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Remote Sensing of Oil Spills

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REMOTE SENSING OF OIL SPILLS

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ABSTRACT

The Canadian federal government, working together with agencies of other governments, is conducting a number of programs related to detection and clean-up of oil spills in the environment.

In both the environmental assessment and clean-up aspects remote sensing technology provides a vital input. This report discusses the state-of-the-art in the remote detection of oil spills specifically in terms of Canadian experience and needs. Three basic types of sensor "packages" are discussed. These are: passive imagery techniques operating in the visible range of the spectrum, microwave systems and active or specialized techniques. Each of these three categories has certain advantages and disadvantages. For example, simple aerial photography or airborne multispectral scanner systems, operating in the visible range of the spectrum, are limited by meteorological conditions and to daytime operation.

Requirements of quasi-operational airborne systems include all weather capability which can be accommodated by microwave systems. Microwave systems can also be used for night-time surveillance and, under certain conditions, for estimating the thickness of oil. The third category covers instrumentation such as active laser line scanner systems (useful for night operations) and laser fluorosensors which may provide means of identification of the type of oil as well as distinguishing between oil and chemical effluents.

RESUME

Le gouvernement fédéral du Canada réalise en collaboration avec d'autres organismes gouvernementaux un certain nombre de programmes concernant le repérage de déversements de pétrole dans l'environnement et le nettoyage des lieux affectés.

La technologie de la télédétection joue un rôle important dans l'évaluation environnementale et les mesures de dépollution. Le rapport traite de l'état actuel des connaissances dans le domaine de la télédétection des déversements de pétrole, plus particulièrement en ce qui concerne l'expérience et les exigences du Canada. On y parle de trois principaux genres de détecteurs: les méthodes de détection passives par images limitées à la partie visible du spectre, les systèmes à micro-ondes et les méthodes actives ou spécialisées. Chacune de ces trois catégories présente certains avantages et certains inconvénients. Par exemple, la simple photographie aérienne ou les systèmes de balayage multi-spectraux aéroportés, fonctionnant dans la partie visible du spectre, sont limités à une utilisation diurne, dans de bonnes conditions météorologiques.

Les systèmes quasi-opérationnels aéroportés doivent pouvoir servir par tout temps, ce qui est le cas des systèmes à micro-ondes. Ces derniers peuvent également servir à la surveillance nocturne et, dans certaines conditions, à évaluer l'épaisseur de la nappe de pétrole. Dans la troisième catégorie entrent les systèmes de détection active fondés sur le laser (utiles pour les opérations de nuit) et les fluoridétecteurs laser qui peuvent identifier le genre de produit pétrolier et même faire la distinction entre le pétrole et effluents chimiques.

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1. INTRODUCTION

The object of this paper is to review the present state-of-the-art regarding the application of remote sensing technology to the problem of oil spills in an aqueous environment.

There are three principal aspects in this regard to which remote sensing technology may be applied, namely, the detection of an oil spill prior to detection by any other means, the monitoring of an oil spill to assist in clean-up operations, and the identification of oil and/or type of oil for legal prosecution purposes.

The first two of these aspects are certainly within the realities of present technology. The third aspect, the positive identification, is not possible at the present time, at least in a definitive sense that would stand up in a court of law. However, there are a number of promising techniques which may soon make remote identification a reality.

Essentially, remote sensing can be considered as the observation of changes in the electromagnetic spectrum due to the properties of the surface under observation. The source of electromagnetic energy may be due to natural sources such as sunlight, thermal and microwave emission or artificially generated by active systems, such as optical lasers, microwaves and radar. The presence of oil on the surface of water has certain characteristic effects on the electromagnetic energy incident upon it which permits its detection against the ambient background. The range of remote sensing techniques is dependent upon the portion of the electromagnetic spectrum under consideration (see Figure 1) as well as specific system requirements, such as all weather operational capability. In general, sensors operating in the visible portion of the spectrum (i.e. photographic sensors or multispectral scanners) are limited to daylight usage and are restricted by meteorological conditions. Microwave and radar systems permit 24-hour operation as well as all weather capability. Other systems such as optical laser scanners, thermal infrared line scanners and low light level television also permit night operations.

