

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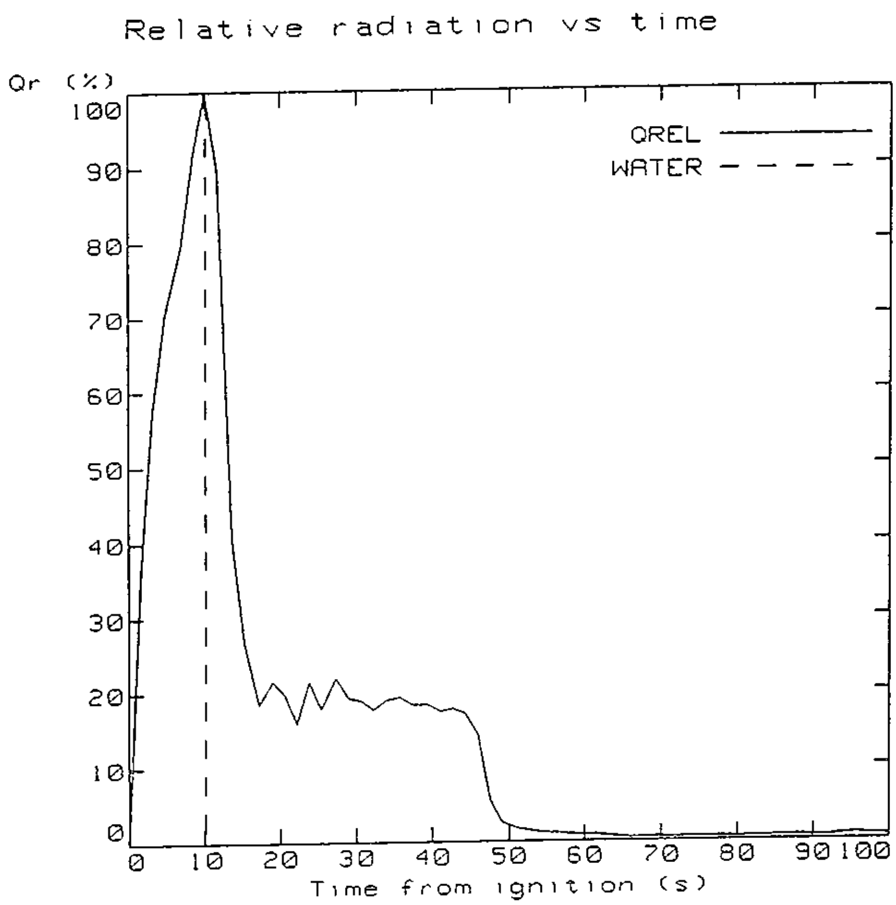

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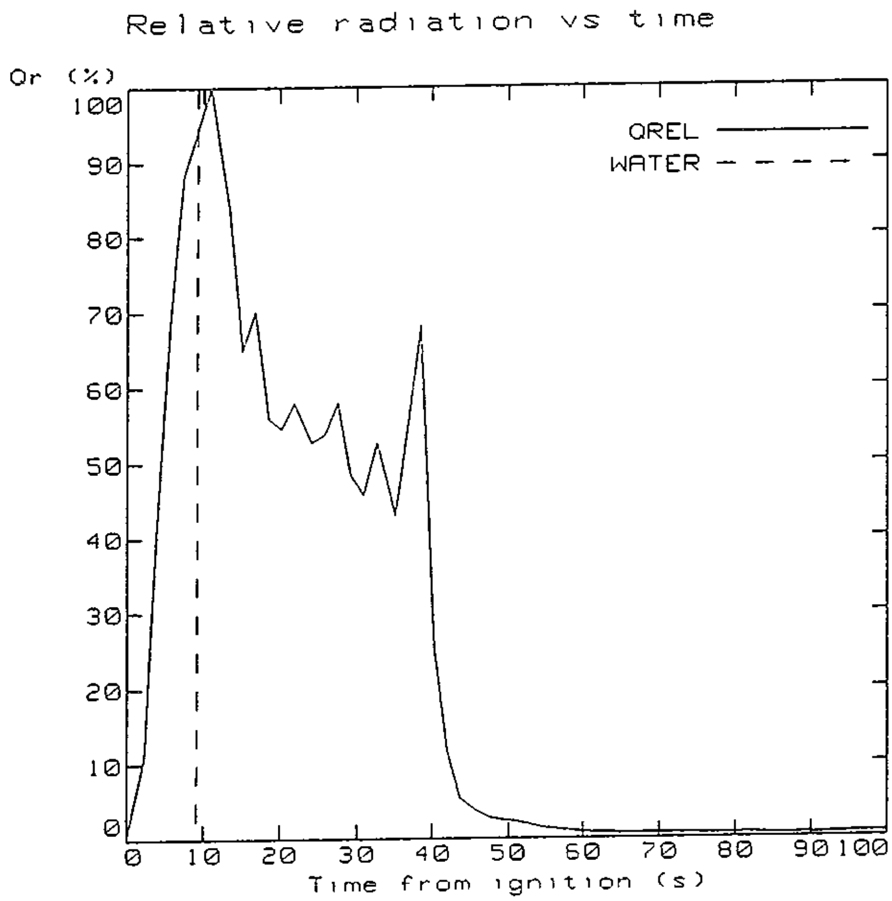

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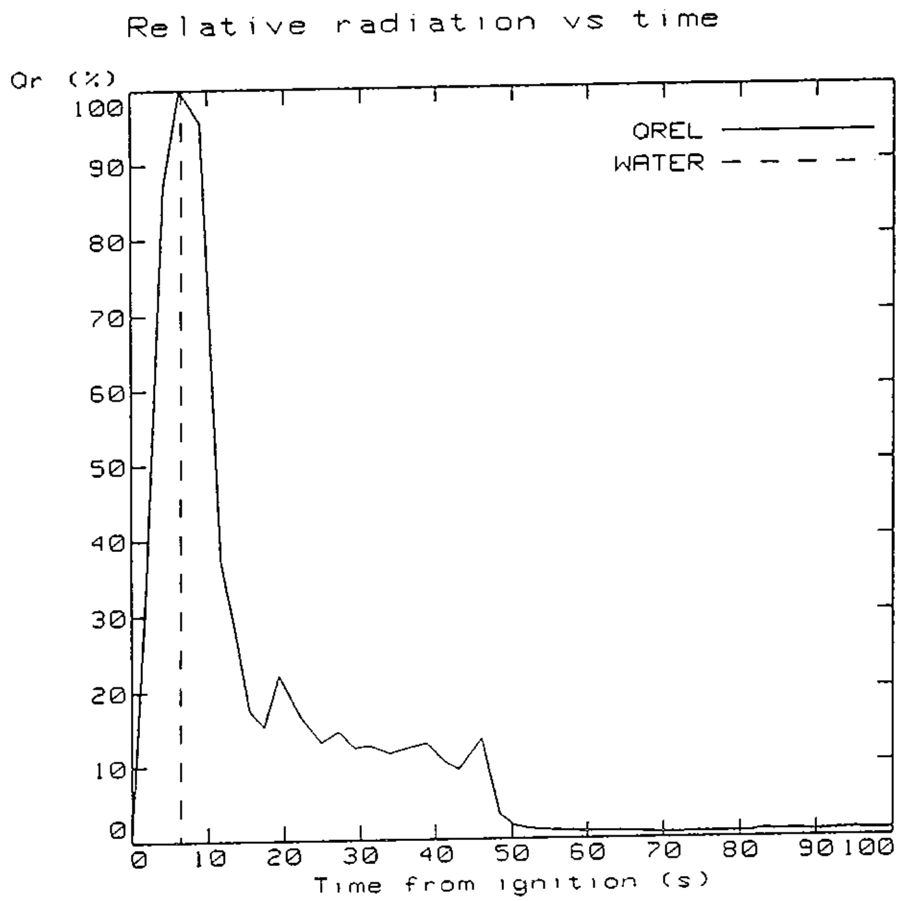

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Enclosure 18

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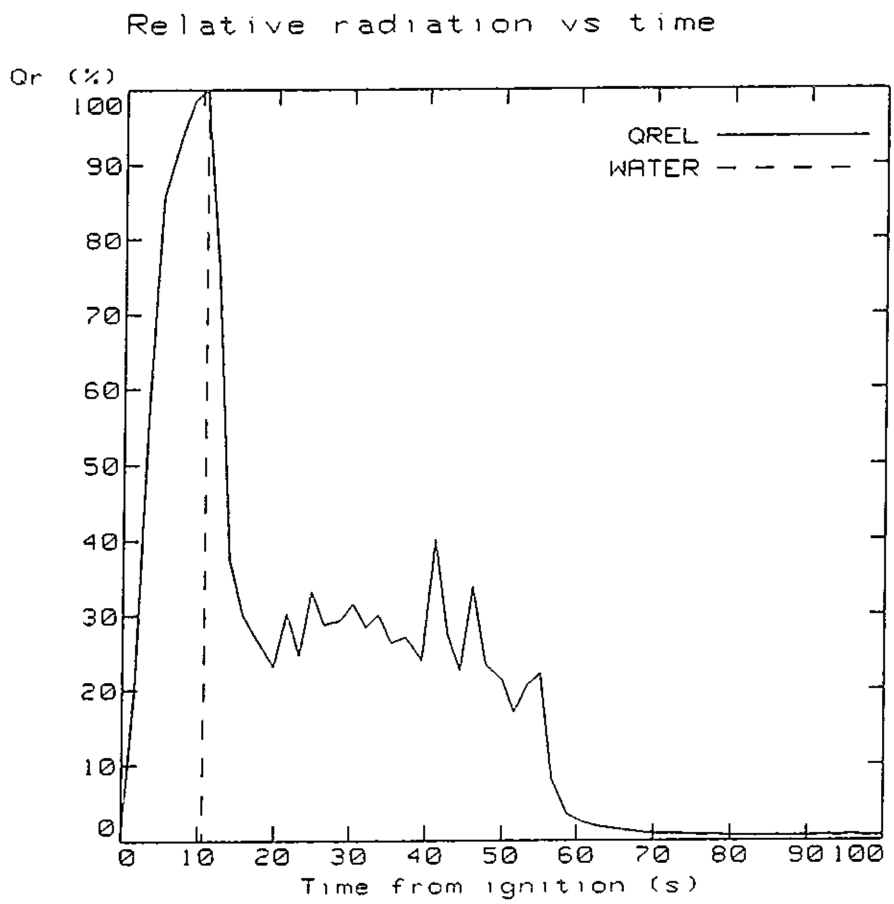

