which should include laboratory instrumentation and experimentation, is essential to develop students' judgment about experimental data. Complete interdisciplinary training is perforce much more intense than the traditional single-discipline program, but it should still be manageable within the time normally needed to earn a PhD.

To benefit from this new generation of theoreticians, experimental biologists should also enlist physical scientists in their studies. That collaboration would cover two areas—the development of instrumentation[5] and the interpretation of experimental data. With such interdisciplinary cooperation, great progress can be expected, much like the contribution of the physical sciences to engineering. Naturally, interdisciplinary research requires that results be accessible to a wide audience, so the relevant mathematical research must be published not only in applied math journals but also in journals in other studied fields.

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LETTERS

Low-dose radiation exposure should not be feared

Scientific achievement has a muddled, disordered topography, with landscapes that include both great pinnacles of success and deep crevices of failure. We focus on one failure that remains uncorrected: the linear no-threshold (LNT) model of radiation-induced cancer, on which governments and advisory bodies have based regulatory policy for 70 years. High-dose radiation can cause cancer, but no such correlation has ever unequivocally been shown at low doses in the range of x-ray and computed tomography (CT) examinations or in the vicinity of nuclear power plants.

The proven consequence of high doses of radiation has simply been assumed to apply even at doses near zero, and no threshold has been given below which it is harmless. Consequently, all doses have been predicted to cause cancer. But as many studies prove,[1,2] the body responds differently to radiation at high and low doses: At low doses, the body eliminates the damage through various protective mechanisms that have evolved in humans from eons of living in a world bathed in low dose-rate but sometimes high-dose natural radiation.

Based on the Japanese government's unwarranted fear that any radiation exposure would increase cancer cases, residents were forcibly evacuated from around the Fukushima nuclear plant, a decision that according to the government's own figures resulted in more than 1600 deaths. The Japanese Cabinet recently decided to lift evacuation orders; whether residents will actually return is uncertain due to the radiophobia instilled in them over the past four years. Reliance on the LNT model has resulted in even larger health and economic impacts at Chernobyl. All such devastating consequences of using the LNT model to form policy and standards have prompted three recent petitions to the US Nuclear Regulatory Commission to reject the flawed model, whose origin can be traced to the work of Hermann Muller and colleagues.

Nobelist Muller, a founding proponent of the LNT model, investigated x-ray effects on fruit-fly gene mutations. He claimed in his 1946 Nobel lecture that the mutation rate was a linear function of dose down to zero, independent of dose rate, with no threshold below which there is no effect. Muller based his claim on his testing at doses that are actually high—at least 4000 mGy. For comparison, US natural radiation exposure averages 3 mGy annually, and a typical CT scan is 10 mGy. Thus Muller's extrapolation of harm down to zero dose was untrue.

In 1948–49, research by Muller's colleague Curt Stern[3] found that at doses below 500 mGy, flies often had mutation rates similar to or even lower than unirradiated flies, and these mutation rate differences decreased if the dose rate was reduced. Those findings clearly suggest protective responses and a no-harm threshold somewhere below 500 mGy. Some of the results were inconsistent, but rather than continue testing, the researchers arbitrarily decided that there was no threshold and that dose rate was irrelevant; they thus reinforced Muller's false claim.

Fortunately, those researchers left a trail of published data that does confirm a threshold, contrary to their claim. Apparently, neither they nor any others noticed that result until we recently discovered it.[4]

Muller's and Stern's approaches survive in the LNT model of today, which says that low-dose radiation increases cancer risk. However, while linearity—the "L" in LNT—was demonstrated only at high doses, the absence of a threshold has never been demonstrated. The only scientific conclusion from the data from 1949 through today is that the linear threshold (LT) model, not the LNT, is correct, and it has a low-dose threshold below which radiation is harmless. Even data from atomic-bomb survivors, the gold standard of dose-response data, do not support the LNT model; adaptive protections mitigate radiation-induced damage at low doses and low dose rates. No epidemiological studies have ever demonstrated a causal relationship between low-dose radiation exposure and carcinogenesis.

Many people, though they admit the absence of evidence, nevertheless believe that "precautions" derived from the LNT model save lives. But misguided application of the LNT model to regulation and policy have caused death and psychological damage from unnecessary mass evacuations and have created adverse health consequences from patients' fear-driven rejection of potentially life-saving x rays and CTs. Additionally, hundreds of billions of dollars are wasted on unnecessary precautionary measures due to unwarranted fear of low-dose radiation.

Scientists have failed in the science of radiation protection. The accurate LT model must become the basis of radiation regulation. Science must finally arrive at summary judgment that the LNT model is fallacious and thereby alleviate suffering and abate needless, paralyzing public fear. The LT model's threshold with no low-dose radiation harm can free people from the grip of groundless phobias. No harm, no fear!

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ANSWERS

Celebrating the International Year of Light

by Naomi Pasachoff

from PHYSICS TODAY, December 2015, page 15

1 T	2 A	3 M	4 P	5 A	■	6 M	7 E	8 S	9 O	10 N	■	11 G	12 U	13 N
14 A	R	I	E	L	■	15 A	R	E	P	A	■	16 A	N	Y
17 L	I	N	A	C	18 S	Y	S	T	E	M	■	19 R	D	A
20 C	A	S	T	A	N	E	T	■	21 R	E	22 E	D	E	D
■	■	■	■	23 T	O	R	■	24 C	A	L	P	E	R	S
25 R	26 E	27 S	28 O	R	T	■	29 S	A	T	Y	R	■	■	■
30 A	R	O	M	A	■	31 A	O	M	O	■	■	32 E	33 L	34 I
35 A	L	H	A	Z	36 E	N	S	P	R	37 O	38 B	L	E	M
39 B	E	O	■	■	40 M	A	U	S	■	41 V	E	A	R	A
■	■	■	42 O	43 P	P	I	E	■	44 B	E	D	L	A	M
45 R	46 E	47 F	U	R	L	S	■	48 E	R	R	■	■	■	■
49 S	T	E	R	E	O	■	50 A	T	E	L	51 I	52 E	53 R	54 S
55 T	U	T	■	56 S	Y	57 N	C	H	R	O	T	R	O	N
58 U	D	I	■	59 T	E	R	R	E	■	60 O	S	A	M	A
61 V	E	D	■	62 O	S	T	E	R	■	63 K	A	T	E	S