$$\tau \times F = \rho C_{10} V^2 F$$
$$= (1.2 \times 10^{-3} \text{gm./cm.}^3) \times (2.6 \times 10^{-3})$$
$$\times (2 \times 10^3 \text{cm./s.})^2 \times (2 \times 10^6 \text{cm.})$$
$$= 25 \times 10^6 \text{ dyne/cm.} = 25 \text{ kg./cm.}$$

If a vessel the size of the *Manhattan*, of length $L = 300$ m. long, has a coefficient of friction $K = 0.15$ between steel and ice,[3] then the retarding friction on two sides of the ship would be

$$\tau F \times 2L \times K = 25 \text{ kg./cm.} \times 2 \times 3 \times 10^4 \text{cm.}$$
$$\times 0.15 = 22.8 \times 10^4 \text{ kg.}$$
$$= 0.50 \times 10^6 \text{ lb.}$$

This friction must be overcome by the thrust from a ship's propellors. Several slightly different formulas are in use, and Barnaby[4] (p. 296) gives

$$T = 221.4\ (K_t/K_Q^{2/3}) \times (P \times D)^{2/3}$$

Again taking *Manhattan* as an example, with $P = 43{,}000$ horsepower and propellors of diameter $D = 22$ feet, and assuming a typical value of $(K_t/K_Q^{2/3}) = 3.0$ from a range of 2.9 to 3.1 in four examples given by Barnaby[4] (Table 32A), the available thrust is approximately 0.65×10^6 lb. This would be just adequate to operate in the conditions assumed in the previous paragraph, and the presence of ridges or local concentrations of pressure might stop a ship with such a small reserve of thrust.

FRICTION WITH ICE AT BREAKING STRESS

Another means of calculating the pressure exerted by the ice is to note that the ice in a converging field is under enough stress to crush at least in some places. Compressional strengths of sea ice from 18 to 107 kg./cm.^{2} have been reported (Pounder[5], p. 107). A block of ice the size of a ship is bound to contain flaws and faults which decrease its effective strength, so let us assume that the worst case might be $P = 35$ kg./cm.^{2} or 500 psi. In ice $H = 3$ m. thick a 300 m. vessel would experience frictional force of

$$P \times H \times 2L \times K = (35 \text{ kg./cm.}^2) \times (300 \text{ cm.})$$
$$\times 2 \times (3 \times 10^4 \text{ cm.}) \times 0.15$$
$$= 94 \times 10^6 \text{ kg.} = 210 \times 10^6 \text{ lb.}$$

The thrust required would be comparable to the weight of the vessel! If the hull could withstand the tremendous pressures, 300 times the thrust of a typical large ship would be required to overcome friction. Perhaps the strength of ice has been overestimated by as much as a factor of 10, but it remains clear that the power necessary to navigate in ice which is failing in compression would be prohibitive.

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Oil Spills in Ice: Some Cleanup Options

In early June, 1970 a spill of diesel oil and gasoline (reported to be about 367,000 gallons of Arctic diesel fuel and 59,000 gallons of gasoline) occurred in Deception Bay, Quebec (western Hudson Strait) after a slide of snow and water moved through a "tank farm" (Fig. 1) located close to the shore. At the time, a flat expanse of sea ice covered all of the bay and closely spaced blocks of ice existed over most of the intertidal zone. Almost all of the oil was contained by the ice so that we were able eventually to dispose of the spill completely. This was accomplished mainly by burning the oil, either after it had been pumped on to the sea ice or where it was contained by the nearshore ice.

Much of the time at the site (June 12 to 26) was spent in survey of the distribution of oil and with evaluation of possible methods of disposal, or recovery, which included pumping the oil on the sea ice to evaporate. It was ascertained relatively soon that pumping and burning did not present major difficulties, but it was some time before adequate estimates of the distribution of oil were obtained, especially of that oil contained by the ice on the intertidal zone in the slide area. Nearby on the intertidal zone, oil could be seen in the spaces between the blocks of ice there.