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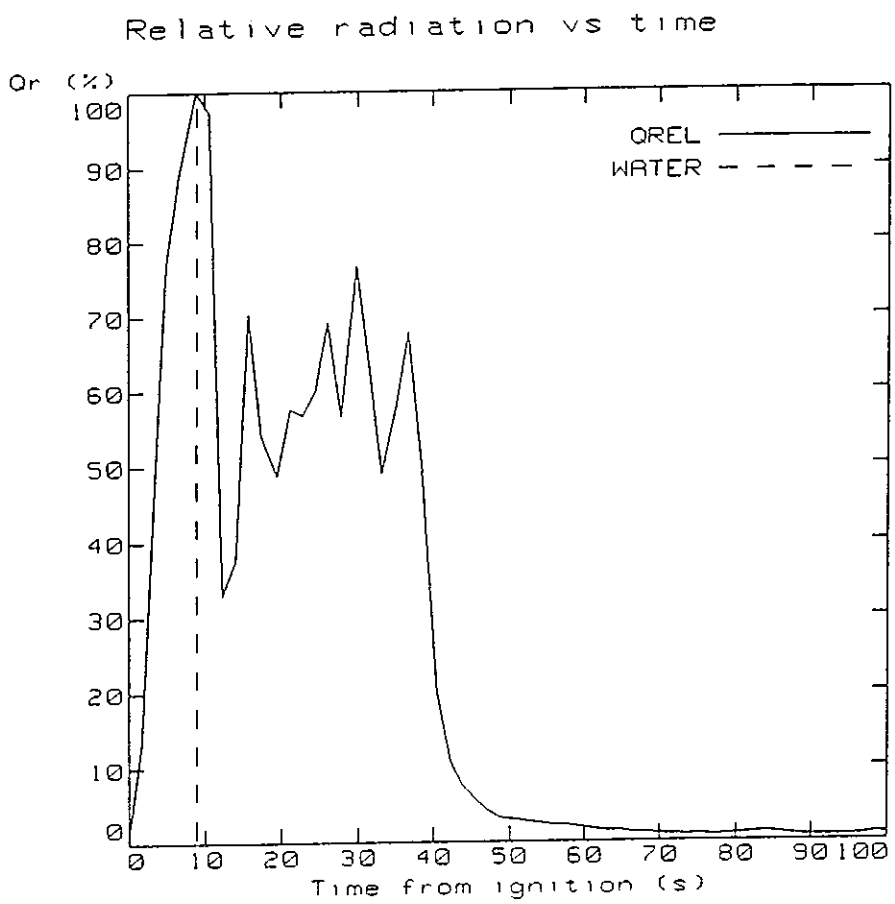

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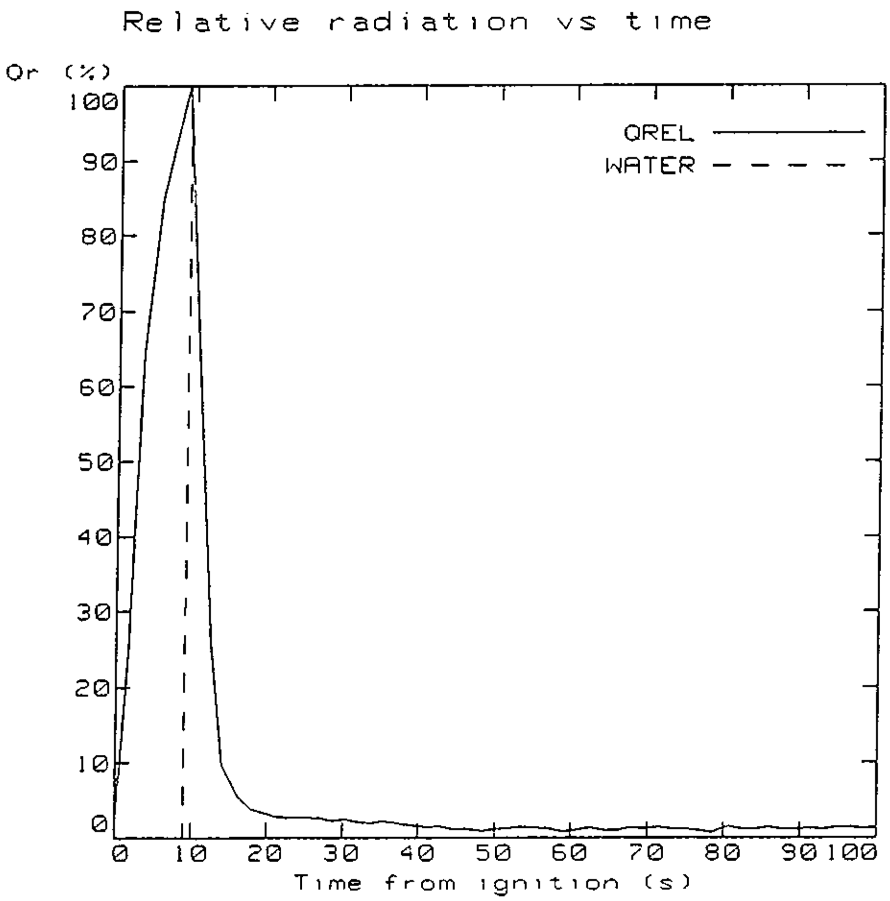

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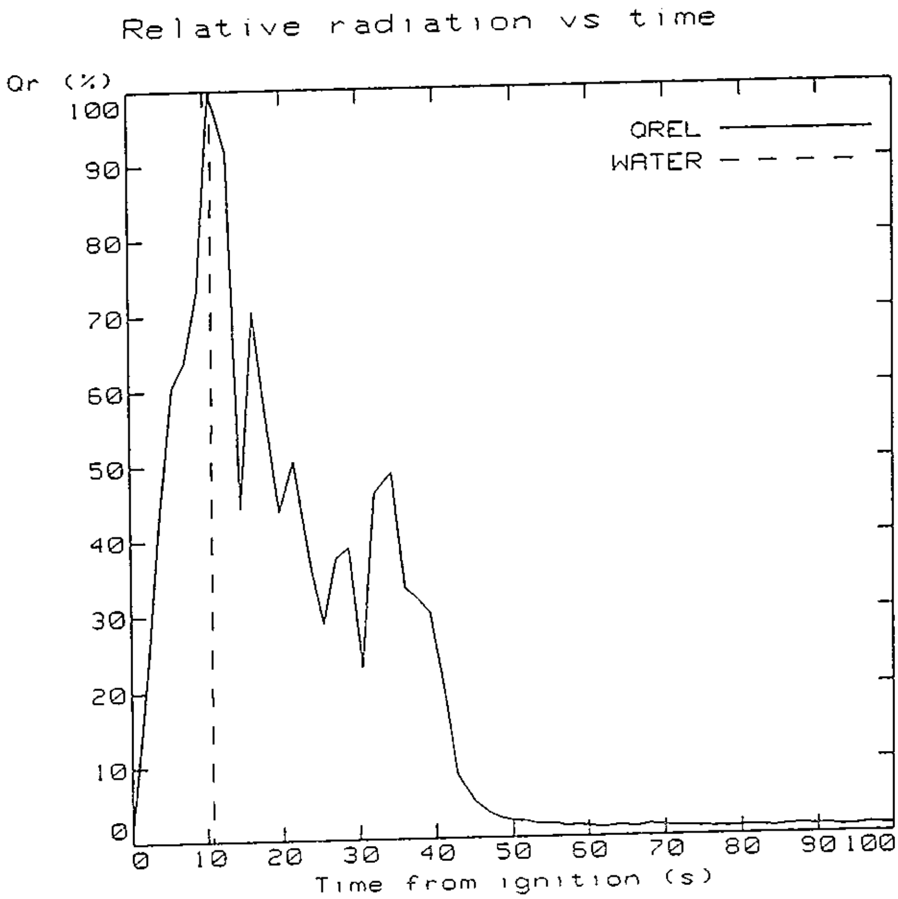

