Natural resistance of Alaska-cedar, redwood, and teak to Formosan subterranean termites

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Abstract

The relative susceptibility of Alaska-cedar (*Chamaecyparis nootkatensis*), redwood (*Sequoia sempervirens*), southern pine (*Pinus* spp.), and Douglas-fir (*Pseudotsuga menziesii*) heartwood to feeding by the Formosan subterranean termite (*Coptotermes formosanus*) was evaluated in 4-week no-choice and two-choice laboratory tests. Termites fed equally on pine and Douglas-fir, and significantly less (at least 50% less) on Alaska-cedar and redwood. Within-species variability in susceptibility, suggesting variability in heartwood extractive content, was apparent with both Alaska-cedar and redwood. Reduced feeding was accompanied by high termite mortality, indicating that the heartwood extractives of both species are toxic to termites. In choice tests, termites avoided feeding on either Alaska-cedar or redwood if Douglas-fir was also present. When presented with a choice of either Alaska-cedar or redwood, termites fed significantly less on Alaska-cedar. The susceptibility of teak (*Tectona grandis*) to termite attack, in comparison to treated (ammoniacal copper zinc arsenate, chromated copper arsenate, or disodium octaborate tetrahydrate) and untreated Douglas-fir, was also evaluated in a 6-week field exposure. In this test, there was no visible evidence of feeding on any of the teak samples. Our results indicate that these naturally durable woods compare favorably in termite resistance to preservative-treated wood.

The use of naturally durable woods, particularly redwood (*Sequoia sempervirens* [D. Don] L.) in North America, in building construction has historically represented an alternative to preservative-treated lumber. This may become a more economically viable alternative as a result of the increasing costs and limited availability in the future of more popular lumber species. Various studies have identified tropical (8,14,27) and North American (11,20,21,23) woods with termite-resistant properties, and have suggested that extractives of such woods could be useful in preserving susceptible timbers (9,10,17).

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the principal wood used in building construction in Hawaii (26) and is very susceptible to attack by the Formosan subterranean termite (*Coptotermes formosanus* Shiraki, Isoptera: Rhinotermitidae). Su and Tamashiro (23) documented that redwood and western redcedar (*Thuja plicata* Donn.) were less susceptible to Formosan subterranean termite attack than either Douglas-fir, ponderosa pine, Engelmann spruce, or western hemlock. A number of tropical hardwoods have also been found to deter feeding by *C. formosanus* (8).

The two studies reported here were conducted as part of ongoing research on the factors affecting Formosan subterranean termite foraging and feeding behavior. One goal of our research is the identification of naturally durable woods for use as construction materials in Hawaii and other regions of high termite hazard. The first study reported here was a laboratory evaluation of the termite resistance of Alaska-cedar (Pacific Coast yellow cedar), *Chamaecyparis nootkatensis* (D. Don) Spach., heartwood in comparison to that of redwood. Heartwood of two susceptible species, Douglas-fir and southern pine (*Pinus* sp.) was included in this evaluation, and both no-choice and

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choice (comparison) tests were conducted. The second study was a short-term (6 weeks) field test of Laotian teak (*Tectona grandis* L.F.) in comparison to locally obtained Douglas-fir boards treated with either ammoniacal copper zinc arsenate (ACZA), chromated copper arsenate (CCA), or disodium octaborate tetrahydrate (DOT) in accordance with accepted treatment practices for residential construction lumber in Hawaii.

Experimental procedure

Laboratory evaluations of Alaska-cedar and redwood

Samples of top-grade all-heartwood gluelam stock of Alaska-cedar, redwood, Douglas-fir, and southern pine were provided by Williamette Industries (Oregon) and Standard Structures Inc. (California). Test wafers (25 by 25 by 6 mm, or approximately 1 by 1 by 0.25 in.) were cut cross grain from the interior of these samples. This was a more rigorous test than one using samples cut in the tangential (3) or radial (6) directions because the cross-grain face absorbs moisture more rapidly and is more accessible to termite penetration.