Each of the above systems has its advantages and disadvantages. The report discusses in some detail the principal systems which can be used at the present time. Where applicable, examples of recent results are mentioned. In particular, attention is drawn to Canadian work and experience in the remote detection of oil spills.

The final section of the report contains conclusions and recommendations concerning Canadian needs for the application of remote sensing technology to the detection of oil spills.

2. REMOTE SENSING SYSTEMS

2.1. Multiband and Multispectral Systems

Multiband or multispectral systems essentially monitor the electro-magnetic spectrum in descrete spectral intervals. The spectral intervals may be defined by photographic fim/filter techniques, such as used in aerial camera systems (Kodak 1968), or by spectroscopic techniques utilized in optical-mechanical scanners.

The general application of optical-mechanical scanners is similar to that of multiband photography. However, the optical-mechanical scanner has the advantage that information is provided in the form of electrical signals which may be recorded and subjected to computer analysis. This type of system is readily adaptable to automated data processing. Multispectral scanners have greater spatial and spectral resolution than can be obtained with multiband photographic systems. Multispectral scanners also span a broader range of wavelenghts than is possible with camera systems. Their range extends from U.V. to the thermal infrared wavelenghts. In the case of oil detection, the results obtained with these scanners, at least in the wavelenght region where the two techniques overlap, are similar to those obtained by photographic techniques.

There has been a great deal of work conducted on the application of multispectral techniques during both controlled and accidental oil spills. The following section is a summary of principal and consistent findings by a number of authors. There is a general consensus that the most useful wavelenght region for delineating oil on water is the U.V.. The fact is borne out by both multiband photography and multispectral scanners (Estes and Senger 1972). This is due primarily to the fact that upwelling light from below the surface is a maximum in the wave-lenght range 500-550 nm, depending on the particular water body. Thus, at shorter wavelenghts this upwelling component will be small compared to the light reflected from the surface of the oil, which, due to its larger index of refraction, has a higher reflectance than water. Similarly wavelenghts greater than 700 nm should also yield better oil/water contrast than the blue-green range (450-550 nm). Millard and Arvesen (1971) found the best contrasts below 400 nm and above 600 nm. The higher contrasts observed at the longer wavelenghts are somewhat in disagreement with other observations (Estes and Senger 1972) particularly form multiband photography. Multispectral scanner observations carried out by Horwath & Stewart (1971) over a controlled oil spill identified the band 360-380 nm as giving the best delineation of the oil slick.

In relatively recent Canadian experience, Thomson and McColl (1973) have reported that panchromatic film with a blue filter peaked at 400 nm (Wratten 39) gave the best oil/water contrast. On a controlled spill in the St. Lawrence River, Harrison (1972) obtained similar results.

It is a general consensus that oil/water contrast is enhanced under overcast sky condition (Welch 1968, Millard & Arvesen 1971). This is due to the predominance of blue light in the diffuse solar spectrum which forms a relatively large proportion of the total intensity under cloud conditions. Further enhancement may be obtained by utilizing polarisation techniques (Millard & Arvesen 1971). Some attempts have been made to estimate oil thickness using multiband and multispectral data. Munday (1971) claimed that colour photography could be used to estimate oil thickness; however, the majority of researchers do not find this method to be of significant value (Estes and Senger 1972).

Multiband and multispectral systems operating in the visible region of the spectrum are limited to daytime use. Even with full moonlight, the intensity is about six orders of magnitude below that of daylight. Night time photography could be achieved with a light source such as a high power xenon flashlamp or a pulsed laser with a beam diffuser to illuminate a sufficiently large spot. However, recent advances in low light level television systems and laser line scanners make these systems more appropriate than photographic techniques, for night surveillance. In particular low light level television has proved to be a most useful sensor for oil detection. These instruments may be used at night or under poor lighting conditions. The television monitor provides a real time data display which can be used to observe surface slicks or assist in navigation. The output of such devices can be stored on video tape and played back at a later time. The principal range of application of these instruments is in the U.V. and visible spectrum (Ketchel and Edgerton, 1973).

2.2 Thermal Infrared Scanners

All natural objects emit electro-magnetic radiation. The characteristics of this emitted radiation are a function of the temperature and emissivity of the emitting body. In the normal range of environmental temperatures (273-300^{o}K) peak emission occurs at infrared wavelenghts in order of 10 μm.