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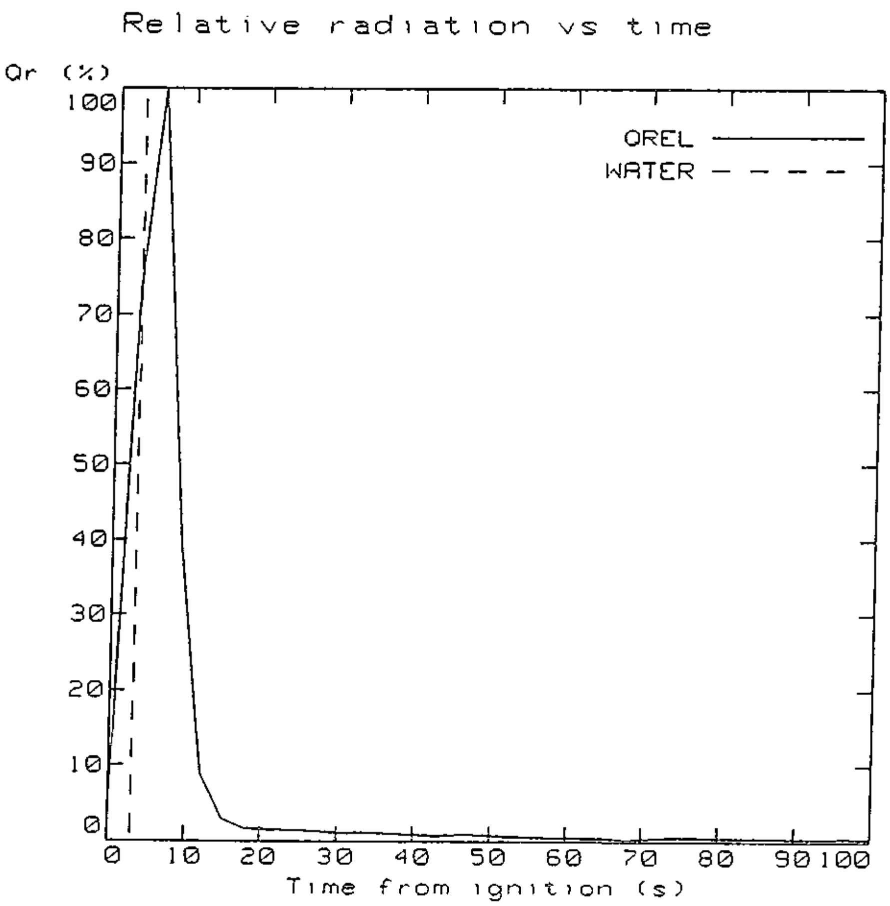

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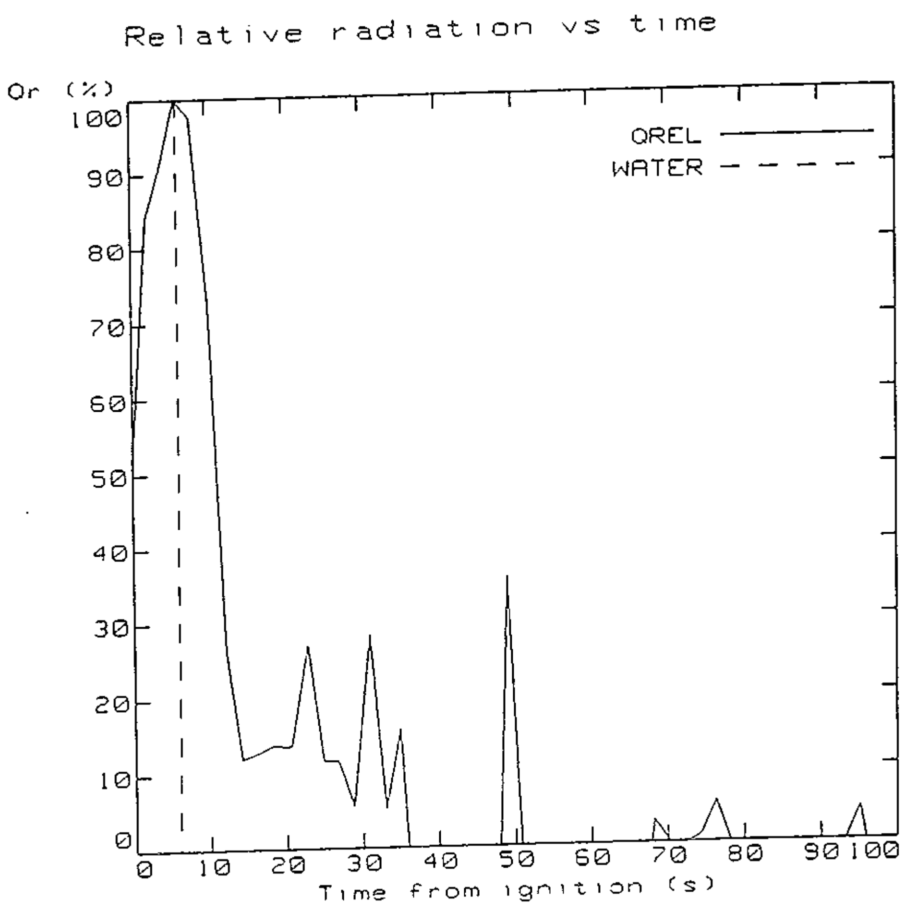

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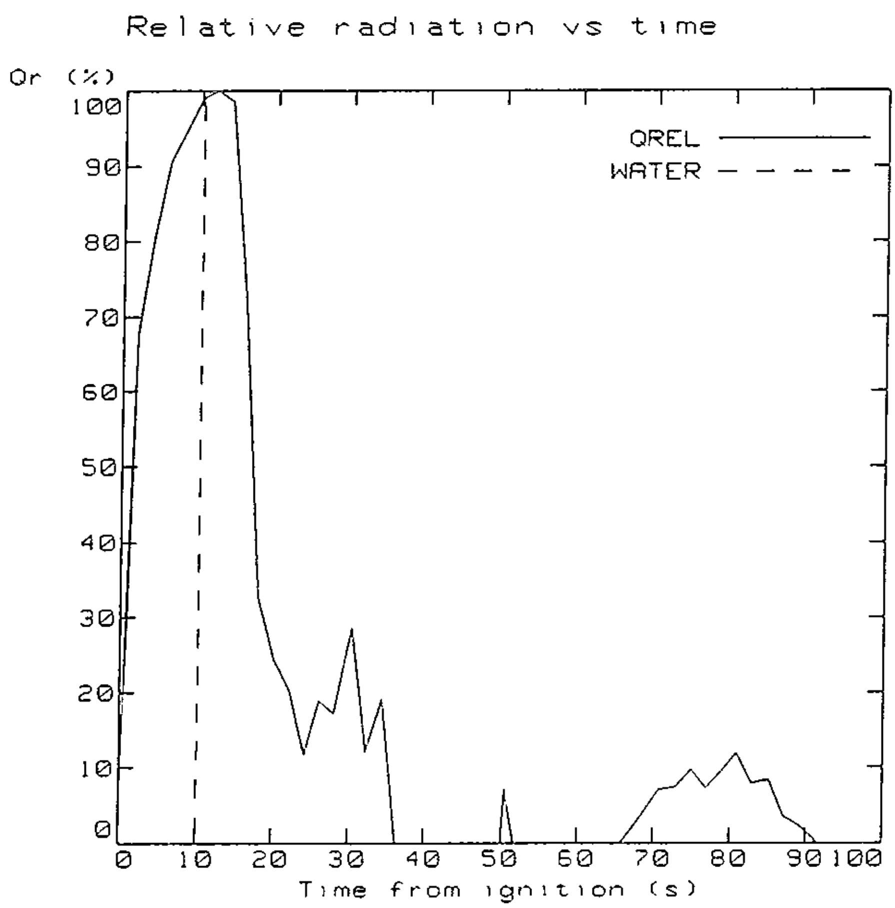

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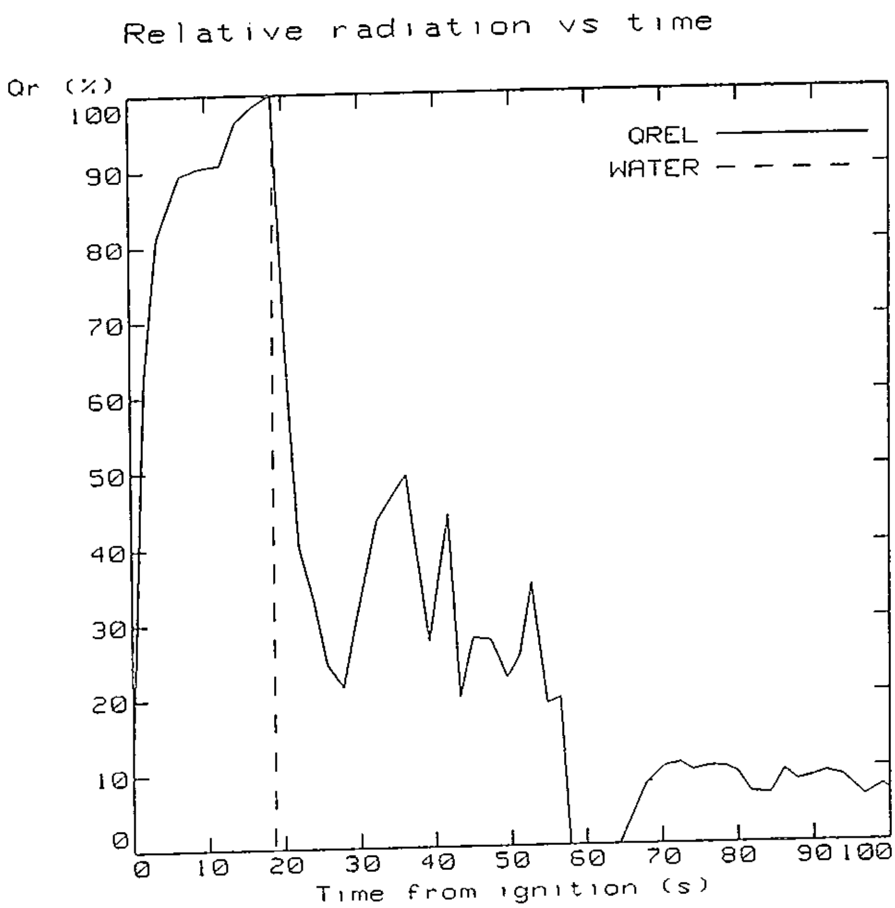