Using a trapping technique, Formosan subterranean termites were collected from an active field colony on the Manoa campus of the University of Hawaii immediately before their use in laboratory assays (24). Test containers were screw-top plastic jars (8-cm diameter by 10 cm high), each containing 150 g washed and ovendried silica sand and 30 mL distilled water. The test wafers were ovendried (90°C for 24 hr.), weighed, and allowed to equilibrate to laboratory conditions for several hours before test initiation. In the no-choice tests, one test wafer was placed on the surface of the damp sand, and 400 termites (360 workers and 40 soldiers, to approximate natural caste proportions) were added to each jar. Each wood species from each supplier (California and Oregon) was replicated five times and the jars were placed in an unlighted controlled-temperature cabinet at 29°C ± 0.5°C for 4 weeks (28 days). At the conclusion of the test, percent termite mortality (transformed by the arcsine of the square root) and the ovendry weight changes in the test wafers were subjected to analysis of variance (ANOVA) and means significantly different at the 5 percent level were separated by Tukey's Studentized Range Test (19).

Two-choice feeding tests were also conducted with Alaska-cedar, redwood, and Douglas-fir. These tests more closely approximated the field situation in which termites have a choice of food (13). The experimental setup was similar to that of the no-choice tests, except that two wafers were placed on the surface of the damp sand, on opposite sides of the jar. Both Alaska-cedar and redwood heartwood were paired with Douglas-fir; Alaska-cedar and redwood were also paired with each other. Each combination was replicated five times. After 4 weeks of incubation, ovendry wood weight changes were recorded and subjected to a paired comparison t-test. Transformed percentage termite mortality was compared by ANOVA and Tukey's Studentized Range Test at the 5 percent level (19).

Field evaluation of teak

Samples of Laotian teak boards were provided by a local contractor (Tom Gentry Construction, Kamuela, Hawaii). This contractor also provided Douglas-fir boards (88 by 38 mm, or nominal 2 by 4 in.) pressure-impregnated with ACZA or CCA from a Honolulu construction site. The ACZA-treated board was incised and reputed by the contractor to meet recognized standards for preservative penetration and retention (4 kg/m^3, or 0.25 pcf) in residential construction lumber out of ground contact (2,4,5). In accordance with accepted practice in Hawaii, the CCA-treated board was not incised and was reputed to have been treated to a retention of 4 kg/m^3, with no requirement for depth of penetration.

Additional Douglas-fir boards (nominal 2 by 4 in.) pressure- impregnated with either CCA or disodium octaborate tetrahydrate (DOT, as HI-BOR®) were purchased from a local lumberyard (Honsador Inc., Honolulu, Hawaii). The CCA-treated board was a product of Honolulu Wood Treating Co. Ltd. and was not incised. This board carried the American Wood-Preservers' Bureau (AWPB) stamp, which indicated that it met an aboveground preservative requirement of 0.25 pcf (4 kg/m^3) and was "AWPB Approved Hawaii Use Only." The DOT-treated board bore the purple dye that indicated treatment at Honolulu Wood Treating Co. to a target minimum retention of 1.1 percent DOT by weight in an 0.6-inch assay zone (18). An untreated Douglas-fir board (nominal 2- by 4-in., construction grade) was also purchased for use as a control in the field test.

Test pieces 1 cm thick (8.8 by 3.8 by 1 cm) and weighing about 40 g each were sliced perpendicular to the long dimension from the middle of each board. Each test piece from either teak or one of the preservative-treated boards was paired with a slice cut from an untreated board, and the two pieces were placed inside a roll of corrugated cardboard within a 15-cm-diameter, 20-cm length of plastic ABS pipe. Each pipe was then placed vertically over the exposed end of a Douglas-fir stake extending into the ground at one of our termite field sites on the Manoa campus of the University of Hawaii. These stakes were all infested by Formosan subterranean termites at the time of trial. Each stake and pipe assembly was covered by a 5-gallon metal can with the bottom cut out and had a sheet-metal lid over the top to protect it from weathering. Each of the 5 different sample boards, including teak, was replicated 5 times, for a total of 25 experimental units.

In this field test, the test specimens were placed directly in contact with active Formosan subterranean termites for 6 weeks. After the 6-week exposure, the condition of the test pieces was evaluated using the standard grading system of 0 (complete failure) to 10 (sound) (1,3,6,7).

Results and discussion

In our no-choice laboratory tests, Douglas-fir and southern pine were equally acceptable to Formosan subterranean termites (Table 1). Termites fed significantly less (at least 50% less) on Alaska-cedar and redwood. This reduction in feeding was correlated with significant increases in termite mortality, 49 to 92 percent compared to 10 to 11 percent mortality observed in groups feeding on Douglas-fir or southern pine.