Thermal infrared instruments are used to detect this radiation and can measure the temperature of the emitting surface. Many multispectral scanners include a 10-12 μm band for thermal infrared detection.

In a number of cases thermal infrared line scanners have successfully detected oil on water. In general the oil appears to have colder radiometric temperature. This is due primarily to the emissivity difference between oil and water. For example, at 10 μm the emissivity of water is 0.993 and that of oil 0.972 (Buttner and Kern 1965). Thomson and McColl (1972) found oil to appear colder than the surrounding water during an infrared survey at Chedabucto Bay oil spill. Isothermal conditions in the bay in the well-mixed water conditions precluded real temperature differences between the sea water and the oil. Similar findings were observed during the Santa Barbara oil spill (Chandler 1970). It should also be noted that the best delineation by these instruments of an oil slick will occure when there is a significant temperature difference between the oil and the water, a condition that is only likely to persist close to the course of the slick (Thomson and McColl 1972).

As a surveillance instrument the infrared line scanner has the advantage that it can operate during the night or day and has real time data acquisition capability. However, it is limited to clear weather conditions.

2.3 Microwave and Radar Systems

The optical oil detection techniques as discussed in the previous section are severely limited to daytime and fair weather conditions. Radar and microwave systems offer the distinct advantage of 24-hour all weather operation, a capability which is of fundamental importance for any environmental surveillance system.

The microwave radiometers that have been investigated for their application to oil detection have mainly been passive systems. That is, they measure radiometrically the emission from the oil against the background emission from the surrounding water. In an active system the radiometer emits its own radiation and one sudies the effect of the environment on the emitted radiation by monitoring the backscattered component.

The microwave characteristics of oil on water have been well documented by a number of workers active in the problems of remote oil detection (Edgerton et al. 1970, Meeks et al. 1971, Hollinger et al. 1973). The total power detected by a microwave radiometer is often expressed as a brightness temperature, T_B; that is, the temperature of a black body filling the antenna beam, for which the brightness of thermal radiation would equal that actually observed.

The microwave radiation reaching a radiometer is composed of several components. These are: the emitted radiation from the sea surface, a component due to sky radiation reflected by water surface, and the emission and attenuation along the atmospheric path between the sensor and the surface under observation.

With a calm water surface the microwave sensor is essentially looking out into space and consequently "sees" a low (cold) brightness temperature. Increasing surface roughness reduces this "cold" reflected component and consequently the brightness temperature increases. Due to its low emissivity ($\simeq 0.4$) at microwave frequencies water always appears relatively cold. Oil on water has two main effects. First, as a result of its larger emissivity ($\simeq 1.0$) oil produces positive signals or, in other words, it has a warmer T_B than the water. Second, oil physically reduces the surface roughness which tends to lower the brightness temperature. Although these effects have a complex interaction, it is generally agreed that oil on water does provide a unique microwave signature which can be easily detected (Edgerton et al. 1970).

In considering polarization effects it has been found that the horisontally polarized component gives better definition (Edgerton and Trexler 1970) than the vertical component. The microwave emission is also affected by the oil thickness. As the thickness increases the apparent brightness temperature at first increases and then passes through a series of maxima and minima which are integral multiples of a quarter wavelength in the oil.

By using two or more frequencies, thickness ambiguities introduced by these oscillations may be removed and the oil film thickness determined (Hollinger 1972). Table 1 shows an examble of thickness estimations made during an experimental microwave flight over a controlled spill at Canada Centre for Inland Waters, Burlington, Ontario, March 1973. This experiment was carried out by Spectran Ltd. under contract to the Environmental Emergency Branch, Environment Canada (Caruso and Oister 1973).

Microwave sensors have a further advantage to offer in the oil surveillance problem in that they are insensitive to many of the features that can confuse optical spectral signatures, such as sediment and chlorophyll concentrations. In keeping with the advances made by optical-mechanical scanners, microwave imagers have also been developed (AOSS 1973). This type of instrument provides the much needed ground coverage required for an operational surveillance system.

A considerable effort on the application of radar systems to oil detection has been carried out by or on contract to the United States Coast Guard (Guinard et al. 1970, Pilon et al. 1971).