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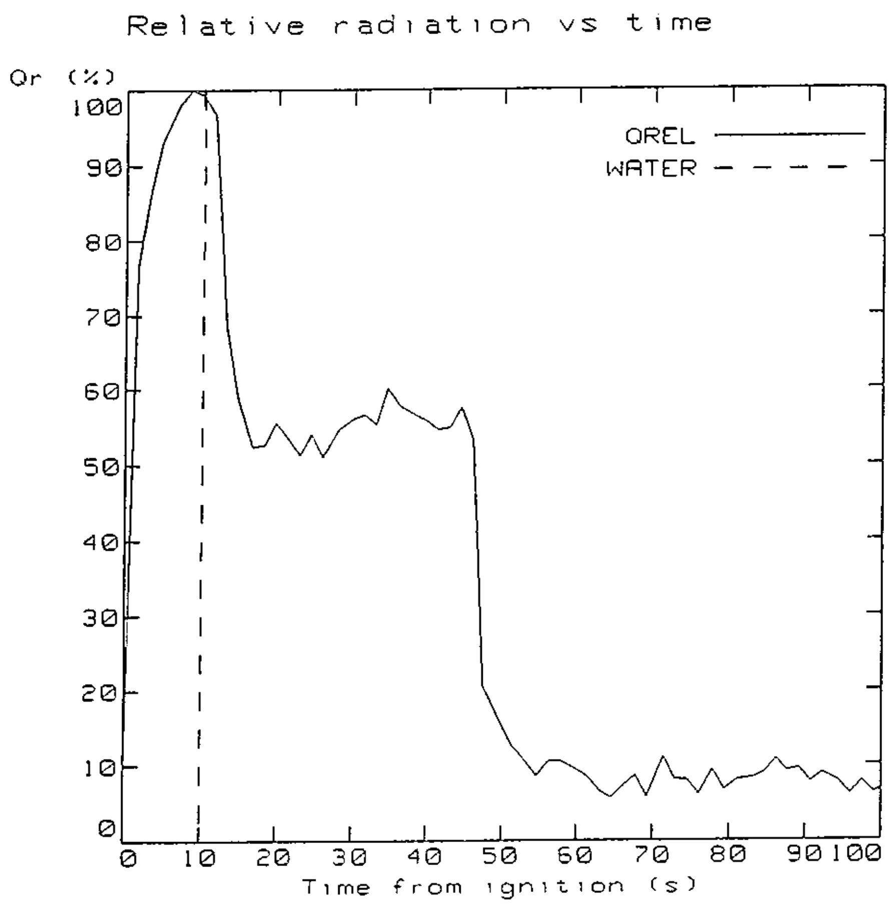

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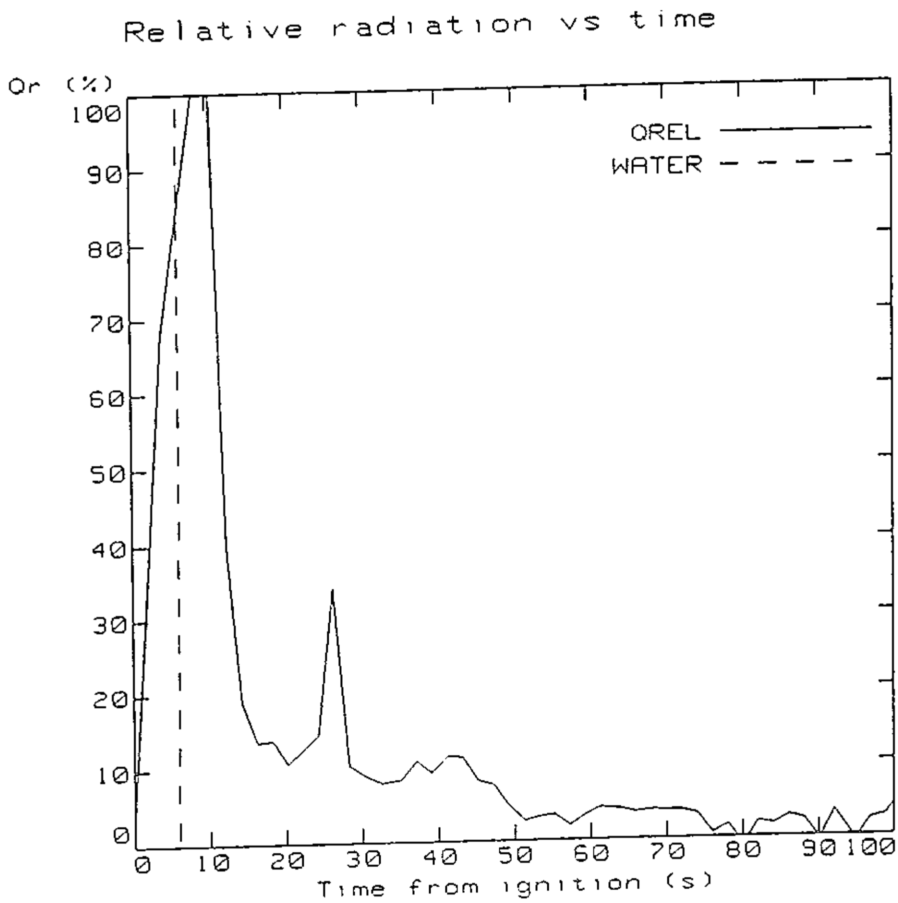

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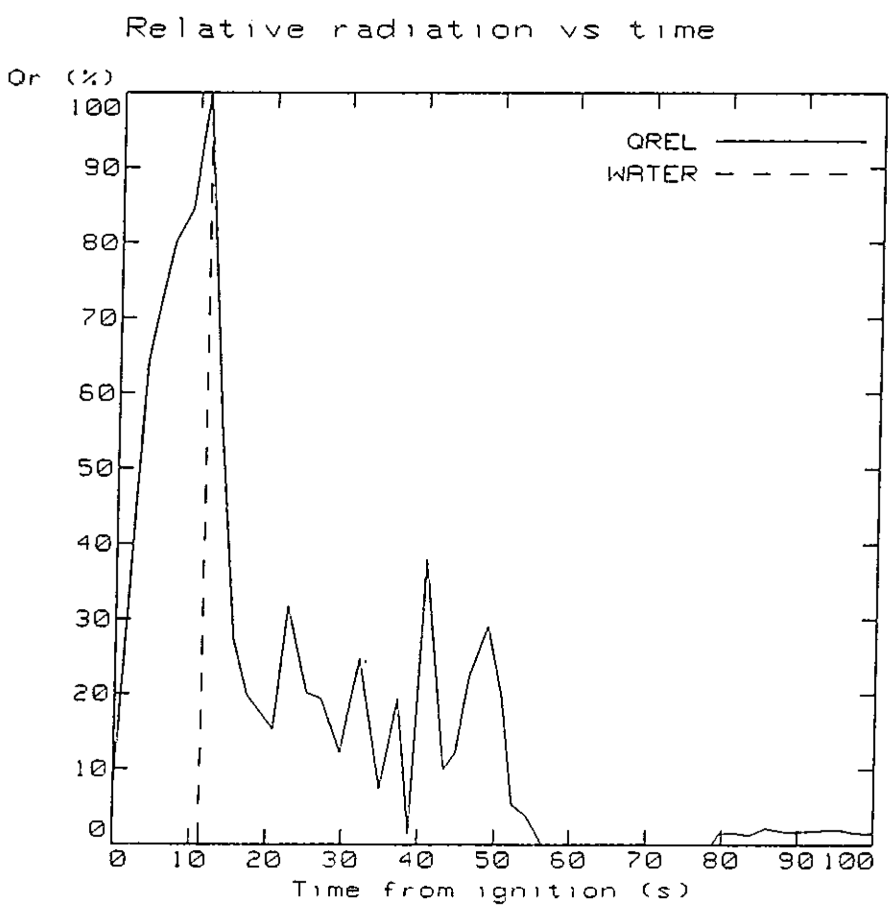

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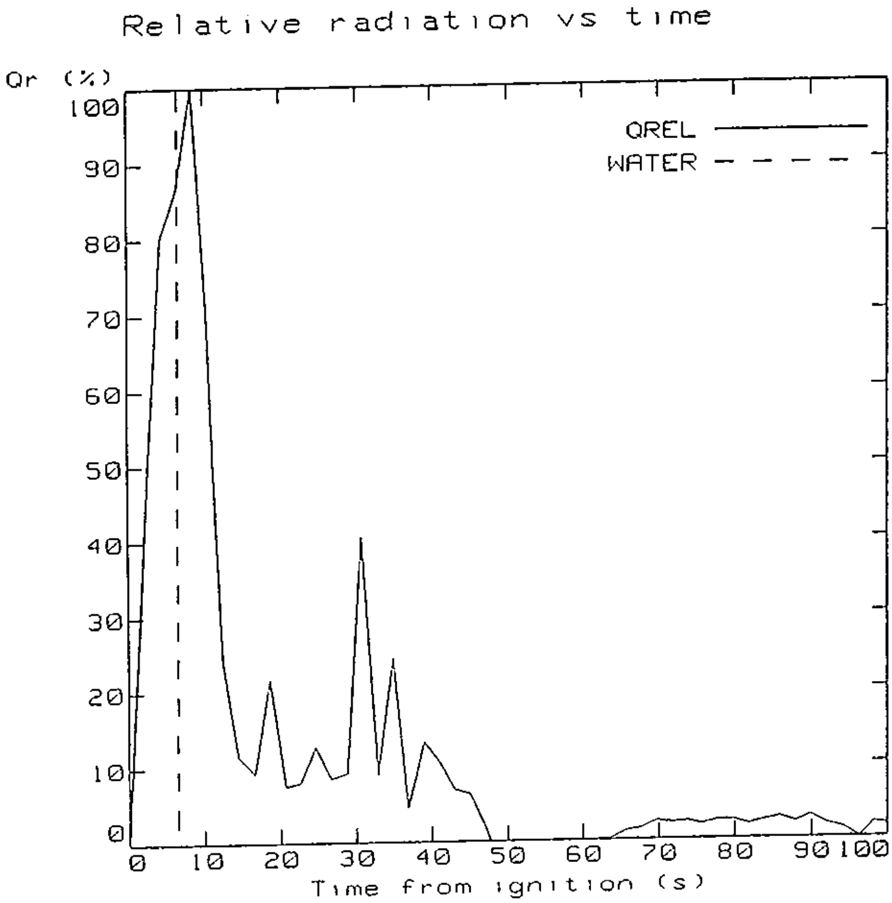