In the choice tests, termites almost completely avoided feeding on Alaska-cedar or redwood when Douglas-fir was present as an alternative (Table 2). When presented with a choice of Alaska-cedar or redwood, termites fed significantly less ($p = 0.0141$) on Alaska-cedar. Interestingly, when both of these less-preferred woods were present, termites suffered less overall mortality (30%) than was the case in no-choice tests in which they were forced to feed on only one of these wood species (49% to 92%). This suggests that the toxic extractives in Alaska-cedar and redwood may have different modes of action and are not additive in their impact on the feeding insects. However, the significantly increased termite soldier mortality in the choice tests with only Alaska-cedar and redwood, in comparison to those tests where Douglas-fir was available as an alternative food source, indicates that feeding on these two woods stressed the test insects and that mortality would likely increase with longer exposures. Since soldiers must be fed by the worker termites, they are sensitive to any decline in worker activity, and may also be cannibalized by workers when food sources are limited.

These laboratory results demonstrate that Alaska-cedar heartwood is at least as resistant to Formosan subterranean termite attack as redwood. They also suggest that Alaska-cedar may be less preferred than redwood when both woods are available to foraging termites. Although data on field performance are needed, Alaska-cedar appears to be a suitable alternative to redwood for use in construction in regions where subterranean termites pose the major hazard. Care must be taken, of course, in extrapolating these results to other wood-boring insects, such as wood-boring beetles or drywood termites (Family Kalotermitidae). Since termites did feed, albeit to a very limited extent, on both redwood and Alaska-cedar in our assays, these naturally durable woods should be considered "termite resistant" rather than "termite proof."

At the conclusion of the 6-week field test, there was no visible evidence of termite attack on the teak test specimens (Table 3). For Douglas-fir, test pieces cut from the ACZA-treated board and from the CCA-treated/lumberyard board also showed no evidence of attack. However, minor termite feeding was apparent on one of the five pieces cut from the CCA-treated/contractor board, and on all five of the DOT-treated test specimens.

Although this was a small-scale field test with actual construction materials, and certainly not a comprehensive evaluation of these wood treatments, our results were not unexpected. The limited penetration of CCA treatments in un-incised Douglas-fir heartwood provides little protection when the inner wood is directly exposed to termites, as in this test.

TABLE 1. — *Formosan subterranean termite mortality and feeding on various heartwoods in a 4-week, no-choice laboratory test.*

Wood[a]	Source	Wood mass loss[b]	Percent termite mortality[b]		
			Workers	Soldiers	Total
		(g)			
Alaska-cedar	CA	0.110 ± 0.057 A	91.55 ± 18.88 A	99.50 ± 1.12 A	92.35 ± 17.11 A
	OR	0.469 ± 0.371 AB	45.00 ± 37.14 BC	80.00 ± 35.13 A	48.50 ± 35.69 BC
Redwood	CA	0.416 ± 0.208 AB	80.72 ± 23.33 AB	72.00 ± 37.18 A	79.85 ± 24.70 AB
	OR	0.626 ± 0.447 B	66.56 ± 28.13 AB	62.00 ± 35.86 AB	66.10 ± 28.86 AB
Douglas-fir	CA	1.191 ± 0.094 C	10.00 ± 2.16 C	12.50 ± 6.37 B	10.25 ± 2.22 C
Southern pine	CA	1.193 ± 0.062 C	10.56 ± 2.78 C	13.00 ± 8.18 B	10.75 ± 2.72 C

[a] Top grade heartwood lam stock. Samples were obtained from manufacturers in California (CA) and Oregon (OR).
[b] Five replicates, mean ± standard deviation. Means within a column followed by the same capital letter are not significantly different at the 5 percent level (ANOVA, Tukey's Studentized Range Test).