One of the most important aspects has been the application of SLAR (Side Looking Airborne Radar) for operational systems. The principal of operation of these radar systems is relatively simple. The decrease in surface roughness caused by an oil slick reduces the radar cross section and consequently a slick appears as a non-scattering area. Experiments by a number of workers (Guinard et al. 1970) indicate that due to the surface roughness effect, detection of oil slicks is best at wind speeds greater than about 2 m sec^{-1}. Detection is also a function of the radar frequency and polarization. Work at the Naval Research Laboratories (NRL) has indicated that vertically polarized systems are desirable for oil slick detection (Ketchel and Edgerton 1973).

An operational SLAR for a surveillance system has been described in detail in a recent report (AOSS 1973). The principal function of such a system is to detect ships at distances of several kilometers as well as oil slick detection. One of the most important factors of radar systems is the all weather detection capability. Radar systems are fairly complex and some thought has to be given to the production and rapid analysis of real time data. Most SLAR systems require some form of on-board computer system for the data processing. In the AOSS system, near "real-time" imagery is produced on hard copy film.

2.4 Laser Systems

The function of the systems discussed in preceding sections has been the detection of oil on water. An additional benefit of course is the thickness estimates by microwave systems. There is an important group of instruments, some under development and others which have been tested, based on the detection of fluorescence of oil. This fluorescence may be excited by an active laser system or by natural sunlight. The fluorescence emission provides a spectral signature which may lead to a positive identification of the fluorescent substance.

A laser fluorosensor system consists essentially of a source to excite the target, a telescope and detector to collect and detect the photons emitted during the fluorescence and an optical system to analyse the spectral characteristics of the fluorescent signal. Most systems that have been tested appear to be able to detect oil by its fluorescence signal quite successfully.

O'Neil *et al.* (1973) have developed a fluorosensor with a continuous wave Helium Cadmium laser operating at a wavelenght of 442 nm. Field trials have been conducted from a DC-3 aircraft over a controlled oil spill in the Bahamas. The passage of the laser spot over the oil patches was confirmed by observation of the reflected laser light with a low light level television system in the aircraft. Bright flashes occurred over the thick ropey features of the slick and were correlated with spiked peaks on the chart recording of the fluorescence signal. The sensor was operated successfully at altitudes of between 150 and 300 m and at aircraft speeds of up to 53 m sec^{-1}.

Measures and Bristow (1971) have reported the remote measurement of oil fluorescence spectra which showed that detection and characterisation of oil in a given slick was possible. Their observations showed that over the thickness range 0.3 - 0.5 μm the fluorescent signal increases linearly with oil thickness. The development of this system is being continued by Bristow (1973) at the Canada Centre for Remote Sensing. Recent airborne experiments (July 1974) by Bristow (private communication) over a controlled oil spill at the Canada Centre for Inland Waters have indicated very promising results for this laser system.

One of the most sophisticated systems under development is an integrated detection and identification system (Fantasia and Ingrao 1973). This is a laser fluorosensor combined with a spectrometer. In the detection mode this instrument will sound an alarm once some pre-set background fluorescent signal is surpassed. The system can then scan the spectrum of the observed signal and identify the oil type. Though this system has been test flown, no extensive results are available at the present time.

The Fraunhofer Line Discriminator (Soertz *et al*. 1969) is an optical instrument for remote detection of substances that fluoresce when irradiated by sunlight. This instrument is a passive system which separates weak fluorescence and bright reflected sunlight. It is not, however, an imaging device, and is limited to daytime use.

While oil may certainly be detected by its fluorescence the unique identification of oil or oil type by the fluorescent spectrum is not easily carried out. The fluorescence spectrum is complex and depends upon a number of factors. For example, it depends upon excitation wavelength and temperature. Oil is composed of complex hydrocarbons and as a result has a complex fluorescent spectrum which can differ from sample to sample (Fantasia *et al*. 1971).

While monitoring of the characteristic fluorescence spectrum is one of the most promising approaches to unique identification of oil, more research into the fluorescence mechanism and the spectral characteristics of oil needs to be carried out.

Some recent work by Measures at the University of Toronto Aerospace Institute (private communication) on the time delay of fluorescence has indicated that the time delay is wavelenght and species dependent. These time delays are in the order of 10^{-6} - 10^{-8} seconds and can be easily measured. Remote measurement of these time delays may provide some specificity for species identification then the fluorescence spectrum itself.