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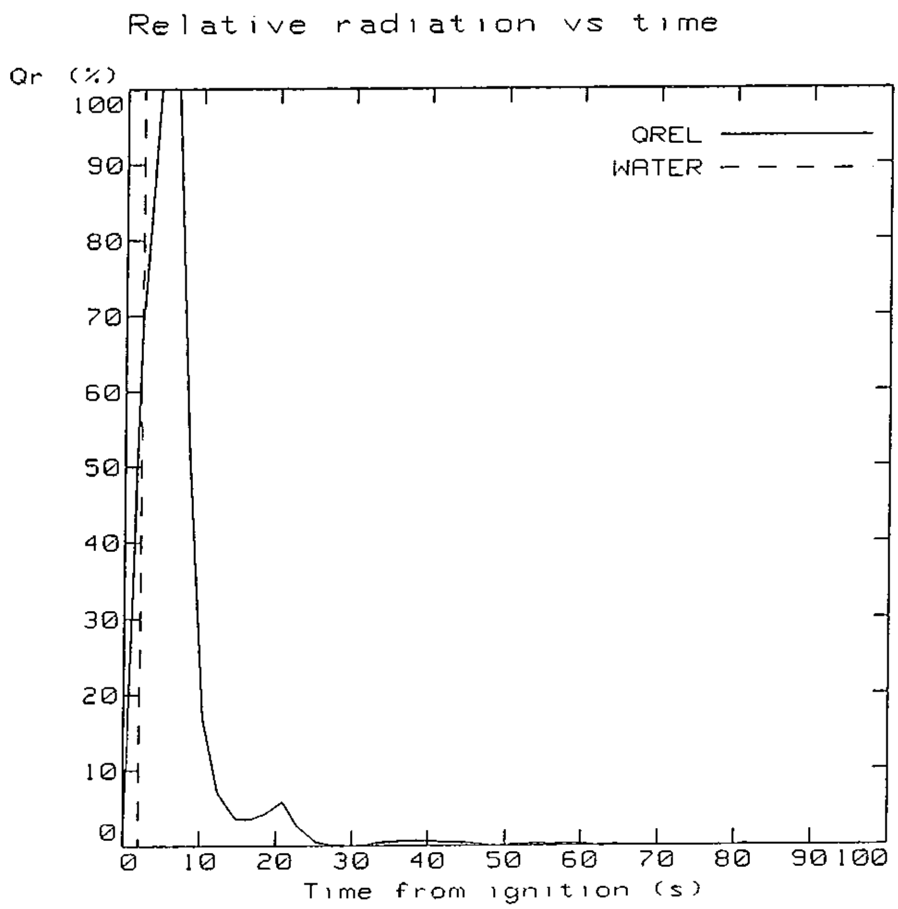

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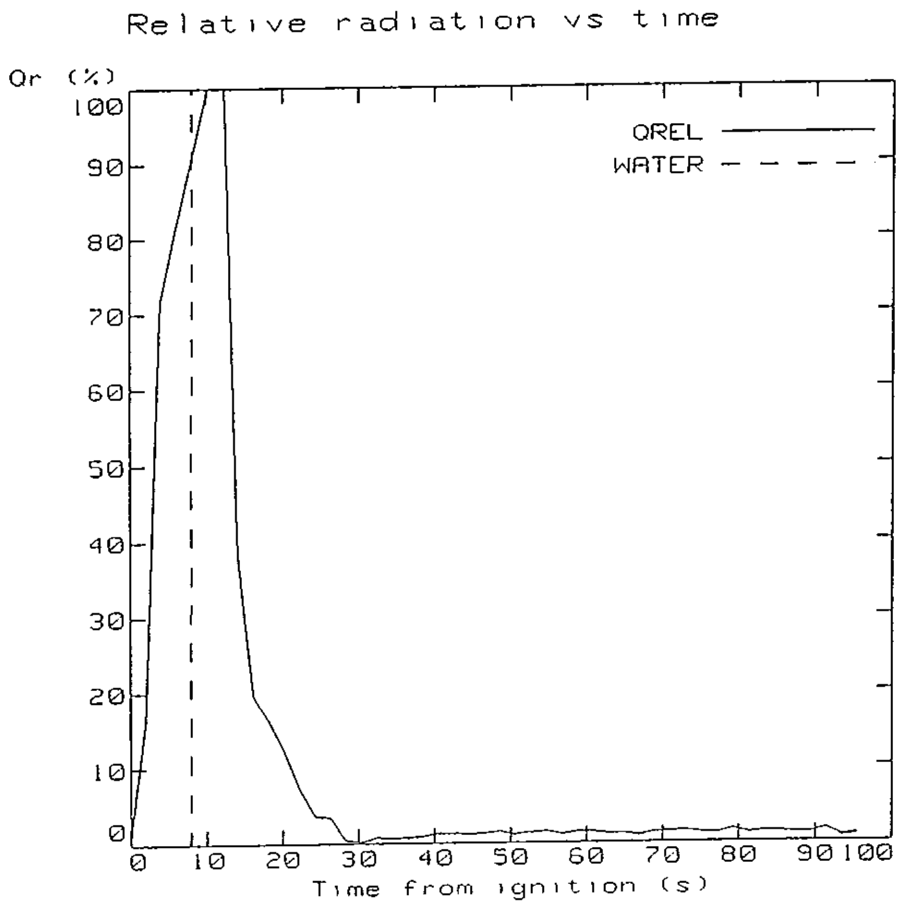

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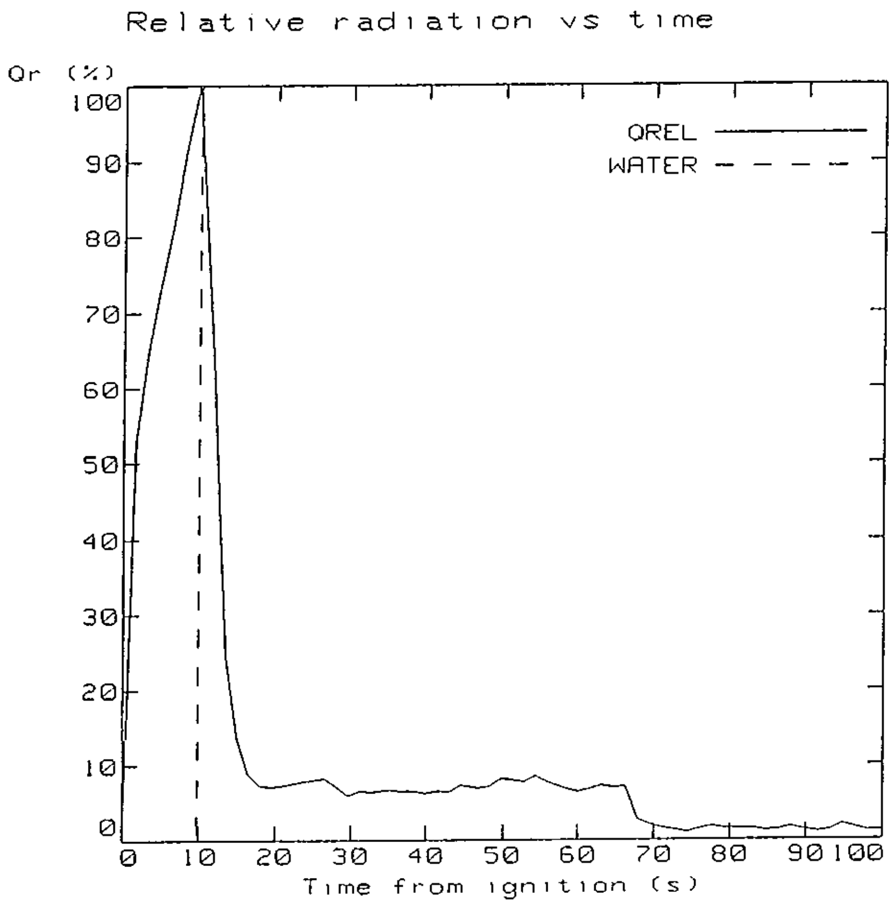