The containment provided by the ice is, of course, a unique aspect of the spill and it permitted consideration and application of pumping and burning as methods of disposal. The pumping capacity, although small, was considerably greater than the capacity to

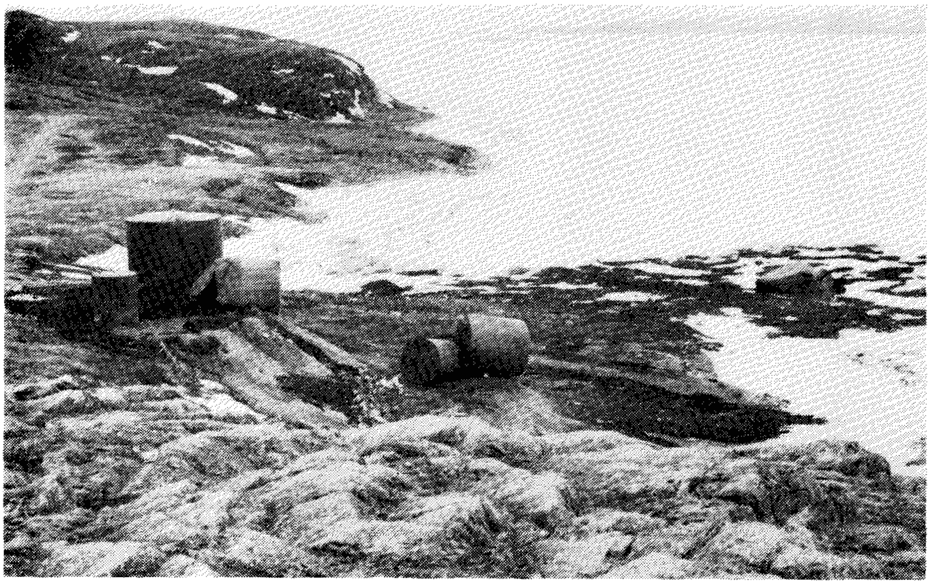

FIG. 1. A photograph of the spill site in which the 6 tanks in the tank farm may be seen. All of the tanks had been at the same level as the 3 on the left and all were damaged; however, the tank on the far left did not spill its contents of gasoline. The tank on the far right, well out on the foreshore, is understood to have been nearly empty at the time of the slide. View to the northwest at about higher high water on 18 June, about 10 days after the slide occurred, but before cleanup.

dispose of the oil ashore, particularly as a significant amount of water is unavoidably pumped with the oil. An attraction of pumping on to the sea ice was that the amount of water pumped would not overload the "system", and hence, it was envisaged that all of the oil might be pumped. As well, disposal by burning would still be possible and at location away from the tank farm where one tank of gasoline still existed and away from the tundra, both of which conceivably could have been set afire. However, the containment was such that the "burns" were generally discrete, both on the intertidal zone and elsewhere, so that we were able to predict the extent of a burn should one be initiated. Eventually each of the larger accumulations had been set afire and finally, by repeated burns, all of the oil was cleaned up.

The cleanup technique, i.e. pumping and burning, relates directly to the character of the oil and we recognize that some oil, if spilled, could neither be pumped nor burned as readily as diesel oil; indeed neither of these operations may be possible. Thus, it may not always be possible to take advantage of the control of spilled oil which can occur in ice covered regions.

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Problems of a Contemporary Arctic Village

There is increasing concern regarding the effects of industrial development on the Canadian and Alaskan north. The problems encountered today by an arctic village may serve to illustrate the fragility of the northern ecosystem, of which the isolated village is still an integral part.

The village of Old Crow is located near the headwaters of the Porcupine River in the north of Yukon Territory at 67°35′N., 139°50′W. Like many remote northern villages the river on which it is located is its lifeline to the outside world, for it is far too expensive for the residents to bring supplies in by air. The location of a village, however, is dependent upon factors other than communication with the outside world, and from several of these aspects the village of Old Crow is well situated. Close by are the Crow Flats. This is an area dotted with numerous small lakes, sloughs and streams which supports a large muskrat population, and which has been a traditional trapping ground for the Vunta Kutchin people of Old Crow. This resource has long formed the backbone of the Old Crow economy, for in a good season