2.5 Satellite Systems

The remote sensing instrumentation described in the previous sections has mainly referred to airborne systems. Most of these systems or at least a modification of the system can be flown as a satellite package. Satellite altitudes provide a means of monitoring large coastal or remote areas for slick detection. Though the presence of slicks has been detected by Strumpf and Strong (1974) on ERTS-1 imagery, the authors were not able to definitively identify the slick as being due to oil.

3. CONCLUSION

In its simplest form the basic criteria for remote sensing oil spill surveillance system are real time data display, all weather capability and day or night operation. The ultimate system must be able to detect and identify the oil and/or species of oil.

In the present generation of sensors some satisfy most of the basic criteria while others are more limited (see Figure 2). For example, microwave and radar sensors are the only group that provide all weather operation. To some extent, the availability of real time data can be a problem with this family of sensors. However, their fundamental disadvantage is that they do not positively identify oil. Sensors restricted to the visible range are generally limited by weather and to daytime operation. The addition of active light sources (i.e. lasers) helps to overcome these deficiencies. At the present time the fluorescent and Raman spectral properties of oil provide the best avenues of research towards definitive identification of oil.

Any surveillance system must, therefore, consist of all or some reasonable combination of the sensors in order to maximize its operational capability.

Finally, remote sensing is the most economical method of surveying large geographical areas for spills, detecting sources of spills and predicting slick movements. Remote surveillance can help in the assignment of hazard priority, assessment of damages and later assessment of the efficiency of clean-up operations and residual damage. Detection of oil is possible with a variety of sensors operating in various regions of the electromagnetic spectrum. Oil/background contrast is a result of relative differences in absorption, scattering, reflectivity, emissivity, conductivity and dielectric constants. Surveillance of oil slicks for aerial extent, direction and speed of movement and prediction of slick behaviour is within the present range of available remote sensing instruments.

RECOMMENDATIONS

A list of significant oil spills in Canada over the last two years is presented in Table 2. The final addition on the list was the accident on the St. Lawrence River when the SS IMPERIAL SARNIA ran aground with a cargo of 4300 barrels of western crude oil on April 15, 1974. This incident and the resulting clean-up operation cost an estimated $300,000. During this spill some high altitude photography was obtained as a result of co-operation at the working level between Canada Centre for Inland Waters and the Canada Centre for Remote Sensing. In the light of the history of past oil spills and the unlikely probability that no more oil spills will occur in Canada, it is important to consider the present facilities in Canada for remote surveillance of oil spills.

At the present time there is no dedicated or even a readily available remote sensing aircraft system for oil spill emergencies in Canada. At various times the Canadian Armed Forces and the Canada Centre for Remote Sensing have provided assistance. However, in view of the fact that Canada is a major oil producing country, some organization of a suitable remote sensing surveillance system appears to be a primary necessity.

For efficient use of resources, such a surveillance system could be operated in co-operation with other agencies. For example, the U.S. Coast Guard plans to use a multi-sensor aerial surveillance system for several types of missions; namely, search and rescue, ice patrol, fisheries surveillance, flood and hurricane assessment, and border patrol. Canada's proposed LRPA (long range patrol aircraft) will be equipped with complex surveillance instrumentation such as side-looking radar and inertial navigation systems, and will be able to monitor Canada's coastal waters which are amongst the high risk pollution areas. It is strongly recommended that their complement of sensors include some reasonable combination of sensors suitable for oil spill detection, monitoring and identification.

In Canada's inland waters an operational airborne surveillance patrol, with a particular emphasis on shipping, is conducted by the Ministry of Transport. This airborne patrol covers the general area from Lake Erie to Newfoundland. However, the system is limited in its effectiveness in that the aircraft concerned does not, at the present time, carry sophisticated remote sensing instrumentation. The heavy ship traffic in the Great Lakes and their connecting channels present a constant hazard for spills in Canada's inland waters. As well as the threat from accidents it is believed that slicks, which are frequently observed in the eastern end of Lake Ontario are due to oily ballast water dumped by ships. It is therefore vital that state-of-the-art remote sensing instrumentation be integrated into any Great Lakes pollution surveillance patrol aircraft.