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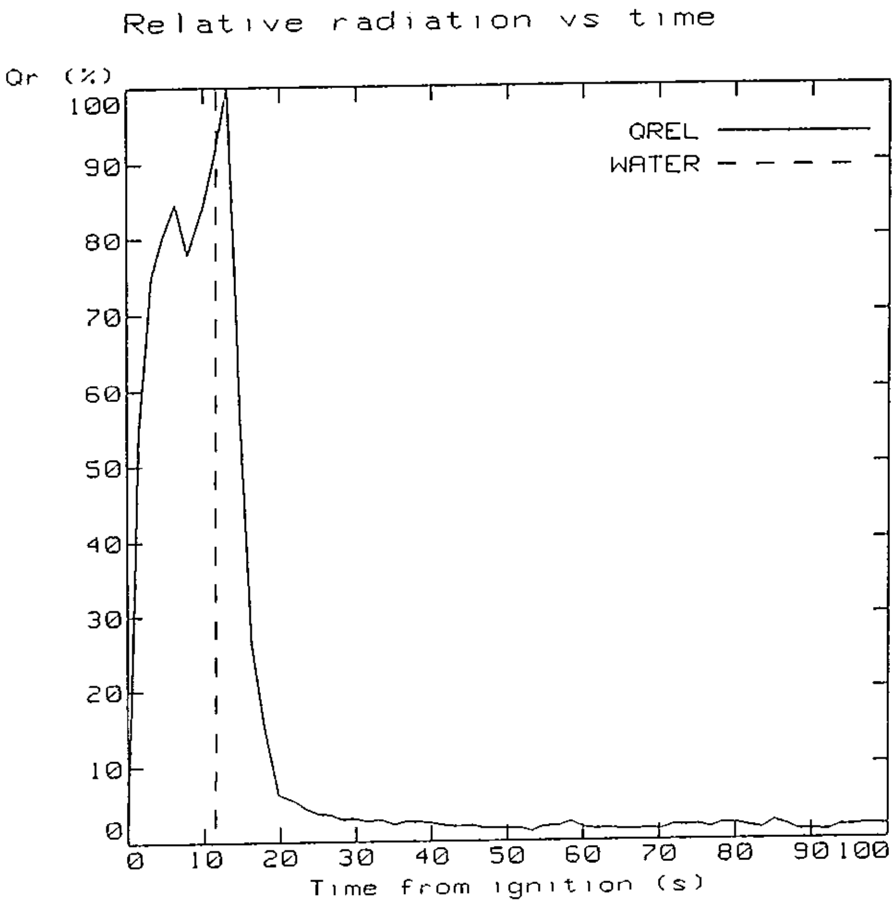

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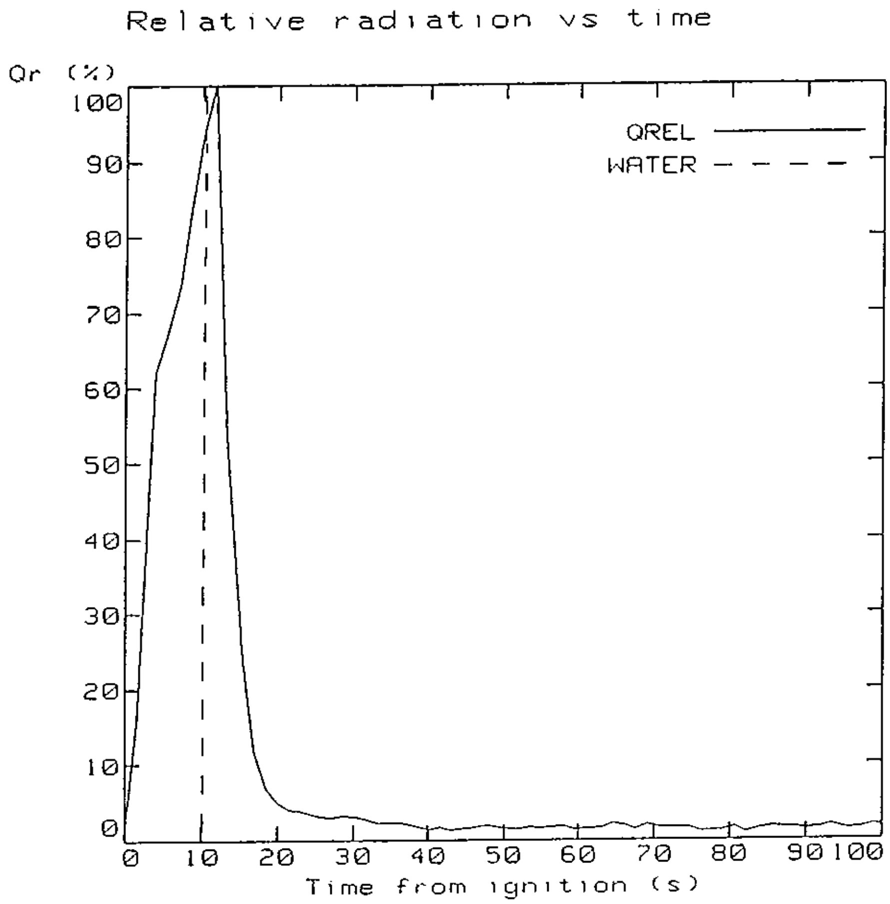

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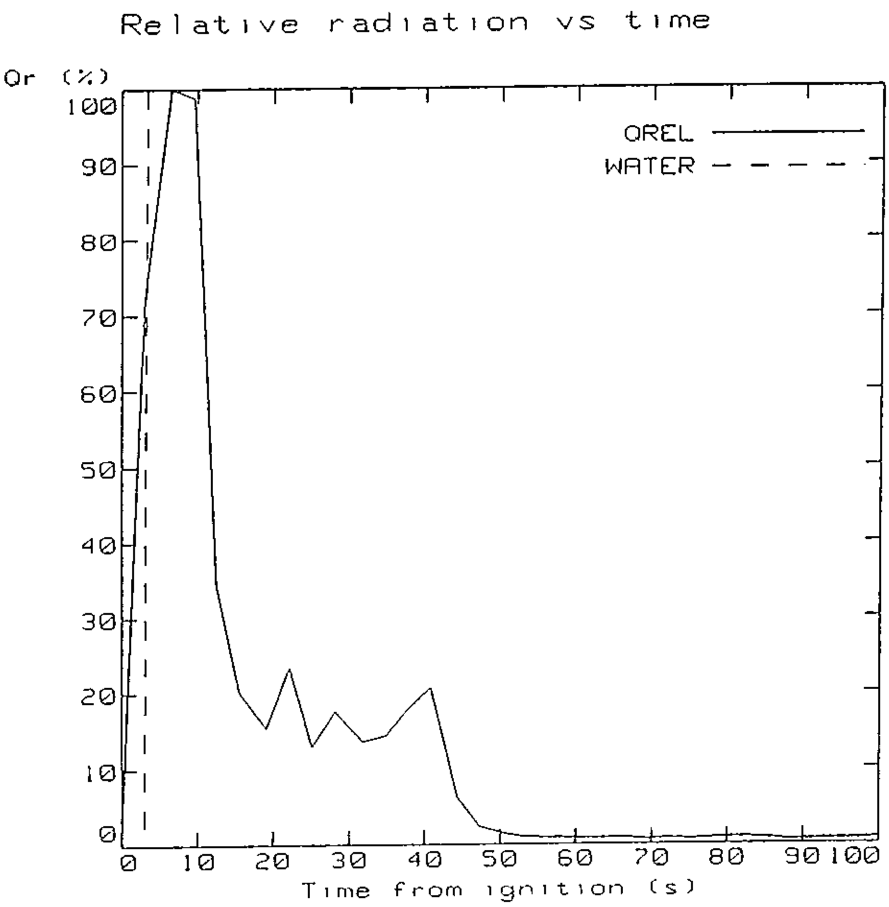

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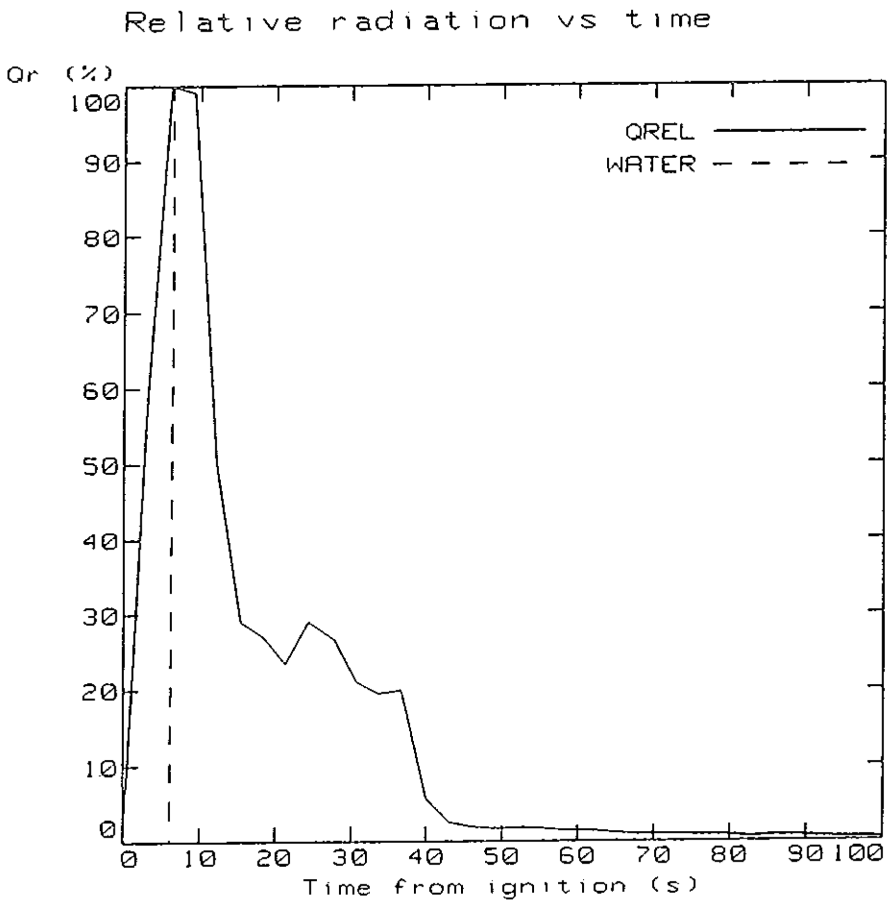