TABLE 2. — *Formosan subterranean termite mortality and feeding on Alaska-cedar (AC), redwood (RW), and Douglas-fir (DF) in 4-week, two-choice laboratory tests.*

Comparison[a]	Wood mass loss			Percent termite mortality[c]		
	Wood 1	Wood 2	$p > t^b$	Workers	Soldiers	Total
		(g)				
AC / RW	0.121 ± 0.035	0.546 ± 0.200	0.0141	29.22 ± 4.32 A	32.50 ± 13.11 A	29.55 ± 5.00 A
AC / DF	0.030 ± 0.010	1.246 ± 0.176	0.0001	33.94 ± 18.56 A	5.50 ± 5.42 B	31.10 ± 17.16 A
RW / DF	0.087 ± 0.026	1.208 ± 0.137	0.0001	34.72 ± 8.82 A	3.13 ± 2.39 B	31.56 ± 7.72 A

[a] Top grade heartwood lam stock from a California manufacturer. Each wood wafer was paired with a wafer of the other species (Wood 1 / Wood 2) in a test container containing 400 termites (n = 5 replicates).
[b] Differences in mass loss for each pair of wood wafers are significant at the 5 percent level (paired comparisons t-test).
[c] Means within a column followed by the same capital letter are not significantly different at the 5 percent level (ANOVA, Tukey's Studentized Range Test).

TABLE 3. — *Termite ratings of teak, Douglas-fir heartwood pressure-impregnated with various preservatives for use in Hawaii, and paired untreated control Douglas-fir samples exposed to a Formosan subterranean termite field colony for 6 weeks.*

		Mean termite rating[a]		Number of treatment samples in each category (0 to 10 scale)			
Treatment	Source	Treatment	Controls	7	8	9	10
Teak	Contractor	10.00 ± 0.00	6.80 ± 2.17	0	0	0	5
ACZA	Contractor	10.00 ± 0.00	7.60 ± 2.79	0	0	0	5
CCA	Contractor	9.40 ± 1.34	6.00 ± 1.58	1	0	0	4
CCA	Lumberyard	10.00 ± 0.00	6.00 ± 1.87	0	0	0	5
DOT[b]	Lumberyard	8.20 ± 1.10	5.90 ± 2.25	2	0	3	0

[a] Mean of 5 replicates, ± standard deviation. Ratings follow the 0 to 10 grading scale, with 0 indicating complete failure and 10 meaning sound. Refer to text for details of wood treatments. Treatments do not necessarily correspond to those used outside of Hawaii.
[b] Post-test cross-sectional DOT retentions of samples were 0.64 and 0.76 percent (category 7); and 0.83, 0.96, and 1.12 percent (category 9).

Despite this limited preservative penetration, the toxicity of the outer layers of CCA-treated wood was sufficient to prevent feeding on 9 of the 10 specimens.

Since DOT treatments have little repellency to Formosan subterranean termites, at least minor feeding on the treated wood is likely when termites encounter it. Our previous field studies with pressure-treated Douglas-fir demonstrated that such minor termite feeding can be progressively reduced, but not completely prevented, by wood treatment to greater DOT retentions (15,16). After exposure in this field test, each of the five DOT-treated wafers was analyzed for boron content by ashing the whole wafer and using inductively coupled plasma (ICP) spectroscopy on the extracted residue (18). On a weight basis, the five wafers contained 0.64, 0.76, 0.83, 0.96, and 1.12 percent DOT. The two wafers with the lowest DOT retentions also showed the most evidence of termite feeding, each receiving a rating of 7 while the other three wafers all received ratings of 9 (Table 3). Although the sample size in the current test was extremely small, our results suggest that it may be advisable to treat Douglas-fir to DOT retentions greater than the 1.1 percent target DOT retention currently in use in Hawaii.

In showing no evidence of termite attack, teak performed comparably to ACZA-treated and CCA-treated/lumberyard Douglas-fir (Table 3). In an earlier field test in Hawaii, ACZA-treated Douglas-fir heartwood also remained completely free from termite attack (25). As a more expensive hardwood, teak is less likely to find widespread use in Hawaiian construction than Alaska-cedar or redwood. However, increased use of teak in paneling, trim, or other building components is worthy of consideration. Again, although teak proved extremely resistant to Formosan subterranean termites, its degree of susceptibility to drywood termites or wood-boring beetles is not known.

Our results support the conclusion that these naturally durable woods compare favorably in their termite resistance to preservative-treated wood. However, neither type of wood product should be considered completely immune from termite attack. No matter the degree of chemical or natural protection, wood products should be used in building construction in conjunction with termite-resistant architectural design, and insecticidal or physical barriers in the soil to foraging termites. Strategically placed baits will also likely be used to control subterranean termite populations in the near future (12,22), and these will also complement the use of termite-resistant wood products.