Canada should continue to have a national co-ordinator for remote sensing of oil spills, whose responsibility will be to continue to make recommendations on remote sensing instrumentation, to obtain coverage of every important spill, to use both accidental and controlled spills for the testing of instruments for research and development purposes, and to foster international co-operation through participation in conferences and meetings with officials having similar responsibilities in other countries.

The question of the amount of oil spilled, as distinct from the areal extent of oil contamination, is expected to be one of great legal and financial significance. Research and development should, therefore, be directed towards testing of appropriate sensor systems that can measure oil thickness. In particular, the development and research into microwave systems would appear to be an important area for Canadian research. The other important research thrust identified in this paper is development of remote sensing systems that can identify oil by its spectral signature such as the fluorescence systems described in a preceding section.

An early detection and warning system should be implemented, especially in both high risk and remote areas. This system should involve periodic overflights and monitoring with appropriate sensors at reasonably high altitudes. The data from such a system must be correlated with surface and environmental data, such as waveheight, air and water temperatures, water quality, wind speed, cloud cover, currents and surface ice or ground temperature. Finally a remote sensing surveillance system must be able to identify the direction and rate of movement of the oil. These parameters are of vital importance in the planning and execution of clean-up operations.

Table 1

THICKNESS MEASUREMENT OF OIL SPILLS

gallons of oil spilled	thickness measurement	actual thickness
38	0.55 mm	0.30 - 0.40 mm
38 (wind action)	11 mm	8 - 10 mm
388	.8 mm	.7 mm

It should be noted that the thickness calculation based on the radiometric signals are estimations only. Because of the relatively small oil slick areas that were sensed, a sustained and easily measurable temperature signal was not possible.

Table 2

SOME RECENT OIL SPILLS IN CANADA

DATE	LOCATION	AMOUNT AND TYPE
May 11-17, 1972	Resolute, N.W.T.	15,000 - 30,000 gal. aviation fuel
June 5, 1972	Sarnia, Ontario. Sinking of SYDNEY SMITH	49,000 gal. Bunker C 2,000 gal. diesel fuel.
August 1972	McKenzie River, Inuvik, N.W.T.	38,000 gal. diesel fuel.
September 1972	Nipisi Oil Field, Alberta. Rupture in Peace River pipeline.	est. as 100,000 bbls. (3,500,000 gal.)
December 12, 1972	Swan Hills, N.W.T. Rupture in pipeline.	52,500 gal.
December 1972	Thunder Bay, Ontario. CPR locomotive fueling facilities.	fuel oil. Unknown quantity spilled, but 35,000 gal. recovered.
January 25, 1973	Broughton Strait, B.C. Vessel IRISH STARDUST grounded.	(450 tons) 112,500 gal. heavy diesel fuel oil
February 4, 1973	Clappison Corners, Waterdown, Ontario. Canadian pipeline fracture.	1,000 bbls. diesel and stove fuel
March 5, 1973	Virginia, Ontario. Gulf oil tanker truck ran off road.	11,000 gal.
April 11, 1973	Papineauville, Quebec. Semi-trailer truck collided with CPR tanker/freight train.	34,000 gal. Bunker C, 100 tons caustic soda.
April 18, 1973	Eureka, N.W.T. Fractured fuel storage bladder.	30,000 gal. J.P.1 fuel.

DATE	LOCATION	AMOUNT AND TYPE
June 18, 1973	Confluence of LaBiche and Liard Rivers, B.C. Flood washed out tank farm.	13,000 gal. diesel fuel.
June 20, 1973	Orillia, Ontario. CNR train derailment.	12,500 gal. fuel oil.
June 22, 1973	Pocahontas, Alberta. Fracture Transmountain Oil Pipeline Co.	35,000 gal. Alberta crude oil.
June 30, 1973	Arvik Mine, Little Cornwallis Is., N.W.T. Leak from bladder farm.	40,000 gal. Arctic diesel oil
July 17, 1973	Near Clinton, B.C. Fracture to Western Pacific Products and Crude Oil Pipeline Ltd.	80,000 gal. B.C. crude oil.
July 24, 1973	Horners Creek, Brant Twp., Ontario. Fracture Sarnia Products Pipeline.	500-550 bbls. (17,500-19,250 gal.) turbo fuel.
August 4, 1973	5 miles S. of Camrose, Alberta. Gulf Canada Ltd. pipeline fracture.	7,000 bbls. (245,000 gal.) crude oil.
August 17, 1973	IPPL Mile 103, 5 miles W. of Hardisty, Alberta. Pipeline damage.	4,000 bbls. (140,000 gal.) crude oil
September 25, 1973	Vancouver Harbour entrance, B.C. Collision of MV SUN DIAMOND and MV ERAWAN.	36,000 gal. bunker C and diesel
April 15, 1974	Belleville, Ontario. SS IMPERIAL SARNIA ran aground.	2,143 bbls (75,000 gal.) crude oil. Oil/water recovered 200,000 gal.