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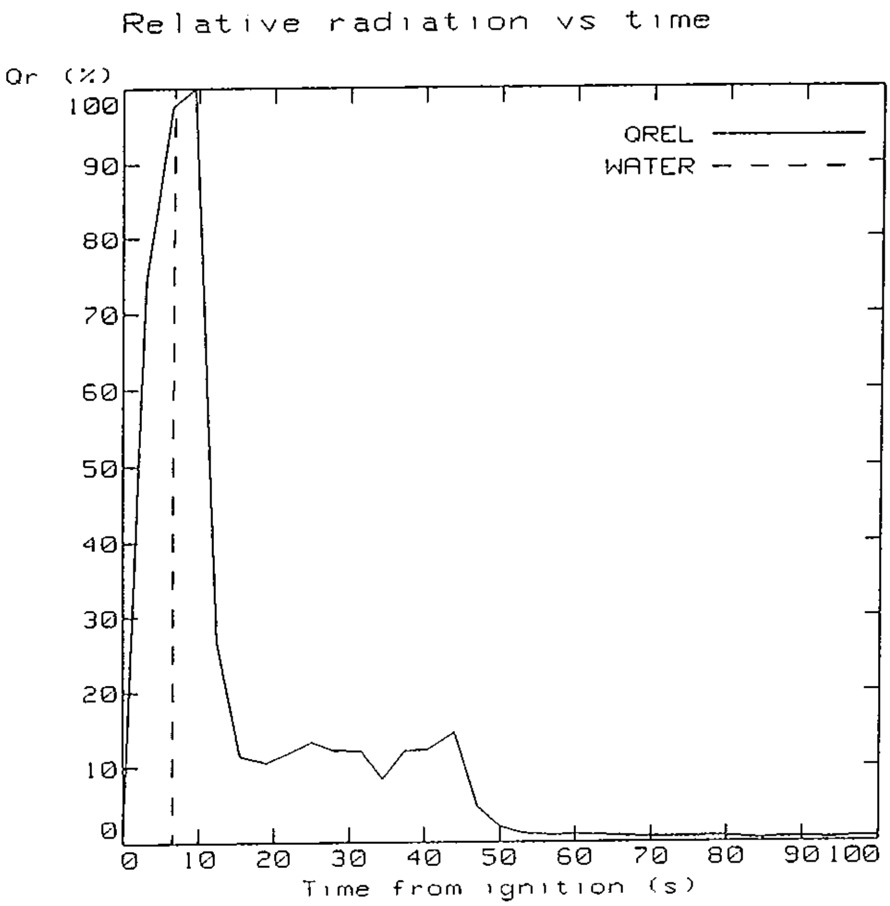

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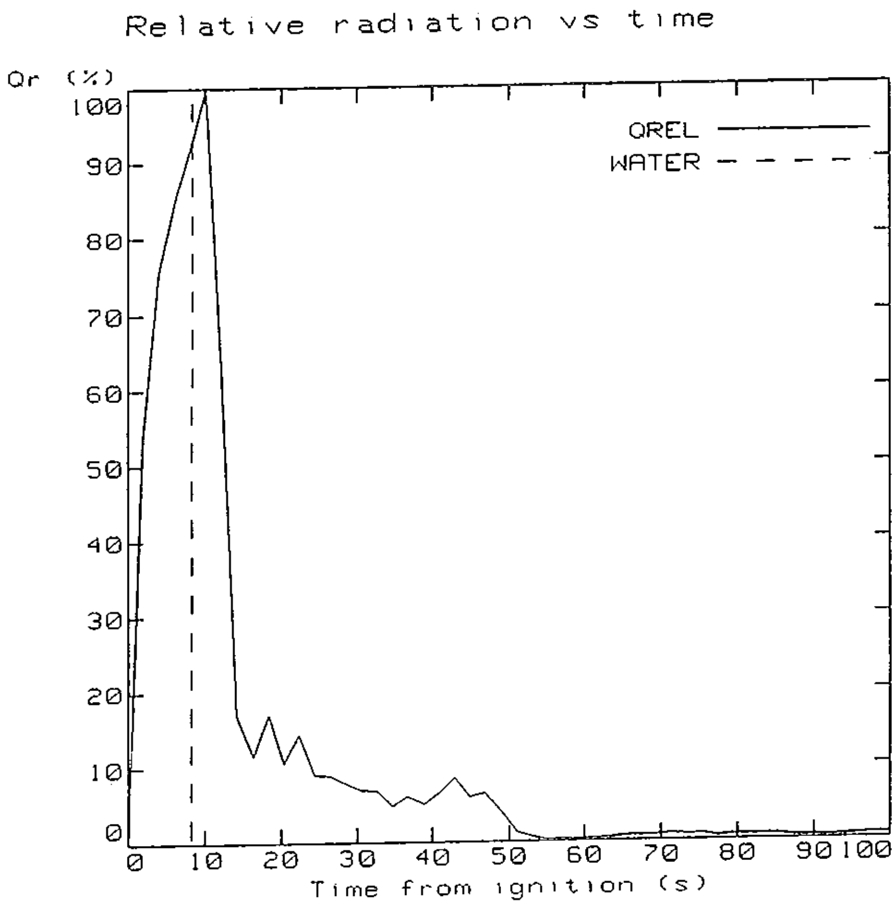

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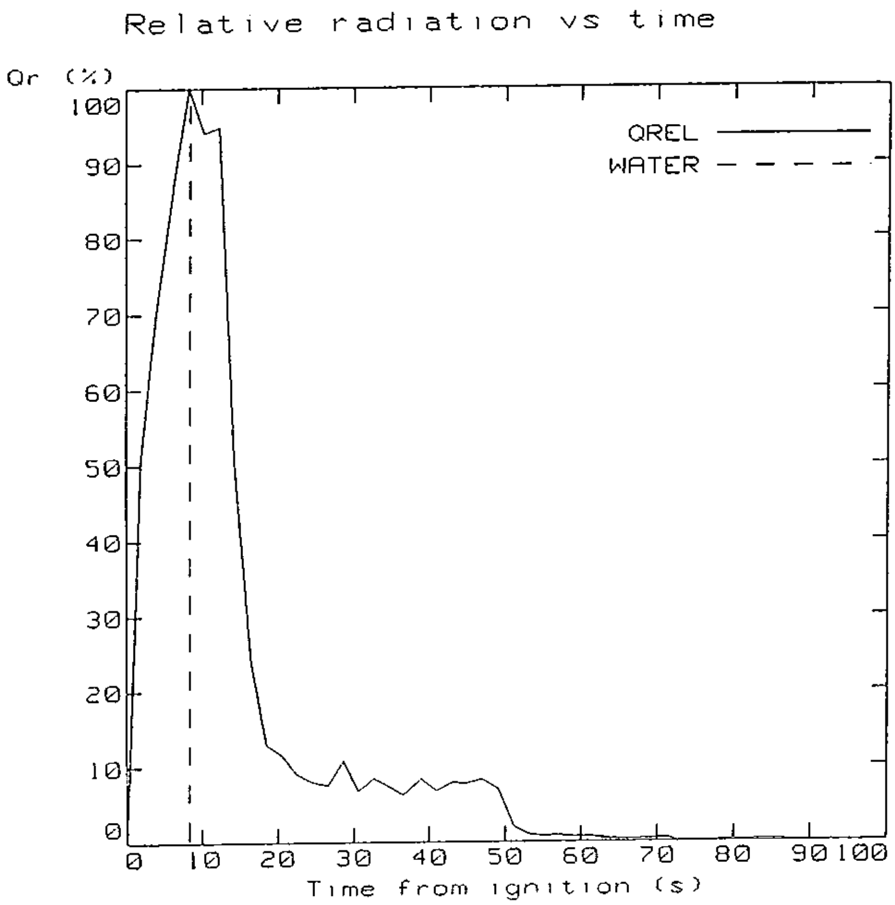