Literature cited

1. American Society for Testing and Materials. 1991. Standard method of evaluating wood preservatives by field tests with stakes. D 1758-86. Annual Book of ASTM Standards, Vol. 04.09 (Wood).
2. ________. 1991. Standard specification for pressure treatment of timber products. D 1760-86a. Annual Book of ASTM Standards, Vol. 04.09 (Wood).
3. ________. 1991. Standard method of laboratory evaluation of wood and other cellulosic materials for resistance to termites. D 3345-74 (reapproved 1986). Annual Book of ASTM Standards, Vol. 04.09 (Wood).
4. American Wood-Preservers' Association. 1992. All timber products — preservative treatment by pressure processes. C1-92. AWPA Book of Standards.
5. ________. 1992. Wood for commercial-residential construction —preservative treatment by pressure processes. C15-92. AWPA Book of Standards.
6. ________. 1992. Standard method for laboratory evaluation to determine resistance to subterranean termites. E1-72. AWPA Book of Standards.
7. ________. 1992. Standard method of testing wood preservatives by field tests with stakes. E7-92. AWPA Book of Standards.
8. Bultman, J.D., R.H. Beal, and F.F.K. Ampong. 1979. Natural resistance of some tropical African woods to *Coptotermes formosanus* Shiraki. Forest Prod. J. 29:46-51.
9. Carter, F.L. and R.H. Beal. 1982. Termite responses to susceptible pine wood treated with antitermitic wood extracts. Int. J. Wood Preserv. 2:185-191.
10. Carter, F.L., S.C. Jones, J.K. Mauldin, and C.R.R. de Camargo. 1983. Responses of *Coptotermes formosanus* Shiraki to extracts from five Brazilian hardwoods. Z. Angew. Entomol. 95:5-14.
11. ________, C.A. Stringer, and R.V. Smythe. 1972. Survival of six colonies of *Reticulitermes flavipes* on unfavorable woods. Ann. Entomol. Soc. Am. 65:984-985.
12. Grace, J.K. 1992. Termite distribution, colony size, and potential for damage. Proc. National Conf. on Urban Entomol., Univ. of Maryland, Feb. 23-26, 1992. pp. 67-76.
13. ________, P.E. Laks, and R.T. Yamamoto. 1993. Efficacy of chlorothalonil as a wood preservative against the Formosan subterranean termite. Forest Prod. J. 43(1):21-24.
14. ________, D.L. Wood, and G.W. Frankie. 1989. Behavior and survival of *Reticulitermes hesperus* Banks (Isoptera: Rhinotermitidae) on selected sawdusts and wood extracts. J. Chem. Ecol. 15:129-139.
15. ________ and R.T. Yamamoto. 1993. Repeated exposure of borate-treated Douglas-fir lumber to Formosan subterranean termites in an accelerated field test. Forest Prod. J. 43(1)65-67.
16. ________, ________, and M. Tamashiro. 1992. Resistance of borate-treated Douglas-fir to the Formosan subterranean termite. Forest Prod. J. 42(2):61-65.

17. Laks, P.E., L.J. Putman, and M.S. Pruner. 1988. Natural products in wood preservation. Proc. Canadian Wood Preserv. Assoc. 9:105-123.
18. Manning, M.J. 1993. Personal communication. U.S. Borax Inc., Valencia, Calif.
19. SAS Institute. 1987. SAS/STAT Guide for Personal Computers. Version 6 ed. SAS Institute, Inc., Cary, N.C.
20. Scheffrahn, R.H., R.-C. Hsu, N.-Y. Su, J.B. Huffman, S.L. Midland, and J.J. Sim. 1988. Allelochemical resistance of bald cypress, *Taxodium distichum*, heartwood to the subterranean termite, *Coptotermes formosanus*. J. Chem. Ecol. 14:765-776.
21. Smythe, R.V. and F.L. Carter. 1970. Survival and behavior of three subterranean termite species in sawdust of eleven wood species. Ann. Entomol. Soc. Am. 63:847-850.
22. Su, N.-Y. 1993. Managing subterranean termite populations. Proc. 1st Inter. Conf. on Insect Pests in the Urban Environ., St. John's College, Cambridge, June 30 to July 3, 1993. K.B. Wildey and W.H. Robinson, eds. (ISBN 0-9521824-0-8.) pp. 45-50.
23. ________ and M. Tamashiro. 1986. Wood-consumption rate and survival of the Formosan subterranean termite (Isoptera: Rhinotermitidae) when fed one of six woods used commercially in Hawaii. Proc. Hawaiian Entomol. Soc. 26:109-113.
24. Tamashiro, M., J.K. Fujii, and P.Y. Lai. 1973. A simple method to observe, trap and prepare large numbers of subterranean termites for laboratory and field experiments. Environ. Entomol. 2:721-722.
25. ________, R.T. Yamamoto, and R.H. Ebesu. 1988. Resistance of ACZA treated Douglas-fir heartwood to the Formosan subterranean termite. Proc. Am. Wood-Preserv. Assoc. 84:246-253.
26. Wilcox, W.W. 1984. Observations on structural use of treated wood in Hawaii. Forest Prod. J. 34:39-42.
27. Wolcott, G.N. 1950. An index to the termite-resistance of woods. Bull. 85. Univ. of Puerto Rico, Agri. Expt. Sta. 26 pp.