SENSOR CAPABILITIES & SURVEILLANCE REQUIREMENTS

Sensor			Real Time Viewing	Day / Night	All Weather	Approx. Spatial Resolution (mrad)	Ease of Rectification	Large Area Coverage	Detection	Area Mapping	Coverage	Oil Type Identification	Thickness	Rate of Movement
ULTRAVIOLET		CAMERA	X	D	HFCR	0.01 to 0.1	1	X	G	G	F	X	*	S
		SCANNER	✓	D	HFCR		3	X	FG	FG	P	X	*	
		VIDEO	✓	D	HFCR		2	X	G	G	P	X	*	
VISIBLE	CAMERA OR SCANNER	0.40 - 0.50 μm	X	D	HFCR	0.001 to 0.01	1/3	X	FG	FG	F	X	X	S
		0.50 - 0.58	X	D	FCR		1/3	X	F	F	P	X	X	
		0.58 - 0.62	X	D	FCR		1/3	X	P	P	P	X	X	
		0.62 - 0.70	X	D	FCR		1/3	X	P	P	P	X	X	
	CAMERA	COLOR	X	D	HFCR		1	X	F	F	P	X	X	
		COLOR INFRARED	X	D	FCR		1	X	FG	FG	P	X	X	
		POLARIZED	X	D	HFCR		1	X	G	G	P	X	X	
		VIDEO COLOR	✓	D	HFCR	>0.01	2	X	FG	FG	P	X	X	
INFRARED		3.5 - 5.5 μm	✓	DN	FCR	1.0	3	X	FG	FG	P	X	*	S
		8 - 14 μm	✓	DN	FCR		3	X	G	G	P	X	*	
PASSIVE MICROWAVE		RADIOMETER	✓	DN	R	-	-	X	G	F	P	X	*	S
		SCANNER	✓	DN	R	10.0	4	X	G	F	P	X	*	
RADAR		X BAND	*	DN	A	10.0	3	✓	P (H), F (V)	P (H), G (V)	P	X	*	S
		C "	*	DN	A		3	✓	P (H), P (V)	P (H), P (V)	P	X	*	
		P "	*	DN	A		3	✓	P (H), F (V)	P (H), G (V)	P	X	*	
		L "	*	DN	A		3	✓	P (H), F (V)	P (H), G (V)	P	X	*	