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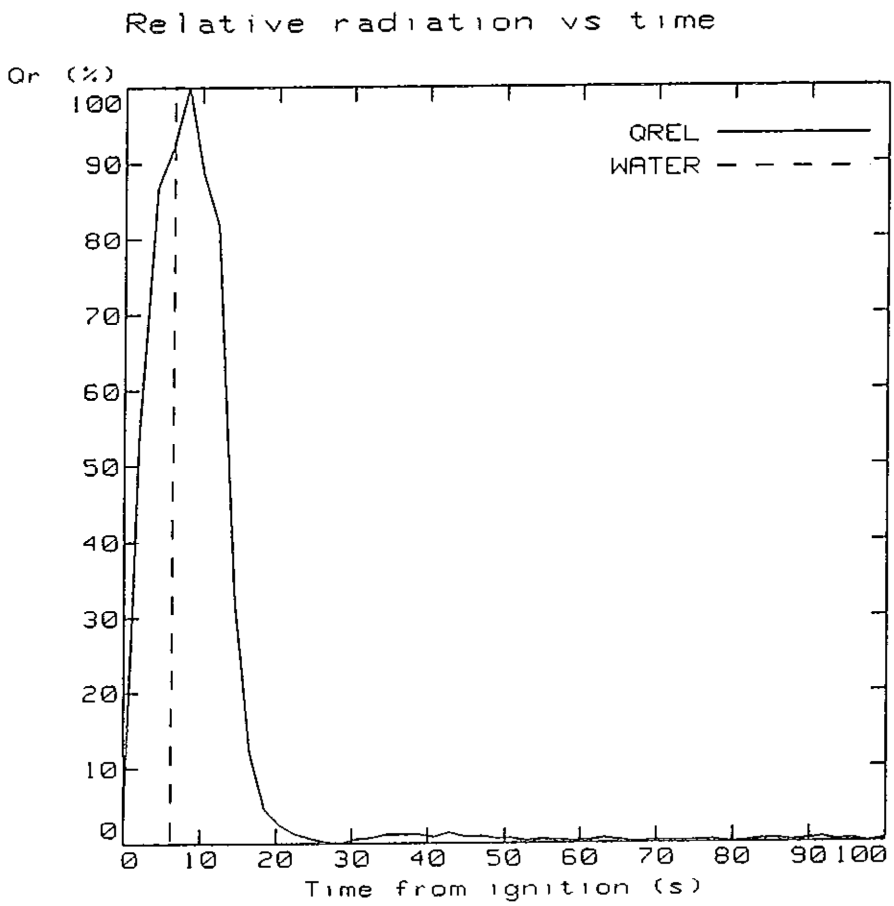

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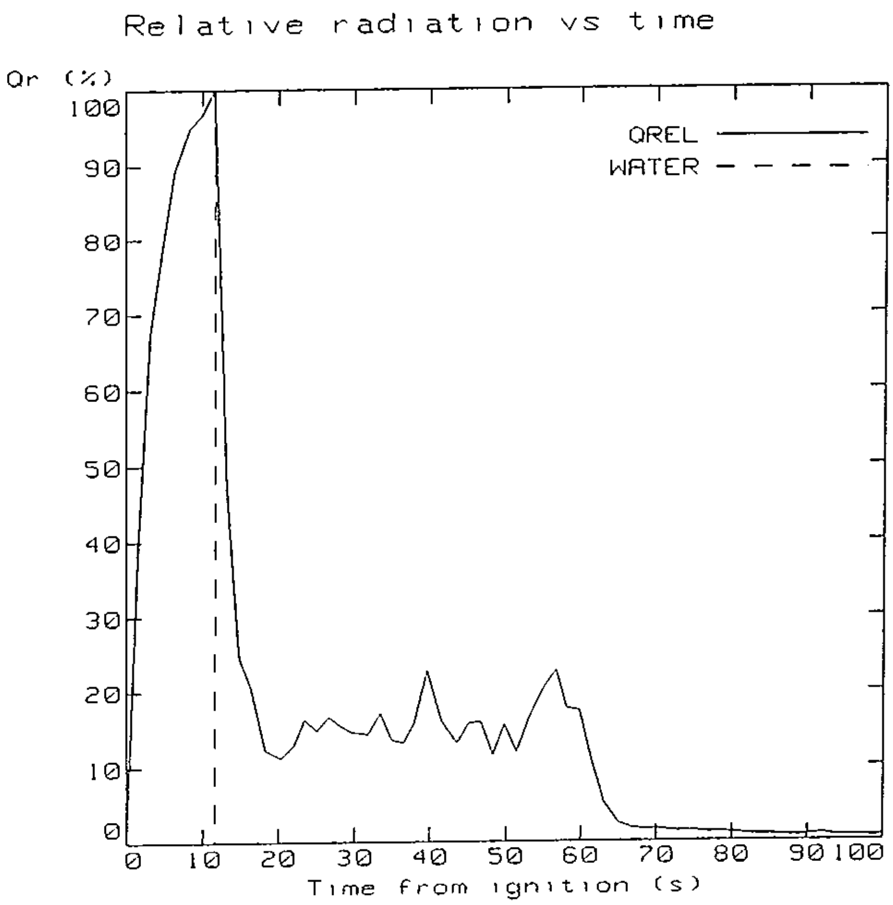
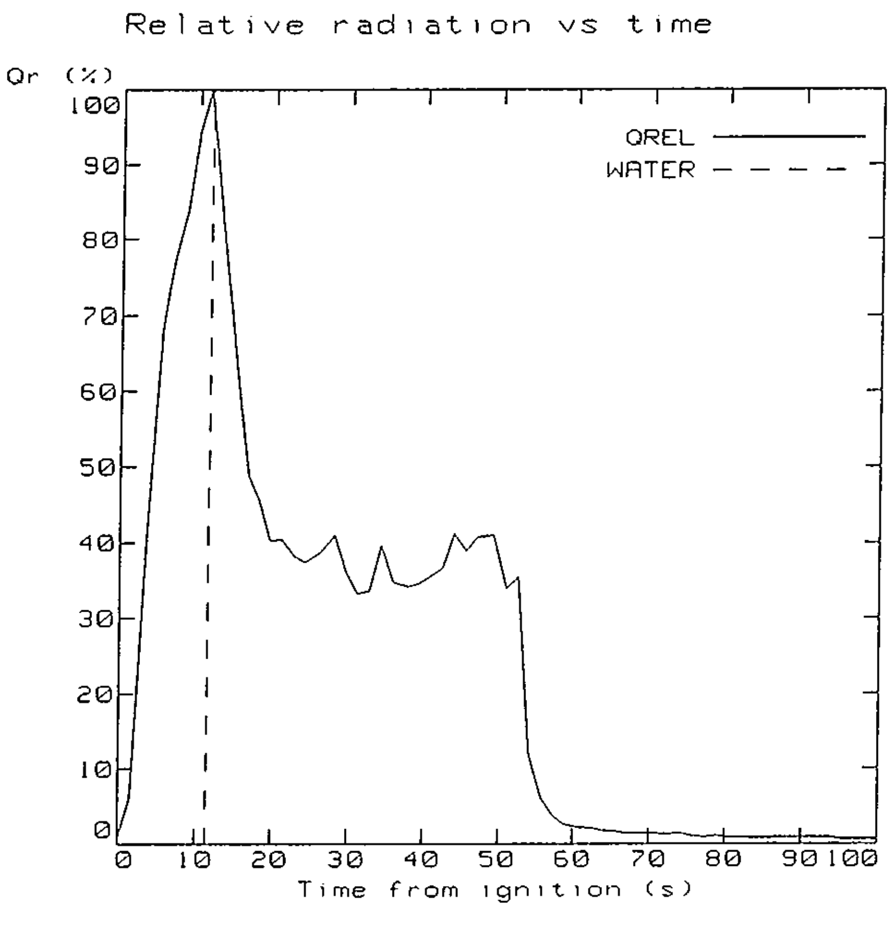


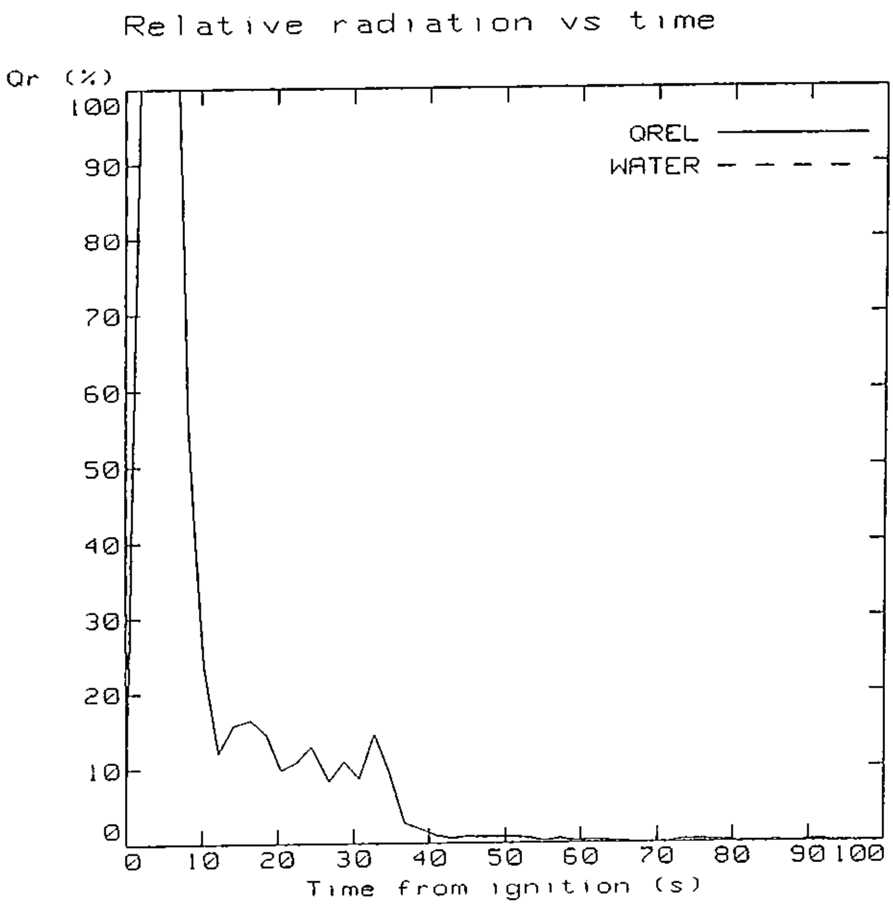
Water was applied at the time where the dashed line intercepts the time-axis

(OILB021 header only for internal reference)



Water was applied at the time where the dashed line intercepts the time-axis

(OILB09 header only for internal reference)



Water was applied at the time where the dashed line intercepts the time-axis

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