Battelle forecasts slight increase in R&D expenditures for 1994

Expenditures for research and development (R&D) in 1994 in the United States are expected to reach $164.5 billion, according to the annual Battelle forecast.

This represents an increase of $3.8 billion, 2.3 percent, over the $160.7 billion the National Science Foundation estimates actually was spent for R&D in 1993.

Since about 2 percent of the R&D increase will be absorbed by inflation, Battelle forecasts a negligible increase in real total R&D expenditures. This is considerably less than the 10-year average real increase of 2.5 percent since 1983.

"The recent slowdowns in industrial support of R&D and the changing priorities of the federal government have resulted in a slowdown in R&D spending, as we have expected for some time," said Douglas Olesen, Battelle president and chief executive officer.

Olesen continued, "The diverse aspects of technology today dictate that industry needs to focus on a few core competencies that are critical to gaining a competitive edge. Technology is so complex, so dispersed, and so expensive that no one can be world-class in everything. Industry also must rely on creating strategic alliances with technology organizations that can provide a critical and constant flow of information about emerging technology.

"In spite of the complex and interrelated factors that are influencing decision-making, it is apparent that the R&D picture will be improving. What is perhaps most striking is the improved environment for capitalizing on our total national science and technology resource, and utilizing that capacity for the betterment of industry and the economy."

Industrial funding for R&D will account for 51.6 percent of the total. Industrial support is forecast to be $83.6 billion, up 1.6 percent from 1993.

Battelle sees an increase of 2.6 percent in federal support for R&D, with funding expected to be $69.8 billion. This is 42.2 percent of the total expenditures for 1994, but it represents a smaller increase than originally proposed in President Clinton's first budget.

Funding by academic institutions is expected to be $6.4 billion, 3.9 percent of the total. Other nonprofit organizations will provide nearly $3.5 billion (2.1%).

Since 1980, industry and government have switched roles as the primary source of R&D support. Government had been the principal funder before 1980. Industrial support will continue to dominate in 1994 and for the next several years.

According to the report, industry will continue to perform the majority of R&D. In 1994, performance by industry is expected to rise to $114.8 billion, slightly less than 70 percent of all research. This compares with $16.8 billion (10.2%) by federal government laboratories, $26.7 billion (16.2%) by academic institutions, and nearly $6.2 billion (3.7%) by nonprofit organizations.

Federal funding supports research in all four sectors. About 46 percent of the federal R&D dollars are used by industry. Federal laboratories and colleges and universities receive about 24 percent each, and the remainder, about 5 percent, goes to other nonprofit organizations.

Industry absorbs almost all of its own funds, either performing the R&D itself or contracting with other industrial performers. Contracts and grants to nonprofit organizations are about half of what is received by colleges and universities. (The figure used for colleges and universities does not include the support of long-range "endowed research" programs). Nonprofit organizations finance both themselves and academic institutions about equally;ly; colleges and universities consume all of their own funds.

Defense, energy, space, and health and human services dominate the federal R&D scene and account for 82.6 percent of the total proposed federal R&D funding for 1994, only slightly less than in 1993. The make-up of this funding will not change significantly in 1994.

Changes in the character of military threats and the associated defense R&D spending, an appreciation of domestic challenges, and the overall federal deficit have had a significant effect on the distribution of resources within the federal R&D budget. This change in emphasis among the principal research-intensive agencies is demonstrated by comparison of historical and planned expenditures.

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