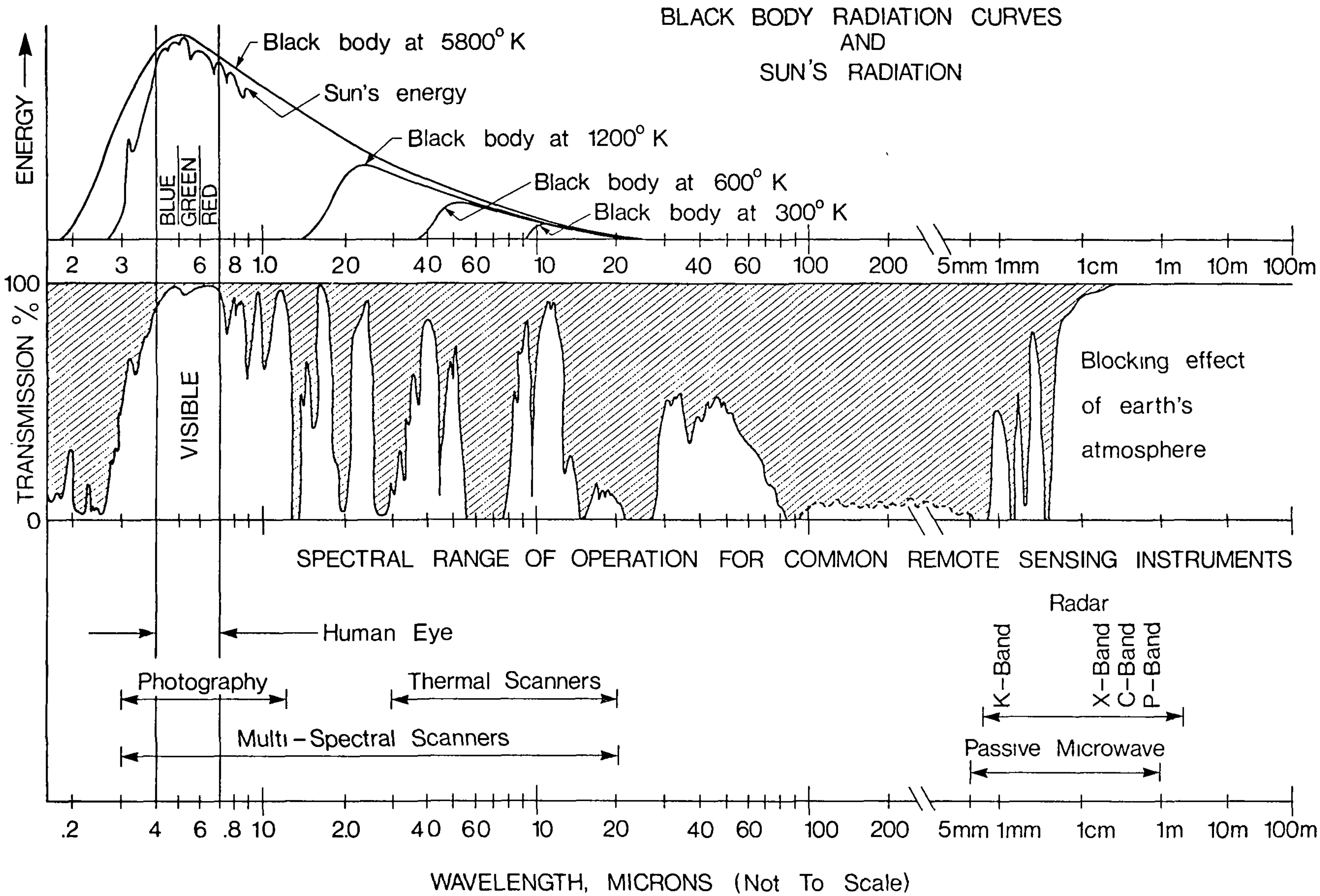
X - NO ✓ - YES
A - ALL WEATHER
D - DAY ONLY
DN - DAY & NIGHT
F - FAIR

* - POTENTIAL FOR DEVELOPM'T
G - GOOD
P - POOR
H - HORIZONTAL POLARIZATION
V - VERTICAL POLARIZATION

FCR - LIMITED BY FOG, RAIN & CLOUD
HFCR - " " " " CLOUD & HAIL
R - " " RAIN
1-4 - RELATIVE EASE OF RECTIFICATION
S - PROVIDED BY SEQUENTIAL COVERAGE

FIGURE 2.

FIGURE 1


BLACK BODY RADIATION CURVES AND SUN'S RADIATION
Black body at 5800° K
Sun's energy
Black body at 1200° K
Black body at 600° K
Black body at 300° K
ENERGY
BLUE
GREEN
RED
2 3 6 8 1.0 20 40 60 10 20 40 60 100 200 5mm 1mm 1cm 1m 10m 100m
100
0
TRANSMISSION %
VISIBLE
Blocking effect of earth's atmosphere
SPECTRAL RANGE OF OPERATION FOR COMMON REMOTE SENSING INSTRUMENTS
Human Eye
Photography
Thermal Scanners
Multi-Spectral Scanners
Radar
K-Band
X-Band
C-Band
P-Band
Passive Microwave
.2 4 6 .8 10 2.0 40 60 10 20 40 60 100 200 5mm 1mm 1cm 1m 10m 100m
WAVELENGTH, MICRONS (Not To Scale)

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